LEGUTEC - MECHANICAL WEED CONTROL IN SOYBEAN CULTIVATION IN LUXEMBOURG

Official final report - October 2020

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> Authors / Laura Leimbrock-Rosch, David Richard, Dr. Stéphanie Zimmer
> in Cooperation with Geocoptix GmbH / Dr. Gilles Rock, Vanessa Hueffer

LeguTec

Sustainable and resource-efficient protein production using various mechanical weed control methods in grain legume cultivation, using soybean as an example

Project duration: 10/2017 – 09/2020

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IBLA
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Project partners

Lycée Technique Agricole

agri-distribution WOLFF-WEYLAND
L-8551 NOERDANGE - 00352 23637-200
www.wowey.eu - info@wowey.eu

GEOCOPTIX

Organic farm „An Dudel" Emering, Sprinkange

Organic farm Mehlen, Manternach

Organic farm François, Hostert

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Sponsoring

agri-distribution WOLFF-WEYLAND
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www.wowey.eu - info@wowey.eu

PIET VAN LUIJK
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Acknowledgements

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Abstract

Soybean is not yet an established crop in Luxembourg and knowledge gaps still mainly occur in mechanical weed control. The aims of the LeguTec project were (i) to test the performance of different mechanical weed control methods to maximize soybean grain yield, (ii) to study their impact on weed communities, (iii) to assess the suitability of remote sensing techniques and geospatial data analyses for agricultural research questions to support or substitute in-situ assessment methods and (iv) to disseminate soybean cultivation knowledge to the farmers. Field trials were set up at three organically managed sites in Manternach, Sprinkange and Hostert in 2018 and 2019 and five different weed control treatments were tested in a randomized complete block design with four replicates: a negative control ($t.1_{neg}$), where no weed control was carried out; a positive control plot ($t.2_{pos}$), where all weed was taken out by hand; harrowing ($t.3_{har}$); hoeing with interrow cultivator with duck foot shares ($t.4_{hoe}$); hoeing with interrow cultivator with duck foot shares and finger weeder ($t.5_{hoe+}$); a flexible system, a combination of treatment 3 and 5 ($t.6_{comb}$) and intercropping of soybean and camelina in combination with harrow ($t.7_{mix}$).

The two trial years were marked by prolonged dry periods and severe water stress especially at flowering, which negatively influenced pod production and resulted in emergency ripening; thus, water availability was the main limiting factor to soybean yield. Nevertheless, significant differences in soybean yield were observed between the different mechanical weed control treatments. Higher yields were generally achieved in hoeing treatments compared to harrowing treatments. Yields were similar for hoeing and hand-weeding, as well as for harrowing and no-weed control. Blind-harrowing on the other hand had no significant effect on grain yield. Furthermore, the finger weeder had no significant influence on the performance of the hoeing method. Overall, hoeing was observed to have a better selectivity towards weeds than harrowing. In the latter, greater plant losses and damages to the soybean crop resulted in higher weed establishment and infestation. This resulted in increased water competition between soybeans and weeds in harrowing compared to hoeing treatments, negatively influencing yield. Intercropping of camelina was shown not to be suitable for Luxembourg, especially during the dry study years.

A high initial weed diversity was observed across all sites. A total of 59 weed species were identified and annual and biannual dicotyledonous species were dominant. The diversity of weeds, shown by the Shannon index, were reduced by mechanical weed control; however, none of the methods completely eliminated all weeds. In general, hoeing impacted more negatively the diversity than harrowing. *Chenopodium album, Elymus repens, Persicaria lapathifolia, Polygonum convolvulus, Tripleurospermum inodorum* and *Viscia spec* were the most problematic weeds, both in terms of resource competition towards soybean and/or causing nuisance at harvest.

High resolution remote sensing techniques present a variety of valuable tools for monitoring experimental setups. But practical remote sensing methods offer only limited advantages compared

to in-situ assessment methods, being the first choice for quantitative data collection in a scientific framework.

Rigorous field management throughout the whole crop rotation in order to reduce weed pressure is the key factor to maximize soybean yield. The efficiency of any treatment was low, when weed infestation was already high after soybean emergence. Where weed infestation was low at the beginning of the soybean vegetative phase, any of the treatments were applicable.

The high number of visitors at field visits showed the keen interest of farmers in soybean cultivation. The dissemination of the gained experience helped to launch first cultivation endeavors of soybeans in Luxembourg. However, for a future successful establishment of soybean production in Luxembourg, continuous research is essential in order to achieve the long-term goal of adapting agriculture to the changing climate, overcoming cultivation barriers and promoting sustainable, resource-efficient protein production. Farmers need to gain more experience in terms of on-farm soybean cultivation, supported by advisors specialised in soybean cultivation. The missing processing infrastructures hampering the profitability still inhibit soybean cultivation in Luxembourg. To promote national soybean production and increase protein autarky, incentives from public authorities are crucial.

1. Introduction

Soybean (*Glycine max* (L.) Merr.), a member of the family *Leguminosae*, has a protein content of up to 40 % and a very high biological value due to an optimal amino acid composition, making it one of the most important feed protein sources in animal nutrition (Hahn et al., 2013). The high content of the two essential amino acids lysine and methionine in soybeans is particularly important for monogastric animals such as pigs and poultry (Bernet et al. 2016). As a legume plant, soybeans have a number of positive properties for use in agriculture: the cultivation of soya widens crop rotation, increases agrobiodiversity, ameliorates soil structure with its extensive root system, improves soil fertility through the ability to fix nitrogen, and thus contributes to savings in nitrogen fertilizers (Köpke et al., 2010; Nemecek et al., 2008).

Being one of the EU-states that signed the European Soya Declaration (2017), Luxembourg aims to promote the regional cultivation of soybeans and other protein crops. The decisive factor is the current dependency on imports from mainly North and South America. The EU imports around 96 % of its soybeans and soya meal, of which around 90 % is expected to be GMO (genetically modified organism) soya (European Commission, 2016). Soybean autarky in Europe is only 4 % and amounts to 2.8 million t, whereas 35 million t are imported every year (Bernet et al. 2016; European Union 2020a, b). Imports from overseas cause various environmental and social problems (Beste et al. 2011). Due to the large-scale cultivation of soya as a monoculture in the producing countries (e.g. U.S., Brazil and Paraguay) and the associated intensive use of chemical-synthetic plant protection products, in particular glyphosate in conventional cultivation, there is a strong loss of biodiversity as well as soil erosion, soil quality loss and health hazards to the population. The high global demand for soybean meal as fodder also leads to strong land pressure, with rainforests being cleared to make way for soybean cultivation areas, which in turn leads to a loss of biodiversity and rural displacement. There is also the risk of mixing with GMO soya and the long transport routes have a negative impact on CO_2 emissions (Beste et al. 2011). In times of climate change, the widespread degradation of our natural resources and the increasing incidence of degenerative diseases, alternatives to these practices must be identified.

In 2018, Luxembourg's soybean autarky and production were 0 % (Service d'Economie Rurale (SER, Department for Rural Economy), 2019) and a national consumption of 27,453 t of soybean extraction meal was calculated by Zimmer (2019). The possibility of reducing the amount of soya meal in feed rations were described by Zimmer (2019) resulting in potential reduction of national soybean consumption to 15,886 t. "Luxembourg is a favourable grassland site with a high potential of using grassland to provide a protein source for dairy cows. Regarding high self-sufficiency with farm-grown fodder, the reduced consumption of soybeans in feed rations and the lower livestock density in organic compared to conventional agriculture, organic agriculture could act as a role model to reach a higher soybean-autarky in Luxembourg as a basis for a national protein strategy" (Zimmer, 2019). This strategy would reduce dependence on imported soya and the associated negative environmental and social impacts and thus contribute to climate protection.

Due to breeding of new varieties with very early maturity and inoculation products adapted to cold growing regions in central Europe, soybean cultivation is nowadays suitable in many parts of Europe (Zimmer et al. 2016a, b). In Luxembourg, soybean cultivation has been successfully tested in field trials and on-farm trials during the last years (Heidt H., 2019; Richard et al., 2020; Zimmer et al., 2016a). However, the organic cultivation of soybean is demanding and, to date, due to missing infrastructure, further processing is not yet guaranteed in Luxembourg nor in the greater region (e.g. toasting as one heat treatment possibility). Above all, knowledge gaps in efficient and sustainable mechanical weed control techniques inhibits soybean cultivation (Zimmer et al., 2016b).

A large range of references are available concerning mechanical weed control and the different methods used in organic agriculture as well as all the factors and indicators playing a key role regarding weed management. They globally bring the same information and knowledge about the different technique and their mode of action. Nevertheless, few scientific studies have been found focusing on mechanical weed control of soybean or other legumes. Neither much studies were found comparing different techniques and its combinations. Scientific researches focus mainly on the effects of row spacing, soybean cultivars or soybean density on the weed pressure. Technical guides for organic soybean growers are available and rich in information, in particular in the European context. France, Germany, Switzerland or Austria seem to be the most implicated nations which is good since they are neighbours of Luxembourg, meaning that for some of the growing context might be similar. Therefore, these references constitute a basis for the choice of the techniques and the favourable time for weeding. However, quantitative data showing the success of the methods are missing, some indications are available but they are true for a certain context. Due to its variations of climate conditions and soil types, Luxembourg cannot rely on global results. The need of local experiences and references is fundamental and necessary to convince the farmers. Zimmer et al. (2016b) found that Luxembourgish farmers feel badly informed about grain legume cultivation due to the lack of knowledge and extension services for these crops. They also found that there is a substantial interest in soybean and grain legume cultivation among Luxembourgish farmers. On the other side, an increase in regional soybean cultivation and other legumes is strived by the Luxembourgish government that signed the European Soya declaration in 2017. To meet the latter requirements, expertise within the production is in turn essential.

LeguTec consisted of exact field trials on three study sites on organic farms spread over Luxembourg, while each site was designed as randomized complete blocks. In addition, one experimental area of the Lycée Technique Agricole (LTA) in Bettendorf was designed as an on-farm trial.

The LeguTec project aims (i) to test the performance of different mechanical weed control methods to maximize soybean grain yield, (ii) to study their impact on weed communities, (iii) to assess the suitability of remote sensing techniques and geospatial data analyses for agricultural research questions to support or substitute in-situ assessment methods and (iv) to disseminate soybean cultivation knowledge to the farmers.

The study focused on contributing on possibilities to increase protein autarky of Luxembourg by promoting a sustainable and resource-efficient national soybean production.

2. State of art

2.1. The characteristics of soybeans and its cultivation

Soybean, *Glycine max* (L.) Merr., is an annual crop from the *fabaceae* family more known as legumes. Soybean vary in term of size, colour (green, yellow, brown) and composition (protein and oil rates). These characteristics allow different usages of the beans. They are used for human consumption as pulses (the entire bean is eaten) or in order to produce oil which is then employed in food processes or other components are extracted such as the lecithin. The most important sector employing soybean is animal feed production. After the extraction of the oil from the beans, the soybean cake results as fodder product. This product is really interesting for animal nutrition since its protein content is about 45 % and the remaining oil content less than 10 % (Bellof, 2014). As a matter of fact, soybean varieties cultivated in Europe for animal feed contain a high rate of oil (around 20 %), a rate of 12 % of starch and sugar and a protein content of 36 % on average (Bellof, 2014). Soybean presents also a very good spectrum of essential amino acids such as lysine, methionine and cysteine which are indispensable for feeding monogastric animals (Zimmer, 2019). These characteristics make soybean a very interesting plant in terms of oil and protein production per hectare thus entering in competition with protein crops such as peas or fava beans (Guéguen et al, 2008) and oilseeds crops like rapeseed or sunflowers.

2.1.1 The growing cycle of soybean and soybean cultivars

Soybean growth is divided into the vegetative development period (from emergence to first flower development) and the reproductive development period (from first flower to physiological maturity) (Board et al., 2011). Soybean is a summer crop sown between mid-April and mid-May and it flowers normally from the summer solstice (21st of June) if the vegetative establishment is well done yet. The ideal conditions for the germination are a minimum of 10 °C for the soil temperature. Growing soybean requires a neutral soil pH between 6.5 and 7.5 (Hahn and Miedaner, 2013; Bernet et al., 2016). As an above ground dicotyledonous plant, the plump cotyledons emerge at the soil surface after 8 to 15 days after sowing (Hahn and Miedaner, 2013; PROTA, 2006). The first two leaves that appear are simple and opposite. Then trifoliate, alternate leaves develop on the nodes (see Appendix 4-6).

Soybean plants emergence relatively slowly and are characterized by slow growth in its juvenile stages. It is helpful to control the upcoming weeds as soon as possible to hinder weeds from having advantage in its development. After emergence, the soya plants are relatively undemanding during the remaining vegetative development. They can survive light frost and drought better than many other thermophilic crops (Bernet et al., 2016). Damage to the shoots caused by feeding, frost, hail or mechanical weed control can also be well compensated by the formation of new leaf mass and side shoots during this phase. Until flowering soybeans can deal with drought to a great extent. Even stands that visibly suffer from drought stress in the juvenile phase can still achieve a good yield later on. Between early summer and midsummer, soya plants depend on a good water supply. Drought stress during flowering leads to the dropping of flowers. These losses can no longer be compensated for even with a later water supply. Between flowering and grain formation, the water requirement of the soya plant is approximately 3 l m^{-2} d^{-1} (Bernet et al., 2016). A water deficit in this phase causes the plants to ripen in an emergency. Water requirements are of 500 mm up to 800 mm of water in the entire growing cycle (Nieuwenhuis et al., 2005; PROTA, 2006).

Flowering occurs between 30 and 40 days after sowing (around 400 to 600 degree-days from emergence to flowering) and complete ripening is attained from 75 to 105 days after blooming (between 1500 and 1900 degree-days after flowering) (Nieuwenhuis et al., 2005). As autogamous plant, soybean is able to pollinate itself. Soybeans start flowering at the lower nodes and flower stepwise up the stem (Hanway et al., 1967). The flowers are clustered in inflorescences and most of them are subjected to abortion. From the beginning of flowering onwards, soya plants are depending on a good water supply to exploit their full yield potential (Bernet et al., 2016). Fertile flowers rapidly form small pods containing from one up to three beans for European varieties (Hahn et al., 2013; PROTA, 2006). Pod formation starts again at the lower nodes, while it might occur that upper flowers are still flowering. The subsequent seed filling period is separated into the initial period of slow seed filling, where pod and seed numbers are determined, and the rapid seed filling period when seed growth rate is maximal (Board et al., 2011). Environmental stress factors like lack of precipitation, light and temperature (e.g. heat waves) during flowering and the slow seed filling period cause greater reduction in yield than the same amount of stress earlier in the growing season. During the rapidly seed filling the demand for moisture and nutrients is large, but yield losses due to drought is twice as great for the period flowering until slow seed filling than for rapidly seed filling (Hanway et al., 1967; Board et al., 2011).

The harvest has to be done before the opening of the pods in order to limit the yield losses. Pods are dehiscent which means they are opening at full ripening and hence it is important to harvest in time. Harvesting is possible and optimal when the beans reach a humidity rate of 14 % to 15 % (Cartter et al., 1962; Dordevik et al., 2019; Hahn et al., 2013; PROTA, 2006).

The latest interest for growing soybean in Europe has been a real challenge in term of selection and production of adapted cultivars to the climatic conditions (Hahn et al., 2013). The aim is to select cultivars with rather short growing cycle that can be harvested before winter. Nowadays, it is possible to find very early ripening varieties representing the maturity groups called “000” and even “0000” that are suitable for Northern regions such as Luxembourg (FIBL, 2016; Hahn et al., 2013; Le Gall et al., 2017; Terres Inovia, 2019). These cultivars are characterised to have a fast determinate growth that requires less amount of temperature until the senescence (from 75 to 90 days) (PROTA, 2006). The early ripening cultivars are less sensible to the photoperiod, therefore making their growing cycle mainly based on temperature and giving them the opportunity to establish and start blooming very early (Dordevik et al., 2019; Hahn et al., 2013).

2.1.2 Soybean as an N_2 fixer

Soybean develops a strong tap root system that can reach a depth up to 1.5 m, and develops axillary branched roots (Hahn et al., 2013; PROTA, 2006). Since soybean is a legume, the roots are able to form a symbiosis with rhizobacteria, *Bradyhizobium japonicum*, resulting in the fixation of N_2 from the air and a transfer to the plant in exchange of carbon compounds required by the bacteria to live (Hahn et al., 2013; Zimmer et al., 2016c). The symbiosis is visible on the roots by forming small nodes (nodules) with a pinkish colour when they are active (see Figure 1). This type of bacteria is non-native of the European soil therefore an inoculation of the seeds or the soil with the bacteria is indispensable.

Figure 1: Process of nitrogen fixation in grain legumes (IBLA).

Nitrogen fixation is usually active beginning in the trifoliate stadium (Casteel, 2010). This ability can bring up to 50 % or 60 % of the nitrogen required during the growing cycle by soybean, representing between 60 kg and 160 kg of nitrogen per hectare (Nieuwenhuis et al., 2005). This characteristic is very interesting in organic farming as a natural source of a limited nutrient and also in conventional farming in order to reduce the application of synthetic fertilizers that are consuming a lot of fossil energy. The most favourable abiotic conditions for the effectiveness of the symbiosis are a temperature range of 14 °C to 24 °C, a neutral pH of the soil, and a not too wet soil which causes the asphyxiation of the bacteria (Cartter et al, 1962; Hahn et al, 2013; Nieuwenhuis et al., 2005; Pioneer, 2019). The nitrogen fixation by *rhizobacteria* requires a lot of phosphorous (Conley et al., 2011; Pioneer, 2019; PROTA, 2006). For an expected yield of 30 dt ha^{-1}, soybean requires an amount of 45 kg of P_2O_5 (COMIFER, 2007; Hahn et al., 2013). The average nitrogen balance of soya is comparable with peas and is hence close to neutral (Paeßens et al., 2019; Salvagiotti et al., 2008).

2.2 Technical aspects of the cultivation of soybean

Soybean grows best in light and aerated soils. Before sowing, a fertilisation might be needed if the soil is not rich enough in P, K or Mg (Cartter et al., 1962). In general case, bringing nitrogen is not recommended as it reduces the fixation of N_2 (Pioneer, 2019). If the pH of the soil is too low (neutral pH is the objective), spreading chalk is necessary (Cartter et al., 1962; Nieuwenhuis et al., 2005; Pioneer, 2019). In cold temperate regions like Luxembourg, soybean should not be sown after mid-May ensuring the entire growing cycle and to be able to harvest in proper conditions since October is often wet in Luxembourg (Bastidas et al., 2008). Also, a too long delay can compromise the yield exposing soybean to more drought risks (Conley et al., 2011).

In organic agriculture, soybean seeds are often sown at a depth of 4 or 5 cm in order to practice a blind harrowing before the emergence of the plants (Le Gall et al., 2017). For early ripening groups such as "000", short row spacing are preferable to ensure good yields since the size and thousand kernel weight of these cultivars are lower than other maturity groups (Hahn et al, 2013). Common practices are varying from 17 to 50 cm between two rows (Bastidas et al., 2008; Caliskan et al., 2007; Hahn et al., 2013; Le Gall et al., 2017; PROTA, 2006; Zhou et al., 2011). The inter-row width is determined by the type of seed-driller used (for cereals or corn for example) and also correlated to the weeding strategy (Le Gall et al., 2017). The number of plant sown per square meter can vary between 55 and 65 or even more (Hamilton et al., 2014; Le Gall et al., 2017). Indeed, if mechanical weed operations are made, it is good to increase the density by a rate of 5 to 15 % (Hamilton et al., 2014; Terres Inovia, 2019).

2.3 Soybean and weed competition

As a matter of facts, soybean has a slow growing pattern in the early stages and the competition with weeds need to be well controlled, it is often identified as the biggest challenge of cultivating soybean (FIBL, 2016; Hamilton et al., 2014). It seems that during the first weeks, soybean is very sensible to weeds and a high presence of them can already affects the yield (Nieuwenhuis et al., 2005). It is very important to keep the field as weed-free as possible in the early stadiums by practising early weed control operations (Dordevik et al., 2019). Shaw (1961) mentioned that in soybean production 50 % of the tillage is directly dedicated for the control of weeds (Cartter et al., 1962). Soybean should not suffer from the competition with weeds before the canopy is over lapping the row-spacing (Hamilton et al., 2014).

Crop rotation

The crop rotation has to be elaborated considering the succession of each crop in such a way they do not have a high competition on each other in terms of diseases, nutrients needs but also regarding to weed management (Bond et al., 2001, 2001; Chauvel et al., 2018; Davies et al., 2002; Gunsolus, 1990; Le Gall et al., 2017; Zaefarian et al., 2016). The length and diversity of the rotation give more chance to deal better with weeds. In Luxembourg, it has been reported that organic farmers cultivate more grain legumes (44.4 % of them) than conventional farmers (3.4 % of them) justifying the goals of fertility and weed management (Zimmer et al., 2016b). Also, farmers who cultivate grain legumes have one crop more in the rotation compared to other farmers: 4.7 against 3.8 respectively (Zimmer et al., 2016b).

Concerning soybean, according to Terres Inovia (2019), it performs well in short or long rotation resecting a minimum delay of 3 to 4 years between two soybeans. A too high N content in the soil impairs the formation and development of nodules and can lead to yield losses and lower protein contents. Cereals (wheat, barley, oat or corn) are good previous crop for soybean. In order to support the water supply of soya plants, preference is given to preceding crops that leave as much water in the soil as possible. Due to the late soil cover, the cultivation of a freezing catch crop is recommended. To prevent the multiplication of diseases, no oil and protein plants should be grown as a preceding or subsequent crop, since e.g. rape and sunflowers could transmit the *Sclerotinia* disease (Bernet et al., 2016). Other legumes can be cultivated in the rotation but they are not good previous crop (Terres Inovia, 2019). Soya is an interesting preceding crop for many crops, especially for winter cereals as it leaves a loose, well aerated soil (good soil fermentation) (Bernet et al., 2016).

2.4. Weed management

Infestation by weeds occurs when the soil is uncovered and newly tilled (seedbed preparation, post-sowing) by putting the seeds in perfect germinating conditions. Pioneer species and perennials which are multiplied are favoured by the agricultural work. Also, along the years, the growing cycle of the weeds seem to mimic the cycle of the crops, enlarging their chance to reproduce and to maintain themselves in the soil seed bank (Chauvel et al., 2018).

2.4.1 Weed-soybean competition

The biomass of the weeds creates faster a denser canopy than soybean which favour good conditions for the development of pests or diseases (due to high humidity rate for example) (Chauvel et al., 2018). The competition towards the crop is mainly due to different traits of weeds (Pousset, 2016). They often have a faster growing rate than the crop taking the advantage on space occupation by covering the seedlings, by shading the plants or by occupying the rhizosphere; also on resources consumption (water, nutrients, light) weakening the crop. The soybean plant is very sensitive to the presence of weeds during the first 4 to 6 weeks of its growth. Weed-control should be applied in the first month after sowing in order to enhance the well establishment of the plants by favouring a good stand of the plant (Pousset, 2016). Indeed, early emerging weeds caused a high competition leading to yield diminution already when they take the advantage over the young slow growing plantlets. After this 4-weeks period, soybean is not so much affected by the emergence of weeds. The late emerging weeds constitute another problem which is more affecting the feasibility of the harvest and contamination of the seeds. Also, they are the main source of new seeds that will enrich the soil seedbank and potentially impact the following crops of the rotation (Burnside, 1979; Pousset, 2016).

The weed flora commonly presents in soybean field has already been recorded. According to BASF (2019), weeds present in soybean fields are the same it is possible to find in maize or sunflower fields. The most problematic and competitive weeds in the view of Terres Inovia (2017) are: ragweed (*Ambrosia artemisiifolia),* thorn apple *(Datura stramonium),* three-cleftbur-marigold *(Bidens tripartita),* knotweed *(Persicaria maculosa),* cocklebur *(Xanthium strumarium),* black nightshade *(Solanum nigrum),* barnyard grass (*Echinochloa crus-galli),* bishop's weed *(Ammi majus),* goose foot *(Chenopodium album)*. Since soybean has not yet been cultivated in Luxembourg, the specific weed flora for this area is not known and has to be enlighten in order to identify the best weeding strategies.

2.4.2 Organic weed control in soybean cultivation

In practise, organic weed-control requires a lot of observation and knowledge about weeds e.g.: identification of the species, their growing cycle, their mode of reproduction, their behaviour in the soil seedbank (Chauvel et al., 2018; Le Bourgeois et al., 1995). It is necessary to take into account all these parameters in order to define a well-adapted weed management. The response of weeds to different weeding technics as well as the most sensible stages of the weeds are essential to proceed in the most efficient way. Knowing the fact that weeds are the most sensible at the "white thread" up to two leaves or until 3-4 leaves when hoeing is used helps the farmers to take the decision of when to act and how efficient it will be (Nieuwenhuis et al., 2005; Sicard et al., 2012). Indeed, using mechanical weed-control methods suppose that each run has a cost in term of machines, time of work and efficiency towards weeds. It is profitable or not when the evaluation of losses without this operations are lower than with the help of weeding (Chauvel et al., 2018). The aim is not to get rid out of all the weeds as they bring the soil to a certain equilibrium in terms of fertility and ground cover (Pousset, 2016). Weeds are also necessary and beneficial for various ecological services. They constitute a source of resources for the fauna (leaves, roots, compounds, etc.) and are good for the pollinators when they get flowers. They protect the soil of erosion. They bring more biodiversity in the field and are host for multiple organisms that can also be predators of pests for example (Chauvel et al., 2018). Weeds should be maintained at a controlled rate which is a compromise between the benefits they can bring and the competition they can cause to crops.

The use of the plough helps to reduce weed pressure. It is therefore generally recommended in soybean cultivation. Ploughing just before soybean sowing increases the risk of overgrowth. If there is a high pressure of root weeds, ploughing should be done after cereals and 4-5 weeks should be allowed for seedbed preparation. Early tillage in February or even in late autumn in heavy soils reduces water evaporation from the soil and contributes to a higher water supply in the soil (Bernet et al., 2016).

An adequate soil preparation has to be made afterwards in the way that one or two false seedbed can be made (Cartter et al., 1962; Gunsolus, 1990). Those seedbeds (see Figure 2) have a big consequence by diminishing the weed density already. They can be realised two to three weeks before the date of sowing (Bernet et al., 2016).

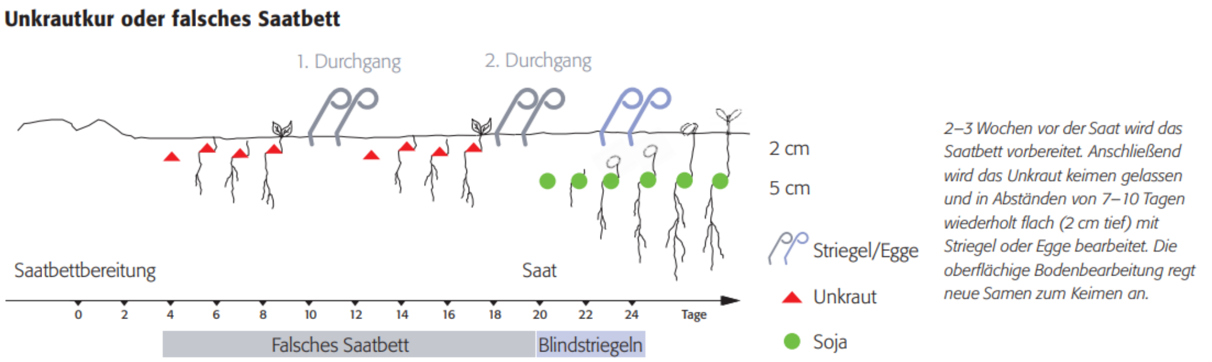


Figure 2: Steps within the false-seedbed preparation and suggested timings before soybean sowing. Red color symbolizes weeds, green color soybeans (Bernet et al., 2016).

Intercropping is also possible combining soybean with other summer crops such as sunflower, maize, buckwheat, cereals, camelina, etc. Some experiments are made in France in this domain and further trials need to be done in order to find possibilities (Boissinot, 2015; Cheriere, 2018; ITAB, 2009). The objective is to diversify the productions and also to compete better with weeds. This kind of cropping require specific competences and techniques in order to success and be able to harvest both of the crops. In Luxembourg most of the crops cited here are not cultivated due to a lack of processes. In Germany, experiments with mixed cultivation of soybeans and camelina took place resulting in a lower weed infestation (Froschhammer et al., 2015). Another possibility to grow soybean is to sow it after the harvest of a winter crop for example or in between corn rows. This technique is called relay-cropping, the competition with weeds is also lower due to the presence of the previous crop during the establishment of the soybean (Brun, 2018). But relay-cropping is hardly worth considering in the Luxembourgish climate context.

Different technologies and methods in mechanical weed control are available while less common such as thermal weed control by flaming, electric weed-control or hot water weed-control. Mulching or biological weed control can also be taken into account. The main used machines are harrows and hoes of different types (Bond et al., 2001; Chauvel et al., 2018; Gunsolus, 1990). Harrow and hoe have different spectrum of action. Harrows are non-selective machines which work on the whole soil surface unlike hoes that usually provide an action in between the rows of the crop. Inter-row cultivation is so-called a selective method and can only be used on wide-rows sown crops while harrowing is independent of the width of the rows (Bond et al., 2001). Mechanical weed control is possible from the pre-emergence of the crop, by post-emergence stages and until the entire closing of the canopy. The most common used machines in organic farming or at least cited in technical and research reviews for weed-control are the flex-tine harrow and hoes, at a lower degree, the rotary hoe. Their mode of operation is explained in more detail below (Bernet et al., 2016).

The flex-tine harrow

A flex-tine harrow consists of several individual frames consisting of multiple flexible tines distributed on several rows in order to be able to work the entire soil surface. Weed-control is possible thanks to the contact of the tines with the soil and the vibrations they make thanks to their flexibility and the speed given by the tractor. The harrow does a work in the first one to three centimetres of the soil and can be run over the crop at proper stages. Harrowing is very efficient on very young weeds from the germination up to the two-leaf stage. It is a good way to control weeds before the emergence of the crop. It can also be used later on stronger crops to prevent too much crop losses. In soybean cropping, it can be used as a pre-emergence treatment (blind harrowing) and as a post-emergence action at the two-leaf or first trifoliate leaf and later when the plants are 10 cm to 20 cm high. The efficiency of the flex-tine harrow relies on appropriate adjustments which are the aggressiveness of the tines (by varying their inclination), the speed given by the tractor influence the vibration of the tines (the more speed the more vibrations are) and the levelling of the machine on the soil surface. Running in small soybean has to be done carefully with a slow speed and low aggressiveness to prevent plant losses that can be higher than 10 % in this case (AGRIDEA, 2018; Bernet et al., 2016, Bond et al., 2001; Chauvel et al., 2018; Davies et al., 2002; Guimas, 2017; Le Gall et al., 2017; Sicard et al., 2012).

The rotary hoe

The rotary hoe is built with discs ended by tooth that work on the whole soil surface too. The rotary hoe has the same effects than the flex-tine harrow on small weeds and can be used at the same stages. Pulling out the weeds and burying them is the way of weed-control of the machine. It has to be well adjusted at the level of the soil and the efficiency is related to the driving speed. The machine is very efficient at high speed like 15 km/h. The rotary hoe is very adapted to work on very crusted or hard soil surface (Bernet et al, 2016).

The hoe

The hoe has another principle of working than the harrow and the rotary hoe. It is made of single elements that can work on the inter-row only. The adaptation of row-spacing is depending on the machine and can vary from 20 cm to 50 cm or more. The working elements can be very different depending on the soil context and the type of soil. They can be simple flexible or more rigid tines that work deeply, larger shares/lames that scalp the soil more widely, flex-tines or discs. The principle is that the elements cut the roots of the weeds or pull them out. Also, in some cases, there is a hilling effect on the row which contribute to the burying of some weeds within the row. The hoe can be used on young stages of the crop but also later when they are more developed. The machine is also able to destroy some more mature weeds that have 3 to 4 leaves and is efficient on perennial weeds too by pulling out the roots. Elements that are working within the row are possible to add. They are called finger weeder. With a rotation movement and the finger, they are able to pull out the young weeds in between the plants. The precision of hoeing relies on a perfect guidance. Nowadays new technologies facilitate the tasks and only one driver is required. Indeed, it is possible to use a GPS or RTK system to follow the rows. Some machines are equipped with a camera that is able to recognise the rows and to guide the hoe. But these technologies represent a high investment for farmers. Buying these machines in cooperative for the use of agricultural equipment or calling a service provider can be solutions to make them accessible and profitable. Hoeing can be performed from the first trifoliate stage of the soybean until the full closure of the rows (AGRIDEA, 2018; Bernet et al., 2016, Bond et al., 2001; Chauvel et al., 2018; Davies et al., 2002; Guimas, 2017; Le Gall et al., 2017; Sicard et al., 2012).

As indicated in the descriptions of the machines, they have different specificity in terms of mode of action and moment of efficiency. The recommended timings for each method in soybean cultivation are shown in Figure 3.

Welches Gerät wann einsetzen?

	Saat	Keimung (BBCH 05)	Aufgang	1. Blattpaar (BBCH 10)	(BBCH 12)	Wachstum (BBCH 32)	(BBCH 39)	Blüte (40–60 cm)	
Ganzflächige Unkrautregulierung									
Striegel	8–12 km/h ●●●● UK < 1–2 cm	3–8 km/h ●●● UK < 1 cm		2–3 km/h ●● UK < 1 cm	3–5 km/h ●● UK < 1 cm	5–8 km/h ●●● UK 1–3 cm	6–12 km/h ●●●●● UK < 3 cm		Bei jungen Pflanzen langsam fahren, damit diese nicht zugedeckt werden!
Rollhacke	10–20 km/h	10–20 km/h UK < 1 cm		6–10 km/h UK < 1 cm	10–15 km/h UK < 1 cm	10–20 km/h UK < 1 cm	10–20 km/h UK < 1 cm		Bei jungen Pflanzen langsam fahren, damit diese nicht zugedeckt werden!
Rollstriegel	8–12 km/h ●●●● UK < 1–2 cm	3–4 km/h ●● UK < 1 cm		2–6 km/h ● UK < 1 cm	4–6 km/h ●● UK < 1 cm	8–10 km/h ●●● UK < 1–2 cm			Gut auf steinigen Böden, verstopft kaum.
Unkrautregulierung *zwischen den Reihen*									
Scharhacke		3 km/h *	3 km/h *	3 km/h *	3 km/h UK < 5 cm	5 km/h UK < 10 cm	5–10 km/h UK < 10 cm	5–10 km/h UK < 10 cm	Bei jungen Pflanzen Schutzscheiben anbringen, in älteren Beständen anhäufeln.
Sternhacke						3–6 km/h UK < 10 cm	3–6 km/h UK < 10 cm		Maximale Bearbeitungstiefe 5 cm. In älteren Beständen anhäufeln.
Zusatzhackelemente zur Unkrautregulierung *in den Reihen*									
Torsionshacke				3 km/h UK < 1–2 cm	3–6 km/h UK < 2–3 cm	3–6 km/h UK < 2–3 cm			Ideal in Kombination mit Striegel oder Hackgerät.
Flachhäufler		3 km/h ● *	3–4 km/h ● *	3–5 km/h ●● *	3–6 km/h ●● UK < 2–3 cm	5–7 km/h ●●● UK < 2–3 cm	5–10 km/h ●●● UK < 5 cm	5–10 km/h ●●● UK < 5 cm	Deckt Unkräuter in der Reihe zu. Nicht ideal auf steinigen Böden.
Fingerhacke		3 km/h ● *	3–4 km/h ● *	3–5 km/h ● *	3 km/h ●● UK < 2–3 cm	5 km/h ●●● UK < 2–3 cm	5–10 km/h ●●●● UK < 5 cm	5–10 km/h ●●●● UK < 5 cm	Bis BBCH 10 kein Eingreifen der Finger in die Reihe möglich.

UK = Unkraut (Länge bzw. Größe in cm)
* leichtes , einmaliges Anhäufeln im Stadium Saat bis 1. Laubblattpaar in der Reihe möglich, Saatreihe muss erkennbar sein

Quellen: CETIOM, Agridea, Expertenbefragung

Geräteeinsatz: Einfach, optimal · Relativ einfach · Mit Vorsicht · Nicht empfohlen!
Geräteeinstellung: ● schwach ●●●●● stark

Figure 3: Overview of the recommended timings (BBCH stages) to use different mechanical weed control techniques. Marks in red color indicate machine should not be used, green color indicating optimal stage for treatment. Dots symbolize the degree of device adjustment from weak to hard (Bernet et al., 2016).

The direct weed-control strategy has to start as early as possible in soybean in order to take advantage on the weeds and to create an interval of growing stages between the crop and the weeds (Sicard et al., 2012). It is essential to ensure good growing conditions for the soybean and to allow the work of machines later when the soybean is better enrooted and weeds are small (Chauvel et al., 2018). Weeding in soybean starts at the pre-emergence stage (generally 3 to 7 days after sowing) (Bond et al., 2001; Chauvel et al., 2018; Dordevik et al., 2019; Le Gall et al., 2017; Place et al., 2009; Pousset, 2016; Terres Inovia, 2019; Zaefarian et al., 2016). Blind harrowing can be made with the help of a flex-tine harrow or a rotary hoe. The aim is to work in the first 1-2 cm of the soil in order to eliminate the emerging weeds at their most sensible stage (Terres Inovia, 2019; Zaefarian et al., 2016). Practicing this technique requires that the soybean is sown deep enough around 4 cm (Dordevik et al., 2019; Terres Inovia, 2019).

From the stage of two leaves of the soybean or at the first trifoliate stage, further mechanical operation are possible such harrowing and hoeing (Chauvel et al., 2018; Pousset, 2016). The advantage of using a harrow or a rotary hoe is that they are non-selective machines which do a work on the whole surface including in the rows of the crops facilitating the weeds control within the row. Harrowing is recommended from the stage of two leaves, to 8 leaves but its efficiency is limited about 10% to 50 % (Chauvel et al., 2018; Sicard et al., 2012). Hoeing in between the rows is also possible at these stages (Anaele et al., 1992; Chauvel et al., 2018) but offer also the possibility to act later in the crop. Inter-row cultivation is possible until the fully closure of the canopy from when driving with the tractor and the machine would damage too much soybean (Anaele et al., 1992; Pousset, 2016; Sicard et al., 2012). The efficiency of the hoe is also better on bigger weeds and perennial species (Pousset, 2016). A longer delay between two runs is not a problem with this technique and offer more flexibility in the time. Controlling the weed population should be done 8 to 10 days after each run, in order to be able to act at the right time (Le Gall et al., 2017). On average, it is showed in previous general studies that soybean performed well with the occurrence of one to three mechanical runs until the closure of the canopy which is often the case at the stage of blooming of the soybean (Anaele et al., 1992; Chauvel et al., 2018; Lecomte et al., 2002; Pousset, 2016; PROTA, 2006; Sicard et al., 2012). No studies were found focusing on the soil conditions and site specifications within Luxembourg or the Greater Region that show how legumes perform under different hoeing constellations.

The speed of driving when using a machine is determinant for the success of weeding. By driving faster, a flex-tine harrow will perform better thanks to more vibrations but can be more aggressive towards the crop (Sicard et al., 2012). By operating on critical plantlets, the speed should be low in order to avoid too much crop damages. Then, an important parameter is the soil. Depending on the texture of the soil (loamy, sandy, clay), the type of machine can differ, at least the tines used. Within soybean cultivation in Europe only few studies focusing on soil textures are available. A very hard crust can be formed at the surface of a loamy soil making the use of a flex-tine harrow difficult since the tines do not have the strength to break it. In this case a device like a rotary hoe is more adapted (Bernet et al., 2016).

Combining different methods often give the best result in terms of weed-control since they have different spectrum of action (Bond et al., 2001; Gunsolus, 1990; Lecomte et al., 2002; Place et al., 2009). Harrow is said to be more efficient on small emerging weeds while hoes give good result on bigger weeds (Dordevik et al., 2019). The combination of blind harrowing, harrowing and then hoeing seemed to be the most satisfying according to previous studies (Chauvel et al., 2018; Le Gall et al., 2017; Lecomte et al., 2002; Pousset, 2016; Sicard et al., 2012). But no expertise focusing on growing conditions and interactions of these mechanical treatments in row crops on Luxembourgish conditions are available.

In addition to weed-control, mechanical weeding provides also side-benefits to the crop and the field. Indeed, by working the first centimetres of the top layer of the soil, the machines break the eventual crust that is formed on the surface of the soil after an episode of rain particularly for loamy soil where the particles are really small and sensible to crusting. Breaking down the crust at the surface facilitates the infiltration of water into the deeper layers of soil (Dordevik et al., 2019; Gunsolus, 1990). It can also help the emergence of the soybean plantlets when an operation is run few days after sowing before the establishment of the cotyledons at the surface. Soil crusting is often source of emerging difficulties for soybean. Losses of 2 to 7 % of the yield can be achieved according to (Casteel, 2010). Soil tillage is good for the oxygenation of the soil therefore favouring the activity of the soil fauna and micro-organisms (Dordevik et al., 2019; Gunsolus, 1990). Furthermore, increases of mineralisation rates are often encountered due to soil tillage which is important in organic farming in order to achieve the nutrients' cycle necessary for the crops but they are also benefiting to weeds (Bond et al., 2001).

Trying to figure out which strategy is the best is essential to ensure the production of soybeans but it is dependant of every context in terms of available methods and in terms of soil type and weed infestation (Bond et al., 2001). Nevertheless, direct weed control has a limited impact on the medium and long-term weed management (Anaele et al., 1992; Dordevik et al., 2019). Besides, performing mechanical weed-control imply new investments in terms of machines and maybe technologies as well as increasing the production costs since every operation requires time, fuel and at least a driver (Bond et al., 2001; Chauvel et al., 2018). Focusing on the time scale dependent effects along the crop rotation period it is to state that there is still need for further research.

To sum up, the choice of the best mechanical weed regulation technique is very complex and, even more important, weather and soil dependant as well as to be adapted regionally. In Luxembourg only few row crops are cultivated. The most common crop cultivated is maize. Here mechanical weed control is also performed but combined with herbicide use in conventional agriculture. Mechanical weeding techniques are limited and experience of these techniques under the Luxemburgish conditions are not existent. Furthermore, to the knowledge of the authors, no study comparing different weeding techniques in soybean cultivation from a national point of view and adapted to the small-scale site conditions exist.

2.5 Remote sensing for vegetation monitoring

Continuous innovation in developing new agricultural techniques, such as monitoring approaches based on innovative geospatial data products is necessary to meet future demands for agricultural production (Atzberger, 2013; Foley et al., 2011). A variety of such techniques already exists, including precision agriculture, drip irrigation, soil conservation and wetland restoration.

Geospatial data is gaining increasing importance in ecological, agricultural and vegetation monitoring applications (Atzberger, 2013), yet these products need to fulfil a number of requirements. These requirements are specific for agricultural applications and comprise amongst others:

- Agricultural production follows strong seasonal patterns related to the biological lifecycle of crops. To accurately estimate crop parameters, it is mandatory that data and derived models provide estimates as early as possible updated periodically (Atzberger, 2013).
- Crop production depends on many parameters (e.g. soil type, climatic variables and agricultural management practices). In areas, where these parameters are highly variable, a high sampling density and a high sampling frequency is mandatory.
- Due to unfavorable growing conditions, productivity can change within short time periods. As a consequence, it is mandatory for agricultural monitoring systems to be timely. According to FAO, the need for timeliness is a major factor underlying agricultural statistics and associated monitoring systems – information is worth little if it is available too late (FAO, 2010).

Optimizing food production is hardly possible in areas where highly technologized monocultures are the predominant agricultural system. Compared to these advanced agricultural techniques, low performing areas have a higher potential of yield increase with lower stress on natural ecosystems (Foley et al., 2011; Tilman et al., 2011; West et al., 2014). These yield gaps are situated mostly in ecologically sensitive areas, which are variable in time and space. To monitor these areas on a global scale, remote sensing methods are assumed to be an effective and promising technique for the acquisition of geospatial data.

Remote sensing is a key technique excellently suited for the collection of objective geospatial data with focus on vegetation (Bastiaanssen et al., 2000). Especially satellite remote sensing has two major advantages against airborne remote sensing or field data collection: satellite remote sensing can provide base data in a timely manner and over large areas (sub regional to global level) with reasonable costs (Roughgarden et al., 1991). Although one technique cannot overcome the entirety of the mentioned challenges, remote sensing techniques provide valuable methods and datasets for a wide applications in a variety of domains such as agriculture, ecology, biodiversity etc. (Kerr and Ostrovsky, 2003).

To date, different satellites provide imagery that is used for vegetation monitoring applications. Here, the classical remote sensing tradeoff between global coverage, revisit time, spatial and spectral resolution becomes relevant. The technical specifications of currently available satellites are designed in order to fulfill the requirements of a wide palette of applications with one sensor system. As a consequence, compromises need to be accepted when focusing on one special topic.

On the one hand, data products from the Advanced Very High Resolution Radiometer (AVHRR) or Moderate Resolution Imaging Spectroradiometer (MODIS) are available with global coverage and high revisit frequencies to the disadvantage of spatial resolution (Prasad et al., 2007; Rembold et al., 2013). On the other hand, high resolution satellites like Quickbird and WorldView collect data of specified hotspots and are not able to cover globally. In addition, these systems often lack spectral resolution. The lack of global coverage and lack of spatial or spectral resolution limits the suitability for vegetation applications. However, the launch of the Sentinel-2 satellite constellation now provides the availability of multispectral image data at high revisit frequencies, high spatial resolutions and at global scale. Revisiting the idea of optimizing agricultural practices in sensitive regions in order to close the yield gap, satellite missions like Sentinel-2 provide the possibility of an operational monitoring.

Among the new advances, unmanned aerial vehicles (UAVs) equipped with perception systems have demonstrated suitability in the timely assessment and monitoring of vegetation. They can be operated at low altitudes, providing an ultra-high spatial resolution image, have great flexibility of flight scheduling for data collection at critical and desired moments and, also, the generation of digital surface models (DSMs) using highly overlapped images and photo-reconstruction techniques or artificial vision.

2.6 Remote Sensing for weed regulation

The use of remote sensing techniques is believed to have big potential in precision agriculture and more precisely in applications of weed monitoring and weed regulation. In conventional agriculture, knowledge of the exact location and species of weed allows a significant reduction of herbicides. The most challenging processing step in remote sensing weed detection in agricultural crops consists in distinguishing geometrically or spectrally weeds from crops. Several methods and procedures have been published in this regard.

Peña et al. (2013) calculated weed maps in maize fields using multispectral recordings. So-called "super pixels" were extracted from the image data based on their spatial and spectral properties. In a subsequent publication by Peña et al. (2015) a similar methodology was used at different altitudes. The best results were achieved with 90% overall accuracy at an altitude of 40 m, which corresponds to a pixel size of 15 mm. Furthermore, it was found that the availability of near-infrared data significantly improves the detection of vegetation.

Artificial intelligence was also used to distinguish crops from weeds in drone-based mapping. Perez-Ortiz et al. (2015) differentiate so-called image patches into the classes of value crops, weeds and soil. For this purpose, pixel intensities from multispectral data and geometric texture parameters representing culture series are used. Different machine learning algorithms were evaluated against each other and achieved overall accuracies of 75 – 87 % in the classification.

Perez-Ortiz et al. (2016) used a Support Vector Machines (SVM) classifier to discriminate crops and weeds based on RGB data in sunflower and maize fields. Different approaches for the detection within the culture series and between the culture series were presented. For this purpose, statistical parameters of pixel intensities, textures and shapes were incorporated into the classification.

A different approach was tested by Guerrero et al. (2012) who published a methodology that allows weeds to be detected in maize fields after they have changed their optical properties due to precipitation, drought or after herbicide application.

Garcia et al. (2015) carried out a study in which sugar beets and thistles were separated using multispectral data. A partial least square discriminant analysis, in which the bands 521, 570 and 658 nm were used for the feature extraction, achieved accuracies of 84 % and 93 % for sugar beet and thistles.

Another approach worth mentioning was that of Mortensen et al. (2016). Different crops were classified using so-called neural networks and the respective biomass was estimated. For this purpose, using RGB image data, which were recorded from an altitude of 3 m above ground, accuracies of 80 % were achieved. Liujun et al. (2016) also used support vector machines and were able to present initial results for differentiating between weed species.

David & Ballado (2017) developed a workflow to differentiate vegetation from soil using 5 cm / pixel RGB data. From the latter, object-based classification methods were applied to previously segmented image areas. The support vector machine algorithm delivered remarkable results, which could be further improved by adding texture features.

The approach used by Lottes et al. (2017) extracts visual and geometric properties in the image data and submits the latter to a random forest classifier to distinguish the weeds from the cultivated plants. Plant rows are optionally detected and included in the classification as further information.

In the framework of the LeguTec project, a mechanical weed regulation and its efficiency are topic of investigation. Using the chosen mechanical equipment (flex-tine harrow, rotary hoe and hoe) a site-specific application is difficult to apply. Here the high-resolution remote sensing techniques are used for phenotyping, i.e. quantitative analysis of crop traits parameters such as crop canopy cover or photosynthetic activity and stresses. Besides being valuable for the analysis of this specific experimental setup, it has been demonstrated that close remote sensing approaches in combination with appropriate experimental designs and data integration can increase accuracy, precision, and throughput of on-field phenotyping experiments while also reducing cost and labor requirements (Mir et al., 2019). The derived crop parameters and especially their temporal changes throughout the growing season yield information about crop growth and performance. Canopy cover, canopy height, etc. could be used for parametrization and fitting plant growth models (Borra-Serrano et al., 2020).

This becomes especially interesting for organic agriculture, where mechanical weed regulation not only reduces the restricting crop weed interactions but also affects crop physiology through mechanical damages. Thus, the knowledge of the exact crop – weed system allows to optimize the number and timing of weed regulations (Bastiaans et al., 2000; Renton, 2017).

3. Materials and methods exact field trial

3.1 General experimental design

The exact-field trial in LeguTec consisted of three study sites on organic farms spread over Luxembourg, while each site was designed as one-factorial-exact-trial. The following organic farms had been selected: Organic farm Patrick François in Hostert, organic farm Alex Mehlen in Manternach and organic farm "An Dudel" of Marc Emering in Sprinkange (see Figure 4).

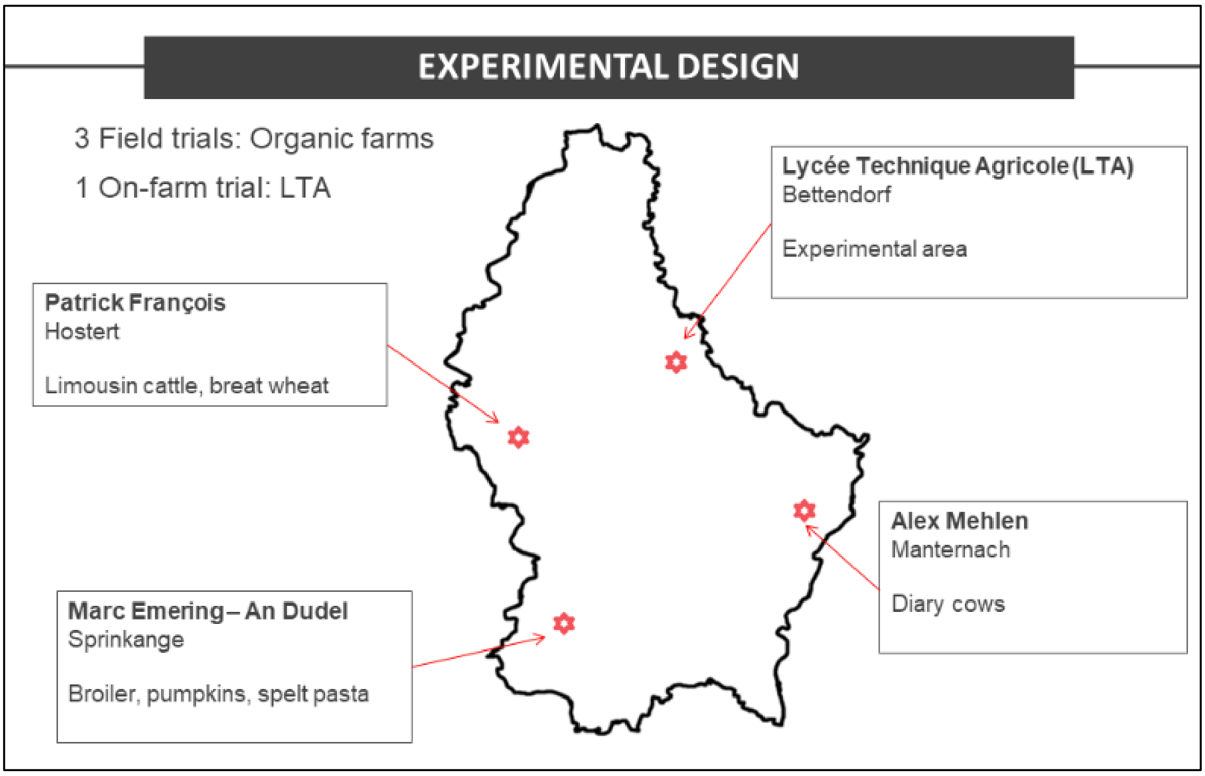


Figure 4: Locations of the study sites in Luxembourg. The main agricultural production of the farmers is given.

The three organic field trials were set as randomized complete blocks consisting of five different systems of mechanical weed control as well as two control plots that were tested and compared: A negative control plot ($t.1_{neg}$), where no weed control was administered, and a positive control plot ($t.2_{pos}$), where all weed was taken out of the plots by hand, were considered as well. Mechanical treatments were implemented including harrowing ($t.3_{har}$), hoeing with interrow cultivator with duck foot shares ($t.4_{hoe}$), hoeing with interrow cultivator with duck foot shares and finger weeder ($t.5_{hoe+}$), a flexible system, a combination of treatment 3 and 5 ($t.6_{comb}$), while the decision was made according to the actual site and weather conditions and, intercropping of soybean and camelina in combination with harrow ($t.7_{mix}$). The treatments were set in four replicates as randomized complete blocks (see Figure 5 and Appendix 1, Appendix 2, Appendix 3). The row spacing of the soybean plants as well as the plot width depended on the treatments. 12.5 cm row spacing was selected for treatments $t.1_{neg,}$ $t.2_{pos,}$ $t.3_{har,}$ $t.7_{mix}$ and 37.5 cm for treatments $t.4_{hoe,}$ $t.5_{hoe+}$ and $t.6_{comb}$.

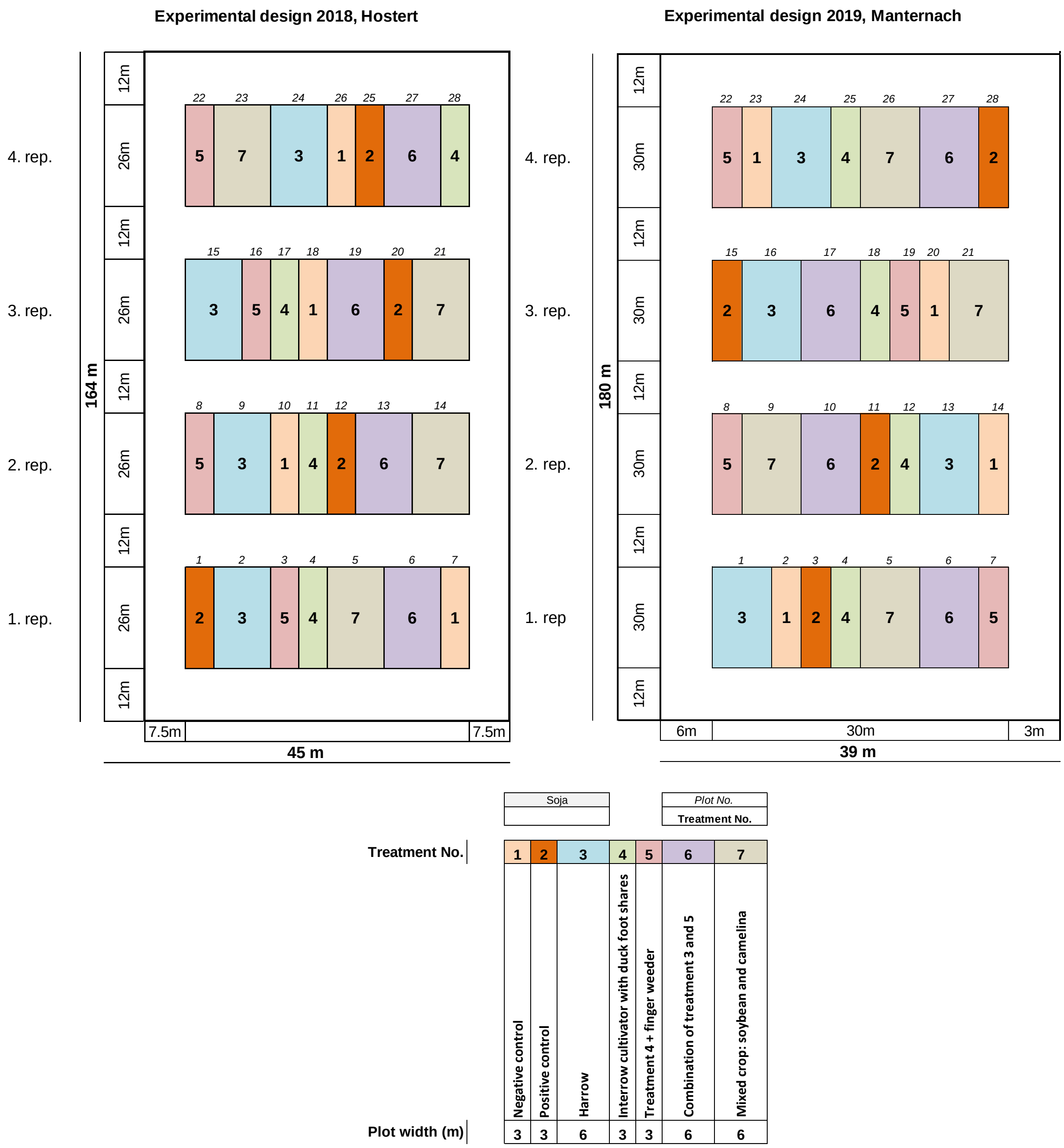


Figure 5: Experimental design of LeguTec study site Hostert 2018 and Mantenach 2019. Numbers within the plots indicate the treatment according to the legend (middle).

The choice of the study sites on the three organic farms in Luxembourg was already made in 2017, having taken into account the criteria that the soybean fits into the crop rotation, that the location of the sites is relatively homogeneous with as little slope as possible and taking different soil types into account.

Weed harrowing was done with the machinery of the respective farmer, whereby the uniform harrow width was six meters. Hoeing was carried out with a technique of the manufacturer Hatzenbichler, which included duck foot shares with the attachment element of finger weeders. The three meters wide hoe was provided by the agricultural engineering company Wolff-Weyland S.A., as well as the 24-row, three-meter-wide mechanical seed drill of the manufacturer Amazone. Sowing, harvesting and the operations with the hoe were carried out in cooperation with the technical staff of the LTA. The weed control dates were tried to be best performed according to common practice criteria such as weather and soil conditions as well as plant development.

3.2. Soybean cropping itinerary

3.2.1 Pre-sowing soil analysis

A soil analysis was made for each site in order to analyse the content of the soil for several nutrients such as $CaCl_2$ for the pH, P_2O_5, K_2O, Mg, Na, C_{org} and N_{min}. Soil samples were taken before the soil preparation and were analysed at Administration des services techniques de l'agriculture (ASTA) laboratory in Ettelbrück.

3.2.2 Soil preparation

Each farmer was in charge to prepare the seedbed of their respective field but with the help of IBLA advisors. All the parcels were ploughed (whether in autumn or in spring). Based on the soil samples taken, it was decided to fertilize the areas with lime and phosphorus to create ideal conditions for the soybean plant, which has its optimum growth range at a pH value in the weakly acidic to neutral growth range (pH 6.5 - 7) (Recknagel, et al., 2018). The target phosphorus content in the soil should have been 10-12 mg/100 g dry soil to counteract the phosphorus removal of about 1.5 kg/dt soybeans (Hahn et al., 2013). The lime (carbonic acid lime 95, dry) was provided by the company MUELLERKALK DE. After ploughing, a few weeks prior to sowing, a tillage was realized with a cultivator, a harrow or a rotary harrow in order to prepare a false seedbed and enhance the germination of weeds. According to weather and soil conditions, this operation was realised twice with an interval of two weeks (for more details see Table 3).

3.2.3 Sowing modalities

The date of sowing was determined by the temperature of the soil, that is advised from 10 °C onwards. The soil temperature in the first 30 cm was recorded by a tensiometer (from the ©Weenat company) placed in each site. When the conditions had been favourable: good soil temperature and not wet soil, sowing is possible. It generally occurred from mid-April until mid-May according to the weather variability of each project year. Sowing was done with a three-meter-wide mechanical seed drill (24 rows) of the manufacturer Amazone provided by the agricultural engineering company Wolff-Weyland SA. The treatments $t.1_{neg}$, $t.2_{pos}$, $t.3_{har}$, $t.7_{mix}$ were sown with a small row-spacing (24 rows, 12.5 cm wide) since only harrowing or no weed control were done in these plots. They were sown first for each replicate. Then, treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ were sown with a 37.5 cm wide rows by opening every third row of the seed drill which represents eight rows on a three meters width. The soybean variety Merlin from the ripening group "000" was cultivated. Merlin had already proven itself as a variety in previous trials in Luxembourg (Stoll et al., 2015; Zimmer, 2016a). Seeding density was adjusted regarding the Thousand Kernel Weight (TKW) of the seeds and the ability of germination. The calculations were based on the aim to reach 65 plants per square meter. A prior necessary inoculation with the inoculant BIODOZ Soya in 2018 and with Rizoliq Top S in 2019 from the manufacturer DeSangosse was made. The inoculation medium had to be change because of the non-availability of BIODOZ in 2019 (see the first picture on the left in Figure 6). Soybean seeds were put at a depth of 4 cm allowing blind harrowing without disturbing the germination of seeds.

Figure 6: Inoculation of the soybean (left, photo: IBLA), view of the seeding from above (center, photo: Serge Heuschling) and blind harrowing (right, photo: IBLA).

3.2.4 Blind harrowing

Blind harrowing was done where possible, according to soil and weather conditions and the stage of development of the seedling (until BBCH 07 see Appendix 4 - Appendix 6) in 3 to 7 days following seeding. The decision of going was made thanks to the observation in the field of the stage of germination of soybean seeds. When the hypocotyl starts to get up just before the emergence on the soil surface, it is too late to act. Also, the wetness of the soil restricts the possibility of harrowing. Blind harrowing was performed with the respective 6 m wide flex-tine harrow of the respective farmers for treatments $t.3_{har}$, $t.6_{comb}$ and $t.7_{mix}$ that were 6 m wide and reached a maximum depth of 2 cm. The aim was to destroy the already emerging weeds (see Figure 6, photo on the right).

3.2.5 Post-emergence weed control

Weed control treatments were performed according to common practice criteria, such as weather, soil conditions and plant development. The aim was to do at least two weeding runs taking into account that mechanical weeding was possible until the interrow closure. Hoeing was carried out with a technique of the manufacturer Hatzenbichler, which included duck foot shares and the attachment elements of finger weeders. Hoeing with duck foot shares was done for treatment $t.4_{hoe}$, and hoeing with duck foot shares and finger weeder, for treatments $t.5_{har+}$ and, if considered as best option, for treatment $t.6_{comb}$ (see Figure 7). It is to mention that finger-weeding applications were only used, when soybean development and soil conditions allowed this. The three meters wide hoe was provided by the agricultural engineering company Wolff-Weyland S.A.. Harrowing was repeated with the 6 m flex-tine harrow of the farmers, in treatments $t.3_{har}$ and $t.7_{mix}$. For treatment $t.7_{mix}$, the camelina seeds were spread by hand at the soil surface before the run of the harrow. The cultivar Celena was sown at a density of 3.6 kg ha^{-1}. Where weather conditions and soybean plant development stage allowed, as much mechanical weed control runs were performed as possible until flowering, where the soybean canopy closes.

Figure 7: Mechanical weed control with harrow (left), hoe with duck foot shares (middle) and hoe with finger weeder (right) (photos: IBLA).

3.2.6 Harvest

The combine plot harvester of the agricultural school threshed out the respective harvest plots and the remaining crop was harvested by the combine harvester of the respective farmer (see Figure 8). In addition to the yield structure, various harvest parameters were collected at harvest (see Table 5) and a partial milled sample was sent to the ASTA laboratory to determine the protein content. Yield structure was determined manually.

Figure 8: Harvesting the soybeans with the plot harvester (left and middle, photos: IBLA) and the combine harvester of the farmer Marc Emering in Sprinkange (right, photo by Nikos Zompolas).

3.3 Experimental design 2018 and site characteristics

According to the previous mentioned steps of soybean cultivation in LeguTec, Table 1 provides an overview of the three study sites in 2018 including i.a. the site characteristics and data on the treatments carried out as well as the assessment dates for each BBCH stage of soybean development according to Munger et al. (1997).

Table 1: Key figures in the LeguTec project as well as data of the work steps carried out in 2018. Temperature and precipitation are given as a 7-year average (2011-2017, agrimeteo.lu) and 3-year average for Manternach. CHU from 01.05.-15.09. The development stage of the soy plant is indicated in brackets with the aid of the BBCH scale according to Munger et al., 1997.

LeguTec		**Manternach (Mehlen)**		**Hostert (François)**		**Sprinkange (Emering)**	
Study site	**Year of investigation**	**2018**					
	FLIK number	P0158691		P0761342, Schlag 2		P0915621	
	area field (ha)	0.69		0.74		0.69	
	m a.s.l.	281		464		336	
	Ø-Temp (°C)	10		9.1		9.7	
	Ø-precipitation ∑ (mm)	671.2		920.9		681.2	
	CHU (crop heat unit)	2972		2708.8		2647.6	
	Soil type	sandy-clayey brown earth from dolomite		stony-loamy and sandy-cleyey brown earth and luvisols		clayey brown earth	
	Soil parameter						
	soil extraction date	Sep.16	Aug.18	Feb.18	Sep.18	Nov.17	Sep.18
	pH (CaCl2)	6.1	6.5	5.3	5.5	6.3	6.2
	K_2O (mg/100 g tr. Boden)	14	11	23	23	14	11
	P_2O_5 (mg/100 g tr. Boden)	8	7	11	9	6	4
	Mg (mg/100 g tr. Boden)	20	21	13	15	10	10
	Na (mg/100 g tr. Boden)	NA	1	1	1	1	1
	Nmin (kg Nitrat-N/ha)	NA	44	NA	44	38	16
	previous crop	Triticale		winter wheat		spelt	
	intercrop			sunflower		summer oat	
Primary cultivation	**Plough**	21.02.		26.03.		24.02.	
Fertilizer	**Liming date**	12.04. (spring-tooth harrow)		06.04. (rotary harrow)		23.04. (spring-tooth harrow)	
	Amount of lime (kg)	800		1500		800	
	Phosphorus date	12.04. (spring-tooth harrow)		13.04. (harrow)		23.04. (spring-tooth harrow)	
	Amount of phosphorus (kg)	120		80		160	
Sowing	**False seed-bed**	12.04.		13.04.		(23.04.) 15.05. (spring-tooth harrow)	
	Inoculation + sowing	23.04.		24.04.		(26.04.) 17.05.	
	Inoculant	Biodoz Soja					
	Seed rate (seeds/m²)	65					
	Sowing camelina	18.05. (BBCH 11)		27.05. (BBCH 11)		27.06. (BBCH 13)	
	Amount of camelina (kg/ha)	5.8		4.9		3.6	
Mechanical weed control	**Blind harrowing**	27.04. (BBCH 05)		28.04. (BBCH 05)		21.05. (BBCH 05)	
	Harrowing 1					25.06. (only treatment 7) (BBCH 13)	
	Hoeing 1	18.05. (BBCH 11)		25.05. (replicate 1 and 2), 27.05. (		22.06. (BBCH 13)	
	Harrowing 2						
	Hoeing 2	-		-		-	
Chemical	**Pulsar 40**						
	Harmony SX	-		-		-	
Assessments, drone flight	**Assessment, flight BWC**	18.05. (BBCH 11)		25.05. (BBCH 11)		20.06. (BBCH 13)	
	Biomass BWC	18.05. (BBCH 11)		26.05. (BBCH 11)		22.06. (BBCH 13)	
	Assessment, flight AWC	19.05. (BBCH 11)		28.05. (BBCH 11-12)		25.06., 27.06. (Var.7) (BBCH 13)	
	Assessment FLO	14.06., 15.06. (BBCH 65)		03.07., 04.07., 05.07. (BBCH 69)		12.07., 13.07. (BBCH 65)	
	Biomass FLO	15.06. (BBCH 65)		09.07., 10.07., 11.07. (BBCH 70,		16.07. (BBCH 65)	
	SPAD measurement, flight FLO	15.06. (BBCH 65)		09.07. (BBCH 70)		13.07. (BBCH 65)	
	Plant height FLO	14.06. (BBCH 65)		06.07. (BBCH 69)		13.07. (BBCH 65)	
	Biomass HAR	23.08. (BBCH 65)		31.08. (BBCH 97)		13.09. (BBCH 97)	
	Assessment, flight HAR	22.08. (BBCH 97)		29.08. (BBCH 97)		12.09. (BBCH 97)	
Harvest	**Harvest date**	24.08. (BBCH 97)		04.09. (BBCH 97)		17.09. (BBCH 97)	

Thanks to the warm and constant weather from March to April, the sowing could already take place in the middle of April and hence relatively early for these latitudes. At Sprinkange, however, the sowing had to take place again one month later, as it became apparent after emergence that the sowing was not homogeneous, due to a problem with the seed drill. It is to mention that the soybeans were not inoculated again. The used seeds were only pre-inoculated seeds ("Fix-Fertig") and hence the effect of double-inoculation could not be guaranteed.

Mechanical weed control started at all the sites with a harrowing run, the so-called blind harrowing, performed in a time window of up to 4 days after sowing in all the harrow treatments. First emerging weeds are taken out without damaging the soybean seedling. As soon as the first pair of leaves is fully developed, the culture could be harrowed or hoed with slight zinc pressure for the first time. Due to the low weed pressure at Manternach, the hoe was used without the finger weeder in all the hoeing treatments, as the risk of damage to the plants was higher than the expected benefit. On the Hostert experimental site, however, the finger weeder was used directly in combination with the duck foot shares, as an above-average weed pressure was found here right from the start (see Table 2). Due to a rain event, the test field in Sprinkange was not passable at this development stage of the soybean plant and the time for weed regulation had to be postponed. Since the crop was already in BBCH stage 13, a decision was made against a harrow pass in treatment $t.3_{har}$. The harrow was only used in treatment $t.7_{mix}$, as camelina had to be sown and harrowed to loosen the soil structure and help camelina to emergence.

Table 2: Overview of the methods used in the treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7) on the study sites in 2018. Corresponding dates shown in Table 1.

		Manternach							Hostert							Sprinkange						
Timing	**Treatment / Method**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. date	Blind harrowing			x			x	x			x			x	x			x			x	x
2. date	Harrowing			x				x			x				x							x
	Duck foot share				x	x	x					x	x	x					x	x	x	
	Finger weeder												x	x						x	x	

On all study sites, the combination ($t.6_{comb}$) was decided against the use of the harrow, but for the use of the hoe, as this seemed to be visibly the more effective treatment.

At the Manternach site, the weed pressure remained low even after the harrowing and hoeing operations and the crop plant closed the rows relatively quickly, so that no further mechanical use was necessary. Since the weed control in Sprinkange was already late, no further run was possible here either due to the fast closing soybean canopy. In Hostert, the rows also closed relatively quickly and, moreover, the weather did not allow the machine to be used again before flowering, which would have been a particular advantage at this location with its strong weed pressure.

Due to the drought from the time of flowering on, the soybean had to be harvested relatively early. In Manternach the plant went into emergency ripening and some of the pods cracked. Therefore, threshing was already carried out there on 24th of August. The Hostert site followed at the 4th of September and the harvest was completed the 17th of September with the Sprinkange site.

Weather conditions 2018

The season 2018 initially offered ideal conditions for soybean cultivation. A warm spring meant that sowing was possible relatively early, as early as the end of April. Spring was warmer in Luxembourg and higher rainfalls occurred compared to the 10 years average (LIST, 2018a). A lack of rain during the first weeks of May made it possible to blind harrow all the sites (see exemplarily for study site Manternach Figure 10 and for all the sites Appendix 7 - Appendix 9). At study site Sprinkange cracks in the upper soil layers were visible during this time as first signs of a drought period right after emergence. But from end of May on the weather was vigorous right up to mid of June, so that the plants could develop well. Due to the rain events within that time period mechanical weeding was only once on each site possible. Especially the loamy soil at Sprinkange had a long drying time after rain events and made it impossible to drive on with the machines. Figure 9 shows the soil cracks at Sprinkange at the beginning of May and the wet soil at the beginning of June. From mid of June on until mid of August only one little rain event with 10 mm precipitation occurred at the time of flowering in Sprinkange. Lack of rain during flowering and pod development resulted in disadvantageous weather conditions for soybean growth. Summer in Luxembourg was much warmer and much too dry compared to the 10-years average (LIST, 2018b). Only during pod filling stage few rain events occurred in Sprinkange end of August (see Appendix 8).

Figure 9: Soil conditions influenced by weather at Sprinkange: soil cracks 07.05.2018 (left) and wet soil 04.06.2018 (right).

At Manternach site, soybeans were full flowering earlier than on the other sides already mid of June, so that these precipitations were beneficial for soybean growth. From flowering onwards, unfavorable conditions with hot temperatures and much too little rain followed until harvest (see Figure 10). No rain event occurred from mid of June till mid of July exactly the time of soybean pod development and only few events within August during the time of pod filling and ripening. As mentioned before, soybeans therefore had to go into emergency ripening with pod opening and forced the LeguTec team to an early harvest.

Hostert was characterized by little more precipitations. During the first stages of soybean development, not only soybeans profited from precipitations but also the high number of weeds. It would have been helpful to treat weeds mechanically some more times but the wet soil conditions didn't allow this. Canopy closed fast and at the beginning of July, shortly before soybeans were fully flowering, again rain events occurred. Like on the other study sites, pod development suffered from lack of precipitation and high temperatures. During pod development, few rain events occurred and helped the soybeans not to go into emergency ripening as observed in Manternach.

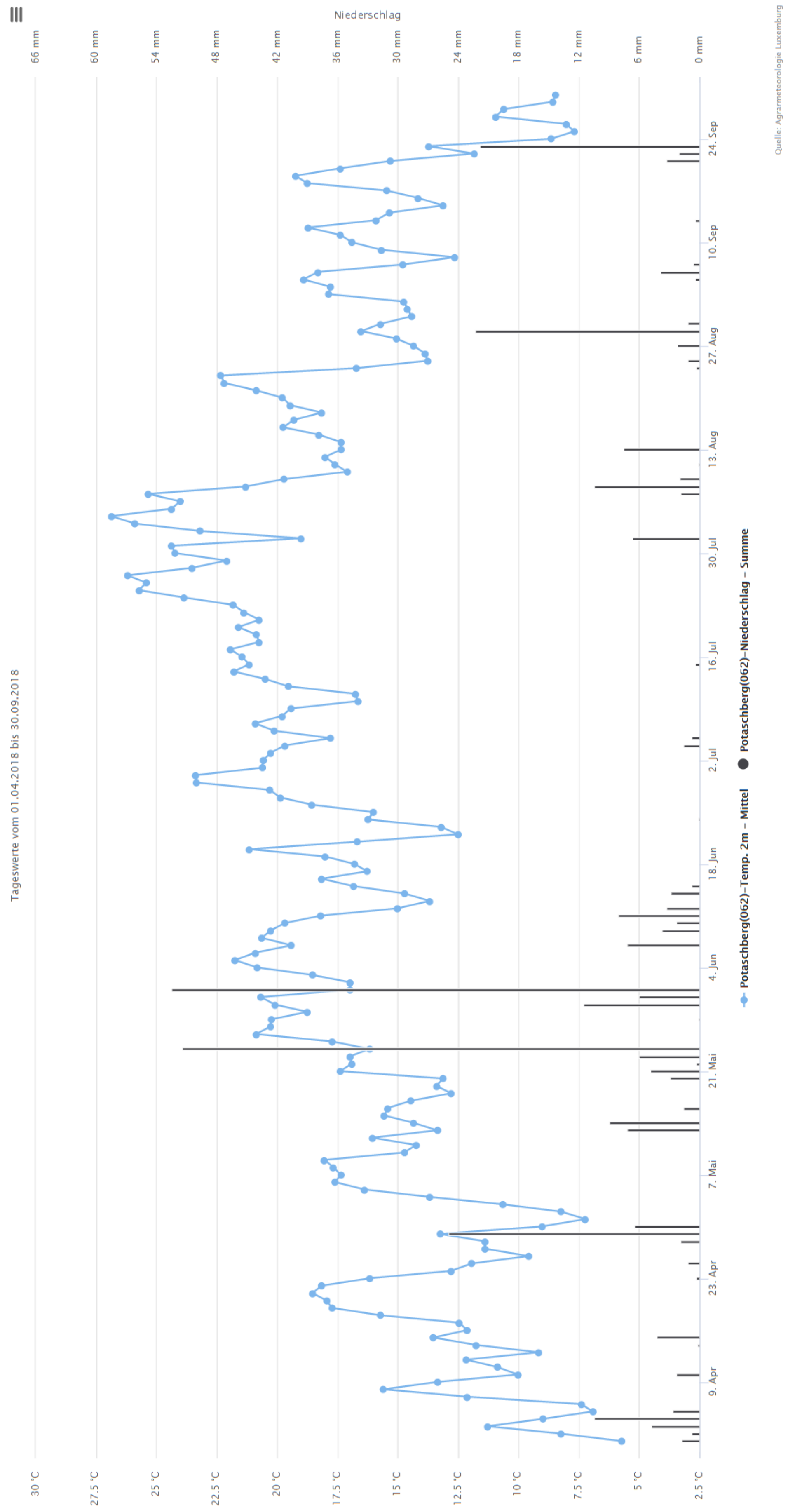


Figure 10: Daily mean temperature (blue line) and precipitation (black bars) of weather station Potaschbierg, representative for study site Manternach in 2018 (agrimeteo.lu).

3.4 Experimental design 2019 and site characteristics

Focusing on the second year 2019 in LeguTec, Table 3 provides an overview of the study sites, site characteristics and data on the treatments carried out as well as assessment dates.

Table 3: Key figures in the LeguTec project as well as data of the work steps carried out in 2019. Temperature and precipitation are given as 7-year average (2012-2018, agrimeteo.lu) and 4-year average for Manternach. . CHU from 01.05.-15.09. The development stage of the soy plant is indicated in brackets with the aid of the BBCH scale according to Munger et al., 1997.

LeguTec		Manternach (Mehlen)			Sprinkange (Emering)		Hostert (François)	
Study site	**Year of investigation**	2019						
	FLIK number	P0502744			P0915621 (2)		P0135925	
	area field (ha)	0.7			0.95		0.87	
	m a.s.l.	279			330		457	
	Ø-Temp (°C)	10.2			9.0		9.8	
	Ø-precipitation ∑ (mm)	695.7			941.5		708.1	
	CHU (crop heat unit)	3247.6			2647.6		2708.8	
	Soil type	stony-clayey brown earth from dolomite			clayey brown earth		stony-loamy brown earth from shale and phyllades	
	Soil parameter							
	soil extraction date	Okt.18	Mai.19	Okt.19	Mai.19	Okt.19	Okt.18	Okt.19
	pH (CaCl2)	6.7	6.8	6.4	6.4	6.3	5.7	5.8
	K_2O (mg/100 g tr. Boden)	16	18	19	14	16	50	14
	P_2O_5 (mg/100 g tr. Boden)	16	13	13	3	4	12	4
	Mg (mg/100 g tr. Boden)	32	32	26	10	12	17	17
	Na (mg/100 g tr. Boden)	1	1	1	2	1	1	1
	Nmin (kg Nitrat-N/ha)	NA	78	20	25	13	NA	6
	previous crop	Cereal			Spelt		Triticale	
	intercrop	Phacelia			Oat		Oat-buckwheat	
Primary cultivation	**Plough**	06.08.2018			23.04.2019		06.03.2019	
Fertilizer	**Liming date**	-			-		18.04.	
	Amount of lime (kg)	-			-		1000	
	Phosphorus date	-			24.04.		17.04.	
	Amount of phosphorus (kg)	-			200		100	
Sowing	**False seed-bed**	01.04., 20.04. (rotary harrow)			01.05. (rotary harrow)		19.04., 01.05. (rotary harrow)	
	Inoculation + sowing	06.05.			07.05.		16.05.	
	Inoculant	Rizoliq Top S						
	Seed rate (seeds/m²)	65						
	Sowing camelina	04.06.			18.06.		13.06.	
	Amount of camelina (kg/ha)	3.6						
Mechanical weed control	**Blind harrowing**	- 08.05. 15 l rain, no blind-harrowing possible			- 11.05. 30 l rain, no blind-harrowing possible		21.05. (BBCH 05)	
	Harrowing 1							
	Hoeing 1	04.06. (BBCH 12)			18.06. (rotary harrow, hoe) + 21.06. (harrow) (BBCH 23)		13.06.(BBCH 11)	
	Harrowing 2							
	Hoeing 2	21.06. (BBCH 23)			02.07. (BBCH 33)		02.07. (BBCH 66)	
Chemical	**Pulsar 40**	-						
	Harmony SX				-		-	
Assessments, drone flight	**Assessment, flight 1 PRE**	03.06. (BBCH 12)			05.06. (BBCH 11)		11.06. (BBCH 11)	
	Biomass 1	04.06. (BBCH 12)			-		13.06. (BBCH 11)	
	Assessment, flight 1 POST	07.06., 11.06. (BBCH 12)			-		18.06. (BBCH 12)	
	Assessment flowering	09.07. (BBCH 65)			24.07.+25.07., 30.07. (BBCH 69)		16.07. (BBCH 68)	
	Biomass 2 (flowering)	09.07. (BBCH 65)			30.07. (BBCH 69)		23.07. (BBCH 69)	
	SPAD measurement, flight flowering	09.07. (BBCH 65)			24.07. (BBCH 69)		23.07. (BBCH 69)	
	Plant height	09.07. (BBCH 65)			24.07. BBCH 69)		23.07. (BBCH 69)	
	Biomass 3	30.08. (BBCH 89)			10.09. (BBCH 97)		14.10. (BBCH 93)	
	Assessment, flight harvest	30.08. (BBCH 89)			10.09. (BBCH 97)		14. + 17.10. (yield structure) (BBCH 93)	
Harvest	**Harvest date**	02.09. (BBCH 96)			11.09. (BBCH 97)		NA	

The high weed pressure in Hostert during the season 2018 caused the project leaders to improve the soil management. With the continuous consulting of IBLA advisors, soil preparation started in autumn 2018 with ploughing and oak-buckwheat intercropping. Phosphorus and lime were applied as a reason of soil analyses and two false seed-beds were done before sowing was possible the 16th of May 2019 (see Table 3). At Hostert, it was not possible to sow earlier due to cold and wet weather conditions. In Manternach and Sprinkange, sowing was practicable two weeks earlier due to better climatic conditions. Blind harrowing was only possible in Hostert and realized 5 days after sowing in treatments $t.3_{har}$, $t.6_{comb}$ and $t.7_{mix}$ (see Table 4). In Manternach the soil was too wet to allow the blind harrowing due to a rain period, which occurred between the 8th and the 11th of May (see Appendix 10). The same counts for Sprinkange, where 30 l of rain occurred during this period. The heavy soil at Sprinkange made it impossible to drive on the field for a long time also affecting the first run of weed control. After the first pair of leaves was developed (BBCH 11), the first run of weed control could take place. In both Hostert and Manternach, treatments $t.3_{har}$ and $t.7_{mix}$ were harrowed and treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ were hoed with the duck foot shares since the soybean plants were too small to use the finger weeder. In Sprinkange first runs were only possible from BBCH 23 on. The combination of high weed pressure from the beginning of the vegetation period on, mainly due to soil mismanagement (late ploughing, immediate soil-bed preparation followed by again immediate sowing, all caused by above average rainfall in spring) with unfavourable weather conditions made it impossible to control weeds properly. Manual weed control in $t.2_{pos}$ was not possible, too. When stepping on the field was possible from BBCH 23 on, $t.2_{pos}$ was already overgrown with weeds. It was decided then to leave this treatment out since high weed pressure already caused negative effects on soybean growth. The first mechanical weed control in $t.3_{har}$ and $t.7_{mix}$ was done with a rotary harrow provided by the organic farmer Mario Kleer, Everlange, LU. This machine seemed to be the better alternative to the simple harrow that was not able to break the soil crust properly and uproot the already larger grown weeds.

Table 4: Overview of the methods used in the treatment t.1neg (1), t.2pos (2), t.3har (3), t.4hoe (4), t.5hoe+ (5), t.6comb (6) and t.7mix (7). Corresponding dates shown in Table 3.

		Manternach							**Hostert**							**Sprinkange**						
Timing	**Method** / **Treatment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. date	Blind harrowing										x			x	x							
2. date	Harrow			x				x			x				x			x				x
	Rotary harrow																	x				x
	Duck-foot share				x	x	x					x	x	x					x	x	x	
	Finger weeder																					
3. date	Harrow			x							x							x				
	Duck-foot share											x	x	x					x	x	x	
	Finger weeder												x	x						x	x	

A second run of weed control has been made in Manternach, 17 days after the first one, but only for treatment $t.3_{har}$. In hoeing treatments ($t.4_{hoe}$ and $t.5_{hoe+}$), the soybean was too big to allow the use of the hoe and the weed pressure was low. In Hostert, treatment $t.3_{har}$ was harrowed a second time and treatment 4 hoed again while the finger weeder could be used in treatments $t.5_{hoe+}$ and $t.6_{comb}$. These operations have been made 21 days after the first runs. In Sprinkange the dry weather also allowed a second run with the harrow and hoe with finger weeder application in the respective plots ($t.4_{hoe}$ and $t.5_{hoe+}$) two weeks later.

Harvest started at the Manternach site at the beginning of September (02.09.2019) followed by Sprinkange the 11^{th} of September 2019. Soybean at both the study sites went into emergency ripening caused by the high temperatures and drought during maturity. It was decided to harvest at 14.2 % moisture content in Sprinkange and at 16.3 % moisture content at Manternach to avoid pod opening as in the first project year. Harvest was finally not possible in Hostert. Most of the plots didn't go into final maturity because of the decreasing temperature and increasing precipitation in the months of September and October. The maturity was very inhomogeneous across all the treatments. At the point, where the first treatments were ready to harvest, harvesting was not possible due to the high precipitation and very quickly the first soybeans started to be affected by fungi (see Figure 11).

Figure 11: Study site hostert 09.10.2019. Pictures point the inhomogenous ripening and the first pods starting to be affected with funghi (right).

On the 17^{th} of October 2019 it was decided to take the yield structure in Hostert to calculate potential yield of the treatments, while final harvest with the harvester was not possible at all.

Weather conditions 2019

The soybean vegetation season 2019 was characterized by extreme weather conditions, mainly in summer. During spring, nationwide above-average April, cooler May but slight rain surplus in the south of Luxembourg could be observed (ASTA, 2019). The extreme summer 2019 in Luxembourg showed three heat waves, temperature records, temperatures above the 10-years average and rain deficits below average (ASTA, 2019), while highest could be observed on the Manternach site (see Figure 12).

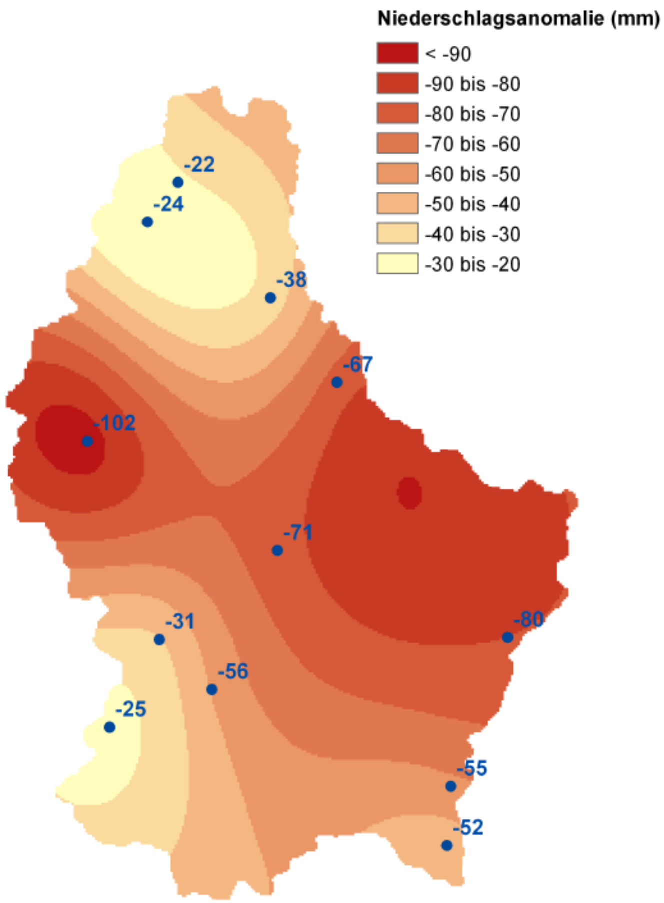


Figure 12: Difference between the precipitation totals of summer 2019 (01.06.-31.08.) and the reference period 1981-2010. Anomalies of the precipitation totals (in blue) at the ASTA stations at which a reference period for 1981-2010 can be determined (ASTA, 2019).

As mentioned before, cold temperatures end of April and beginning of May and rain events end of April resulted in a postponed sowing compared to the previous year. A short period with no precipitation was catched to sow the soybeans but blind-harrowing was not possible due to heavy rain events at Sprinkange and Manternach. In Hostert, the later sowing allowed blind harrowing during a precipitation free short period end of May. Until the beginning of the first development of flowers good growing conditions with continuous rain events in the first half of June were observed on all the sites. Mean temperature and precipitation diagrams were drawn in Appendix 10 - Appendix 12. Only at study site Hostert, soybean growth was shortly interrupted by a hail event taking place the 19th of June and injuring soybeans slightly. Nevertheless, the plants seemed to be able to deal with this without disadvantages. Bernet et al. (2016) describe the ability of soybean plants to compensate damages like this during the vegetative development.

Flowering in Manternach was dated to the beginning of July and in Hostert and Sprinkange to the end of July. Two of the three heatwaves in Luxembourg with temperatures > 30 °C were observed within these time periods (see Figure 13). Temperatures reached up to 35 °C around 26. June up to 39.2 °C around 25. July and additionally up to 33 °C around 7. August (temperatures exemplarily given for study site Manternach). From mid of June till mid of July, the time of flowering in Manternach, no precipitation was observed. During the following weeks of pod development only minor rain events happened so that lack of precipitation negatively influenced soybean growth during these development stages. First half of August, few small rain events occurred but again followed by lack of rainfall until harvest at the beginning of September resulting in soybeans that again went into emergency ripening (see Figure 13).

At Sprinkange, since soybeans flowered later, the August precipitations occurred immediately after flowering and were advantageous for pod developing. But again, no precipitations in the second half of August could be observed that might have be advantageous during the time of pod filling and resulted also in emergency ripening.

Soybeans at Hostert study site profited from immediate precipitations after flowering like in Sprinkange. Decreasing temperatures from end of August on and lack of rain resulted in maturity delay. Soybeans were not yet ripe at the end of September. Continuous precipitation from second half of September on and low temperatures made it impossible for the soybeans to ripe homogeneously. Since rainfall continued within October, the soybean stand couldn't dry up and harvest was not possible at all.

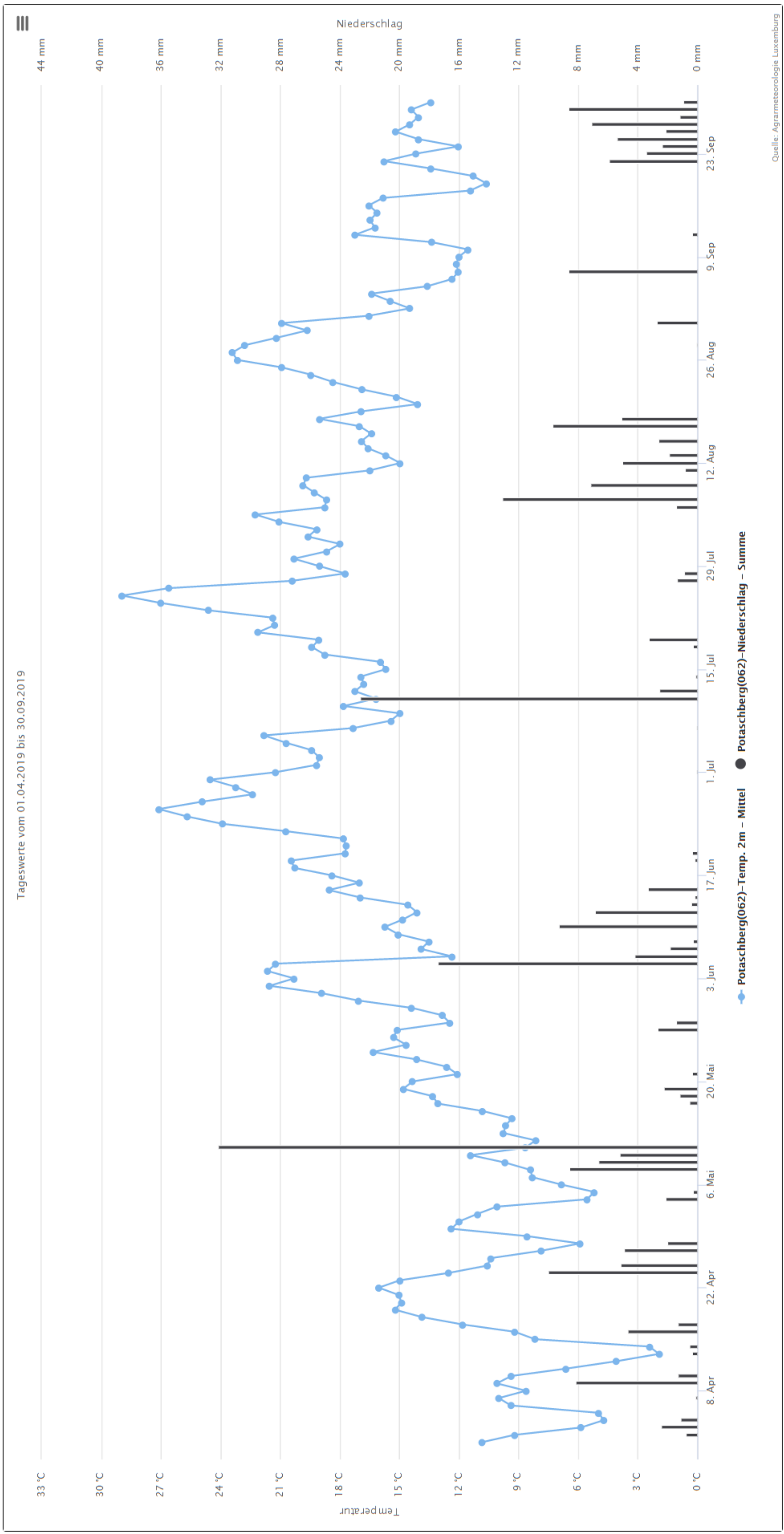


Figure 13: Daily mean temperature (blue line) and precipitation (black bars) of weather station Potaschbierg, representative for study site Manternach in 2019 (agrimeteo.lu).

3.5. Data collection

During the vegetation period several assessments on weed control efficiency, weed composition, soybean plant features and yield characteristics took place manually (see Table 5) and were accompanied by aerial photographs of the project partner Geocoptix GmbH. The assessments were done at different timings: Before Weed Control (BWC), After Weed Control (AWC) both at the moment of the first weed control, at FLOwering (FLO) and at HARvest (HAR).

Table 5: Overview of the surveys and assessments at different timings in the project LeguTec along the two vegetation periods 2018 and 2019.

Timing	**Assessment**
Before sowing	Soil analysis (basic analysis and N_{min})
Before (BWC) and After (AWC) Weed Control	• Number of soybean plants m^{-2} • Cover of plants, weeds and ground [%] total, in- and between rows • Number of weeds m^{-2} and weed species • Soybean plant and weed biomass (BWC) [g m^{-2}] • Plant damages (after Vanhala et al., 2004)
Flowering (FLO)	• Number of soybean plants m^{-2} • Cover of plants, weeds, ground and camelina [%] total, in- and between rows • Number of weeds m^{-2} and weed species • Number of camelina m^{-2} • Soybean plant and weed biomass [g m^{-2}] • Plant damages (after Vanhala et al., 2004) • Chlorophyll content [$\mu mol\ m^{-2}$] measured with SPAD meter • Plant height [cm]
Harvest (HAR)	• Number of soybean plants m^{-2} • Cover of plants, weeds, ground and camelina [%] total, in- and between rows • Number of weeds m^{-2} and weed species • Number of camelina m^{-2} • Soybean plant and weed biomass [g m^{-2}] • Plant height [cm] • Yield structure (YS): yield [dt ha^{-1}], plants m^{-2}, first pod height [cm], pods $plant^{-1}$, beans pod^{-1}, TCW • Yield [dt ha^{-1}] • Moisture content [%], thousand kernel weight [g] (TKW), hectoliter weight [kg hl^{-1}] (HLW) • Protein content of soybeans [%] • Soil analysis (basic analysis and N_{min})

3.5.1 Soil analysis

Soil samples at 0-25 cm soil depth were taken in autumn at the time of site selection, at spring and shortly after harvest and were analyzed at the ASTA laboratory. PH ($CaCl_2$), phosphorus (P_2O_5) and potassium (K_2O) [mg 100 g^{-1} dry soil], magnesium (Mg) and natrium (Na) [mg 100 g^{-1} dry soil] were determined according to VDLUFA A.5.1.1, VDLUFA A.6.2.1.1 CAL Extrakt, VDLUFA A.6.2.1. 7 $CaCl_2$

Extrakt, respectively and soil mineral nitrogen (N_{min}) content [kg nitrate-N ha^{-1}] according to VDLUF A A.6.1.4.1. Additionally, EUF soil analysis of the three study sites was done in autumn 2018 at the BodenGesundheitsDienst in Ochsenfurt, DE to check for plant available portions of nutrients.

3.5.2 Design of the subplots

The single data collections took place in pre-defined areas within each plot. For each plot, 9 fixed subplots with an area of 1 m^2 and a 12 m^2 harvest plot were marked to ensure assessments along the vegetation period at the same position. Figure 14 exemplary shows the subdivision of each plot for the treatments t.4_{hoe} and t.5_{hoe+}.

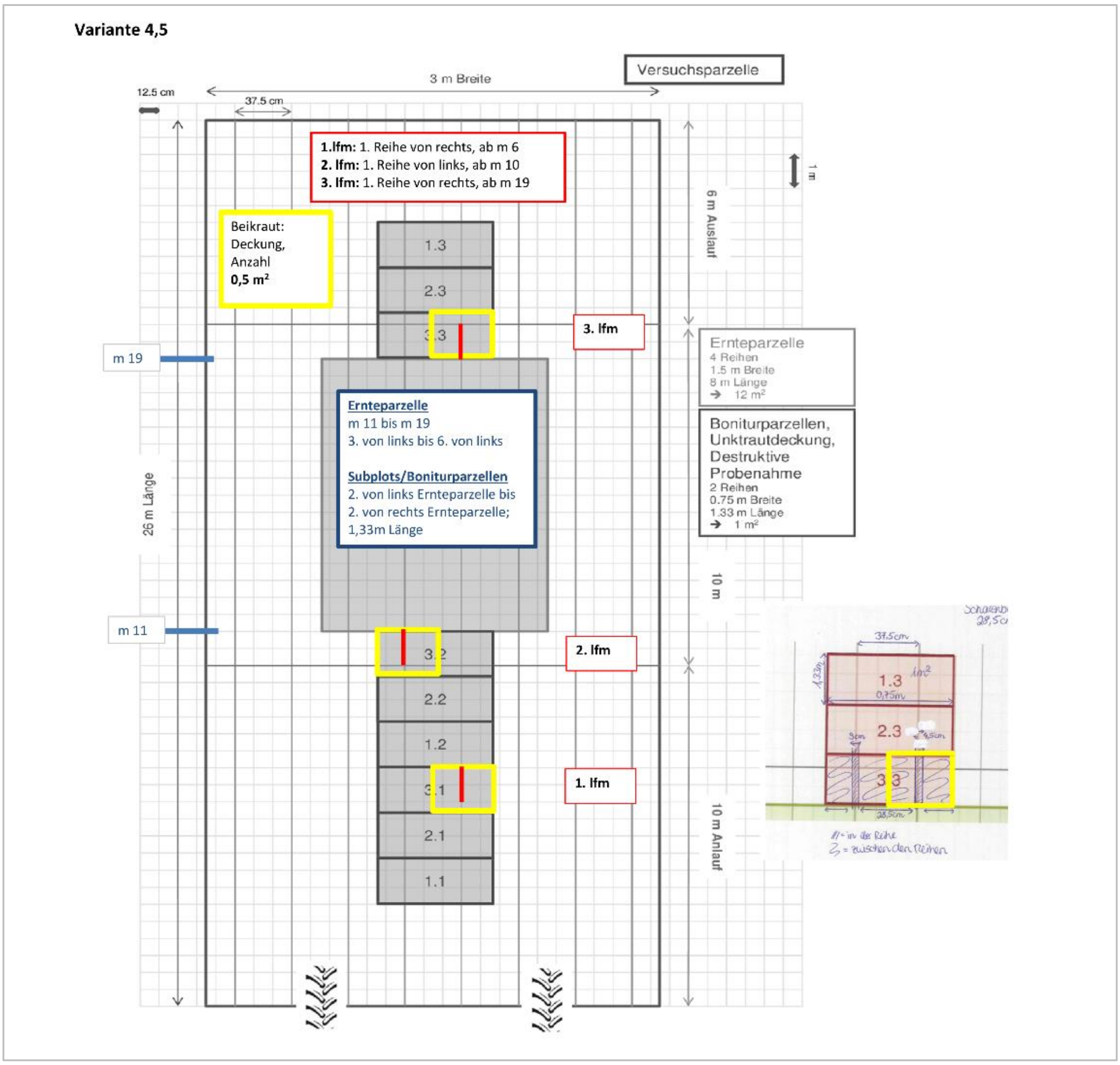


Figure 14: Exemplary scheme of the subdivision of each parcel into its subplots (yellow), the meter for counting the soybean plants (red) and the harvest plot (blue).

Within the subplots 3.1, 3.2 and 3.3 coverage [%] and weed species and number were determined BWC, AWC and at FLO (see the yellow squares in Figure 14). The number of soybean plants was counted in these subplots per running meter (see the red lines in Figure 14). The destructive samplings of the biomass were taken in the subplots 1.1, 1.2 and 1.3 before the first weed control run and in subplots 2.1, 2.2 and 2.3 at flowering. Subplots 3.1, 3.2 and 3.3 were reserved for the biomass assessment at harvest. All assessments done BWC and AWC as well as at FLO were made with the help of a 0.5 m^2 score frame (self-made) adapted for each row situation: 133 cm * 37.5 cm for the 37.5 cm width row plots (treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$) and 100 cm * 50 cm for the 12.5 cm width row plots (treatments $t.1_{neg}$, $t.2_{pos}$, $t.3_{har}$ and $t.7_{mix}$) (see the pictures in Figure 15).

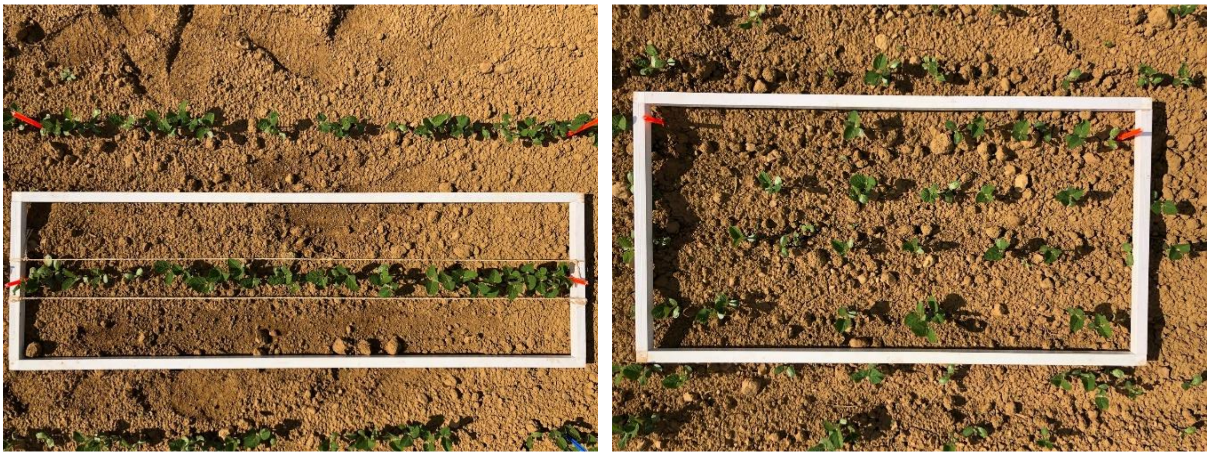


Figure 15: Score frame for the row-dependent treatments (left) and the row-independent treatments (right).

3.5.3 Soybean plant stand

For each treatment, the number of soybean plants was counted along one meter within the subplots 3.1, 3.2 and 3.3 (see the red lines in Figure 14). The number of plants was an indicator to evaluate the emergence of soybean as well as to quantify the loss of plants due to mechanical runs (or any other natural reason) during the growing cycle. The number of plants was counted for BWC, AWC, FLO and HAR. The growing stage of plants was determined at each observation thanks to the BBCH scale for soybean, after Munger et al. (1997) (see Appendix 4 - Appendix 6).

3.5.4 Soil cover

Weed cover [%] and weed species were determined BWC, AWC, FLO and HAR with the help of a score frame (see Figure 15) measuring 0.5 m^2. Weed cover, soybean cover, bare soil cover and, where necessary, camelina cover in $t.7_{mix}$, was visually estimated according to the scale of Braun-Blanquet (1932) attributing a score from 0 % to 100 % (see Appendix 13). Total cover was given for all treatments, whereas cover between and in rows was distinguished in the hoeing treatments (see Figure 15).

3.5.5 Number of weed individuals and species

Weeds were counted, each by species within the score frames for BWC, AWC, FLO and HAR and again distinguished in the hoeing treatments. Expertise of the observers and a botanical book (Klaassen et al., 2004) helped to identified weed species. At Sprinkange19 weed individuals have not been counted from AWC on, since the weed pressure was extremely high. Here only the occurrence and name of weed species were given for each subplot.

3.5.6 Number of camelina

Camelina plants were counted within the frame for FLO and HAR only for treatment t.7_{mix}.

3.5.7 Biomass

The destructive sampling of the biomass took place in the remaining subplots of a size of 1 m^2. Above-ground soybean and weed biomass, plus Camelina in treatment t.7_{mix}, were cut out BWC in subplot 1.1, 1.2 and 1.3, at FLO in 2.1, 2.2 and 2.3. At HAR weed and soybean parameters were determined first in 3.1, 3.2 and 3.3 and afterwards biomass was taken. Exceptionally in 3.2, only 0.5 m^{-2} was cut out for biomass and in the remaining 0.5 m^{-2} soybean plants were cut out for yield structure determinations. Biomass samples were weighted to receive fresh weight information and then oven dried at 80 °C for 48 hours to fully dry. Total weed dry biomass of each sample is finally expressed on unit area [g m^{-2}].

3.5.8 Plant damages

While counting soybean plant number (2.5.3.), at AWC and FLO, damages on plants were visually scored after the scale of Vanhala et al. (2004) (see Figure 16). The scale varies from 0 % (no crop reduction or injury) to 100 % (complete crop destruction).

Rating	Weed Control	Crop Damage	Precision (%)
0	No weed control	No crop reduction or injury	2
10	Very poor weed control	Slight crop discoloration or stunting	5
20	Poor weed control	Some crop discoloration, stunting, or stunt loss	5
30	Poor to deficient weed control	Crop injury more pronounced, but not lasting	10
40	Deficient weed control	Moderate injury, crop usually recovers	10
50	Deficient to moderate weed control	Crop injury more lasting, recovery doubtful	10
60	Moderate weed control	Lasting crop injury, no recovery	10
70	Weed control somewhat less than satisfactory	Heavy crop injury and stand loss	10
80	Satisfactory to good weed control	Crop nearly destroyed - A few surviving plants	5
90	Very good to excellent weed control	Only occasional live crop plants left	5
100	Complete weed destruction	Complete crop destruction	2

Figure 16: Crop damage scoring scale used after a weeding operation to detect damages on soybean plant (Vanhala et al., 2004).

3.5.9 Chlorophyll measurement

Information on the nutritional condition of the soybean plants are taken from estimations of the chlorophyll content present in the plant leaves since they are highly correlated (Buttery et al., 1977). Usually, the leaf chlorophyll concentration (chl) is determined by plant destructive, expensive and time-consuming spectrophotometric measurements. A more applicable, rapid and non-destructive method is the estimation of the chlorophyll content using hand-held meters (Uddling et al., 2007). In LeguTec, the chlorophyll content is determined at flowering using the *SPAD 502 Plus Chlorophyll Meter* (SPAD-meter) developed by Minolta. The SPAD-meter is absorbance-based and measures the transmittance of the red (650 nm) and near-infrared (950 nm) radiation through the leaf and calculates a numerical SPAD value (Uddling et al., 2007). For this purpose, 10 measurements within a subplot are averaged. For each plot the mean SPAD value within the three subplots is determined.

3.5.10 Soybean plant stand

The height of soybean plants was measured once in each subplot at FLO and HAR.

3.5.11 Yield structure

The soybean plants cut out in subplot 3.2 at HAR were taken to assess yield structure. Number of soybean plants m^{-2}, number of pods per plant, number of beans per pod were counted and first pod height determined. Yield was calculated from yield structure (YS yield in dt ha^{-1}) and TKW (YS TKW in g) was measured. Information on yield structure were used to explain soybean yield. Soybean yield is controlled by four soybean yield components: plants per m^{-2}, pod number per plant, seeds per pod and seed size (Lui et al., 2010). Furthermore, yield structure information was taken to focus on yield characteristics for Hostert19, because harvesting with the plot combine harvester was not possible.

3.5.12 Yield and parameters

Soybean plants were harvested at physiological maturity with a plot combine harvester in each plot once in the pre-defined harvest plots on an area of approx. 12 m^2 (see Figure 14). The exact area is measured in each plot right before harvest. Grain yield was measured in kilograms per hectare [kg ha^{-1}] at 86 % dry matter as well as thousand kernel weight (TKW) in grams and hectoliter weight (HLW) in kilograms per hectoliter [kg hl^{-1}]. Samples were milled plot-wise and crude protein content [g kg^{-1}] was analytically determined at the ASTA laboratory using near-infrared reflectance spectroscopy calibrations (NIRS - FOSS XDS) and cross checked with the Kjeldahl method (protein factor PF = 6.25) (Kjeldahl, 1883). Protein yield was calculated and given in kilograms per hectare [kg ha^{-1}].

Yield for study site Hostert 2019 was estimated based on the yield calculated from yield structure. Studies have shown an average yield loss of 10 % caused by the harvester (Asam et al., 2014). Yield is labeled as $H2019_{est}$ to point the yield estimations.

3.6. Data analysis

3.6.1 Plant density and losses

Plant density [plants m^{-2}] was calculated for the four timings (BWC, AWC, FLO, HAR) to compare the treatments that differ in row spacing according to the following formular:

$$plant\ density\ [plants\ m^{-2}] = \frac{100}{row\ spacing\ [cm]} * \frac{number\ of\ plants}{1\ [m]} \quad (1)$$

Furthermore, plant density is used to calculate plant losses [%] of crops due to weed control. Plant $losses_{single\ impact}$ [%] is determined to show the immediate mechanical effect between BWC and AWC, whereas plant losses$_{\text{stand impact}}$ [%] focuses on the effect between BWC and HAR. It is to mention that for both the control plots plant losses AWC were set to 0, because no mechanical treatment was done here and it was assumed that plant density did not change within the few days in between. Since in 2019 second runs with hoe and harrow were possible, the plant losses were again calculated between BWC and FLO (plant losses$_{\text{mechanical impact}}$ [%]) to point out the effects from the second runs. For all plant losses the following equation was used:

$$plant\ loss\ [\%]_{x,y} = \frac{100}{plant\ density\ (x)} * (plant\ density\ (x) - \ plant\ density\ (y)) \qquad (2)$$

where x is date 1 and y is date 2, where number of plants m^{-2} were counted.

Recorded damages were converted in damaged plant density [$plants\ m^{-2}$] for each damage rank (from 10 to 100 %) using equation (1).

Weed control efficiency (WCE) indicates the efficiency of the agricultural machineries to control weeds and is expressed as the percentage reduction in weed cover or density BWC and AWC. The higher WCE, the better the treatment preforms in weed suppression. According to Lindner et al. (2006) WCE is calculated as follows:

$$WCE\ [\%] = \frac{(w_{BWC}\ -\ w_{AWC})}{w_{BWC}} * 100 \qquad (3)$$

where w_{BWC} is weed density (or cover) BWC and w_{AWC} is weed density (or cover) AWC. Both WCE, based on weed density ($WCE_{density}$) and based on weed cover (WCE_{cover}) is calculated.

To evaluate the weeding success in relation to the negative control, the weed control index (WCI) is calculated for each site and year for AWC and FLO based on the treatment means (adapted based on Pannacci et al., 2018):

$$Weed\ control\ Index\ (WCI) = \frac{weeds_{t.1neg} - \ weeds_{treatment\ x}}{weeds_{t.1neg}} \qquad (4)$$

where $weeds_{treatment\ x}$ is either weed biomass or weed cover for *treatment x* and $weeds_{t.1neg}$ is the respective weed variable of the negative control. A result of -1 indicates a complete weed control of 100 %, 0 showing no effects and positive values indicating worse effects than in the negative control. The values are negative when the weeding contributes to the reduction of the variable.

3.6.2 Chlorophyll content

The relationship between the SPAD value and the leaf chlorophyll concentration is non-linear and plant specific. According to Markwell et al. (1995) the chlorophyll concentration (chl) for soybeans was then derived from the output SPAD value (M) using the following equation:

$$chl\ [\mu mol\ m^{-2}] = 10^{(M^{0,265})} \tag{5}$$

3.6.3 Ecological groups and abundance

Weed species were listed by botanical Latin names following the alphabet order and classified according to ecological traits in ecological groups: 1) Annual and biannual dicotyledonous, 2) Perennial dicotyledonous, and 3) Monocotyledonous. This classification aims to characterize the weed communities and to assess the impact of mechanical weeding on them as well as to identify the most problematic weeds. For each site and year, the abundance of each species in terms of weed individuals, meaning the frequency of occurrence of a species, was calculated and expressed in percentage [%] as follows:

$$abundance\ species\ [\%] = \frac{individuals\ of\ a\ species\ \ [number\ m^{-2}]}{Total\ number\ of\ individuals\ [number\ m^{-2}]} \tag{6}$$

3.6.4 Diversity indicators

Apart from the reduction in number of weeds, it is interesting to look at the number of species and its evolution along time. The calculation of a diversity index such as the Shannon index was performed (Shannon and Weaver, 1964). It records the quantity of information carried out by individuals about the structure of the community and reflect their distribution within species (Daget at al, 1978). This calculation gives a result varying from zero to a theoretical Shannon maximum index (treatment specific according to the number of individuals and the number of species). A value equaling zero states for no diversity and the maximum value is the ideal situation where all encountered species are equally distributed. Shannon index calculation:

$$Shannon\ index(i) = -\sum_{i=1}^{S} pi\ \ln(pi) \tag{7}$$

Where i is a weed species, S is the specific richness (total number of species), pi = ni /N where ni is the number of individuals of the species i and N is the total number of individuals.

Shannon index maximum formula:

$$Shannon\ index\ maximum\ (i) = \ln(S) \tag{8}$$

*W*here S is the specific richness (total number of species)

To assess the quality of the distribution of weed individuals within species, the equitability ratio was calculated. This ratio varies from zero to one, where in the case of one, there is a complete equitability of the distribution of weeds and, zero when all individuals belong to the same species. It specifies the distance between the Shannon index (H') and its theoretical maximum (Hmax) (Barbault, 1995).

Equitability calculation (where i is a species):

$$Equitability\ (i) = \frac{Shannon\ index\ (i)}{Shannon\ index\ maximum\ (i)} \tag{9}$$

Shannon index, Shannon index maximum and the equitability were recorded in tables for each treatment, for each assessment BWC, AWC, FLO and HAR.

3.7. Statistical analysis

3.7.1 Analysis of variance

Data were treated site and year specific due to the availability of only two consecutive years and the different site characteristics, e.g. farming management and pedoclimatic conditions. For those traits, where three sub-plots per plot were measured, the average was computed for each plot since the subplots can be regarded as pseudo-replications or subsamples. Hence, an accurate plot mean is derived for further calculations. Variables of interest dependent on each treatment were selected out of the overall and before measured and calculated variables and were analysed according to the linear model for a randomized complete block design as defined by Piepho (1997):

$$y_{ij} = \mu + \tau_i + \beta_j + e_{ij} \tag{10}$$

where y_{ij} is the response variable of the *i*th treatment within the *j*th block, μ is the grand mean, τ_i is the effect of the *i*th treatment, β_j is the effect of the *j*th block and e_{ij} is the residual error term associated with the response y_{ij}.

Data analysis was performed using R studio Version 1.3.1073 (RStudio Team, 2020). Mean and standard deviations were calculated. Model residuals were visually checked and additionally tested for normal distribution and homogeneity of variances using Shapiro-Wilk-Test and Levene-Test, respectively. Analysis of variances (ANOVA) was computed when the assumptions were met. The r package '*agricolae'* was used for post-hoc multiple comparison and grouping (de Mendiburu, 2020). The Tukey's honest significant difference test (Tukey-HSD Test) was applied for testing significant differences on a significance level of $\alpha = 5\ \%$ ($p \leq 0.05$). Fisher's least significant difference test (LSD) test was only applied when Tukey-HSD test was not-significant but ANOVA showed significant differences (marked with "*"). In case of heteroscedasticity or non-normality, the non-parametric Kruskal-Wallis test was used followed by the LSD post-hoc test as predefined in the '*agricolae'* package. To better distinguish results of Kruskal-Wallis test p-values were marked in orange colour and significances marked with “**”. If “*” are enclosed by brackets ANOVA and Kruskal-Wallis are only significant on α = 10 % ($p \leq 0.1$).

3.7.2 Correlation and regression analysis

Correlations of variables were calculated according to Piepho (2018) based on the treatment means to eliminate the block effect. Pearson correlation coefficient was therefore used in case of normal distribution and Spearman correlation coefficient in case of non-normality, where differences at $p \leq 0.05$ were considered significant.

Linear regression is used to analyse the functional relationship between a target variable and an influencing variable. Requirements of normal distributed and homogenous residues were tested and the degree of relationship is expressed as the coefficient of determination R^2.

For presentation of data, means followed by a common letter differ not significantly at a α = 5 % level of probability. Significance levels for ANOVA are given ‘***’ 0.001, ‘**’ 0.01, ‘*’ 0.05, ‘.’ 0.1.

3.8. Geospatial data analysis

BWC, AWC, at FLO and at HAR, the manual assessments were complemented with drone-supported aerial photographs. The project partner Geocoptix GmbH flew over the respective experimental fields by means of unmanned aerial vehicles (UAVs).

3.8.1 Data collection

To collect multispectral datasets, a UAV-platform was equipped with a multispectral camera. A DJI Phantom 4 Pro is a versatile UAV that provides the capacity of lifting additional payload, although this is not foreseen by the manufacturer. It has a weight of 1.3 kg and a MTOW (Maximum TakeOff Weight) of 1.5 kg. The multispectral camera attached to the UAV is a Micasense RedEdge-M Camera (see Figure 17).

Figure 17: UAV-setup: DJI Phantom 4 Pro (left) with Micasense RedEdge-M camera (right).

The multispectral sensor provides five spectral bands, which cover the visible light and the near infrared region. Table 6 summarizes the central wavelengths with the respective bandwidth of each band as published by the manufacturer.

Table 6: Spectral characteristics of the Micasense RedEdge-M Camera.

Band Nr.	Band Name	central Wavelength (nm)	Bandwidth (nm)
1	Blue	475	20
2	Green	560	20
3	Red	668	10
4	Red Edge	717	10
5	NIR	840	40

It should be pointed out, that the fourth band represents a very characteristic region of transition between the visible and near infrared. This is commonly known as the Red Edge, which is distinctive for its limit between the chlorophyll absorption feature in the visible red and the reflection behaviour due to internal leaf structures in the near infrared. These spectral features are highly suitable to calculate multiple vegetation indices and further to gain access to the dynamics of a growing season (Jorge et al., 2019).

The default parameters of the mapping flight are adjusted so that a 75 % overlap in flight direction and a lateral overlap of 70 % of the captured images is ensured. Further the flight altitude is set to 30 – 35 m, in order to meet the qualitative requirements considering the level of detail, which results in a resolution of 2 – 2.5 cm per pixel.

Additional radiometric parameters were recorded during the flight, such as the incoming light by using the Downwelling Light Sensor (DLS). The sensor is mounted on top of the drone, which obtained data enables the correction of varying light conditions during the flight.

An overlook table with the flight campaigns and the research period between 2018 and 2019 for Hostert, Sprinkange and Manternach (Luxembourg) is presented in Table 7.

Table 7: Dates of multispectral data collection on the experimental sites Hostert, Manternach and Sprinkange in the years 2018 and 2019.

	Hostert	Manternach	Sprinkange
2018	25.05.2018 27.05.2018 (BWC) 27.05.2018 (AWC) 09.07.2018 28.08.2018	18.05.2018 (BWC) 18.05.2018 (AWC) 19.05.2018 (AWC) 24.08.2018	21.06.2018 23.06.2018 13.07.2018 12.09.2018
2019	14.06.2019 22.07.2019 21.10.2019	03.06.2019 14.06.2019 09.07.2019	26.07.2019

The following images are outlining the study sites for each location and year (see Figure 18, Figure 19 and Figure 20).

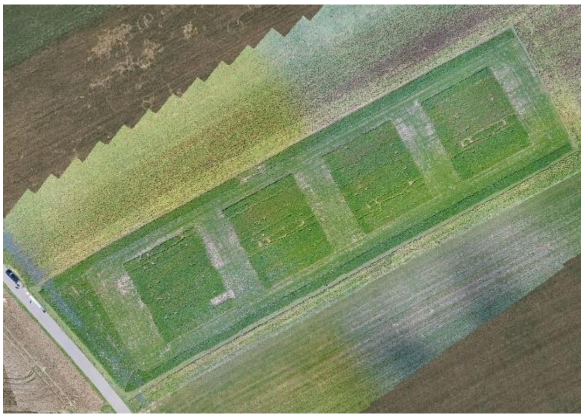



Figure 18: Experimental sites in Hostert in the years 2018 (left, date of data collection: 08.07.2018) and 2019 (right, date of data collection: 16.06.2019).


Figure 19: Experimental sites in Sprinkange in the years 2018 (left, date of data collection: 21.06.2018) and 2019 (right, date of data collection: 26.07.2019).


Figure 20: Experimental sites in Manternach in the years 2018 (left, date of data collection: 18.05.2018) and 2019 (right, date of data collection: 09.07.2019).

3.8.2 Data pre-processing

The pre-processing procedure can be separated into three steps, which were necessary for deriving the desired multispectral reflectance map: 1. Radiometric correction of flight images, 2. Photogrammetric evaluation and 3. Empirical Line Correction.

1. **Radiometric correction of flight images**

   The radiometric correction considers the transformation from digital numbers (DN) into reflectance values for all pixels within each image. Depending on the circumstances of illumination during the flight, adjustments of the implied parameters need to be done. Thus, for clear weather conditions, the correction factor depending on a calibrated reflectance panel is used, which is recorded before take-off. However, the DLS information recorded for every single image during the flight are considered additionally, if overcast conditions were present. An inclusion of this parameter for clear weather conditions has been disregarded, since the obtained DLS Information is depending on the flight direction and the associated relative position and incline of the DLS sensor towards the sun.

2. **Photogrammetric evaluation**

   The second processing step deals with the photogrammetric evaluation of the reflectance images, using the Agisoft Metashape Software. After a successful alignment of the images, a point cloud can be calculated, which further is used to derive the digital surface model and the orthomosaic.

3. **Empirical Line Correction**

   The empirical line correction is based upon a set of suitable outdoor greyscale panels (see Figure 21), of which the reflectance values are measured in a laboratory environment. Since the greyscale panels are placed before the flight and within the boundaries of the flight path, it can be found within each orthomosaic. The reflectance values of the greyscale panels can be used for validation purposes of the previous correction as well as a final bandwise correction of the whole orthomosaic.

Figure 21: Reflectance target used for empirical line correction.

Depending on the illumination situation a recurring consequence can be the overexposure of brighter panels of the greyscale, regarding the micasense bands individually. To approach this problem, the correction is conducted bandwise, by avoiding the overexposed reference panels. Therefore, a preliminary investigation of the raw data displaying the greyscale is necessary, to exclude such images from the empirical line correction.

A band wise comparison between the reflectance panel's median and the corresponding laboratory measurements is shown in Figure 22 (Dataset: Manternach 03.06.2019). To identify overexposed reference panels, a regression line is derived from the three lower reflectance panels. If the residue of the higher reflectance panels exceeds a specific value (usually 10 %), these panels are excluded from further ELC-processing.

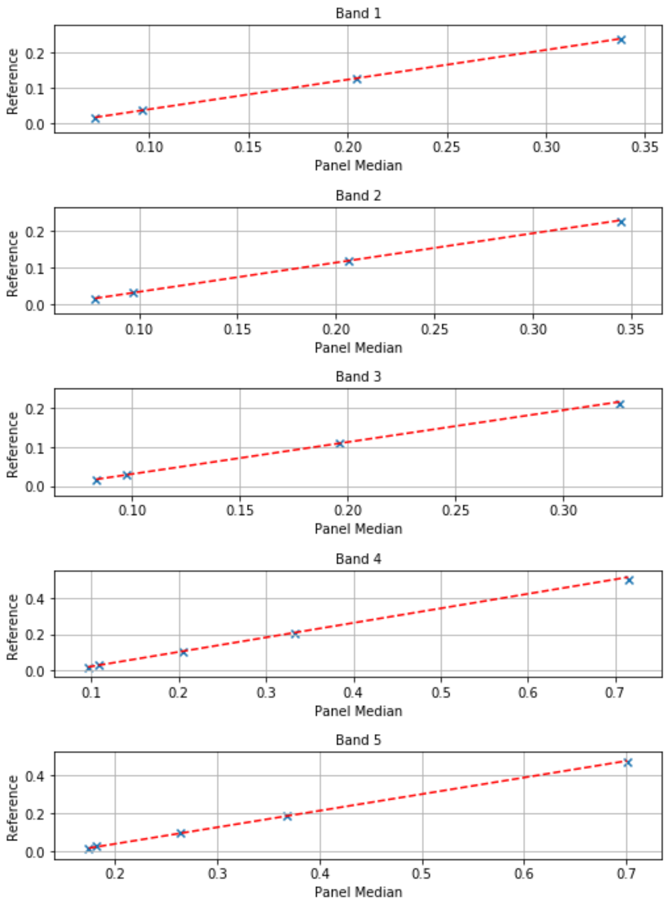


Figure 22: Regression between reflectance panel median values and laboratory reference measurements.

3.8.3 Vegetation indices

Due to the additional spectral information in the Red Edge and NIR range, the Micasense data sets allow the calculation of a large number of indices. These indices can be used, for example, to classify vegetation and non-vegetation or enable statements to be made about the vitality of the vegetation. Probably the best known index is the Normalized Difference Vegetation Index (NDVI), which has been used since Rouse et al. (1974) as a reference to identify photosynthetically active vegetation on the basis of the red and NIR bands (see Equation (11)).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{11}$$

Various drone-based use cases have been analyzed since then, whereby, for example, the correlation between NDVI and the application of fertilizer could be demonstrated (Guan, et al., 2019). In the study areas with little vegetation, the NDVI should be viewed critically, as it reacts strongly to the soil background. The Soil Adjusted Vegetation Index (SAVI), for example, addresses this problem. In addition to the spectral information, a correction factor L is also taken into account in the calculation (see Equation (12)). The correction factor can have values between 0 and 1, the denser the vegetation, the closer the value approaches 0 (Huete, 1988). Here the assumption of an average value of L = 0.5 was chosen.

$$SAVI = \frac{NIR - RED}{NIR + RED + L} \cdot (1 + L) \tag{12}$$

$$\text{with } L = 0.5$$

The Normalized Difference Red Edge Index (NDRE) replaces the red band with the red edge band and can therefore also be calculated with the Micasense data (see Equation (13)). According to Maccioni, Agati & Mazzinghi (2001), this index turned out to be more sensitive with regard to transition phases of photosynthetic activity in crops.

$$NDRE = \frac{NIR - RE}{NIR + RE} \tag{13}$$

Another index that was calculated is the Green Normalized Difference Vegetation Index (GNDVI). Compared to the NDVI, the red band is replaced by the green band in the calculation (see Equation (14)). Compared to the NDVI, which already saturates at a low chlorophyll content, the GNDVI reacts more sensitively to variations in the chlorophyll content of a plant (Gitelson, Kaufman, & Merzlyak, 1996).

$$GNDVI = \frac{NIR - GREEN}{NIR + GREEN} \quad (14)$$

3.8.4 Classification of vegetation / non-vegetation

The NDVI was used to separate vegetation from non-vegetation. Using different threshold values for each point in time and location, a separation into these two basic classes can be made. Different illumination conditions and inhomogeneous phenological development of the plants at each date of data collection, cause different reflection properties of the surface objects. Therefore, a threshold is individually set for each location and time.

The NDVI can assume values between -1 and 1, whereby values close to > 0.3 indicate photosynthetically active vegetation. Thus, this method is a very effective way of distinguishing vegetation from other types of land cover.

The threshold values set for each location and point in time are shown in Table 8.

Table 8: NDVI thresholds for discrimination of vegetation and soil for every site and date.

SITE	DATE	NDVI THRESHOLD
HOSTERT	25.05.2018	0.60
	09.07.2018	0.55
	28.08.2018	0.20
	14.06.2019	0.50
	22.07.2019	0.40
MANTERNACH	18.05.2018	0.55
	24.08.2018	0.10
	03.06.2019	0.35
	14.06.2019	0.45
	09.07.2019	0.35
SPRINKANGE	21.06.2018	0.35
	23.06.2018	0.35
	13.07.2018	0.55
	12.09.2018	0.35
	26.07.2019	0.55

3.8.5. Supervised classification algorithms

Due to the spectral differences between objects (e.g. vegetation, soil, water), it can be tried to automatically identify these objects using various classification methods and to discriminate these classes

There are two types of classifications: unsupervised and supervised classifications. While in the first case only information contained in the image material is used, additional information such as field or training data is taken into account in the supervised classification. The latter method offers the advantage that the user can determine the criteria for determining the class membership for each object class due to the identification of clear training areas, while in the unsupervised methods the spectrally separable classes do not necessarily have to match real object classes. Supervised classifiers learn the typical properties of a class from the spectral patterns and can apply this “knowledge” to new areas.

Within the project, the two supervised classification were applied: Random Forest and Support Vector Machine (SVM) were used with the aim of differentiating the separability of soybean plants, weeds and soil on the basis of the multispectral data. The training data were visually collected in the orthomosaics.

3.8.5.1 Random Forest

The Random Forest classification algorithm consists of several uncorrelated decision trees, which are built up successively and independently of one another during the training process based on random samples of the original data set. When classifying test data, each individual tree makes a prediction, while the final decision on which class to belong to is determined by the cumulative majority (Liaw & Wiener, 2002).

With conventional decision trees, it is common to consider all variables at each node at which the division of the data set is determined by the most suitable variable. In contrast, the Random Forest algorithm intervenes at this point as well and only offers a random sample of the variables at the individual nodes. Another special feature of the random forest classifier is the “out-of-bag” error, which estimates the model fit based on the data that does not belong to the selected sample (Liaw & Wiener, 2002). This means that subsequent cross-validations or separate independent tests can be dispensed with, as this already happens during training. In addition, you get an approximate idea of the accuracy of the model after training. In addition, the algorithm calculates a parameter for the importance of the variables based on a random permutation of all values in order to record effects on the class assignment of the data points (Breiman & Cutler, 2003).

3.8.5.2 Support Vector Machine (SVM)

Within an SVM, an attempt is made to define separation levels or decision boundaries based on training data so that classes can be separated from one another. When training an SVM, the classifier learns how important individual training data points are for defining the decision limits. The data points that lie on the boundary between the classes and are necessary for defining the decision limit are called support vectors (Müller & Guido, 2017). The support vectors all have the same distance from the parting plane (Ertel, 2009). For the prediction of the class of new data points, the distance between the data points and all support vectors is calculated and a decision is made about the class affiliation based on the distance (Müller & Guido, 2017).

If the data can be separated linearly, i.e. by a straight line, plane or hyperplane, one speaks of a linear SVM (Müller & Guido, 2017). The problem that many classification tasks cannot be linearly separated is solved by using kernels, which are based on the idea that at some point in a higher dimensional space all data points can be linearly separated. By means of a non-linear transformation of the original vector space, which is referred to as the kernel, the data is transformed into a so-called feature space, in which it is linearly separable. The number of dimensions of the new vector space thus increases exponentially with the number of original dimensions. However, since the parting plane can be determined by only a few parameters through the use of support vectors, this higher dimensionality should not be regarded as problematic (Ertel, 2009). A non-linear SVM can thus be understood as a linear SVM in a corresponding feature space (Vedaldi & Zisserman, 2012).

For individual bands not to dominate the classification, the SVM needs to normalize the data. Here the values were scaled between -1 and 1 with a mean value of 0 and a standard deviation of 1.

3.8.6 Spatial statistics

The calculation of zonal statistics makes it possible to determine parameters of several cells of a grid within defined zones. As a result, inhomogeneities and differences can become visible and a large number of grid cells can be represented by one or more representative statistics, which leads to a reduction in the amount of data.

First, a network of hexagons with a diameter of 50 cm was placed over the study areas and used as limiting zones for calculating the statistical parameters. The result from the vegetation / non-vegetation classification was used as the input raster, where only vegetation pixel were further analysed. This initially served to get an overview of the distribution of photosynthetically active vegetation and, for example, to determine inhomogeneities within the study areas.

Since the hexagonal analysis showed that the distribution of photosynthetically active vegetation within the individual fields was inhomogeneous (see Chapter 3.6.5 Zonal statistics), larger zones, aggregating a majority of a field were placed over the middle of the field rows. Based on these new zones, the zonal statistics were determined (see Figure 23 - Figure 28).

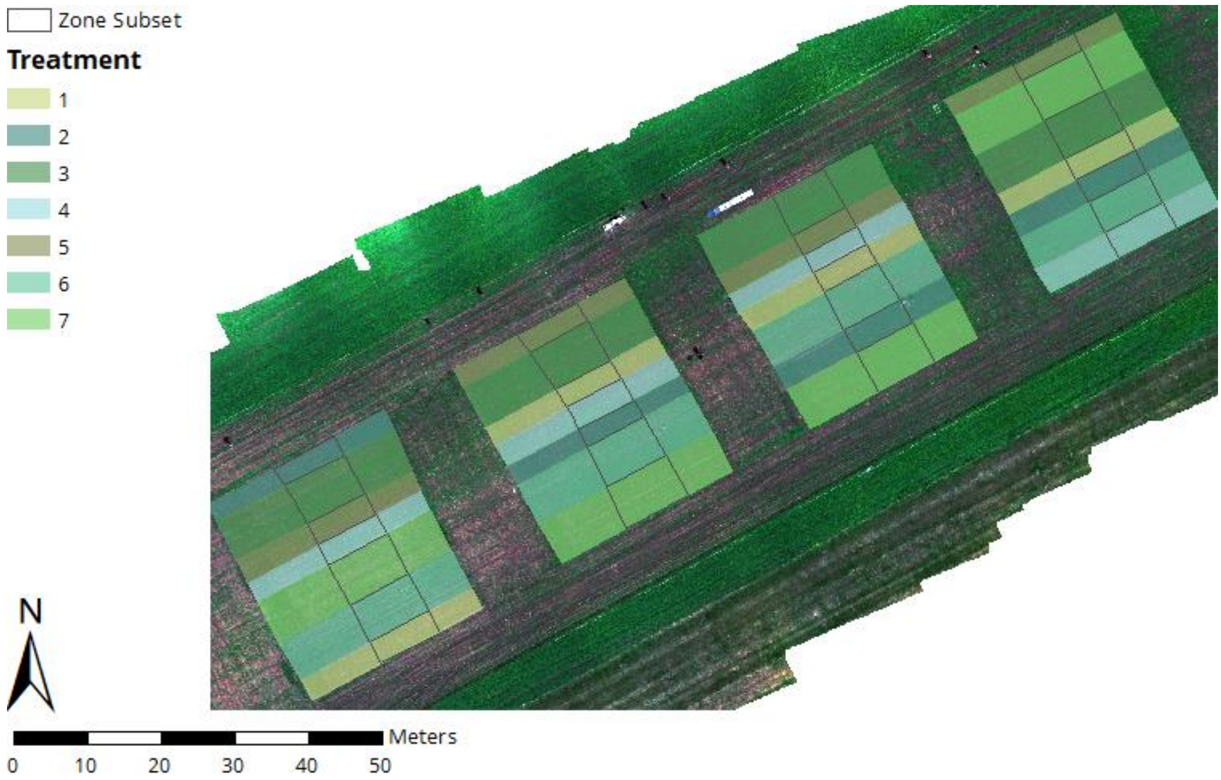


Figure 23: Central subset for extraction of spatial statistics in Hostert 2018.

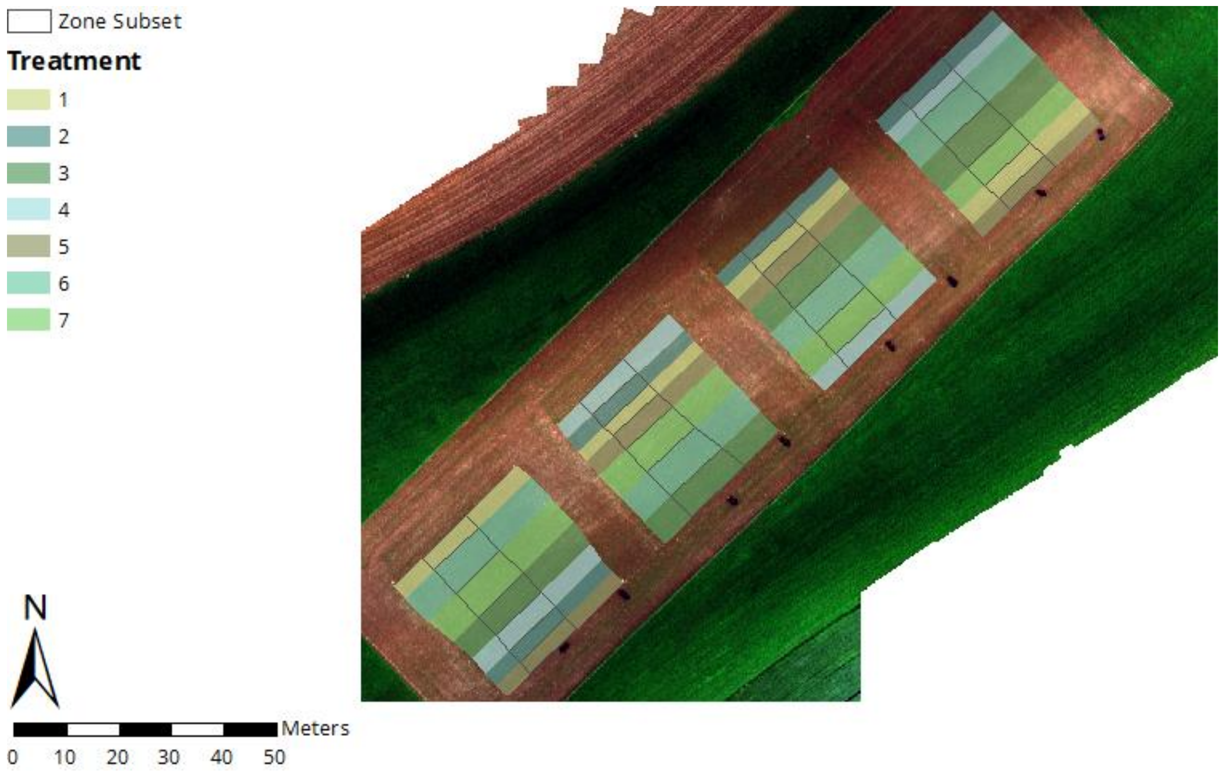


Figure 24: Central subset for extraction of spatial statistics in Hostert 2019.

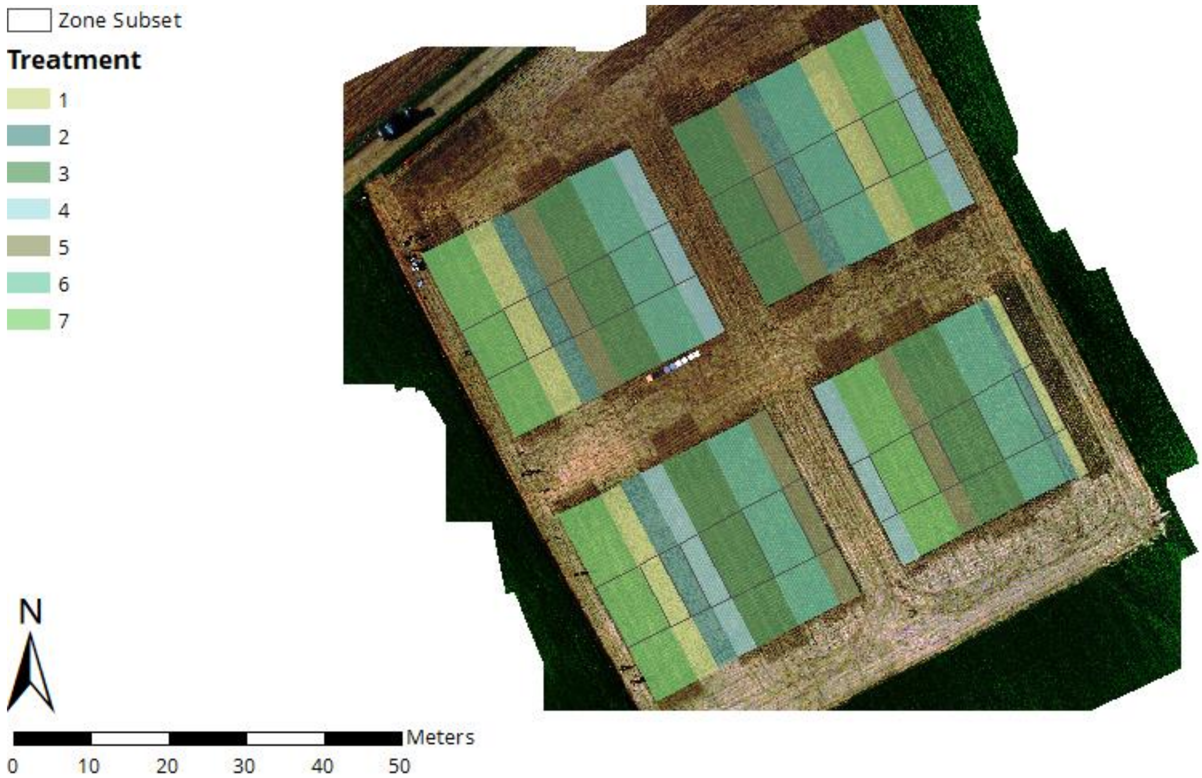


Figure 25: Central subset for extraction of spatial statistics in Mantemach 2018.

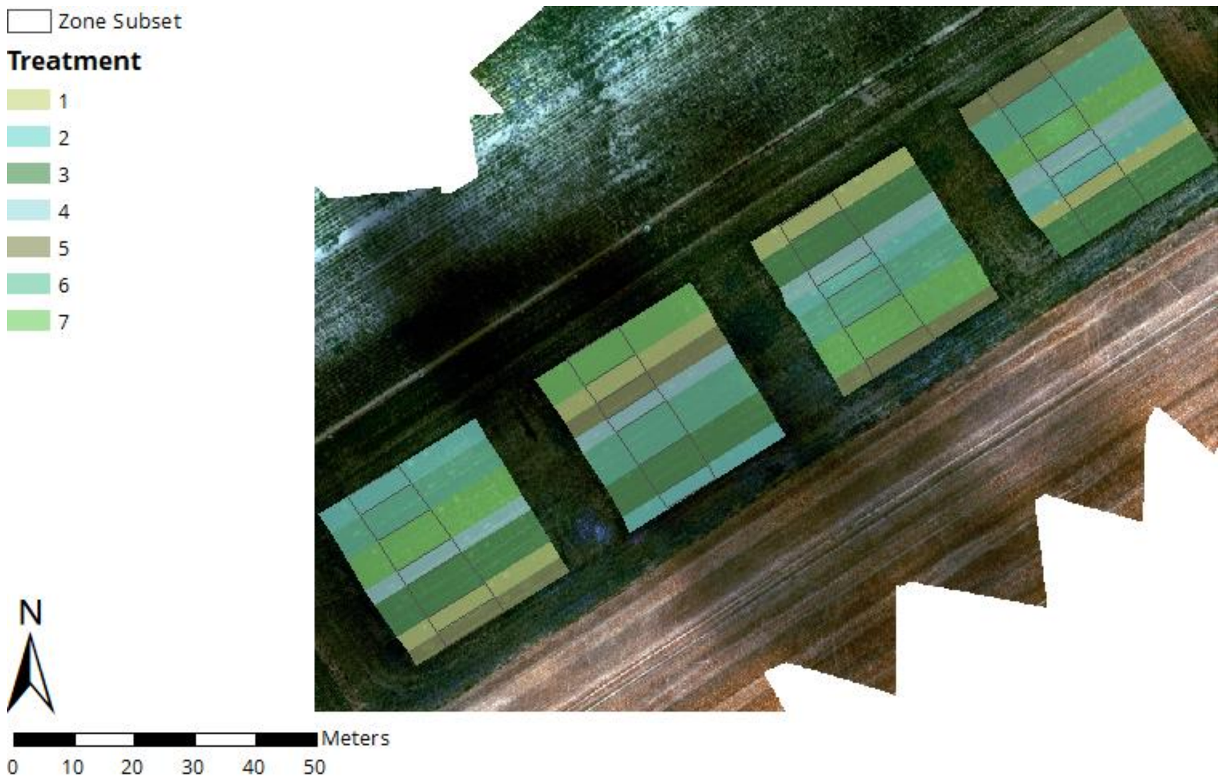


Figure 26: Central subset for extraction of spatial statistics in Manternach 2019

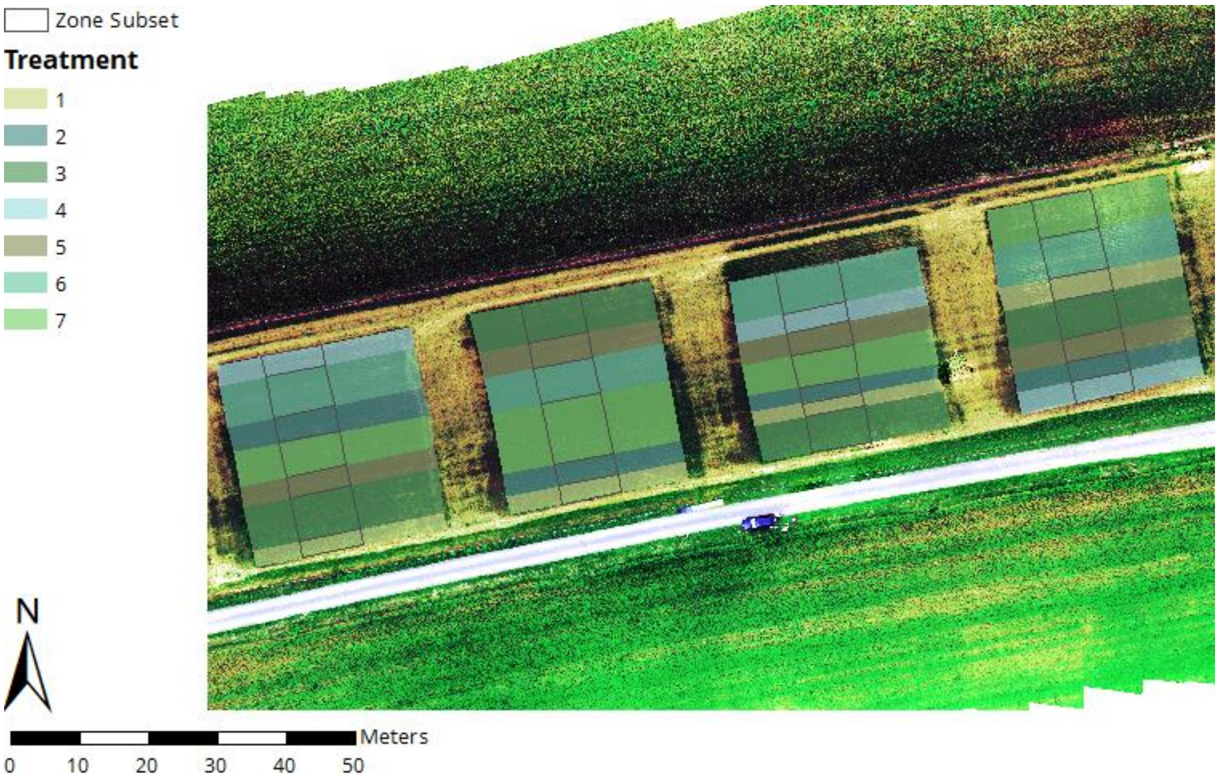


Figure 27: Central subset for extraction of spatial statistics in Sprinkange 2018.

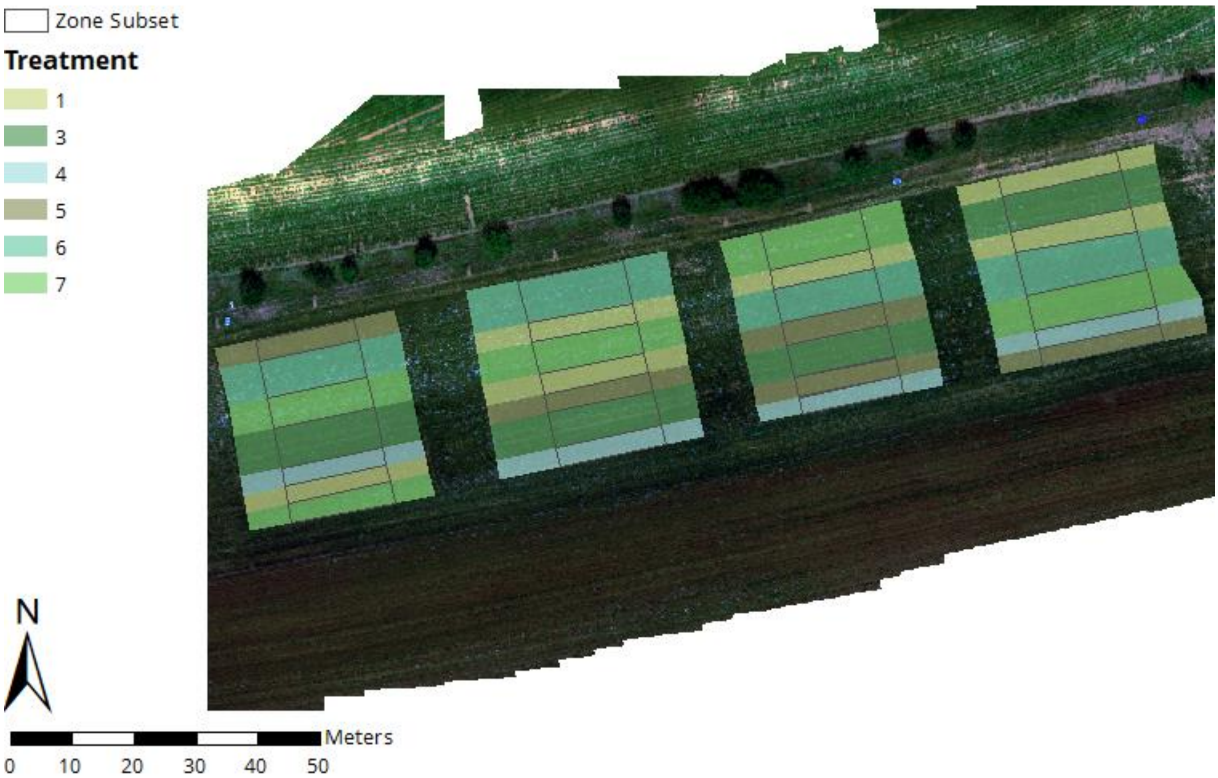


Figure 28: Central subset for extraction of spatial statistics in Sprinkange 2019.

From the wide range of available zonal statistics, only the following parameters were derived:

- Median: provides a representative value for every zone, less sensitive to outlier values
- SD: gives an indication on the homogeneity of every zone.

4. Results exact field trial

4.1. Crop yield parameters

Soybean yields were consistently higher in the hoeing than in the harrowing treatments at all three study sites in 2018 (18) and 2019 (19). Significant differences in yield were observed for all sites except for Manternach (see Table 9), whereas Manternach18 showed significant differences at $p \leq 0.1$.

*Table 9: P-values for F test of sources of variation (ANOVA) for yield parameters at the three study sites for the seven treatments in 2018 and 2019. Significance levels for ANOVA are given '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.*

	Manternach				Sprinkange				Hostert			
variable	**2018**		**2019**		**2018**		**2019**		**2018**		**2019**	
Yield [dt/ha] 86 % DM	0.578		0.083	.	0.003	**	0.001	**	0.005	**	0.007	**
TCW [g] 86% DM	0.097	.	0.219		0.648		0.124		0.116		NA	
HLW [kg/hl] 86%DM	0.550		0.838		0.003	**	0.068	.	0.343		NA	
Protein [%]	0.194		0.009	**	0.020	*	0.056	.	0.035	*	NA	
Protein yield [kg/ha]	0.486		0.082	.	0.125		0.002	**	0.008	**	NA	
First pod height [cm]	0.013	*	0.180		0.690		0.429		0.081	.	0.779	

4.1.1 Crop yield

The highest yields were observed in Hostert19$_{est}$ with 19.9 dt ha^{-1} in t.4$_{hoe}$ and with 17.8 dt ha^{-1} in t.5$_{hoe+}$, while in Hostert18 yield was highest in t.2$_{pos}$ amounting 15.1 dt ha^{-1} in comparison to the remaining treatments. Sprinkange18 showed highest yields in t.2$_{pos}$ with 16.2 dt ha^{-1} and in t.6$_{comb}$ with 14.1 dt ha^{-1}, while Sprinkange19 only reached 14.6 dt ha^{-1} in t.6$_{comb}$. In Manternach18 yields of 14.8 dt ha^{-1} and 14.0 dt ha^{-1} in t.5$_{hoe+}$ and t.4$_{hoe}$ and in Manternach19 of 14.4 dt ha^{-1} and 13.1 dt ha^{-1} in t.5$_{hoe+}$ and t.4$_{hoe}$ were observed. Lowest yields were found in half of the negative treatments (Manternach18: 11.8 dt ha^{-1}; Sprinkange19: 5.4 dt ha^{-1}; Hostert18: 6.7 dt ha^{-1}) as well as in half of the harrowing plots (t.3$_{har}$ in Manternach19 and Sprinkange18 (7.2 dt ha^{-1} and 10.3 dt ha^{-1}) and in t.7$_{mix}$ for Hostert19 (7.2 dt ha^{-1}) (see Table 10 and Figure 29)).

Table 10: Mean soybean yield [dt ha^{-1}] at 86 % dry matter of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p<0.05 according to Tukey's test or Fisher's test and ANOVA p≤0.1 (*). Yields for Hostert 2019 were estimated (2019$_{est}$).

	Yield [dt ha^{-1}] 86 % DM					
	Manternach		Sprinkange		Hostert	
treatment	**2018**	**2019(*)**	**2018**	**2019**	**2018**	**2019$_{est}$**
t.1 neg	11.8 n.s.	8.1 bc	12.7 ab	5.4 c	6.7 b	7.8 b
t.2 pos	13.6	9.5 abc	16.2 a	-	15.1 a	14.6 ab
t.3 harrow	13.8	7.2 c	10.3 b	7.5 bc	8.2 b	8.5 ab
t.4 hoe	14.0	13.1 ab	13.9 ab	12.5 ab	10.1 ab	19.9 a
t.5 hoe+interrow	14.8	14.4 a	13.9 ab	12.5 ab	10.0 ab	17.8 ab
t.6 combination	13.9	12.6 abc	14.1 ab	14.5 a	10.4 ab	13.8 ab
t.7 mix	12.8	7.8 bc	11.2 b	7.1 bc	7.5 b	7.2 b

Significant differences between hoe and harrow occurred in Sprinkange19, where $t.6_{comb}$ (14.5 dt ha^{-1}) was significantly higher than $t.3_{har}$ (7.5 dt ha^{-1}) and $t.7_{mix}$ (7.1 dt ha^{-1}). The latters did not differ significantly from the negative control ($t.1_{neg}$). In Hostert19 yield was significantly higher in $t.4_{hoe}$ (19.9 dt ha^{-1}) compared to $t.7_{mix}$ (7.2 dt ha^{-1}) and $t.1_{neg}$ (7.8 dt ha^{-1}) as well. Also, Manternach19 showed significant higher yields, but only on a significant level of 10 %, in $t.5_{hoe+}$ (14.4 dt ha^{-1}) and $t.4_{hoe}$ (13.1 dt ha^{-1}) compared to $t.3_{har}$ (7.2 dt ha^{-1}) and $t.5_{hoe+}$ again differs significantly from $t.7_{mix}$ (7.8 dt ha^{-1}) and $t.1_{neg}$ (8.1 dt ha^{-1}). No significant differences in yields resulted within the single hoeing treatments at all the sites; not even where finger weeder application was performed in Hostert18 and Sprinkange18 and during the second run in Hostert19 and Sprinkange19. But here, a tendency is seen with advantage to $t.4_{hoe}$ in Hostert19 and to $t.5_{hoe+}$ in Manternach19 (see Figure 29). Where statistic significances were observed, even $t.3_{har}$, $t.7_{mix}$ and $t.1_{neg}$ did not differ in yield as exemplarily seen for Sprinkange19. Significant higher yields in favor for the positive control, were achieved in Sprinkange18 and Hostert18 compared to $t.3_{har}$ and $t.7_{mix}$, where $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ did not differ from $t.2_{pos}$. Focusing only on the negative control $t.1_{neg}$, mean yields of $t.7_{mix}$ were even lower in Hostert19 and Manternach19, and mean yields of $t.3_{har}$ were lower in Manternach19 and Sprinkange18 but with no significant differences (see Figure 29).

To sum up, higher yields were assigned to hoeing treatments and lower yields to the harrowing treatments. Within hoeing, no significant differences were observed. Only a tendency was seen for lower yields under finger weeder application in Hostert19 but to slightly higher yields under finger weeder applications in Manternach19. On half of the sites, harrow treatments showed even lower values than the negative control plot. With exception of Manternach19, yields under hoeing behaved like yields under the positive control and ranged up to 16.2 dt ha^{-1} in Sprinkange18 and up to 19.9 dt ha^{-1} in $Hostert19_{est}$.

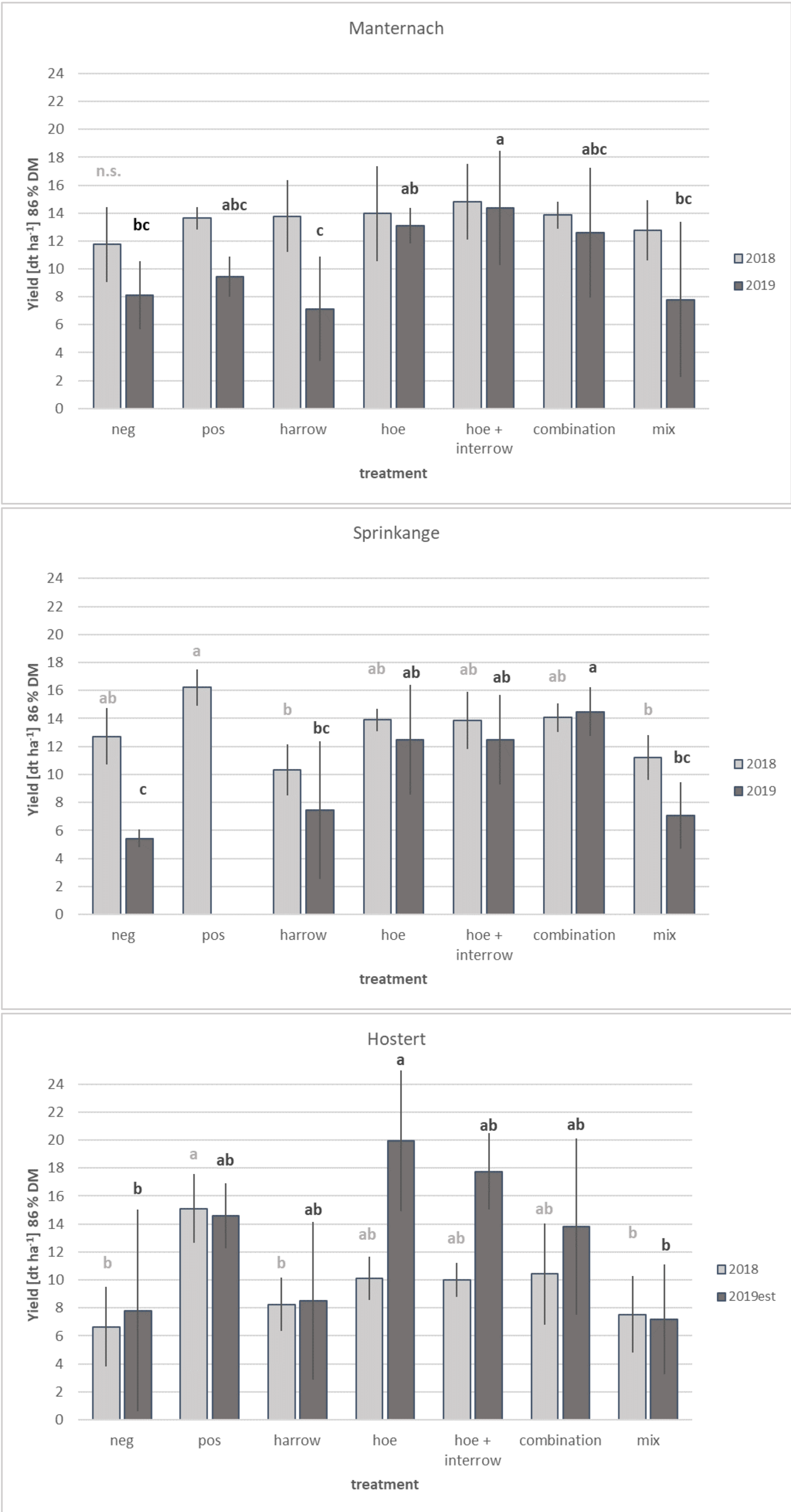


Figure 29: Average mean values for each treatment and site for 2018 and 2019. Bars indicate standard deviation. Common letters indicate no significant differences according to Tuckey's (and Fisher's test for Manternach19) within the cultivation years (2018: light grey; 2019: dark grey).

4.1.2 Thousand kernel weight and hectoliter weight

Focusing on further yield characteristics, TKW and HLW were considered. For Hostert19 no results were achieved from combine harvester, since harvesting was not possible. Instead, values from yield structure were shown here (Hostert19$_{est}$), since no statistically comparison between years has been made. Regarding TKW no significant differences between the single treatments at all the study sites were observed except for Manternach18 ($p \leq 0.01$; see Table 9). T.3$_{har}$ differs from t.6$_{comb}$ as well as from both control plots (see Table 11 and Appendix 14). TKW ranged between 122.3 g (t.1$_{neg}$) and 130.8 g (t.3$_{har}$) in Manternach18, between 127.3 g (t.6$_{comb}$) and 139.7 g (t.4$_{hoe}$) in Sprinkange18 and between 112.6 g (t.1$_{neg}$) and 136.1 g (t.2$_{pos}$) in Hostert18. In 2019, TKW are much higher than in 2018. In Manternach19 TKW range between 156.6 g (t.5$_{hoe+}$) and 169.8 g (t.2$_{pos}$), in Sprinkange19 between 176.6 g (t.7$_{mix}$) and 186.1 g (t.6$_{comb}$) and in Hostert19$_{est}$ between 126.0 g (t.1$_{neg}$) and 145.3 g (t.5$_{hoe+}$).

Setting TKW in relation, the variety Merlin showed generally lower TKM compared to other 000-varieties the soybean variety field trials in Luxemburg. Average TKW of Merlin in 2018 was 186 g and in 2019 average TKW was 204 g (Keßler, 2018; Heidt, 2019).

Table 11: Mean thousand kernel weight [g] at 86 % dry matter of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey's test and Fisher's test (ANOVA p≤0.1) (*).

	TKW [g] 86% DM					
	Manternach		Sprinkange		Hostert	
treatment	**2018(*)**	**2019**	**2018**	**2019**	**2018**	**2019$_{est}$**
t.1 neg	122.3 b	168.8 n.s.	136.7 n.s.	180.0 n.s.	112.6 n.s.	126.0 n.s.
t.2 pos	122.6 b	169.8	139.6	-	136.1	135.6
t.3 harrow	130.8 a	160.3	139.1	180.7	118.9	129.3
t.4 hoe	127.8 ab	158.1	139.7	183.7	125.1	133.3
t.5 hoe+interrow	127.6 ab	156.6	136.2	185.0	125.0	145.3
t.6 combination	124.3 b	159.8	127.3	186.1	128.2	129.1
t.7 mix	125.4 ab	159.3	137.1	176.6	120.9	128.7

To sum up the results from TKW, much higher amounts were observed in 2019 than in 2018, while ranges were similar for all the sites within each year. A slight tendency towards lower values in t.1$_{neg}$ was observed but no clear tendency between mechanical treatments could be derived.

HLW behave contrary to TKW and were generally higher in 2018 than in 2019 (see Table 9 and Appendix 15). In Manternach18 values ranged from 70.6 kg hl^{-1} (t.1$_{neg}$) to 73.2 kg hl^{-1} (t.2$_{pos}$), in Sprinkange18 from 70.4 kg hl^{-1} (t.1$_{neg}$) to 73.6 kg hl^{-1} (t.6$_{comb}$), and with slightly lower values in Hostert18 from 65.2 kg hl^{-1} (t.6$_{comb}$) to 69.2 kg hl^{-1} (t.3$_{har}$). In 2019 values ranged from 63.5 kg hl^{-1} (t.7$_{mix}$) to 65.7 kg hl^{-1} (t.5$_{hoe+}$) in Manternach19 and from 56.3 kg hl^{-1} (t.7$_{mix}$) to 67.2 kg hl^{-1} (t.4$_{hoe}$). Significant differences were calculated only for Sprinkange for both years. In Sprinkange18 t.6$_{comb}$ showed higher weights compared to t.3$_{har}$ and t.1$_{neg}$. The hoeing treatments did not differ in weights as well as t.3$_{har}$ and t.1$_{neg}$. In Sprinkange19 t.4$_{hoe}$ had significant higher HLW than in t.7$_{mix}$ and t.1$_{neg}$.

Again, no significant differences were found within the hoeing treatments. Regarding harrowing, t.7$_{mix}$ and t.1$_{neg}$ were same (see Table 12). For Hostert19 no results were obtained, since harvesting was not possible and HLW could not been measured within YS assessments.

Setting HLW in relation, variety Merlin showed generally higher HLW compared to other 000-varieties the soybean variety field trials in Luxemburg. Average HLW of Merlin in 2018 was 73.07 kg hl^{-1} and in 2019 average HLW was 72.93 kg hl^{-1} (Heidt, 2018; Heidt, 2019).

*Table 12: Mean hectoliter weight [kg hl^{-1}] at 86 % dry matter of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey's test and Fisher's test *.*

	HLW [kg hl^{-1}] 86 % DM					
	Mantarnach		Sprinkange		Hostert	
treatment	2018	2019	2018	2019*	2018	2019
t.1 neg	70.6 n.s.	63.8 n.s.	70.4 c	56.6 bc	68.2 n.s.	NA
t.2 pos	73.2	66.1	73.5 ab	-	68.1	
t.3 harrow	71.3	64.4	70.7 bc	58.6 abc	69.2	
t.4 hoe	71.8	65.5	73.3 ab	67.2 a	67.1	
t.5 hoe+interrow	73.0	65.7	72.8 abc	66.1 ab	67.9	
t.6 combination	72.5	65.0	73.6 a	65.7 abc	65.2	
t.7 mix	71.1	63.5	71.5 abc	56.3 c	67.3	

To sum up the results from HLW, generally higher values were observed for 2018 compared to 2019 (contrary to the variable TKW). Lowest values were observed in the negative control plots and in the harrowing plots, except for Hostert18 (showing a tendency towards lower values under hoeing).

4.1.3 Protein content and protein yield

Organic soybeans growing in our regions contain 36 % of crude protein content on average (Bellof, 2014). At Manternach18 protein contents were very similar between all the treatments ranging from 39.2 % in t.7$_{mix}$ to 40.5 % in t.6$_{comb}$. (see Table 13).

Table 13: Mean protein contents [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey-test and Fisher's test (but ANOVA p≤0.1) (*).

	Protein content [%]					
	Manternach		Sprinkange		Hostert	
treatment	2018	2019	2018	2019(*)	2018	2019
t.1 neg	39.5 n.s.	41.5 a	31.3 ab	41.2 a	38.5 ab	NA
t.2 pos	38.9	39.4 ab	30.9 ab	-	38.1 b	
t.3 harrow	39.8	39.9 ab	34.5 a	38.9 b	38.7 ab	
t.4 hoe	39.7	39.6 b	30.4 ab	39.0 b	39.2 ab	
t.5 hoe+interrow	40.4	39.0 b	29.6 b	39.1 b	38.3 ab	
t.6 combination	40.5	40.3 ab	28.3 b	39.0 b	39.7 a	
t.7 mix	39.2	38.1 ab	31.1 ab	38.8 b	38.4 ab	

At Sprinkange19 a similar range was detected between 38.8 % (t.7$_{mix}$) and 41.2 % (t.1$_{neg}$). At Manternach19, Sprinkange18 and Hostert18 crude protein content significantly differed by treatment (see Table 13). Highest protein content was reached in t.1$_{neg}$ (41.5 %) compared to t.4$_{hoe}$ (39.6 %) and t.5$_{hoe+}$ (39.0 %) at Manternach19. At Hostert18 only t.6$_{comb}$ (39.7 %) and t.2pos (38.1 %) differ significantly in soybean protein content. In Sprinkange18 protein contents are lowest in comparison to the other sites and years and show significant differences in t.3 with 34.5 % compared to t.5$_{hoe+}$ and t.6$_{comb}$ with 29.6 % and 28.3 % (see Table 13 and Appendix 16).

Protein yield [kg ha^{-1}] was calculated from protein content and soybean yield, since protein content and yield generally correlate negatively with each other (Assefa et al., 2018) and hence protein yield gives better interpretable protein results for comparing the treatments. Highest protein yields were reached in the hoeing treatments at Manternach18 (6.0 kg ha^{-1} in t.5$_{hoe+}$), Manternach19 (5.3 kg ha^{-1} in t.5$_{hoe+}$) and Sprinkange19 (5.7 kg ha^{-1} in t.6$_{comb}$), whereas in Sprinkange18 and Hostert18 highest protein yields were reached in t.2$_{pos}$ amounting 5.0 kg ha^{-1} and 5.7 kg ha^{-1} (see Table 14). Significant differences were observed for Sprinkange19 and Hostert18 and for Manternach19 at $p \leq 0.01$. At Sprinkange19 t.6$_{comb}$ significantly differs from t.7$_{mix}$, t.3$_{har}$ and t.1$_{neg}$ (2.8 kg ha^{-1}, 2.9 kg ha^{-1} and 2.2 kg ha^{-1}). At Hostert18 t.2pos significantly differs from t.7$_{mix}$, t.3 and t.1$_{neg}$ (2.9 kg ha^{-1}, 3.2 kg ha^{-1} and 2.6 kg ha^{-1}). No significant differences were observed within hoeing on both sites. The highest mean protein yield reached in Manternach in t.5$_{hoe+}$ significantly differs from t.7$_{mix}$ and t.3 (3.0 kg ha^{-1} and 2.9 kg ha^{-1}). In general, a tendency towards the hoeing treatments and the positive control and against the harrowing treatments and the negative control was observed (see Table 14 and Appendix 17).

Table 14: Mean protein yield [kg ha^{-1}] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test or Fisher's test but with ANOVA p≤0.1 (*).

	Protein yield [kg ha^{-1}]					
	Manternach		Sprinkange		Hostert	
treatment	2018	2019(*)	2018	2019	2018	2019
t.1 neg	4.7 n.s.	3.4 abc	4.0 n.s.	2.2 c	2.6 b	NA
t.2 pos	5.3	3.7 abc	5.0	-	5.7 a	
t.3 harrow	5.5	2.9 c	3.7	2.9 bc	3.2 b	
t.4 hoe	5.6	5.2 ab	4.2	4.9 ab	4.0 ab	
t.5 hoe+interrow	6.0	5.3 a	4.1	4.9 ab	3.9 ab	
t.6 combination	5.6	5.1 abc	4.0	5.7 a	4.1 ab	
t.7 mix	5.0	3.0 bc	3.5	2.8 bc	2.9 b	

Summing up, protein contents ranged from 38.1 % up to 41.2 %, except at Sprinkange18, where contents were much lower (less than 30 %). A tendency to higher values in the negative control and/or harrowing was observed. Regarding protein yield, a tendency towards hoeing and the positive control having higher protein yields was found. Within hoeing no significant differences were observed. Protein yields in harrowing plots behaved similar to the negative control plots.

4.1.4 First pod height

When focusing on the physiology of the manual harvested soybean, first pod height was taken under investigation. It is an important factor during harvest with the combine harvester, since pod heights less than 12 cm result in yield losses (Tkachuk, 2019). First pod heights tended to be higher in the first project year on all the sites compared to the second year. Highest pod heights in 2018 reached up to 17.3 cm in t.1$_{neg}$ and 15.7 cm on average in t.4$_{hoe}$ at Hostert and in 2019 up to 13.8 cm in t.1$_{neg}$ at Sprinkange and 11.1 cm in t.5$_{hoe+}$ at Hostert site. Lowest pod heights were measured in t.7$_{mix}$ at Manternach19 (7.5 cm) (see Table 15 and Appendix 18).

Table 15: Mean soybean pod heights [cm] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test.

	First pod height [cm]					
	Manternach		Sprinkange		Hostert	
treatment	2018	2019	2018	2019	2018	2019
t.1 neg	11.6 ab	10.8 n.s.	14.9 n.s.	13.8 n.s.	17.3 a	10.1 n.s.
t.2 pos	12.4 ab	9.4	13.8	-	9.6 b	11.8
t.3 harrow	9.5 b	9.1	14.5	9.6	15.0 ab	9.5
t.4 hoe	12.3 ab	9.0	13.5	11.0	15.7 ab	10.4
t.5 hoe+interrow	13.6 a	11.0	15.0	10.9	13.8 ab	11.1
t.6 combination	13.3 a	9.6	15.9	10.0	13.0 ab	9.9
t.7 mix	10.9 ab	7.5	15.1	10.5	14.9 ab	10.4

Soybean pod heights generally tend to be highest in the hoeing treatments compared to the harrowing treatments. Except for two sites, pod height in t.3$_{har}$ have heights less than 10 cm. At Sprinkange18, all pods heights averaged 14.7 cm. Pod heights showed significant differences in Manternach18 and Hostert18 (see Table 16). Significant higher first pod heights were observed in t.5$_{hoe+}$ (13.6 cm) and t.6$_{comb}$ (13.3 cm) compared to t.3$_{har}$ (9.5 cm) at Manternach 18. At Hostert18, only t.1$_{neg}$ (9.6 cm) and t.2$_{pos}$ (17.3 cm) behave different, while the remaining treatments show similar results in first pod height. Here, all treatments, except t.1$_{neg}$, showed higher pod heights than 13.0 cm.

In general, first pod heights were higher in 2018 than in 2019 with tendency towards higher fist pod heights under hoeing. Harrowing seemed to result in even lower first pod heights than the negative control plots.

4.2 Yield structure

The evaluation of yield parameters was complemented by yield structure (YS) assessments. YS parameters had been taken under investigation to explain the yield determining parameters. Therefore, the counted plants per m^2, pods per plant and beans per pod as well as the yield at 86 %

dry matter calculated from the manual plot harvest (YS yield), the measured TKW (YS TKW) were considered as describing factors. Table 16 gives an overview of the statistical significations for the single YS parameters resulted from ANOVA.

*Table 16: P-values for F test of sources of variation (ANOVA and Kruskal-Wallis in orange color) for yield structure parameters at the three study sites for the seven treatments in 2018 and 2019. Significance levels for ANOVA are given '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.*

	Manternach		**Sprinkange**		**Hostert**	
variable	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
YS plants m^{-2}	0.002 **	0.152	0.025 *	0.109	0.030 *	0.122
YS pods $plant^{-1}$	0.003 **	0.115	0.087 .	0.015 *	0.002 **	0.038 *
YS beans $pods^{-1}$	0.615	0.273	0.011 *	0.147	0.209	0.751
YS yield (dt/ha) 86% DM	0.016 *	0.173	0.029 *	0.004 **	0.000 ***	0.007 **
YS TKW (g) 86% DM	0.099 .	0.599	0.336	0.206	0.492	0.491

Number of soybean plants per m^2 were counted within YS determination. The target number of soybeans per m^2 was set to 65 plants m^2 at sowing. At all the study sites soybeans m^{-2} tend to be higher at the hoeing plots and lowest at the harrow plot $t.3_{har}$ and the negative control (see Appendix 19). At harvest, significant differences in soybean plants per m^2 for the different treatments were observed at all the sites in 2018 (see Table 16). In Manternach $t.6_{comb}$ had highest average number of plants counting 64.5 soybeans m^{-2} and lowest in $t.3_{har}$ and $t.1_{neg}$ counting 44.0 and 43.5 soybeans m^{-2}. The same was observed at Hostert18, where $t.4_{hoe}$ (65 plants m^{-2}) was significantly higher compared to $t.7_{mix}$ (47 plants m^{-2}) and $t.1_{neg}$ (45 plants m^{-2}). Correlation with YS yield was only found for Hostert19 ($r = 0.97$ at $p = 0.0026$).

Focusing at the number of pods per plant and number of beans per pods within the YS determinations, number of pods per plant seemed to be the most interesting variable. Number of beans per pod was not significantly influenced by mechanical treatment except at Sprinkange18, where 2.4 beans per pod were observed in $t.2_{pos}$ and significant lower number in $t.1_{neg}$ and $t.3_{har}$ amounting 2.0 and 2.1 beans per pod. Highest number of beans per pods were observed in the hoeing treatments at Sprinkange19 with 2.9 beans per pod in $t.5_{hoe+}$ and 2.6 beans per pod in $t.4_{hoe}$, in the positive control at Hostert19 with 2.6 beans per pod and in $t.7_{mix}$ with 2.7 beans per pod. Lowest number with 1.9 pods per beans was counted in the negative control at Hostert18. The remaining average number range between 2.0 and 2.4 number pf beans per pod (see Appendix 20). Correlation with YS yield was only found for Manternach18 ($r = 0.82$ at $p = 0.0225$).

The average number of pods per plant significantly influences the treatments at all the site (Sprinkange only at $\alpha = 10\%$) expect at Manternach19 (see Table 16). Number of pods per plant range from 10.8 ($t.6_{comb}$) pods to 17.0 ($t.3_{har}$) pods at Manternach18. At Sprinkange19 number of pods is generally lower ranging from 4.8 pods in $t.1_{neg}$ to 11.5 pods per plant in $t.6_{comb}$. A similar range could be observed at Hostert18, with 4.4 pods in $t.1_{neg}$ ranging up to 11.8 pods per plant in $t.2_{pos}$. At

Hostert19 t.5$_{hoe+}$ shows significant highest pods number (10.3 pods) compared to t.7$_{mix}$ (5.5 pods), t.1$_{neg}$ (6.1 pods) and t.3$_{har}$ (6.9 pods) (see Table 17).

*Table 17: Mean number of pods per plant taken within YS determinations of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test, according to Fisher's test * and Fisher's test but with ANOVA p≤0.1 (*).*

	YS pods plant^{-1} [number m^{-2}]					
	Manternach		Sprinkange		Hostert	
treatment	**2018**	**2019**	**2018(*)**	**2019**	**2018**	**2019***
t.1 neg	11.6 b	7.7 n.s.	10.2 ab	4.8 b	4.4 b	6.1 cd
t.2 pos	12.1 b	7.0	10.5 ab	-	11.8 a	8.8 abc
t.3 harrow	17.0 a	11.2	9.0 bc	9.4 ab	6.4 b	6.9 bcd
t.4 hoe	13.0 ab	9.9	10.4 ab	8.7 ab	6.9 b	9.8 ab
t.5 hoe+interrow	11.9 b	10.0	11.2 a	10.3 a	6.3 b	10.3 a
t.6 combination	10.8 b	10.3	9.7 abc	11.5 a	7.3 b	8.5 abcd
t.7 mix	14.0 ab	12.3	8.1 c	7.0 ab	6.2 b	5.5 d

YS yield showed high correlation with YS pods per plants at Sprinkange19, Hostert18 and Hostert19 with correlations of r = 0.90 (p = 0.014), r = 0.91 (p = 0.005) and r = 0.97 (p = 0.000). The remaining sides did not show significant correlations. A significant linear regression of YS pods per plant on YS yield was found for three of the study sites and hence an increased number of pods per plant results in an increased yield. For Hostert19 a high amount of 93.4 % of YS yield could be explained by YS pods per plant (see Figure 30). For Hostert18 and Sprinkange19 still more than 80 % of YS yield could be explained by YS pods per plant. Here, other factors seemed to have minor influences.

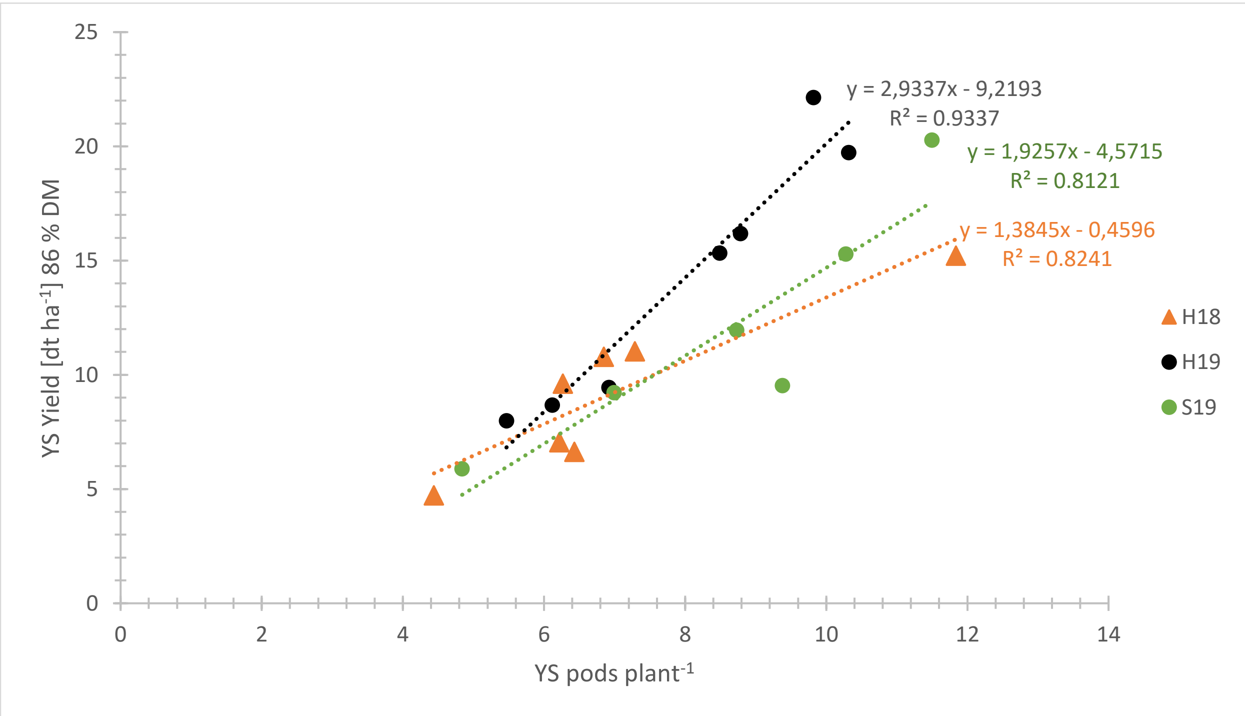


Figure 30: Regression of YS pods per plant on YS yield [dt ha^{-1}] of the three sites Hostert18, Hostert19 and Sprinkange19. Regression was computed based on the treatment means for each site and year separately.

YS TWK were very similar for all the sites and years and no significant differences within the treatments could be observed (see Table 16). YS TKW were determined in similar ranges than TKW from combined harvester yield (not shown here).

Higher yields from yield structure were observed compared to the results from the combine plot harvester. This expected trend is explained by yield loss of mechanical harvest compared to manual harvest and by the small area of sampling for yield structure. Yield calculated from YS differs on all the sites and years except on Manternach19 (see Table 16). On this site, a trend for higher yields under hoeing, especially for t.4$_{hoe}$ (24.6 dt ha^{-1}), and for lowest yield in t.1$_{neg}$ (11.8 dt ha^{-1}) was observed (see Table 18).

Table 18: Mean soybean yield calculated from yield structure (YS) [dt ha^{-1}] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test.

	YS yield [dt ha^{-1}] at 86 % DM					
	Manternach		Sprinkange		Hostert	
treatment	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
t.1 neg	13.6 b	11.8 n.s.	15.3 ab	5.9 b	4.7 c	8.7 b
t.2 pos	19.1 ab	14.6	20.0 a	-	15.2 a	16.2 ab
t.3 harrow	20.9 a	16.3	13.3 b	9.5 b	6.6 bc	9.5 ab
t.4 hoe	20.4 a	24.6	17.5 ab	12.0 ab	10.8 b	22.2 a
t.5 hoe+interrow	20.2 a	20.0	16.4 ab	15.3 ab	9.6 b	19.7 ab
t.6 combination	17.6 ab	21.8	16.8 ab	20.3 a	11.0 b	15.3 ab
t.7 mix	17.9 ab	18.2	14.3 ab	9.2 b	7.1 bc	8.0 b

Manternach18 showed no significant differences between t.3$_{har}$ (20.9 dt ha^{-1}), t.4$_{hoe}$ (20.4 dt ha^{-1}) and t.5$_{hoe+}$ (20.2 dt ha^{-1}), whereby these in turn differed from t.1$_{neg}$ (13.6 dt ha^{-1}). In Sprinkange18 YS yields only differ significantly between t.2$_{pos}$ (20.0 dt ha^{-1}) and t.3$_{har}$ (13.3 dt ha^{-1}), while in Sprinkange19 YS yields were considerably lower in t.1$_{neg}$ (5.9 dt ha^{-1}), t.3$_{har}$ (9.5 dt ha^{-1}) and t.7$_{mix}$ (9.2 dt ha^{-1}) compared to t.6$_{comb}$ (20.3 dt ha^{-1}). It is obvious, that yields from harrowing did not differ from yields from the negative plot. YS yields were very similar between the hoeing plots in Hostert18 but much higher than in t.1$_{neg}$ (4.7 dt ha^{-1}) and lower than in t.2$_{pos}$ (15.2 dt ha^{-1}). As already seen in Sprinkange19, t.3$_{har}$ (6.6 dt ha^{-1}) and t.7$_{mix}$ (7.1 dt ha^{-1}) did not vary from t.1$_{neg}$ (4.7 dt ha^{-1}) as well. YS yield in Hostert19 was considerably higher in t.4$_{hoe}$ (22.2 dt ha^{-1}) than in t.1$_{neg}$ (8.7 dt ha^{-1}) and t.7$_{mix}$ (8.0 dt ha^{-1}).

As expected, YS yield highly correlated with the yield for study sites Hostert18: r= 0.97 (p<0.001) and Sprinkange18: r = 0.98 (p<0.001) and correlated significantly for Manternach18 with r = 0.85 (p = 0.016) and Sprinkange19 with r =0.93 (p = 0.008). For Hostert19 correlations were r = 1 since the yield was calculated based on the YS yield.

To sum up YS parameters, the number of soybeans m^{-2} was higher in the hoeing plots compared to the harrowing plots. No clear tendencies within hoeing plots were observed but slightly higher numbers of plants were counted in Hostert and Manternach, where no finger weeder was used. At Sprinkange, a tendency to higher numbers was generally achieved under finger weeder applications within hoeing plots. The number of pods per plant seemed to have high influence on yield, since positive correlations were observed for three study sites (Hostert18, Hostert19 and Sprinkange19). At the latter mentioned sites, number of pods per plants tended to be slightly higher in hoeing than in harrowing treatments and lowest in t.1$_{neg}$ and t.7$_{mix}$. Site Manternach showed different results with slight advantages for harrowing treatments. Beans per pods showed similar results for all treatments with a slight tendency towards slightly less beans per pod in the harrowing treatments and negative control. Yields calculated from yield structure were significantly higher under hoeing compared to harrowing. At Sprinkange19 finger-weeding applications might have resulted in higher yields, whereas finger-weeding on the other study sites seemed to result in lower yields compared to the single use of duck foot shares.

4.3. Soybean characteristics, losses and damages

Soybean growth and external influences on growth were detected along the vegetation period. Soybean plant density after emergence, soybean height at flowering and chlorophyll content at flowering were considered. Plant losses were calculated based on plant density to check for negative impacts of the treatments on soybean growth. Table 19 gives an overview of the results from ANOVA for the considered soybean parameters within this subchapter.

*Table 19: P-values for F test of sources of variation (ANOVA and Kruskal-Wallis in orange color) for soybean characteristics at the three study sites for the seven treatments in 2018 and 2019. Significance levels for ANOVA are given '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.*

	Manternach		Sprinkange		Hostert	
variable	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
plants m² BWC	0.006 **	0.729	0.277	NA	0.206	0.769
height at flowering [cm]	0.002 **	0.024 *	0.532	0.023 *	0.035 *	0.000 ***
chl [µmol m^{-2}]	0.727	0.018 *	0.033 *	0.067 .	0.051 .	0.040 *
plant losses$_{stand\ impact}$ [%]	0.259	0.022 **	0.688	NA	0.022 *	0.778
plant losses$_{single\ impact}$ [%]	0.015 *	0.069 .	0.084 .	NA	0.073 .	0.479

4.3.1 Soybean density BWC

The soybean plant density BWC was investigated to show the initial point of number of soybean plants after emergence (see Appendix 21). On all study sites no significant differences in plant density was observed, except for Manternach18 (see Table 19). As shown in Figure 31, soybean plants at Manternach18 were significant lowest in t.3$_{har}$ (43.3 plants m^{-2}) and highest in t.2$_{pos}$ (59.3 plants m^{-2}), t.4$_{hoe}$ (63.3 plants m^{-2}) and t.5$_{hoe+}$ (61.8 plants m^{-2}). Soybean plants evenly emergence at the remaining study sites ranging from 56.0 plants m^{-2} (t.2$_{pos}$) to 68 plants m^{-2} (t.3$_{har}$) on average at Manternach19, from 56.0 plants m^{-2} ($t.7_{mix}$) to 66 plants m^{-2} ($t.4_{hoe}$) at Sprinkange18, from 53.3 plants m^{-2} up to 70.9 plants m^{-2} ($t.6_{comb}$) at Hostert18 and from 54.7 plants m^{-2} ($t.3_{har}$) to 69.1 plants m^{-2} ($t.4_{hoe}$) at Hostert19.

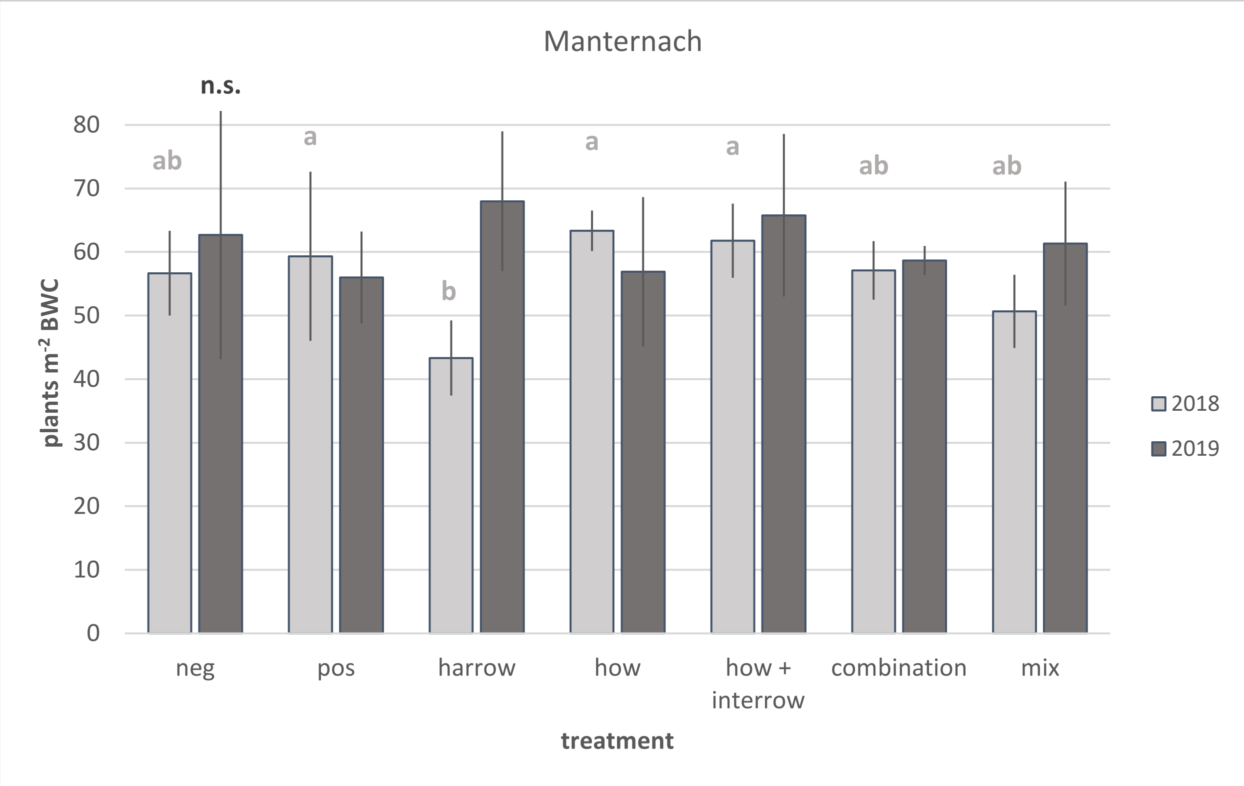


Figure 31: Average mean values of plants per m^2 BWC of the different treatments for study site Manternach. Common letters indicate no significantly differences at p≤0.5 according to Tuckey's test within the cultivation years (2018: light grey; 2019: dark grey).

To sum up, soybean plants seemed to emergence homogeneously except on Manternach18, where $t.3_{har}$ had the lowest mean number of soybean plants.

4.3.2 Soybean stand height at FLO

Soybean stand height at FLO measured within the plots were significantly influenced by treatments, except at Sprinkange18 (see Table 19). Stand heights tend to be lower in 2019 than in 2018, especially at study site Hostert (see Table 20).

Table 20: Mean soybean stand heights (cm) of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test or Fisher's test.*

	Height [cm] FLO					
	Manternach		Sprinkange		Hostert	
treatment	**2018**	**2019**	**2018**	**2019**	**2018***	**2019**
t.1 neg	46.8 ab	43.8 ab	51.8 n.s.	48.0 ab	70.0 a	34.0 b
t.2 pos	45.5 abc	42.0 ab	54.0	-	60.0 b	36.8 ab
t.3 harrow	38.8 c	35.8 b	52.3	41.0 ab	69.0 a	34.3 b
t.4 hoe	48.8 ab	44.8 a	53.5	48.8 ab	69.8 a	43.5 a
t.5 hoe+interrow	51.0 a	42.5 ab	48.3	45.8 ab	68.8 a	44.3 a
t.6 combination	46.0 abc	44.3 ab	45.8	50.3 a	68.0 a	42.8 a
t.7 mix	43.3 bc	38.0 ab	49.8	36.8 b	64.0 ab	34.0 b

A tendency towards lower stand heights with harrowing compared to hoeing was measured. At Manternach 18 height of soybean under t.5_{hoe+} measuring 51.0 cm was significantly higher than under t.7_{mix} (43.3 cm) and t.3_{har} (38.8 cm). T.4_{hoe} (48.8 cm) also differs from t.3_{har}. Manternach19 shows significant differences in t.4_{hoe} (44.8 cm) compared to t.3_{har} (35.8 cm). At Sprinkange19, t.6_{comb} (50.3 cm) differs significantly from t.7_{mix} (36.8 cm). Stand heights at Hostert18 range up to 70.0 cm, while the significantly lowest height was found in t.2_{pos} (60.0 cm). At Hostert19, hoeing treatments significantly differ from harrowing plots and negative control with mean heights of 44.3 cm in t.5_{hoe+} and 34.0 cm in t.7_{mix} and t.1_{neg}.

In general, soybean stand was higher in 2018 compared to 2019. Highest differences were observed at Hostert with more than 30 cm in height differences. Lower heights within the treatments were observed with harrowing.

4.3.3 Chlorophyll content

Chlorophyll (chl) contents [µmol m^{-2}] of soybeans at flowering were calculated. A tendency towards higher values in 2019 compared to 2018 was observed (see Table 21). Significant differences in chl contents were calculated for Manternach19, Sprinkange18 and Hostert19 sites (see Table 19). At Sprinkange18 the lowest chl content (280.3 µmol m^{-2}) was calculated for t.6_{comb} and the highest for t.2_{pos} (372.5 µmol m^{-2}). Much higher values were observed at Hostert19 where t.3_{har} showed a significantly higher chl content (543.7 µmol m^{-2}) than t.7_{mix} (491.4 µmol m^{-2}). At Manternach19 the highest values were found in t.3_{har} (470.9 µmol m^{-2}) and t.5_{hoe+} (463.1 µmol m^{-2}) and lowest in t.2_{pos} (410.6 µmol m^{-2}).

Table 21: Mean chlorophyll content [µmol m^{-2}] at FLO of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test.

	chl [µmol m^{-2}]					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
t.1 neg	320.5 n.s.	438.5 ab	356.1 ab	460.8 n.s.	408.6 n.s.	505.4 ab
t.2 pos	348.0	410.6 b	372.5 a	-	403.2	505.6 ab
t.3 harrow	340.0	470.9 a	363.5 ab	500.5	388.4	543.7 a
t.4 hoe	344.8	451.7 ab	316.0 ab	445.0	426.9	502.4 ab
t.5 hoe+interrow	338.2	463.1 a	316.1 ab	494.8	415.8	502.4 ab
t.6 combination	331.0	459.5 ab	280.3 b	493.8	431.8	507.2 ab
t.7 mix	342.4	439.6 ab	324.7 ab	406.8	400.4	491.4 b

At Manternach18 a tendency towards highest chl contents in t.2$_{pos}$ and t.4$_{hoe}$. and lowest in t.1$_{neg}$ was described. For this study site, high correlation with r = 0.81 (p = 0.029) were found between chlorophyll content at FLO and YS yield (r = 0.81). A correlation with protein content of r = 0.76 (p = 0.049) was observed at Sprinkange18 and at a level of significance of α = 10 %, r = 0.69 (p = 0.087) at Hostert18. No clear relation has been found between chl content and soybean yield parameters that are valid for more than one study site.

In general, chlorophyll values were lower in 2018 compared to 2019. Highest contents were observed in Hostert19. No clear trend could be described from these findings, since differences seemed to depend on the site.

4.3.4 Plant losses

One of the most important parameters in mechanical weed control in soybean cultivation is the loss of soybean plants due to mechanical impacts. Plant losses$_{single\ impact}$, the difference of plants m^{-2} BWC and AWC, was investigated to check for immediate effects after the first mechanical runs. Highly significant differences in plant losses along the treatments only were observed at Manternach18, whereas Manternach19, Sprinkange18 and Hostert18 showed differences only on a 10 % significance level (see Table 19). Study site Sprinkange19 was not considered due to missing data of plant density AWC.

Table 22: Mean plant losses$_{single\ impact}$ [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and Fisher's test but with ANOVA p≤0.1 (*) and Fisher's test with Kruskal-Wallis test but p≤0.1 (**).

	Plant losses$_{single\ impact}$ [%]					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018**	**2019(**)**	**2018(*)**	**2019**	**2018(*)**	**2019**
t.1 neg	0.0 a	0.0 a	0.0 a	NA	0.0 a	0.0 n.s.
t.2 pos	0.0 a	0.0 a	0.0 a		0.0 a	0.0
t.3 harrow	12.0 b	6.4 bc	-		3.0 abc	4.8
t.4 hoe	5.5 ab	0.9 ab	1.0 a		1.4 ab	3.0
t.5 hoe+interrow	2.3 ab	1.5 abc	3.0 ab		8.2 bc	5.1
t.6 combination	3.8 ab	1.9 abc	2.0 ab		1.6 ab	3.6
t.7 mix	7.9 ab	22.3 c	5.9 b		8.8 c	1.9

At Manternach18 the highest plant losses$_{single\ impact}$ were observed on t.3$_{har}$ (12 %) and no losses, as previously defined, on the control plots. At Manternach19 high plant losses of 22.3 % on average were detected in t.7$_{mix}$ and only 0.9 % losses in t.4$_{hoe}$. The similar occurred at Sprinkange18 with plant losses of 5.9 % in t.7$_{mix}$ and 1.0 % in t.4$_{hoe}$). In general, higher plant losses$_{single\ impact}$ tend to occur when harrowing was done compared to hoeing. Within hoeing treatments, slightly higher plant losses tended to occur, where finger weeder application was used e.g. in Sprinkange18, Hostert18 and Hostert19 (see Table 22 and Appendix 22).

In 2019, a second mechanical run was performed on all study sites. To detect the influence of both mechanical runs, plant losses from BWC and FLO (plant losses$_{mechanical\ impact}$) were calculated as well for Manternach19 and Hostert19 (see Appendix 23). No significant differences in plant losses were found for Hostert19 but a tendency towards the lowest plant losses in t.4$_{hoe}$ was observed. Whenever finger weeder was used during the second run (t.5$_{hoe+}$ and t.6$_{comb}$) and harrow twice (t.3$_{har}$), a trend to higher plant losses was observed (see Figure 32). The similar applies for Manternach19, where significant higher plant losses were observed for t.3$_{har}$ (18.3 %) compared to t.4$_{hoe}$ (0.4 %) and t.6$_{comb}$ (0.4 %). Here, only in t.5$_{hoe+}$ finger weeder applications were used during the second run resulting in 4.6 % plant losses. T.3$_{har}$ was only harrowed once that's why the amount of plant losses remains 22.9 %. T.3$_{har}$ and t.7$_{mix}$ showed significant higher plant losses than t.1$_{neg}$ (2.7 %).

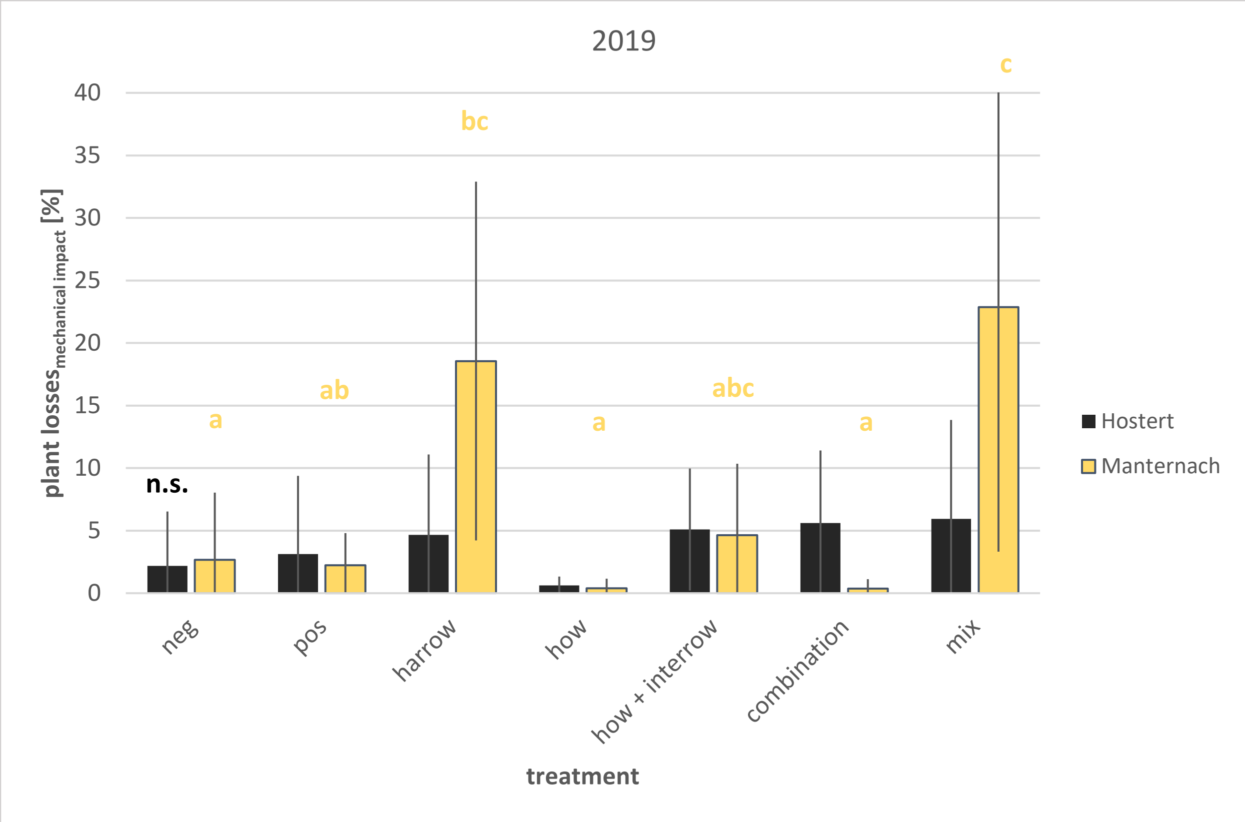


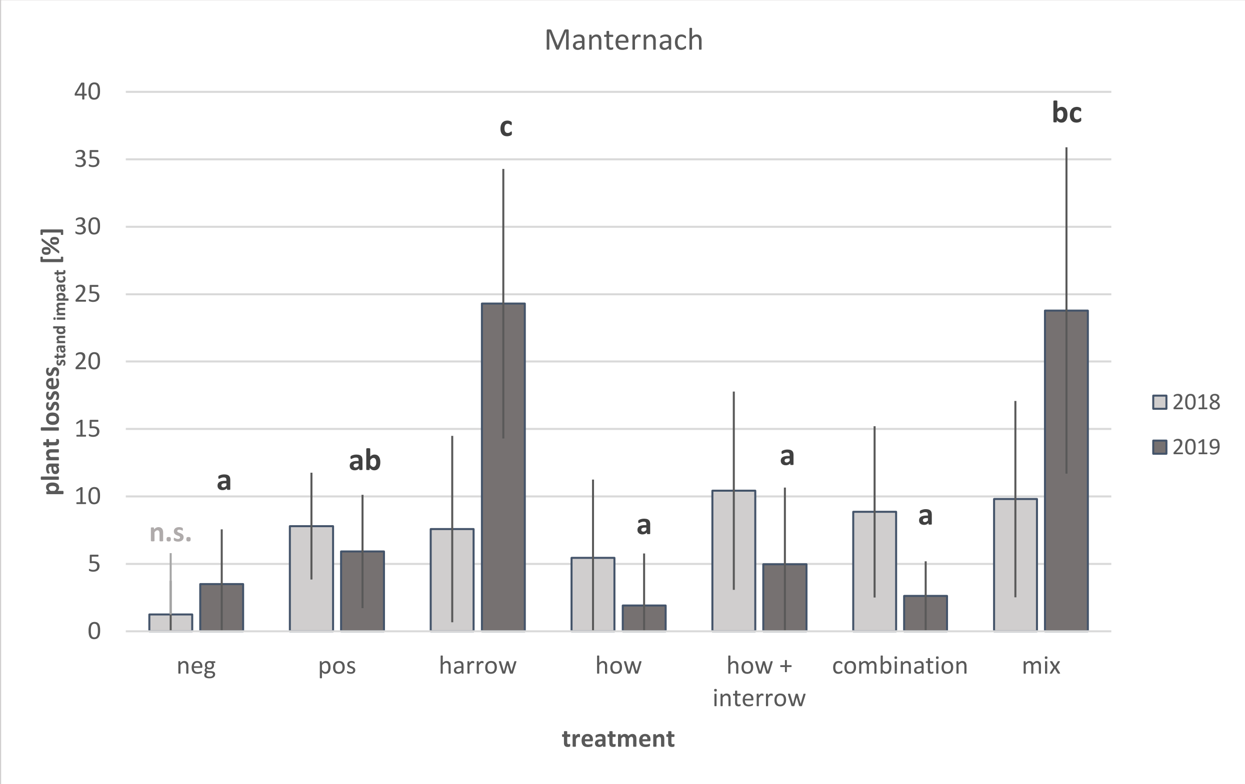
Figure 32: Plant losses [%] of the mechanical impact from BWC and FLO for Hostert (black) and Manternach (yellow) in 2019. Common letters indicate no significantly differences at p≤0.5 according to Fisher's test.

Plant losses$_{stand\ impact}$ [%] was additionally calculated to assess impacts along the whole vegetation period based on differences in plants m^{-2} BWC and HAR. In general, plant losses increase from the first observation point (plant losses$_{single\ impact}$) until harvest. In general, within the mechanical weed control, simple hoeing with duck foot shares seemed to have lowest plant losses, while highest were found in harrowing (see Table 23). Significant differences in plant losses$_{stand\ impact}$ were found in Manternach19 and Hostert19 (see Table 19 and Appendix 24).

*Table 23: Mean plant losses$_{stand\ impact}$ [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and according to Fisher's test as post-hoc for Kruskal-Wallis **.*

	Plant losses$_{stand\ impact}$ [%]					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018**	**2019****	**2018**	**2019**	**2018**	**2019**
t.1 neg	1.3 n.s.	3.5 a	9.1 n.s.	NA	5.8 a	9.7 n.s.
t.2 pos	7.8	5.9 ab	11.4		6.3 a	8.8
t.3 harrow	7.6	24.3 c	2.6		19.7 ab	13.0
t.4 hoe	5.5	1.9 a	4.1		4.2 a	4.4
t.5 hoe+interrow	10.4	5.0 a	7.0		10.2 ab	7.5
t.6 combination	8.9	2.6 a	9.2		10.6 ab	6.7
t.7 mix	9.8	23.8 bc	11.9		34.8 b	13.5

As already described in the previous plant losses calculations, significantly lowest plant losses were found in in the hoeing plots $t.4_{hoe}$ (1.9 %), $t.5_{hoe+}$ (5.0 %) and $t.6_{comb}$ (2.6 %) compared to the harrowing $t.3_{har}$ (24.3 %) and $t.7_{mix}$ (23.8 %). Within hoeing, a tendency for the use of finger weeder applications in $t.5_{hoe+}$ was observed (see Figure 33). Soybean plant losses in positive control tend to be higher than in negative control due to manual weeding impacts. At Hostert18, the lowest number of plant losses was observed in $t.4_{hoe}$ (4.2 %) and the significantly highest number in $t.7_{mix}$ (34.8 %). Here, within hoeing treatments, finger weeder application in $t.5_{hoe+}$ and $t.6_{comb}$ tend to result in higher plant losses than the simple use of duck foot shares in $t.4_{hoe}$.



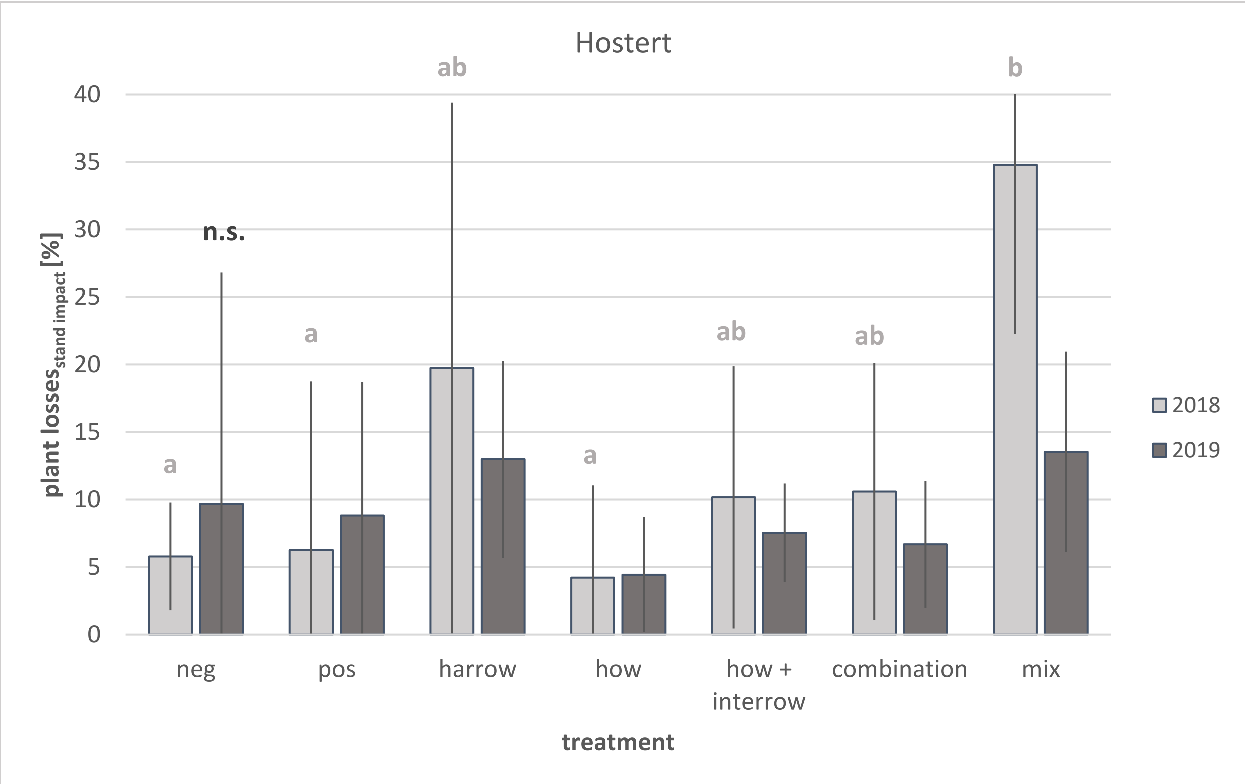


Figure 33: Average mean values of soybean plant losses$_{stand\ impact}$ (%) and standard deviation of the different treatments for study site Manternach and Hostert in both the project years. Common letters indicate no significant differences.

To sum up plant loss calculations, high direct negative impacts AWC were observed within t.3$_{har}$ at Manternach18 and t.7$_{mix}$ at Manternach19, Sprinkange18 and Hostert18 compared to the hoeing treatments. A tendency towards higher plant losses when finger weeder was used during the first run in 2018 compared to single use of duck foot shares was observed. The second run of mechanical weed control further increased plant losses in t.3$_{har}$ and t.7$_{mix}$ at Manternach19; alike the use of finger-weeding during the second run tended to increase plant loss, too. Nevertheless, highest plant losses were observed with harrowing compared to hoeing. Lowest plant losses after the second run were observed in t.4$_{hoe}$ where single duck-foot shares were used compared to finger-weeding at Hostert19.

4.3.5 Damages on soybean plants

The visual assessment of damages on soybean plants for AWC and FLO has not been as rigorously done in 2018 as in 2019. Damages have not been recorded in Sprinkange19. Nevertheless, some global trends were observed. It seemed that mechanical weed control damaged more soybean plants for AWC than for FLO, when two mechanical runs were performed (in 2019). For Hostert19, a high number of damages was observed since an episode of hail affected all treatments so, no distinction between hail damages and machine damages could be distinguished.

For Hostert18, damages are shown in Table 24. Less than 3.0 damaged plants per square meter [DP m^{-2}] were counted. For AWC, from 0.9 to 1.1 DP m^{-2} were assessed for t.4$_{hoe}$, t.5$_{hoe+}$ and t.6$_{comb}$, while, 2.7 DP m^{-2} for t.7$_{mix}$. In the treatments, where damages were found, most of the plants were 100 % damaged. At FLO, only 0.4 DP m^{-2} damaged at 90 % were assed for t.4$_{hoe}$.

Table 24: Average values of the number of damaged soybean plants [number m^{-2}] per range of intensity of damage (from 10 % to 100 %) for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for AWC and FLO, for Hostert 2018. According to the scale of Vanhala (2004) (in Table 5).

Hostert 2018	**Damaged soybean plants [number m^{-2}]**													
	AWC							FLO						
Damages [%]	1	2	3	4	5	6	7	1	2	3	4	5	6	7
10 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 %	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 %	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 %	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
100 %	0.0	0.0	0.0	0.7	1.1	0.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Damages for Hostert19 are recorded in Table 25. For AWC, each mechanical treatment showed damaged plants, from 1.6 DP m^{-2} for treatment t.5$_{hoe+}$ to 8.7 DP m^{-2} for t.7$_{mix}$. On average, more plants were damaged in harrowed treatments, t.3$_{har}$ and t.7$_{mix}$, than in hoed treatments, t.4$_{hoe}$, t.5$_{hoe+}$ and t.6$_{comb}$, but more plants were 100 % damaged in hoed treatments than in harrowed ones. For FLO, after the second mechanical weed control for treatments t.3$_{har}$, t.4$_{hoe}$, t.5$_{hoe+}$ and t.6$_{comb}$, an important proportion of damaged plants of 10 % was assessed. This is partly explained by the impacts of a hail event which occurred before flowering. Therefore, there were plants damaged in the positive and the negative control, too. A distinction between the impacts of hail and the machines was not possible. There was a minimum of 3.4 DP m^{-2} for t.4$_{hoe}$ compared to 19.3 DP m^{-2} for t.6$_{comb}$ where a problem with the machine by driving occurred.

Table 25: Average values of the number of damaged soybean plants [number m^{-2}] per range of intensity of damage (from 10 % to 100 %) for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for AWC and FLO, for Hostert 2019. According to the scale of Vanhala (2004) (in Table 5).

Hostert 2019	**Damaged soybean plants [number m^{-2}]**													
	AWC							FLO						
Damages [%]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10 %	0.0	0.0	2.7	0.4	0.4	0.2	3.3	6.7	4.7	2.7	3.3	14.9	13.1	4.7
20 %	0.0	0.0	1.3	0.0	0.4	0.2	2.7	0.0	0.0	0.0	0.4	0.0	0.9	0.0
30 %	0.0	0.0	0.0	0.2	0.0	0.4	0.0	0.7	0.0	0.0	0.0	0.0	4.7	1.3
40 %	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.7
50 %	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 %	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.7	0.0	0.0	0.4	0.0
70 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 %	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
100 %	0.0	0.0	2.0	1.6	0.4	2.2	1.3	0.7	0.0	0.0	0.2	0.4	0.2	0.0

For Manternach18, some damages were only recorded for AWC (see Table 26). Damages on soybean plants were visible for each mechanical treatment. 1.6 DP m^{-2} were assessed for t.5$_{hoe+}$ in comparison to 6.0 DP m^{-2} for t.7$_{mix}$. Most of the plants were damaged at 100 % and were from harrowed treatments. The tendency is that more damages were caused in harrowed treatments t.3$_{har}$ and t.7$_{mix}$ than in others.

Table 26: Average values of the number of damaged soybean plants [number m^{-2}] per range of intensity of damage (from 10 % to 100 %) for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for AWC and FLO, for Manternach18. According to the scale of Vanhala (2004) (in Table 5).

Manternach 2018	**Damaged soybean plants [number m^{-2}]**													
	AWC							FLO						
Damages [%]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
20 %	0.0	0.0	0.7	0.0	0.2	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
30 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
40 %	0.0	0.0	0.0	1.1	0.0	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
50 %	0.0	0.0	0.0	0.2	0.0	0.0	1.3	NA	NA	NA	NA	NA	NA	NA
60 %	0.0	0.0	0.0	0.0	0.0	0.0	0.7	NA	NA	NA	NA	NA	NA	NA
70 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
80 %	0.0	0.0	0.0	0.0	0.0	0.2	0.0	NA	NA	NA	NA	NA	NA	NA
90 %	0.0	0.0	0.0	0.0	0.2	0.0	0.0	NA	NA	NA	NA	NA	NA	NA
100 %	0.0	0.0	3.3	2.2	1.1	2.0	4.0	NA	NA	NA	NA	NA	NA	NA

For Manternach19, more damages were caused by the first mechanical weed control than by the second one, comparing the number of damaged plants for AWC and for FLO (see Table 27). For AWC, damaged plants were found for all weeded treatments (1.6 DP m^{-2} for treatment t.6_{comb} to 23.3 DP m^{-2} for t.7_{mix}). Harrowed treatments t.3_{har} and t.7_{mix} damaged more plants than hoed ones. A large part of the plants damaged were affected at 10 %. For FLO, the second harrowing for t.3_{har} caused damages at 10 % of the soybean plants. The exclusive use of the finger weeder for t.5_{hoe+} has damaged, at 100 %, 1.8 plants per square meter. Only 0.2 DP m^{-2} at 100 % were counted for the second performance of the hoe for t.6_{comb}.

Table 27: Average values of the number of damaged soybean plants [number m^{-2}] per range of intensity of damage (from 10 % to 100 %) for each treatment t.1_{neg} (1), t.2_{pos} (2), t.3_{har} (3), t.4_{hoe} (4), t.5_{hoe+} (5), t.6_{comb} (6) and t.7_{mix} (7), for AWC and FLO, for Manternach19. According to the scale of Vanhala (2004) (in Table 5).

Manternach 2019	**Damaged soybean plants [number m^{-2}]**													
	AWC							FLO						
Damages [%]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10 %	0.0	0.0	4.0	2.4	5.3	1.1	8.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0
20 %	0.0	0.0	4.0	0.2	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 %	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 %	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50 %	0.0	0.0	4.7	0.0	0.2	0.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 %	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0
70 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 %	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90 %	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100 %	0.0	0.0	0.7	0.4	0.2	0.2	6.7	0.0	0.0	0.0	0.0	1.8	0.2	0.0

For Sprinkange18, for AWC, no weed control has been done for treatment t.3_{har}. 0.7 DP m^{-2} were counted for t.7_{mix} while 3.3 DP m^{-2} were found for t.6_{comb} (see Table 28).

Table 28: Average values of the number of damaged soybean plants [number m^{-2}] per range of intensity of damage (from 10 % to 100 %) for each treatment t.1_{neg} (1), t.2_{pos} (2), t.3_{har} (3), t.4_{hoe} (4), t.5_{hoe+} (5), t.6_{comb} (6) and t.7_{mix} (7), for AWC and FLO, for Sprinkange 2018. According to the scale of Vanhala (2004) (in Table 5).

Sprinkange 2018	**Damaged soybean plants [number m^{-2}]**													
	AWC							FLO						
Damages [%]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
10 %	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0
20 %	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
40 %	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
50 %	0.0	0.0	0.0	0.7	0.4	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60 %	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70 %	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80 %	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90 %	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.4	0.2	0.4	0.0
100 %	0.0	0.0	0.0	0.2	1.8	0.4	0.0	0.0	0.0	0.0	0.2	1.3	0.4	0.0

The most affected plants were monitored in hoed treatments. For t.5$_{hoe+}$, most of the plants were damaged at 100 % and for t.6$_{comb}$, most were damaged at 60 %, finger weeder was used in both cases. At FLO, even though no more weed control occurred, in lower proportions, some damages were recorded. They varied between 0.9 DP m^{-2} for t.6$_{comb}$ and 2.4 DP m^{-2} for t.5$_{hoe+}$. A delay in damage occurrence from AWC to FLO was observed and damages seemed to be visible only later. No more damages were visible for harrowed t.7$_{mix}$.

It appears that harrowed treatments (t.3$_{har}$ and t.7$_{mix}$) contained more damaged plants than hoed ones (t.4$_{hoe}$, t.5$_{hoe+}$ and t.6$_{comb}$). The larger part of the plants has been damaged to a degree of 10 % or 100 % (complete destruction) both for AWC and FLO. When damages occur with hoeing, plants are mostly completely destructed while harrow results in lower degree of damages.

4.4. Weed characteristics and weed control efficacy

Several weed occurrences describing parameters have been taken under investigation. Weed biomass [g], weed cover [%] and weed density [weeds m^{-2}] have been selected to describe weed distribution at the study sites. Weed control efficiency [%] based on weed cover and density was calculated to look for the weed control success of the mechanical treatments. Weed success indices were finally presented and described. Table 29 gives an overview of the results from ANOVA or Kruskal-Wallis for the considered weed parameters as described as follows. All the investigated parameters showed high significant differences at all the sites and years.

*Table 29: P-values for F test of sources of variation (ANOVA and Kruskal-Wallis in orange color) for soybean characteristics at the three study sites for the seven treatments in 2018 and 2019. Significance levels are given '***' 0.001, '**' 0.01, '*' 0.05.*

	Mantenach				Sprinkange				Hostert			
variable	**2018**		**2019**		**2018**		**2019**		**2018**		**2019**	
Weed cover [%] BWC total	0.437		0.797		0.001	***	NA		0.099	.	0.836	
W biomass [g] FLO	0.000	***	0.017	**	0.002	**	0.000	***	0.009	**	0.000	***
W cover [%] FLO total	0.001	***	0.032	*	0.000	***	0.000	***	0.000	***	0.001	***
W density [weeds m^{-2}] FLO	0.004	**	0.005	**	0.001	***	NA		0.000	***	0.000	***
WCE [%] cover	0.036	*	0.003	*	0.000	***	NA		0.005	**	0.001	***
WCE [%] density	0.000	***	0.001	***	0.000	***	NA		0.002	**	0.002	**
W cover [%] HAR total	0.006	**	0.011	*	0.000	***	0.000	***	0.000	***	0.000	**

4.4.1 Weed cover BWC

Weed cover [%] BWC was detected to show the initial weed coverage after soybean emergence and potential influences of blind-harrowing. In general, low weed cover BWC was found at Manternach18, Manternach19 and Hostert19 and high weed cover was found at Sprinkange19 and Hostert18 (see Table 30 and Appendix 25). Average weed cover BWC at Sprinkange19 ranged between 16.8 % in t.6$_{comb}$ and 40.0 % in t.1$_{neg}$. and at Hostert18 between 35 % in t.6$_{comb}$ and 55 % in t.5$_{har+}$. Weeds seemed to emergence heterogeneously at Sprinkange18 and Hostert18, hence significant differences in weed cover BWC were found at Sprinkange18 and, with α≤0.1, at Hostert18 (see Table 29). No statistical indication could be made for Sprinkange19 due to the low sampling size (n = 2).

Table 30: Mean weed cover [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and Fisher's test but with ANOVA p≤0.1 (*). NA indicates no statistical testing due to low sampling size of n=2.

	Weed cover [%] BWC					
	Manternach		Sprinkange		Hostert	
treatment	**2018**	**2019**	**2018**	**2019**	**2018(*)**	**2019**
t.1 neg	3.0 n.s.	5.6 n.s.	16.3 ab	40.0 NA	40.0 a	3.8 n.s.
t.2 pos	2.7	6.8	26.3 bc	33.3	42.1 ab	3.9
t.3 harrow	2.3	5.2	25.0 bc	31.2	46.8 ab	3.4
t.4 hoe	1.6	5.5	12.5 a	35.8	38.3 a	4.6
t.5 hoe+interrow	1.8	8.0	16.0 ab	16.8	55.0 b	4.7
t.6 combination	2.3	4.8	17.1 ab	24.7	35.0 a	3.2
t.7 mix	2.4	10.2	30.8 c	24.3	43.3 ab	3.0

At Sprinkange18 lowest weed cover BWC was observed in $t.4_{hoe}$ (12.5 %) and highest in $t.7_{mix}$ (30.8 %). $T.4_{hoe}$ significantly differs from $t.7_{mix}$, $t.2_{pos}$ (26.3 %) and $t.3_{har}$ (25.0 %). No differences were found within hoeing treatments. Since blind harrowing was done in $t.3_{har}$, $t.7_{mix}$ and $t.6_{comb}$, the observed differences in heterogenous weed emergence within these treatments were not explained by blind-harrowing. At Hostert18, no significant difference was observed within the blind harrowed plots $t.3_{har}$ (46.8 %), $t.6_{comb}$ (35 %) and $t.7_{mix}$ (43.3 %).

Summarizing, high weed cover BWC at Hostert18 and Sprinkange19 were observed while weed cover at both Manternach sites was low. Blind-harrowed plots showed no significant differences with untreated plots.

4.4.2 Weed biomass FLO

Weed biomass FLO had distinct amounts according to sites and years. Having a look at both project years, at Sprinkange weed biomass FLO was much higher in 2019 than in 2018, unlike in Hostert, as can be seen in Figure 34. Only Manternach had lower weed pressures in both years. Weed biomass FLO were consistently lowest in $t.2_{pos}$ at all sites attributed to the manual weeding (see Table 31) and differ significantly from $t.1_{neg}$.

*Table 31: Mean weed biomass [g] dry matter at FLO of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and to Fisher's test after Kruskal-Wallis p≤0.05 **.*

	Weed biomass [g] DM FLO					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018**	**2019**	**2018****	**2019**	**2018****	**2019**
t.1 neg	47.9 c	82.1 b	58.4 cd	248.3 b	411.6 d	109.3 c
t.2 pos	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
t.3 harrow	9.2 ab	32.2 ab	98.7 d	207.7 b	344.1 cd	67.0 bc
t.4 hoe	8.9 ab	33.2 ab	33.4 bc	149.3 b	276.9 bc	16.6 ab
t.5 hoe+interrow	10.0 ab	32.3 ab	25.8 b	210.8 b	293.1 bc	13.2 ab
t.6 combination	15.0 ab	16.2 ab	23.6 b	160.3 b	254.7 ab	13.3 ab
t.7 mix	19.2 b	64.0 ab	119.2 d	177.3 b	333.9 bcd	79.5 c

The negative control had highest amounts, except for Sprinkange18, where $t.3_{har}$ and $t.7_{mix}$ tended to have even higher weed biomasses on average.

Weed biomass FLO at Manternach18 showed similar results for $t.2_{pos}$ and $t.3_{har}$, $t.4_{hoe}$, $t.5_{hoe+}$, $t.6_{comb}$ but significant differences between $t.2_{pos}$ (0 g), $t.7_{mix}$ (19.2 g) and $t.1_{neg}$ (47.9 g). Significantly highest amounts were attributed to $t.1_{neg}$. At Manternach19 similar amounts between treatments on average were found, with a difference only in $t.1_{neg}$ (82.0 g) and $t.2_{pos}$. Significantly higher biomasses in $t.3_{har}$ (98.7 g) and $t.7_{mix}$ (119.2 g) were measured compared to the hoeing treatments $t.4_{hoe}$ (33.4 g), $t.5_{hoe+}$ (25.8 g) and $t.6_{comb}$ (23.6 g) at Sprinkange18. Here, in turn, harrowing plots behave similar to $t.1_{neg}$. At Sprinkange19, only $t.2_{pos}$ differs from the remaining plots that range from 149.3 g in $t.4_{hoe}$ up to 248.3 g in $t.1_{neg}$. Hostert18 showed significantly lower mean biomass in $t.6_{comb}$ (254.7 g) compared to $t.3_{har}$ (344.1 g) and similar values were observed in $t.3_{har}$, $t.7_{mix}$ (333.9 g) and $t.1_{neg}$ (411.6 g). The latter counts for Hostert19. Here, $t.4_{hoe}$ (16.6 g), $t.5_{hoe+}$ (13.2 g) and $t.6_{comb}$ (13.3 g) significantly differ from $t.7_{mix}$ (79.5) and $t.1_{neg}$ (109.3).

No significant differences in weed biomass at FLO could be observed within the hoeing plots and not even a tendency towards single duck foot shares or finger weeder applications.

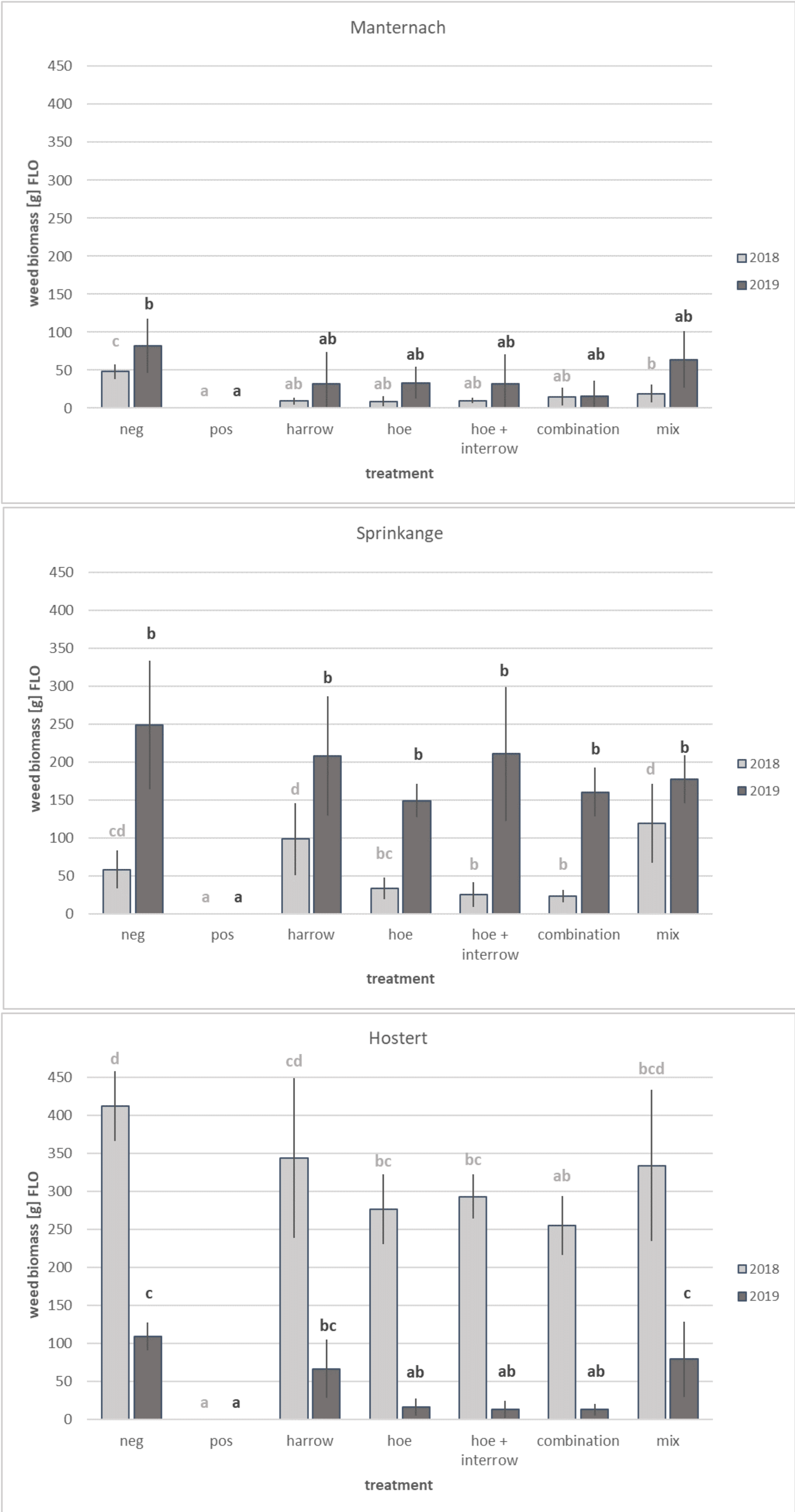


Figure 34: Mean weed biomass (g) dry matter at FLO and standard deviation for all the sites and years. Common letters indicate no significant differences according to Tuckey's (and Fisher's test for Sprinkange18 and Hostert18) within the cultivation years (2018: light grey; 2019: dark grey).

Correlation between weed biomass FLO and yield were taken under investigation to check for possible interactions. High significant correlations (Pearson correlation, $p \leq 0.05$) were found with r= -0.81 (p = 0.026) for Manternach18, r = -0.94 (p = 0.001) for Sprinkange18, r = -0.98 (p = 0.000) for Hostert18 and r = -0.84 (p = 0.017) for Hostert19, indicating higher yields with less weed biomasses at flowering. The regression analysis points out that for e.g. Hostert18 96.2 % of yield could be explained by weed biomass at FLO (see Figure 35).

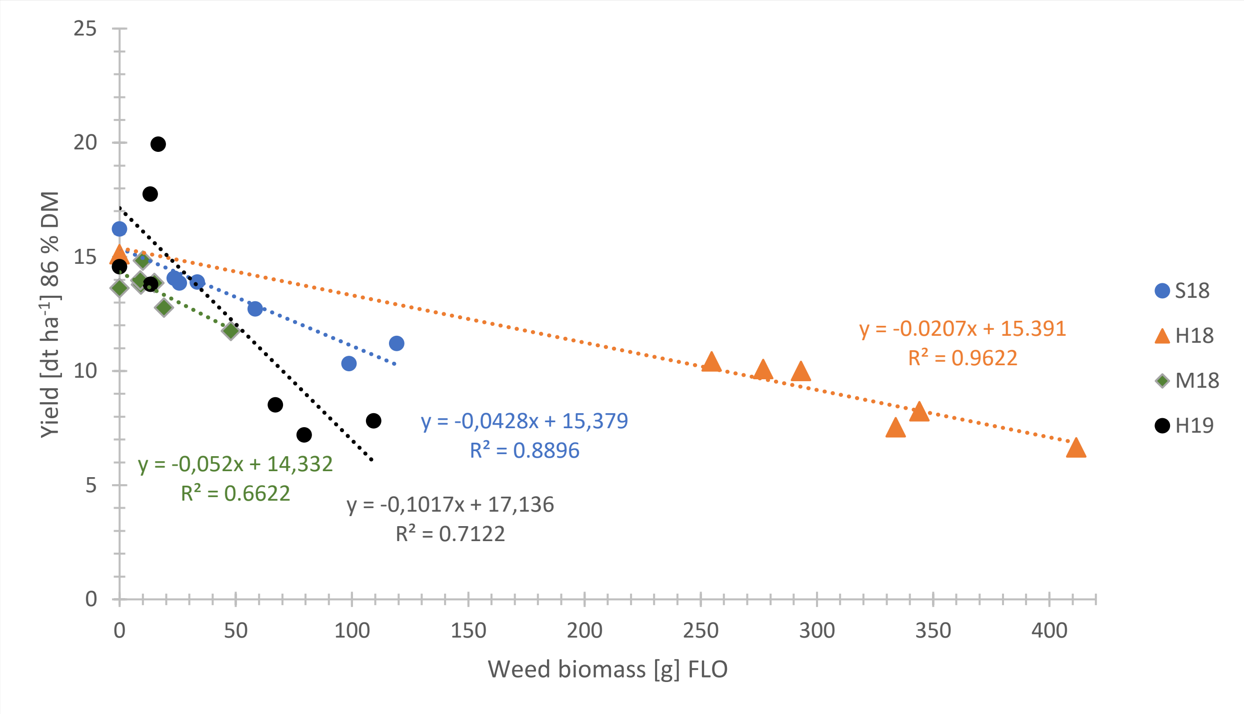


Figure 35: Regression of weed biomass [g] FLO on yield [dt ha-1] of the three sites Sprinkange18, Hostert18, Manternach18 and Hostert19. Regression was computed based on the treatment means for each site and year separately.

In general, weed biomass FLO at Hostert was obviously higher in 2018 than in 2019 and at Sprinkange higher in 2019 than in 2018. Manternach was characterized by low weed pressure in both years with little higher amount in 2019. Mostly, negative control had highest biomasses, except at Sprinkange18, where harrowing plots had even higher amounts. Hoeing tended to result in lower biomasses compared to harrowing. Focusing on differences within hoeing, a tendency towards higher weed biomasses was found for $t.5_{hoe+}$ on the sites characterized by high weed pressure. For four study sites, the correlation of weed biomass FLO with yield was highly negative.

4.4.3 Weed cover FLO

An additional weed parameter that had been taken under consideration was the visual estimated weed cover [%]. Highly significant differences were observed on the investigated sites, as well. T.2_{pos} varied significantly from t.1_{neg}, except at Manternach19 (see Table 32).

*Table 32: Mean weed cover [%] at FLO of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and to Fisher's test * and preceeded Kruskal-Wallis **.*

	Weed cover [%] FLO					
	Manternach		Sprinkange		Hostert	
treatment	**2018***	**2019**	**2018**	**2019**	**2018****	**2019**
1 neg	21.7 d	16.7 ab	17.1 bc	50.8 c	74.6 d	30.0 c
2 pos	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
3 harrow	5.0 c	7.8 ab	24.6 cd	33.8 bc	58.3 cd	20.8 bc
4 hoe	1.3 b	9.7 ab	7.7 ab	26.3 b	43.3 bc	7.3 ab
5 hoe+interrow	2.2 b	6.7 ab	6.2 ab	23.3 b	43.3 bc	5.7 ab
6 combination	4.4 c	3.8 ab	6.1 a	22.1 b	25.4 b	3.9 ab
7 mix	7.6 c	21.6 b	30.0 d	42.5 bc	67.9 d	15.0 abc

In general, lowest weed cover at flowering was observed on both sites in Manternach. Weed cover tended to be highest at Sprinkange19 and Hostert18, as already found within weed biomass investigations (see Figure 36). At Manternach18 all mechanical treatments differ significantly from both control plots. T.4_{hoe} and t.5_{hoe+} resulted in lower weed cover (1.3 % and 2.2 %) compared to t.6_{comb} (4.4 %), t.7_{mix} (7.6 %) and t.3_{har} (5.0 %). At Manternach19 the highest mean weed cover was observed in t.7_{mix} (21.6 %) and hence differing from t.2_{pos} as the only parameter. Hoeing treatments were characterised by lower weed cover compared to harrowing treatments at Sprinkange18. Similar values for the mechanical treatments were found at Sprinkange19 but with a tendency to higher cover with harrowing. At Hostert18 highest average weed covers were found (74.6 % in t.1_{neg} and 67.9 % in t.7_{mix}). Here, t.6_{comb} showed significant lower cover (25.4 %) compared to t.3_{har} (58.3 %) and t.7_{mix} and similar results within hoeing plots. At Hostert19 t.3_{har} (20.8 %) goes along with t.1_{neg} (30.0 %), whereas the other treatments showed similar mean weed covers.

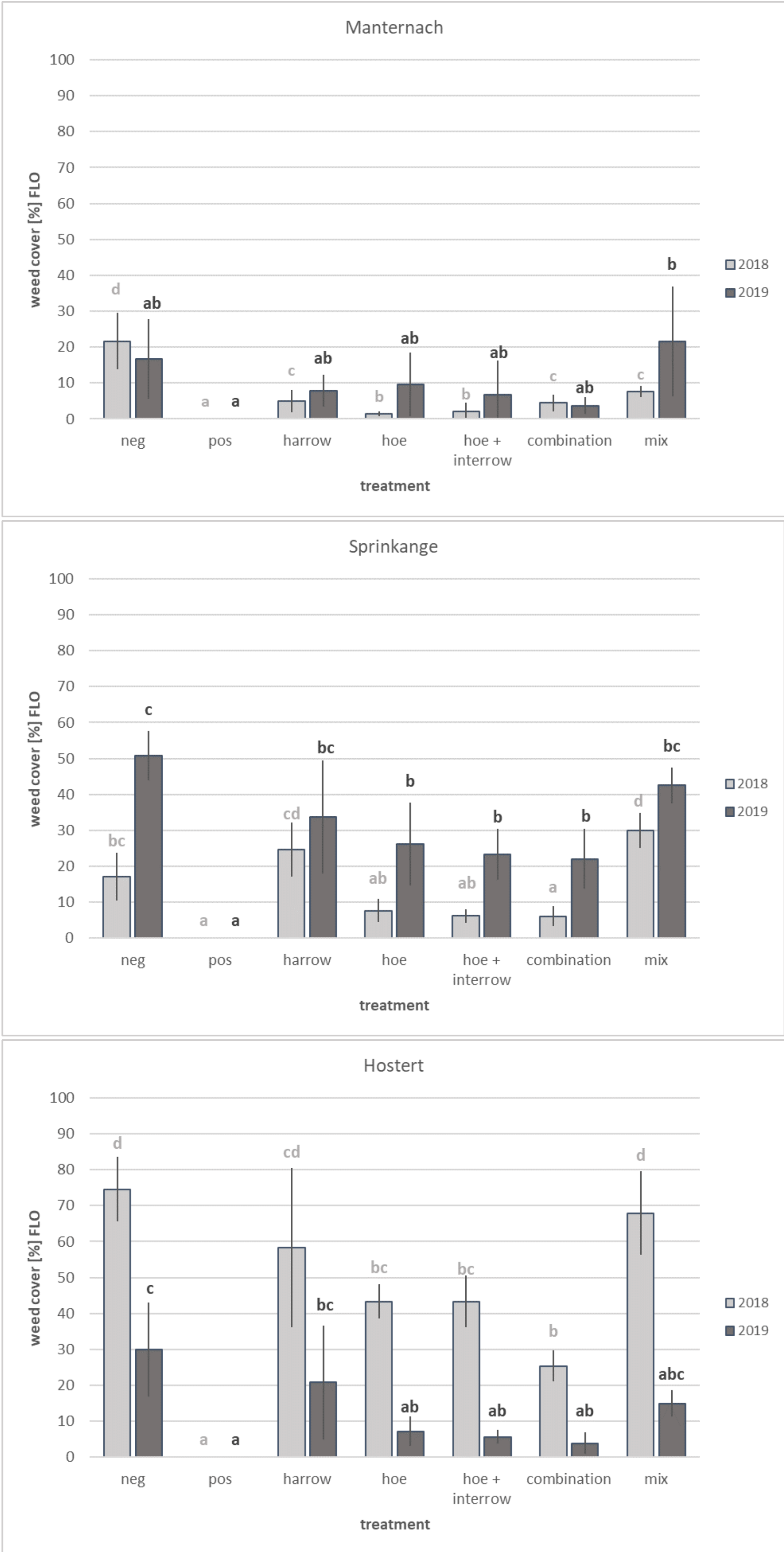


Figure 36: Mean weed cover [%] at FLO and standard deviation for all the sites and years. Common letters indicate no significant differences according to Tuckey's (and Fisher's test for Manternach18 and Hostert18) within the cultivation years (2018: light grey; 2019: dark grey).

As this parameter showed high correlations with weed biomass at FLO similarities were expectable.

Correlations of weed cover FLO and yield were investigated. High significant correlations were found between yield and weed cover FLO with r = -0.94 (p = 0.002) for Sprinkange18, r = -0.97 (p = 0.000) for Hostert18, r = -0.86 (p = 0.012) for Manternach18, r = -0.94 (p = 0.005) for Sprinkange19 and to be considered carefully with r = -0.74 (p =0.059) for Hosert19. The afterwards performed regression analysis showed similar results like the regression analysis with weed biomass. Only the site Sprinkange19 showed additionally high regression coefficient of R^2 = 0.89. At Hostert18 again 94.8 % of crop yield could be explained by weed cover.

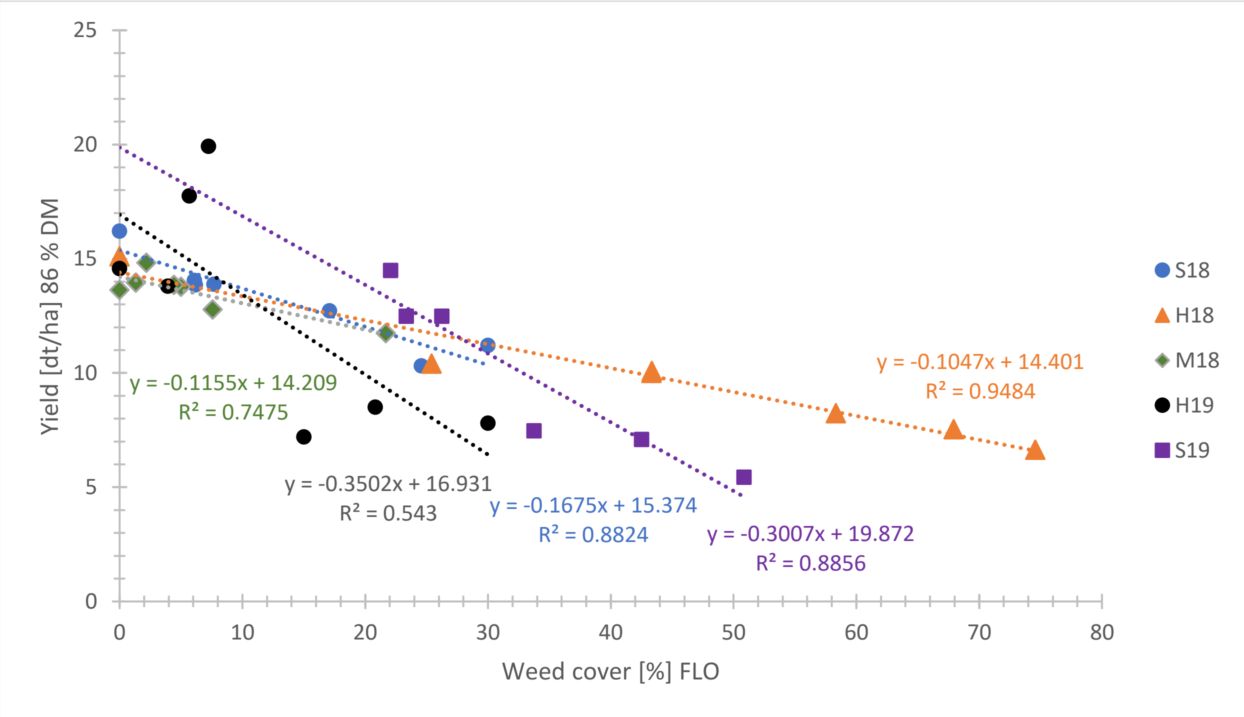


Figure 37: Regression of weed cover [%] FLO on yield [dt ha-1] of the three sites Sprinkange18, Hostert18, Manternach18 and Hostert19. Regression was computed based on the treatment means for each site and year separately.

As recently described, weed cover and weed biomass at FLO seemed to behave similar in their value distributions. To show this relation, a correlation analysis was calculated. As expected, significantly high correlations between both weed parameters were found for all the sites (e.g. r = 0.98 with p = 0.000 for Manternach18) except for Sprinkange19. Within the regression analysis pointed in Figure 38, both weed parameters showed high regression coefficients for all five study sites, whereas highest R^2 was given for Sprinkange18 (R^2 = 0.992) and Manternach (R^2 = 0.965) (see Appendix 26 - Appendix 31). Increasing weed biomasses went along with increasing weed cover and one parameter could be explained by the other.

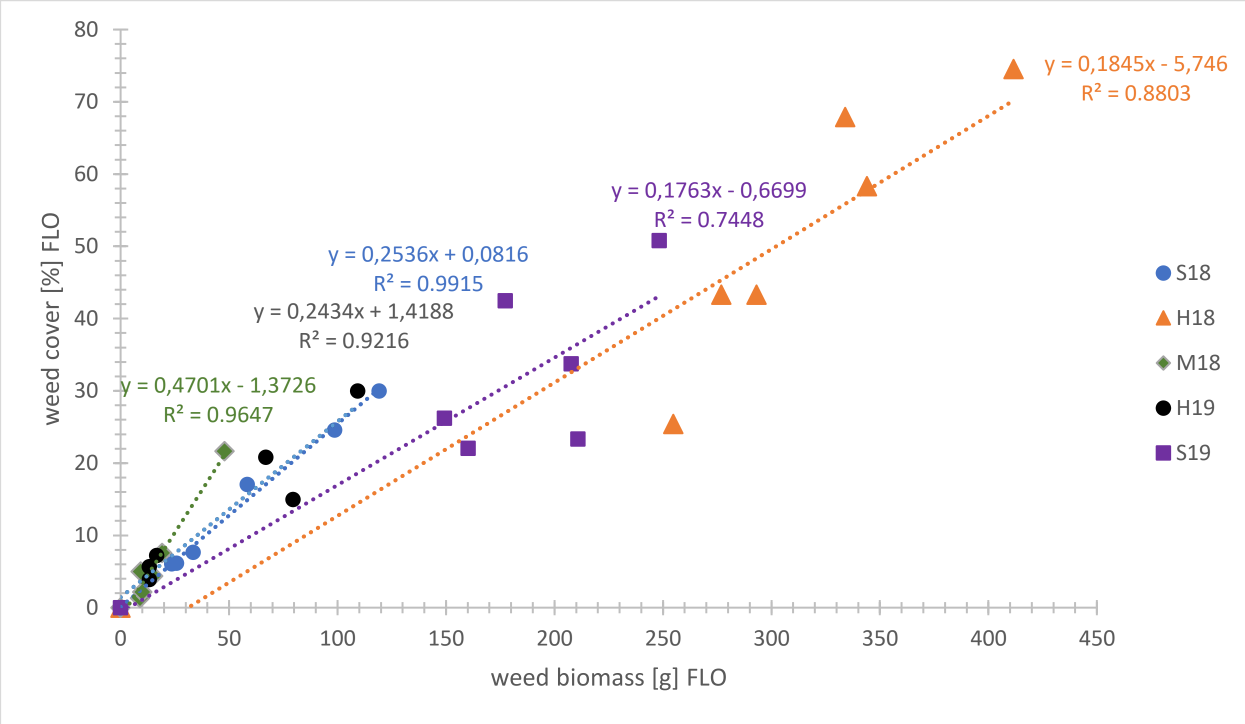


Figure 38: Regression of weed biomass [g] FLO and weed cover [%] of the three sites Sprinkange18, Sprinkange19, Hostert18, Manternach18 and Hostert19. Regression was computed based on the treatment means for each site and year separately.

To sum up the parameter weed cover FLO, lowest weed cover was observed at Manternach and was even lower in 2018 than 2019. Weed cover was highest at Sprinkange19 and Hostert18. Weed cover tended to be higher in harrowing plots compared to hoeing plots, whereas $t.7_{mix}$ mostly even tended to be higher than $t.3_{har}$. Mainly highest cover in $t.1_{neg}$ were still topped by $t.7_{mix}$ at Manternach19 and by $t.3_{har}$ and $t.7_{mix}$ at Sprinkange18. Weed cover FLO correlated highly negative with yield at almost all sites. The weed parameters weed cover FLO and weed biomass FLO showed high correlations, too.

4.4.4 Weed density FLO

Weed density was calculated as the third linked weed parameter based on weed numbers counted. Only for Sprinkange19 a calculation was not possible due to not having counted each weed individuum. Significant differences between the treatments were again found for weed density (see Table 33). Here also, $t.2_{pos}$ and $t.1_{neg}$ significantly differ at all the study sites.

*Table 33: Mean weed density [weeds m^{-2}] at FLO of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at $p \leq 0.05$ according to Tukey's test and to Fisher's test with preceeded Kruskal-Wallis **.*

	Weed density [weed m^{-2}] FLO					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018****	**2019****	**2018**	**2019**	**2018**	**2019**
t.1 neg	137.0 d	68.3 d	81.8 b	NA	212.0 d	178.5 c
t.2 pos	0.0 a	0.0 a	0.0 a		0.0 a	0.0 a
t.3 harrow	46.2 b	15.3 bc	113.3 b		146.7 bcd	124.0 bc
t.4 hoe	71.8 cd	16.3 bc	40.7 a		114.5 b	28.8 a
t.5 hoe+interrow	66.0 bc	12.7 b	33.7 a		127.5 bc	14.5 a
t.6 combination	69.8 bc	13.8 b	34.8 a		97.7 b	11.0 a
t.7 mix	47.5 b	33.3 cd	100.5 b		195.3 cd	102.5 b

Contrary to previous observations within weed parameters, the number of total weeds was significantly lower in $t.3_{har}$ (46.2 weeds m^{-2}) and $t.7_{mix}$ (47.5 weeds m^{-2}) compared to $t.4_{hoe}$ (71.8 weeds m^{-2}) at Matnernach18. A higher weed number in $t.4_{hoe}$ but less cover was observed here. At Manternach19 weed density values behaved similar within mechanical treatments, except with $t.7_{mix}$ with highest mean weed number of 33.3 weeds m^{-2}. Hoeing treatments ($t.5_{hoe+}$: 33.7 weeds m^{-2}) showed significant lower weed numbers compared to harrowing treatments ($t.3_{har}$: 113.3 weeds m^{-2}), while hoeing goes along with $t.2_{pos}$ and harrowing with $t.1_{neg}$ (81.8 weeds m^{-2}) at Sprinkange18. Same was found for Hostert19 (see Table 33). Hostert18 had generally the highest weed numbers. Weed density was significantly lower in $t.4_{hoe}$ (114.5 weeds m^{-2}) and $t.6_{comb}$ (97.7 weeds m^{-2}) compared to $t.7_{mix}$ (195.3 weeds m^{-2}) and $t.1_{neg}$ (212.0 weeds m^{-2}).

Proofing relations between weed density and weed biomass at FLO, correlations were also calculated here. For all study sites, highly significant correlations were found between weed density and weed biomass ranging from r = 0.88 (p = 0.008) for Manternach18 up to r = 0.98 (p = 0.000) for Hostert19. Calculation for Sprinkange19 was not possible due to missing values of weed density at FLO. The results of the regression analysis are shown in Figure 39. Highest regression coefficients were found for Hostert19 amounting R^2 = 0.965 and R^2 = 0.908 for Hostert18 (see Appendix 26 - Appendix 31).

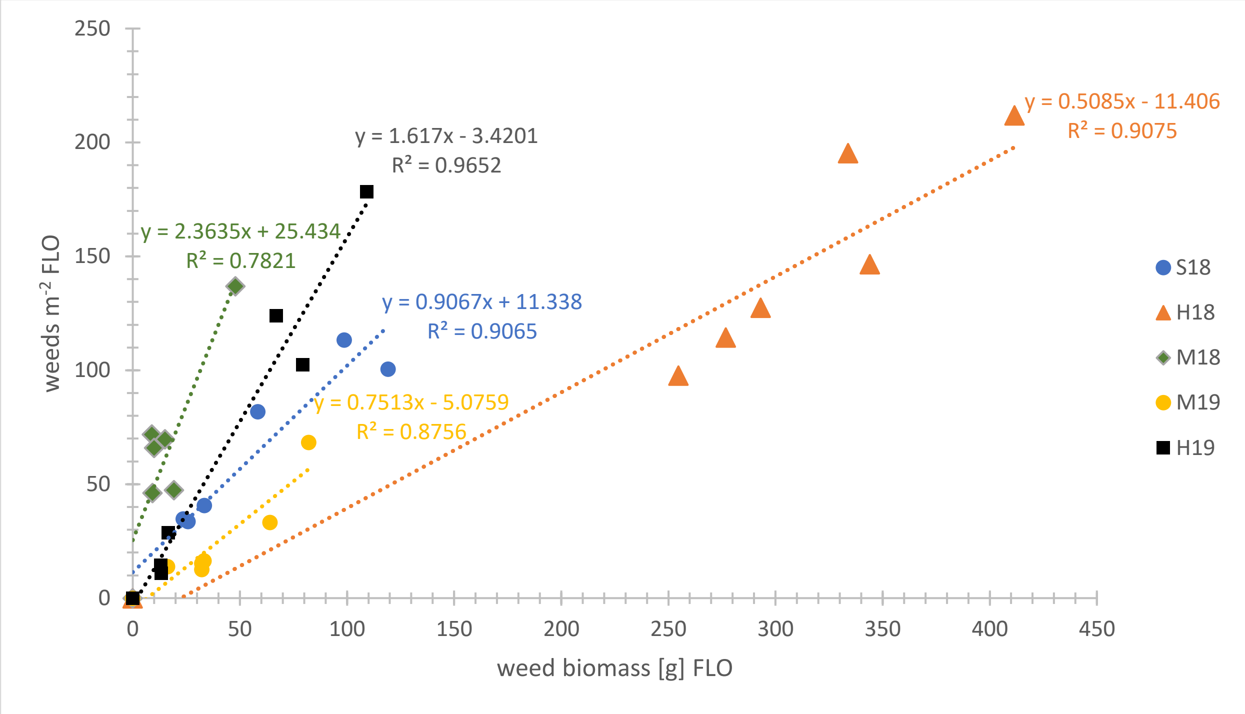


Figure 39: Regression of weed biomass [g] FLO and weed density [weeds m^{-2}] of the three sites Sprinkange18, Manternach19, Hostert18, Manternach18 and Hostert19. Regression was computed based on the treatment means for each site and year separately.

Summarizing weed density, highest numbers of total weeds was found in the negative plot, except on Sprinkange18, where both harrowing plots exceeded $t.1_{neg}$. Hoeing plots tended to have lower number of weeds than harrowing plots with exception for Manternach18, where a tendency towards lower weed density in harrowing was observed. Correlation of weed density and weed biomass were high for five study sites.

Weed assessments shown here, highly correlate with each other. It is to discuss weather one weed parameter, that is time-consuming during data collection, could be left out within future weed studies.

4.4.5 Weed cover HAR

Focusing on the weed situation at harvest, only weed cover was taken under consideration in the report at hand, since the weed parameters show high significant correlations as described before. Weed cover at HAR was used to investigate weed pressure impacts on the harvest with combine harvester. At all the study sites significant differences between the treatments were found for weed cover HAR (see Table 34).

*Table 34: Mean weed cover [%] at HAR of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and to Fisher's test with preceeded Kruskal-Wallis test **.*

	Weed cover [%] HAR					
	Manternach		Sprinkange		Hostert	
treatment	**2018****	**2019**	**2018**	**2019**	**2018**	**2019****
t.1 neg	24.2 c	34.6 b	40.8 b	80.4 d	67.5 b	31.7 e
t.2 pos	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
t.3 harrow	9.8 bc	19.3 ab	45.4 b	63.7 cd	59.2 b	21.4 de
t.4 hoe	6.2 b	13.5 ab	11.6 a	52.9 bc	50.4 b	6.8 bc
t.5 hoe+interrow	7.3 b	17.3 ab	10.0 a	48.8 bc	50.8 b	3.4 b
t.6 combination	6.0 b	13.3 ab	10.0 a	40.0 b	40.9 b	3.9 b
t.7 mix	17.9 c	31.3 b	57.5 b	62.1 bcd	58.8 b	14.5 cd

Weed cover at Manternach18 was significant higher in $t.7_{mix}$ (17.9 %) compared to the hoeing treatments (e.g. $t.6_{comb}$ with 6.0 %). No significant differences were found between $t.7_{mix}$, $t.3_{har}$ (9.8 %) and $t.1_{neg}$ (24.2 %). The same was observed at Sprinkange18, whereby hoeing treatments and positive control had similar weed covers. $T.6_{comb}$ (40.0 %) and $t.3_{har}$ (63.7 %) showed high significant differences in weed cover at Sprinkange19. Harrowing treatments and $t.1_{neg}$ showed similar results. At Hostert18, all the treatments were at the same weed cover level, except $t.2_{pos}$. At Hostert19 highest weed cover was observed in $t.1_{neg}$ (31.7 %) and $t.3_{har}$ (21.4 %) and hence showed significant higher weed cover compared to the hoeing treatments (e.g. 3.4 % in $t.5_{hoe+}$).

High correlations were found between weed cover HAR and yield for all study sites, except Manternach18 (e.g r = -0.98 at p = 0.000 for Hostert18 and r =-0.91 at p = 0.005 for Sprinkange18) (see Appendix 26 - Appendix 31)).

Summarizing, weed cover HAR was generally higher in the harrowing plots compared to the hoeing plots. Mostly, not even harrowing showed differences from the negative plots.

4.4.6 Speciality in $t.7_{mix}$

Camelina in $t.7_{mix}$ only germinated in Manternach18, Manternach19 and Hostert19. In Hostert19 an average of 172 camelina plants m^{-2} at flowering was counted and only 11 plants m^{-2} in Manternach19 at FLO. This number decreased at harvest to 52 plants m^{-2} in Hostert19. In Manternach19 the number of camelina plants was the same for FLO and HAR. At Manternach18, 41 plants m^{-2} were counted at FLO while this number decreased to 14 plants m^{-2} at HAR (see Table 35).

Table 35: Mean and standard deviation (sd) for camelina parameters at Mantenach18, Mantenach19 and Hostert19.

	Mantenach				Hostert	
	2018		2019		2019	
variable	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
L DM FLO (g)	15.6	4.1	0.8	0.8	11.2	8.6
L DM HAR (g)	11.3	12.7	5.4	10.2	58.1	47.5
L cover (%) FLO	9.4	5.3	0.8	0.5	10.1	9.9
L cover (%) HAR	8.7	6.7	5.8	6.3	9.3	5.3
L m^{-2} FLO	40.7	21.1	10.8	14.5	172.2	166.9
L m^{-2} HAR	13.8	11.0	10.7	12.8	51.7	40.6

Camelina cover at FLO reached up to 10 % at Matnernach18 and Hostert19 and only slightly decreased until HAR. At Mantenach19 camelina seemed to germinate later since an increase in cover from FLO to harvest was observed.

4.4.7 Weed control efficiency (WCE)

To be able to point out the effect of each mechanical treatment on weeds, WCE was calculated based on weed density (WCE_{dens}) and weed cover (WCE_{cov}) of BWC and AWC. WCE_{dens} gave information on the percentual reduced number of weeds, while WCE_{cov} considered the cover of each single weed and in turn the area taken. Significant differences in WCE in the treatments were found for alle the study sites (see Table 29). WCE was always highest for $t.2_{pos}$, since all weeds were taken manually and lowest for $t.1_{neg}$ since no weed control was performed. For Sprinkange19 a calculation was not possible due to missing values.

As pointed in Table 36, highest WCE_{dens} for plant density of all sites were found in Mantenach18, ranging from WCE_{dens} = 86.2 % ($t.4_{hoe}$) to WCE_{dens} = 98.8 % ($t.7_{mix}$). Here, significant differences in WCE_{dens} were found for $t.7_{mix}$ compared to the hoeing treatments $t.4_{hoe}$ and $t.6_{comb}$ (86.2 % and 87.1 %), with higher number of weeds cut in $t.7_{mix}$. $T.5_{hoe+}$, where finger weeder application was performed, did not differ from the harrowing treatments and also not from the hoeing treatments, where single shares were used.

*Table 36: Mean WCE [%] based on weed density of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and Fisher's test as post-hoc for Kruskal-Wallis **.*

	WCE [%] density					
	Mantenach		Sprinkange		Hostert	
treatment	**2018**	**2019****	**2018****	**2019****	**2018****	**2019**
t.1 neg	0.0 d	0.0 d	0.0 d	NA	0.0 e	0.0 d
t.2 pos	100.0 a	100.0 a	100.0 a		100.0 a	100.0 a
t.3 harrow	95.5 abc	45.7 c	-		63.3 cd	40.3 bc
t.4 hoe	86.2 c	88.6 b	76.1 b		72.8 bcd	79.6 a
t.5 hoe+interrow	88.3 bc	84.0 b	76.2 b		78.7 bc	73.9 ab
t.6 combination	87.1 c	84.4 b	82.3 b		81.8 b	75.2 ab
t.7 mix	98.8 ab	58.5 c	35.3 c		57.1 d	35.0 cd

At Manternach19 hoeing plots showed higher WCE_{dens} in comparison to harrowing plots (e.g. $t.5_{hoe+}$: 84 % and $t.3_{har}$: 45.7 %) and similar was observed at Sprinkange18. At Hostert18 $t.5_{hoe+}$ (78.7 %) and $t.6_{comb}$ (81.8 %) showed significant higher WCE_{dens} in plant density than $t.7_{mix}$ (57.1 %). 79.6 % weed control success was found in $t.4_{hoe}$ at Hostert19 and was significantly higher than $t.3_{har}$ (40.3 %) and $t.7_{mix}$ (35.0 %), whereby the latter was the lowest value of all mechanical treatments at all the sites. Additionally, at Hostert19, hoeing plots did not even differ from $t.1_{neg}$. In general, hoeing plots treatments tended to had similar effects on WCE_{dens} for plant density. Where finger weeder application was used during the first run slightly higher WCE_{dens} were observed as can be seen at Hostert18 and Sprinkange18, where in $t.5_{hoe+}$ and $t.6_{comb}$ finger-weeding was done and not in $t.4_{hoe}$.

Weed control efficiency was additionally calculated based on the weed cover estimations (WCE_{cov}) (see Table 37 and Figure 40). At Manternach18 treatments showed similar results but with tendency towards higher WCE_{cov} in the harrowing treatments and $t.6_{comb}$, while all three did not differ from $t.2_{pos}$. Manternach19 was characterized by significantly higher WCE_{cov} in $t.4_{hoe}$ (70.8 %) than in $t.3_{har}$ (32.5 %) and $t.7_{mix}$ (28.7 %). T.4 and $t.6_{comb}$ (54.0 %) showed significant differences, even if no differences in mechanical treatment was performed. At Sprinkange18 significantly higher WCE_{cov} were found in the hoeing plots (e.g. $t.6_{comb}$ with 80.7 %) compared to $t.7_{mix}$ (17.9 %) and $t.1_{neg}$. Mechanical treatments behaved similar at Hostert18 but at the same time harrowing did not differ from $t.1_{neg}$. The latter was observed for Hostert19.

*Table 37: Mean WCE [%] based on weed cover of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Fisher's test as post-hoc for Kruskal-Wallis **.*

	WCE [%] cover					
	Manternach		**Sprinkange**		**Hostert**	
treatment	**2018****	**2019****	**2018****	**2019****	**2018****	**2019****
t.1 neg	0.0 c	0.0 e	0.0 c	NA	0.0 c	0.0 d
t.2 pos	100.0 a	100.0 a	100.0 a		100.0 a	100.0 a
t.3 harrow	83.3 ab	32.5 de	-		25.4 bc	15.0 d
t.4 hoe	45.0 bc	70.8 b	70.6 b		43.4 b	77.0 ab
t.5 hoe+interrow	45.8 bc	69.3 bc	80.3 b		58.5 b	54.9 c
t.6 combination	71.2 ab	54.0 cd	80.7 b		55.3 b	57.4 bc
t.7 mix	89.4 ab	28.7 de	17.9 c		23.9 bc	11.3 d

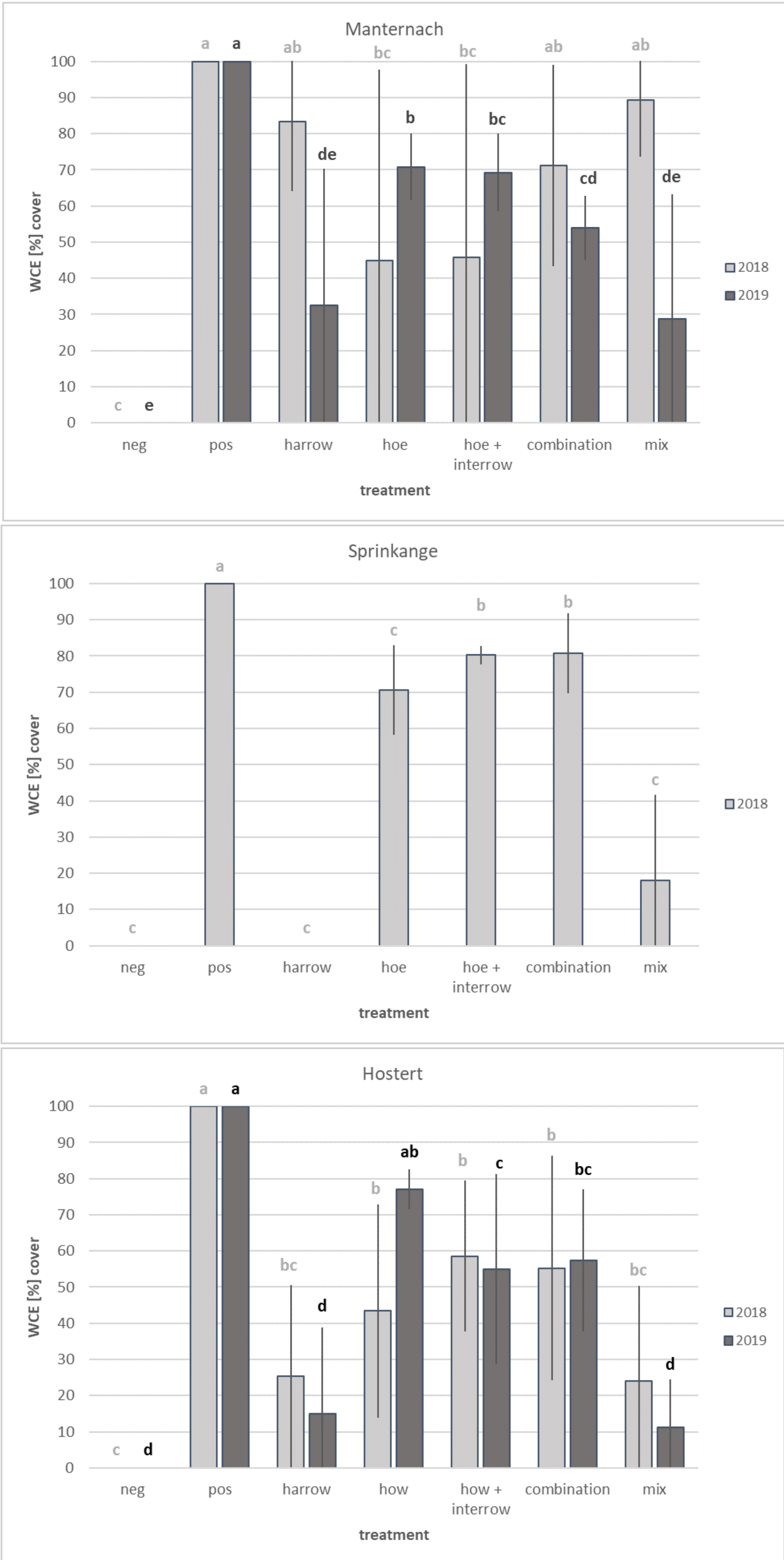


Figure 40: Mean WCE_{cov} [%] and standard deviation for all the sites and years. Common letters indicate no significant differences according to Fisher's test within the cultivation years (2018: light grey; 2019: dark grey).

To sum up WCE, positive control plot performs best at all the sites. Where weed pressure was lowest (Manternach18), harrow showed a tendency towards higher weed control success in number of weeds (WCE_{dens}) compared to the single use of duck-foot shares. Slightly higher weed pressure in Manternach19 and Sprinkange18 showed contrary results, while all hoeing treatments had significant higher WCE_{dens} than harrowing. Same could be observed at Hostert19, while a tendency towards single use of duck-foot shares within hoeing treatments was seen. Under high weed pressure (Hostert18) hoeing performed better than harrowing and finger weeder application seemed to result in better weed control success compared to single use of shares.

Focusing at the same time on the weed control success of weed cover (WCE_{cov}), on the site with low weed pressure (Mantenrach18), success with harrowing was comparable with manual weed control. Same counted for $t.6_{comb}$. A tendency towards lower weed control success was observed here with hoeing but with no significant differences within the mechanical treatments. Higher weed reductions were found within hoeing compared to harrowing at Sprinkange18 and Manternach19. Where weed pressure was already high (Hostert18) efficiency in weed control could not perform well. As observed with weed numbers, hoeing seemed to perform better than harrowing but only around half of the weeds present were reduced. A slight tendency towards better results with finger-weeding was seen. At Hostert19, the use of a single hoe ($t.4_{hoe}$) was as efficient as manual weeding. But harrowing showed lowest efficiencies that were comparable with no weed control ($t.1_{neg}$).

4.4.8 Weed control index (WCI)

When focusing on the differences between negative control $t.1_{neg}$, where no weed was taken out, and the plots where mechanical treatment was performed, the weed control index (WCI) can help identifying the success in weed control. Table 38 shows indices calculated based in weed cover WCI_{cov} (and based on weed biomass WCI_{bio} for Sprinkange19) at the time of AWC and FLO, where mechanical runs finished because of soybean canopy closure. WCI_{cov} at FLO for Sprinkange19 could not be calculated due to missing cover values.

Table 38: Weed control index (WCI) at flowering for the sites and years, separately. Green color indicates the highest effects in the corresponding treatment in comparison to the negative control ($t.1_{neg}$). Positive values in red indicate worse effects compared to $t.1_{neg}$.

	Manternach				Sprinkange				Hostert			
	2018		2019		2018		2019		2018		2019	
	WCI_{cov} AWC	WCI_{cov} FLO	WCI_{cov} AWC	WCI_{cov} FLO	WCI_{cov} AWC	WCI_{cov} FLO	WCI_{bio} AWC	WCI_{cov} FLO	WCI_{cov} AWC	WCI_{cov} FLO	WCI_{cov} AWC	WCI_{cov} FLO
$t.1_{neg}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00
$t.2_{pos}$	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00		-1.00	-1.00	-1.00	-1.00
$t.3_{har}$	-0.94	-0.77	-0.22	-0.53	0.54	0.44	-0.16		-0.05	-0.22	-0.22	-0.31
$t.4_{hoe}$	-0.78	-0.94	-0.72	-0.42	-0.77	-0.55	-0.40		-0.54	-0.42	-0.74	-0.76
$t.5_{hoe+}$	-0.81	-0.90	-0.66	-0.60	-0.81	-0.64	-0.15		-0.41	-0.42	-0.54	-0.81
$t.6_{comb}$	-0.86	-0.80	-0.63	-0.78	-0.78	-0.64	-0.35		-0.69	-0.66	-0.70	-0.87
$t.7_{mix}$	-0.94	-0.65	-0.10	0.30	0.62	0.76	-0.29		-0.02	-0.09	-0.33	-0.50

$T.2_{pos}$ was characterized by100 % of weed control success compared to $t.1_{neg}$ at the time of AWC and FLO on all the sites due to the manual weeding. Overall highest effects in weed control compared to $t.1_{neg}$ were found in the hoeing treatments. Highest effects in weed control success were found at Manternach18 at FLO in $t.4_{hoe}$, where compared to $t.1_{neg}$, 94 % of weeds were taken out of the plot. At this site, the remaining treatments showed high results, too. $T.3_{har}$ and $t.7_{mix}$ seemed to have highest WCI_{cov} of 94 % AWC compared to $t.1_{neg}$ but this again decreased until flowering. No second weed control was done in 2018 indicating the infestation of new weeds. Effects at Sprinkange19 and Hostert18 were limited due to high weed pressure. Here, highest weed control success tended to occur in $t.6_{comb}$ and worst effects in the harrowing treatments. Positive values indicated even worse effects compared to $t.1_{neg}$. These effects could be observed in all the harrowing treatments at Sprinkange18. At Hostert19 the second run with finger-weeding in $t.6_{comb}$ increased the weeding effect, because the effect increased from AWC to FLO.

In general, highest differences between the treatments and the negative control plot were observed for the hoeing treatments. Only at Manternach18, where weed pressure was low, also harrowing performed well. At Sprinkange18, harrowing performed even worse than no weed control. Finger weeder applications showed minimum the same results like simple hoeing but with a slight tendency to higher success, especially at Hostert19 where an increase in weed control was observed after the second run. Sites with high weed pressure resulted in smaller differences in all the treatments compared to the control plot.

4.4.9 Weed control in soybean rows

Concerning the efficiency of the finger weeder in the soybean rows, a comparison between treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ was made. An analysis of the results is only possible for site and study year for which this technique has been used. Therefore, only the results for Hostert18 and Hostert19 are presented. For Sprinkange18, no trends were observed at all, tables of means values for this site are available in Appendix 36. For Manternach19, finger weeder was only applied in $t.5_{hoe+}$.

For hoed treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$, mean number of weed individuals and species as well as the cover of soybean, weeds and ground in soybean rows are recorded in Appendix 35, for Hostert18 and Hostert19.

For Hostert18, the effects of finger-weeding could only be evaluated for AWC, since finger weeders were used once at this time. The number of weed individuals and the number of species (see Figure 41) as well as the cover of weeds (see Figure 42) had diminished for AWC in comparison to BWC. For these parameters, the lowest average values were measured for treatment $t.6_{comb}$, followed by treatment $t.5_{hoe+}$ except for weed cover. The number of weed individuals in soybean rows was significantly lower in treatment $t.6_{comb}$ (with finger-weeding) than in treatment $t.4_{hoe}$ (Appendix 35), considering that for treatment $t.6_{comb}$, means were the lowest for BWC and also remained the lowest for FLO and for HAR, just from the beginning on.

For Hostert19, the finger weeder was only used shortly before FLO. No significant differences of variances had been found between the treatments for each parameter assessed (Appendix 35). At FLO, average values of the number of weed individuals and the number of weeds (see Figure 43) as well as for the cover of weeds (see Figure 44) were almost equal one to another for treatments $t.5_{hoe+}$ and $t.6_{comb}$ but lower than for treatment $t.4_{hoe}$. When performed, it seems that the finger weeder reduced more the presence of weed in soybean rows than the single use of the duck foot shares in the interrow.

The statistical analysis of the dataset did not reveal much significant differences between treatments according to each parameter and assessment time. Using the finger weeder tended to lower the number of weed individuals and species as well as the cover of weeds in soybean rows but not much significant effects were visible.

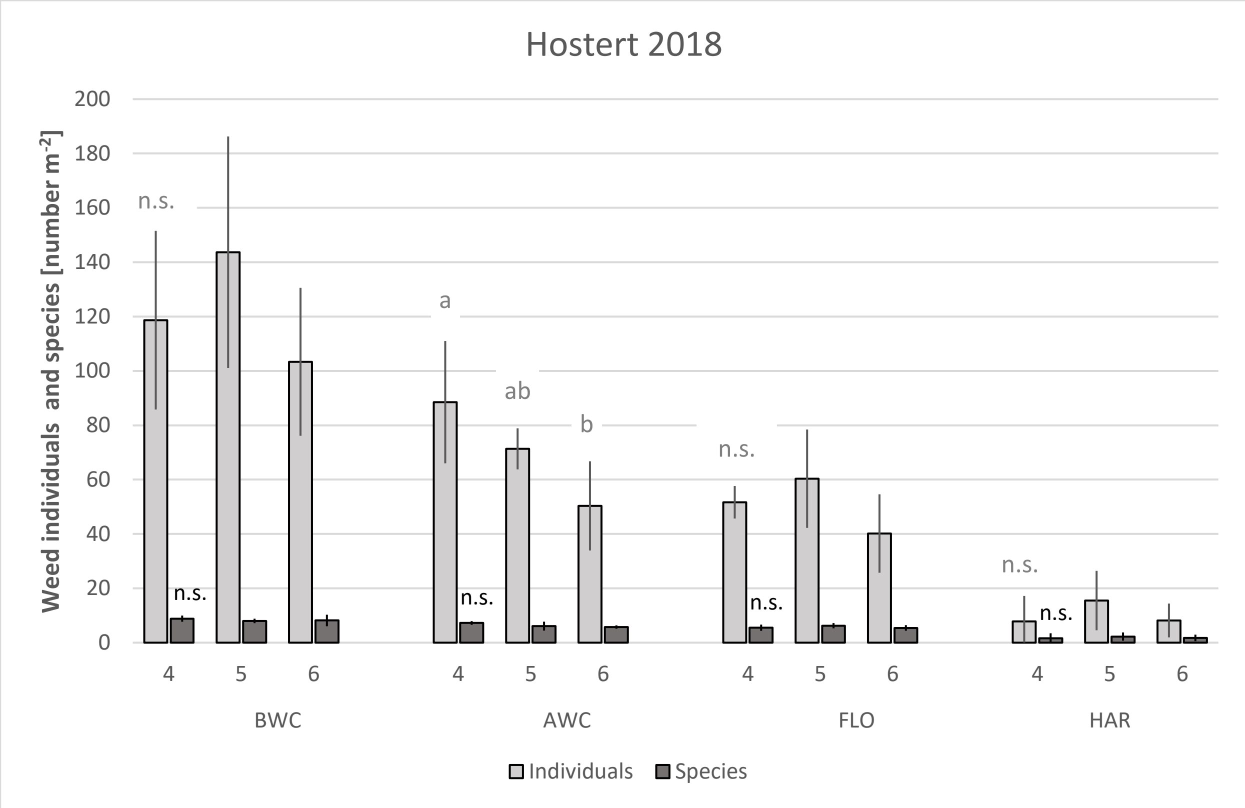


Figure 41: Average mean values of the number of weed individuals and species in soybean rows for each treatment t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5) and t.6$_{comb}$ (6) for Hostert 2018. Bars indicate standard deviation. Letters on top of the bars indicate significant variances between treatments at p≤0.05 according to Tukey's test.

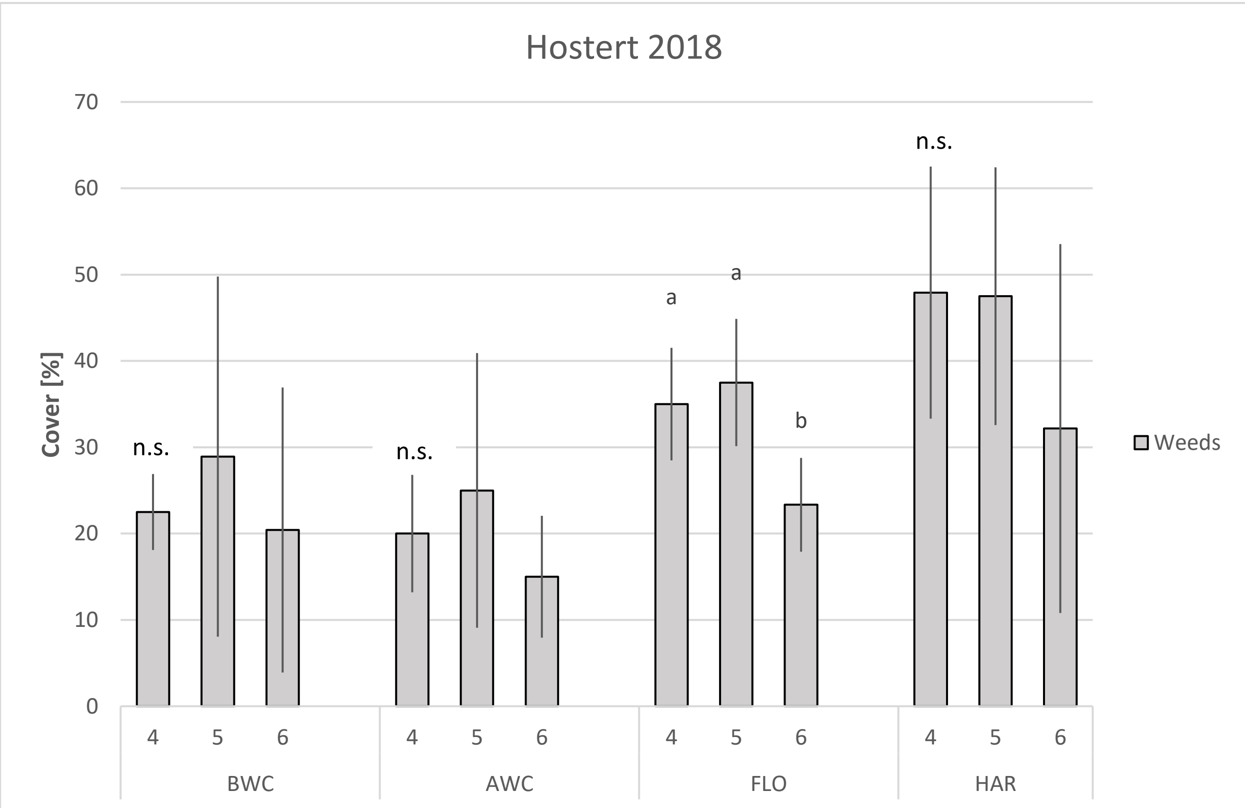


Figure 42: Average mean values of the Weed cover in soybean rows for each treatment t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5) and t.6$_{comb}$ (6) for Hostert 2018. Bars indicate standard deviation. Letters on top of the bars indicate significant variances between treatments at p≤0.05 according to Tukey's test.

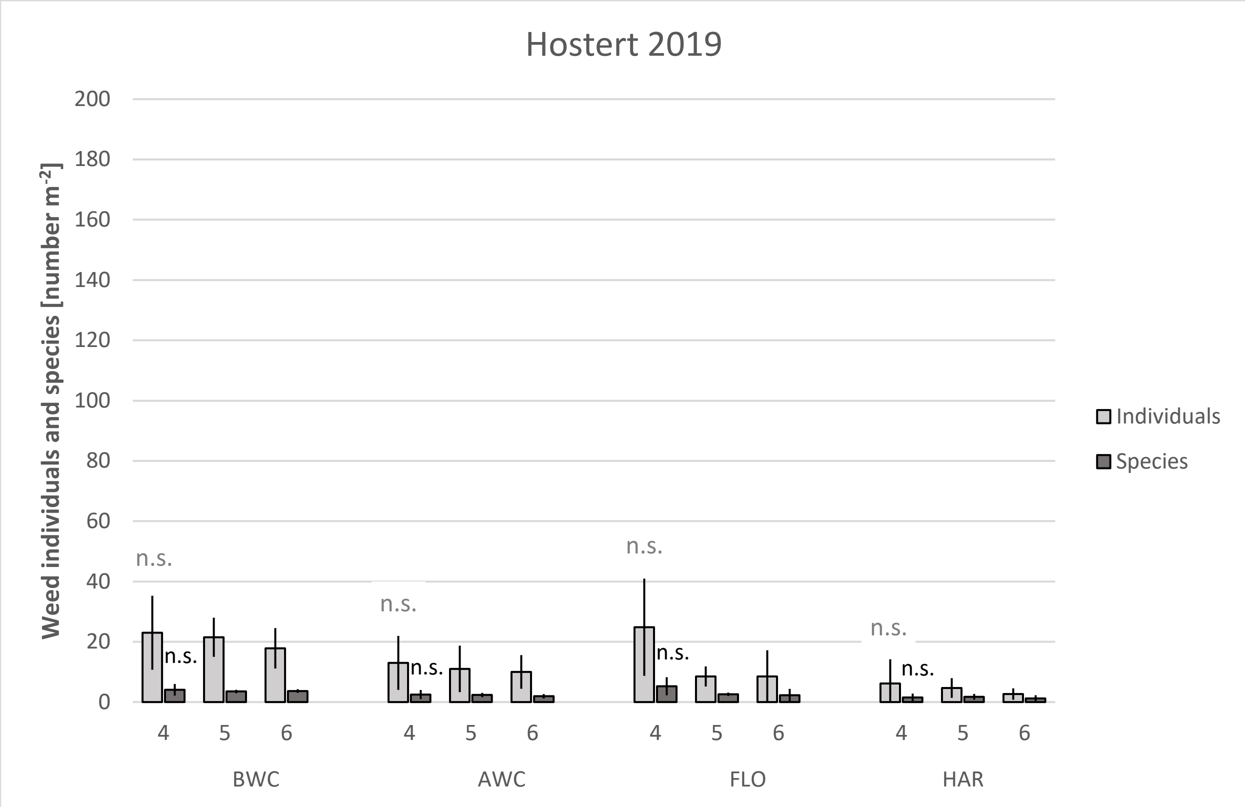


Figure 43: Average mean values of the number of weed Individuals and Species in soybean rows for each treatment $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5) and $t.6_{comb}$ (6) for Hostert 2019. Bars indicate standard deviation. Letters on top of the bars indicate significant variances between treatments at p≤0.05 according to Tukey's test.

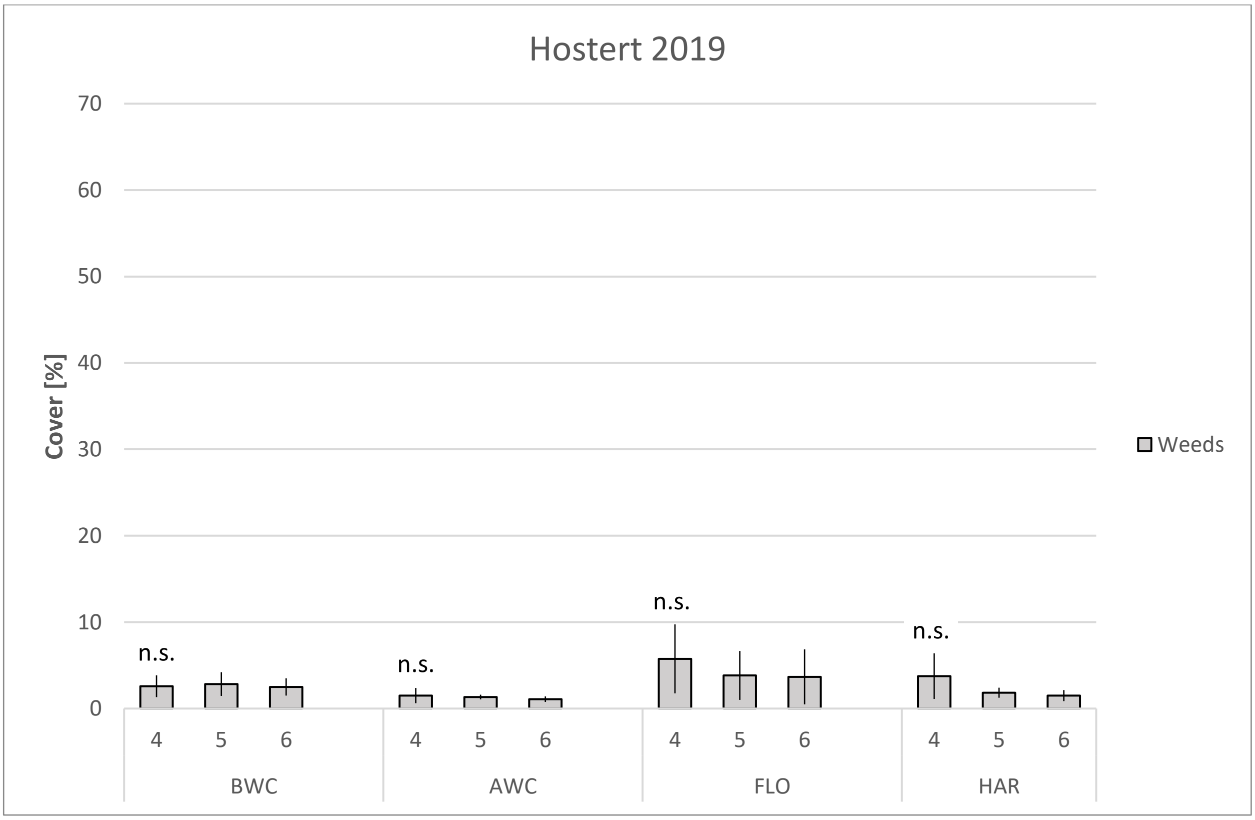


Figure 44: Average mean values of the Weed cover in soybean rows for each treatment $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5) and $t.6_{comb}$ (6) for Hostert 2019. Bars indicate standard deviation. Letters on top of the bars indicate significant variances between treatments at p≤0.05 according to Tukey's test.

4.5. Weed diversity

4.5.1 Number of weed species

Figure 45, Figure 46 and Figure 47 show the distribution of weeds species within the ecological groups. For each treatment, the number of weed species and respective statistical groups are recorded in Appendix 32, Appendix 33 and Appendix 34 (see Weed species) for each site and experiment year. Weed Species' (WS) numbers tend to be homogenous for BWC, across all sites and experimental years. For Hostert18, there were 10.9 WS m^{-2}, for Hostert19 were 8.0 WS m^{-2}, for Manternach18 were 4.2 WS m^{-2}, for Manternach19 were 7.2 WS m^{-2}, for Sprinkange18 were 9.9 species and for Sprinkange19 were 10.6 WS m^{-2}.

Mechanical weed control has a negative effect on the number of WS, observable for AWC in all experiment sites. For Hostert18, significant lowest WS numbers were counted in treatments $t.3_{har}$, $t.5_{hoe+}$ and $t.6_{comb}$, with a minimum of 6.4 WS m^{-2} in treatment $t.5_{hoe+}$. For Hostert19, the number of WS were significantly lower in treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$, where 3.3 WS m^{-2} were counted in treatment $t.4_{hoe}$. For Manternach18, the number of WS were very low AWC. In treatments $t.3_{har}$ (0.3 WS m^{-2}) and $t.7_{mix}$ (0.2 WS m^{-2}), lower WS were counted than in other treatments. In Manternach19, the number of WS were the lowest in treatment $t.4_{hoe}$ and $t.5_{hoe+}$ with, respectively, 3.1 and 2.6 WS m^{-2}. For Sprinkange18, WS' numbers were significantly lower in treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ (4.3 WS m^{-2}) than in $t.1_{neg}$, $t.3_{har}$ and $t.7_{mix}$. For Sprinkange19, no data is available for AWC.

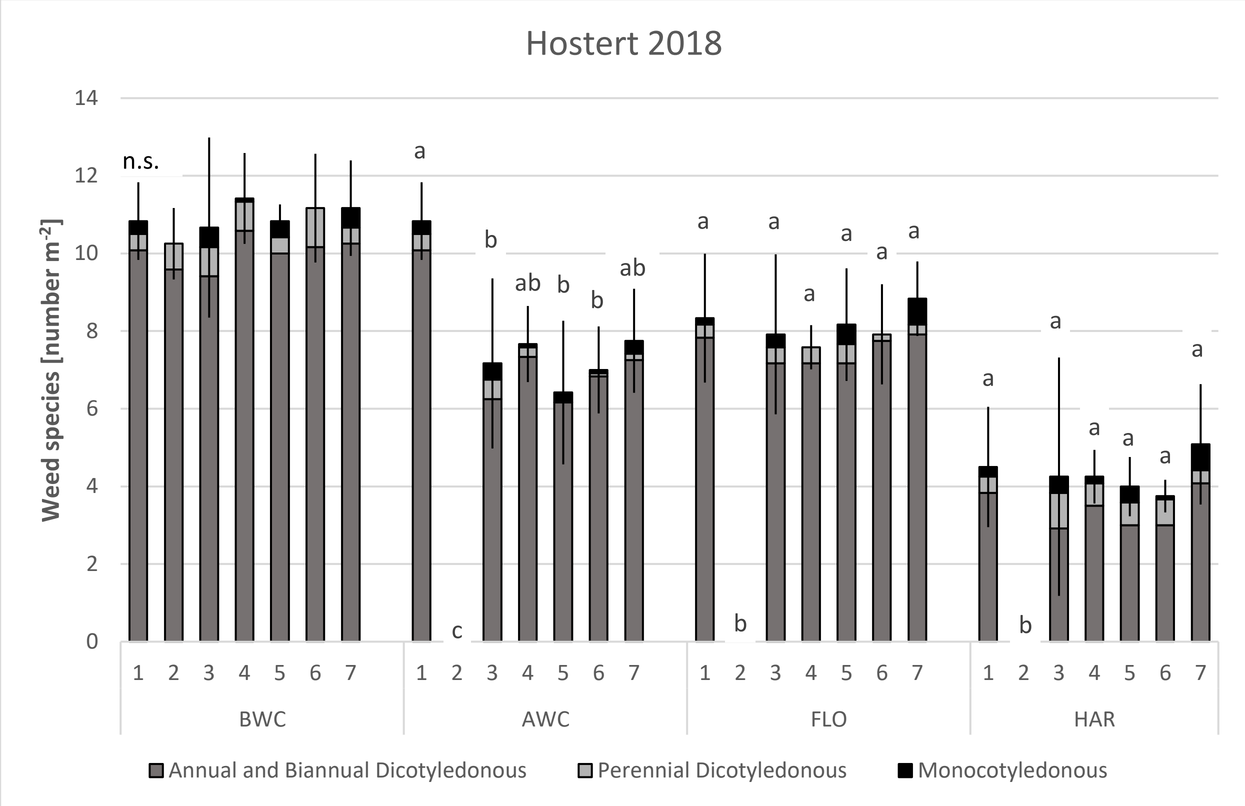
At FLO, globally, two trends were observable. In a first case corresponding to experiment year 2018 for all sites, since no further mechanical weeding was done, the number of WS re-increased in comparison to the stand for AWC. In a second case corresponding to experimental year 2019, the number of WS decreased more when another run of weeding was done. For Hostert18, WS' numbers of weeded treatments were not different than in the negative treatment, an average of 8.1 WS m^{-2} was counted. For Hostert19, in treatment $t.6_{comb}$ was the lowest number of WS (2.8 WS m^{-2}). For Manternach18, treatment $t.3_{har}$ to $t.7_{mix}$ show values of the same range (5.8 WS m^{-2} on average), significantly different than the negative and positive controls. For Manternach19, 2.1 WS m^{-2} in treatment $t.5_{hoe+}$ is the lowest average while there were 2.7 WS m^{-2} in treatment $t.3_{har}$. For Sprinkange18, the number of WS re-increased in comparison to AWC. Treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ have significant lower WS' number (from 5.9 to 6.9 WS m^{-2}) than treatments $t.1_{neg}$, $t.3_{har}$ and $t.7_{mix}$ (10.5 to 11.3 WS m^{-2}). For Sprinkange19, only the most abundant species were counted (1.9 WS m^{-2} on average) therefore, the results are not consistent.

For HAR, the number of WS tend to be lower than for BWC, for all treatments in all experiments, respectively. Nevertheless, in the case of Hostert19 and Manternach19, where mechanical weeding was also conducted another time short before FLO, the number of WS tends to increase in further weeded treatments but, WS were still in a lower number than BWC. For Hostert18, the WS' number were homogeneous in all treatments (4.3 WS m^{-2} on average), with a minimum of WS in treatment

$t.6_{comb}$. For Hostert19, there were more variations, but less WS in treatment $t.6_{comb}$ (2.5 WS m^{-2}). For Manternach18, the number of WS was on average 4.9 m^{-2}, with a minimum of 4.1 WS m^{-2} counted in treatment $t.4_{hoe}$. For Manternach19, there was no variations of WS' number between treatments, on average were 4.0 WS m^{-2} (minimum 3.1 WS m^{-2} in treatment $t.5_{hoe+}$). For Sprinkange18, in treatment $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ were still the significant lowest number of WS, varying from 6.2 to 6.6 WS m^{-2}) while, about 10 WS were counted in treatments $t.1_{neg}$, $t.3_{har}$ and $t.7_{mix}$. For Sprinkange19, an amount of 7.5 WS m^{-2} on average was counted across all treatments, no significant differences were observed.

Identified WS are recorded in Table 39**.** In total, 59 WS have been counted during the assessment period, from BWC to HAR, across all experiment sites. This total is divided in 40 Annual and Biannual Dicotyledonous (ABD) WS, 13 Perennial Dicotyledonous (PD) WS and 6 Monocotyledonous (M) WS. In Hostert18, 33 WS have been identified, 37 in Hostert19, 26 in Manternach18, 34 in Manternach19, 32 in Sprinkange18 and 26 in Sprinkange19. Besides, 18 species have been found in common for each site and experiment year (see species in bold text in Table 39) and three species are registered on the red list of the vascular plants in Luxembourg (Colling 2005): *Centaurea cyanus* (vulnerable), *Geranium rotundifolium* (extremely rare) and *Papaver rhoeas* (nearly threatened). For each experiment site, these WS were not all present simultaneously for BWC, AWC, FLO and HAR. Some were eliminated by the mechanical weed control while, other grew after or in the period between the weeding operations. As observable in Figure 45 **-** Figure 47, the number of ABD WS were always predominant for each assessment, for each site respectively. Nevertheless, the number of PD and M WS were higher in Manternach18, Manternach19, Sprinkange18 and Sprinkange19 than in Hostert18 and Hostert19. Globally, the ABD WS tended to be more affected by mechanical weed control. At least for AWC, the fractions of ABD were more reduced than PD and M ones.

While the number of weed species were homogenous for BWC, mechanical weeding has significantly reduced them at AWC and at FLO in the case where a second run of weeding was performed. Otherwise, the number of species tended to have augmented for FLO. At HAR, the trend is that weeds species were less numerous than for FLO, even though no further weed control was done. Globally, hoeing tended to lower the most the number of weed species in comparison to harrowing. Annual and biannual dicotyledonous weed species were the most abundant across all sites and tended to be more affected by mechanical weeding. The composition of the weed communities tended to evolve along time, so that new species grew while other disappeared along time.



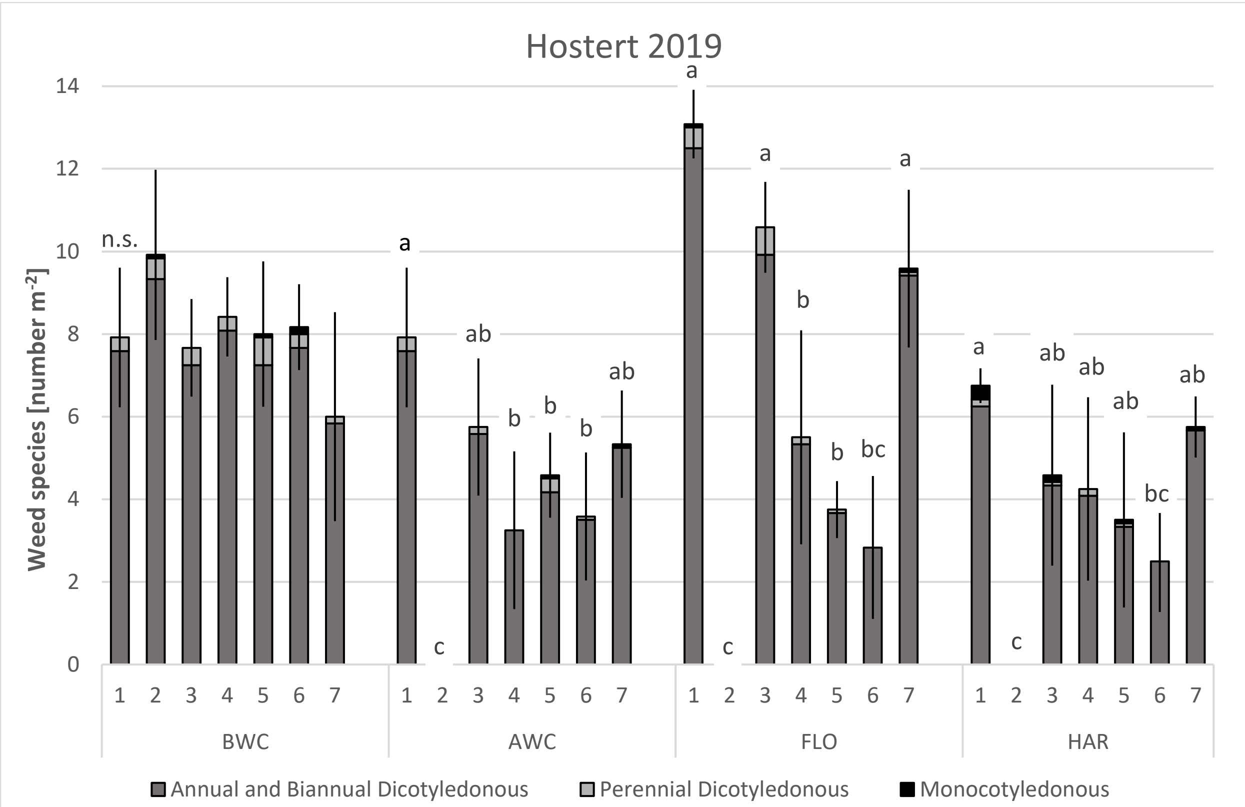
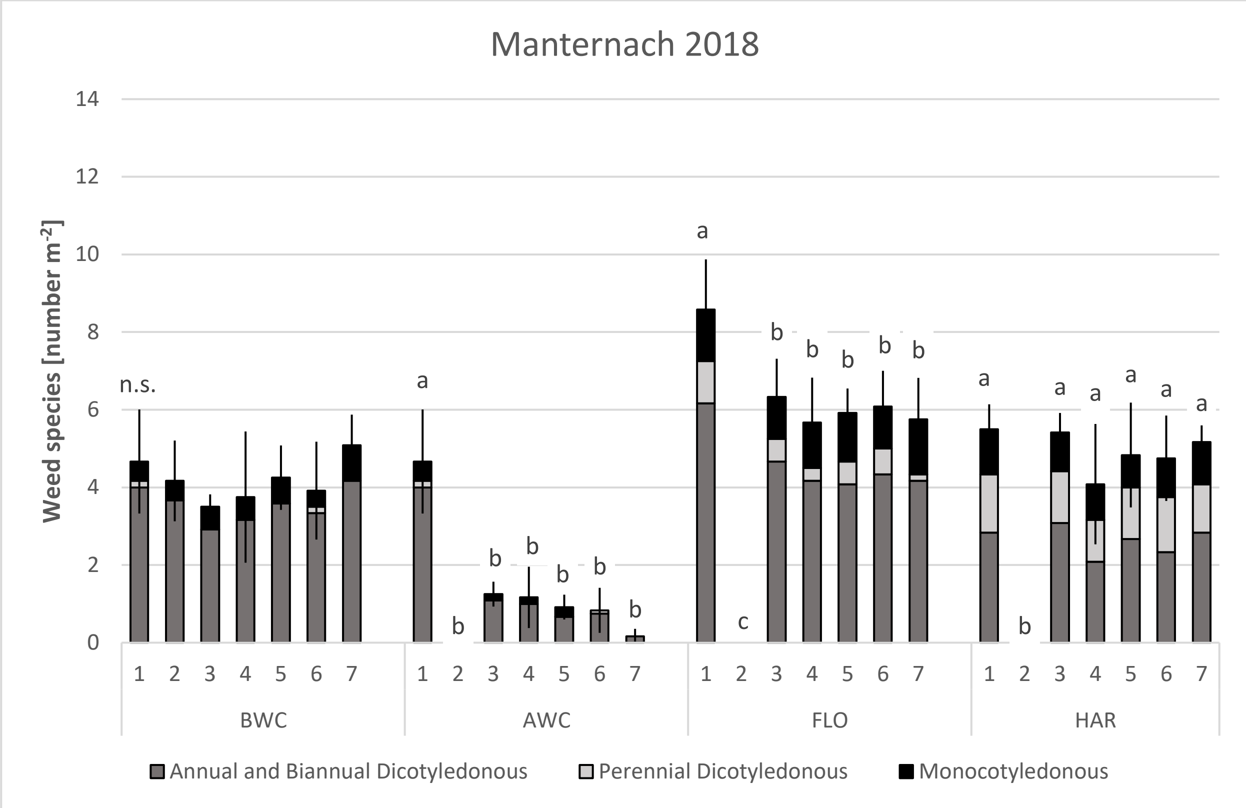


Figure 45: Average values of the number of weed species within each ecological group (Annual and biannual dicotyledonous, Perennial dicotyledonous, Monocotyledonous) for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Hostert 2018 (on top) and Hostert 2019 (at the bottom). Bars indicate standard deviation of the total number of weed species for each treatment. Letters on top of the bars indicate significant variances between treatments at $p \leq 0.05$.



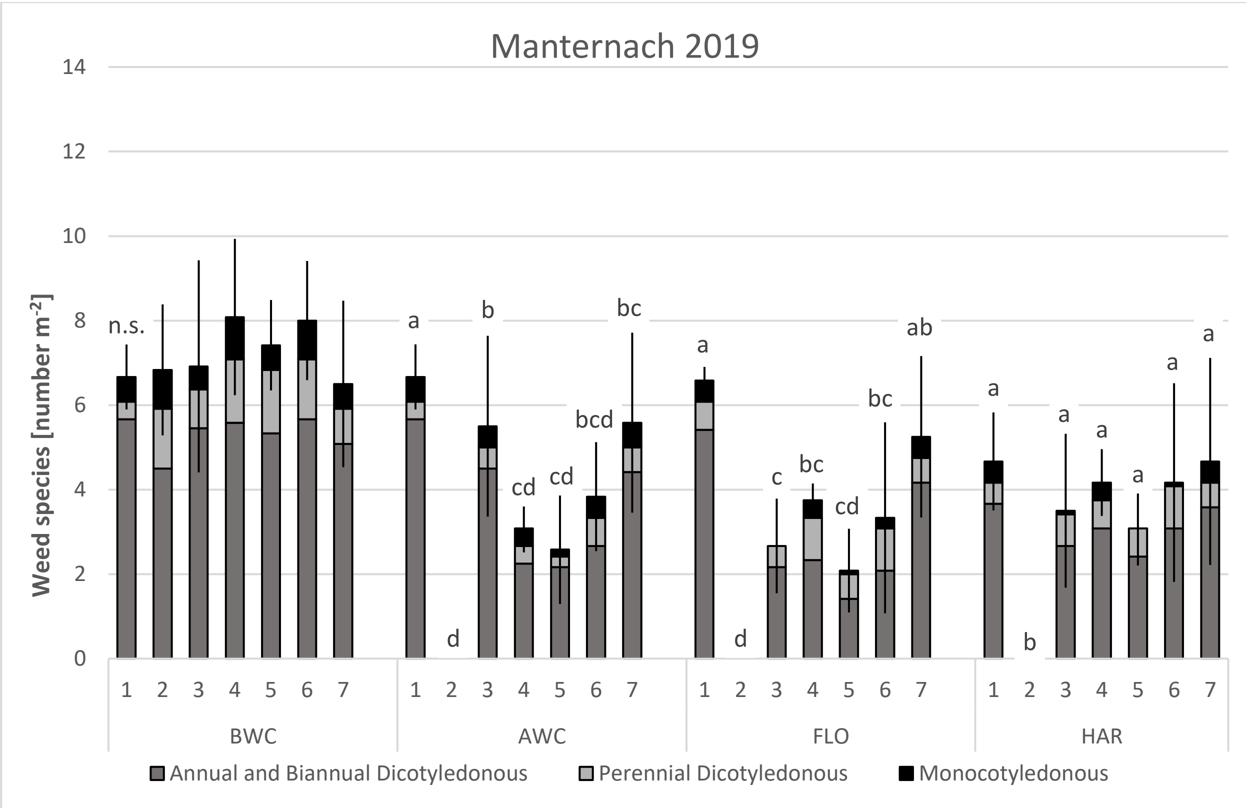


Figure 46: Average values of the number of weed species within each ecological group (Annual and biannual dicotyledonous, Perennial dicotyledonous, Monocotyledonous) for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Manternach 2018 (on top) and Manternach 2019 (at the bottom). Bars indicate standard deviation of the total number of weed species for each treatment. Letters on top of the bars indicate significant variances between treatments at $p \leq 0.05$.

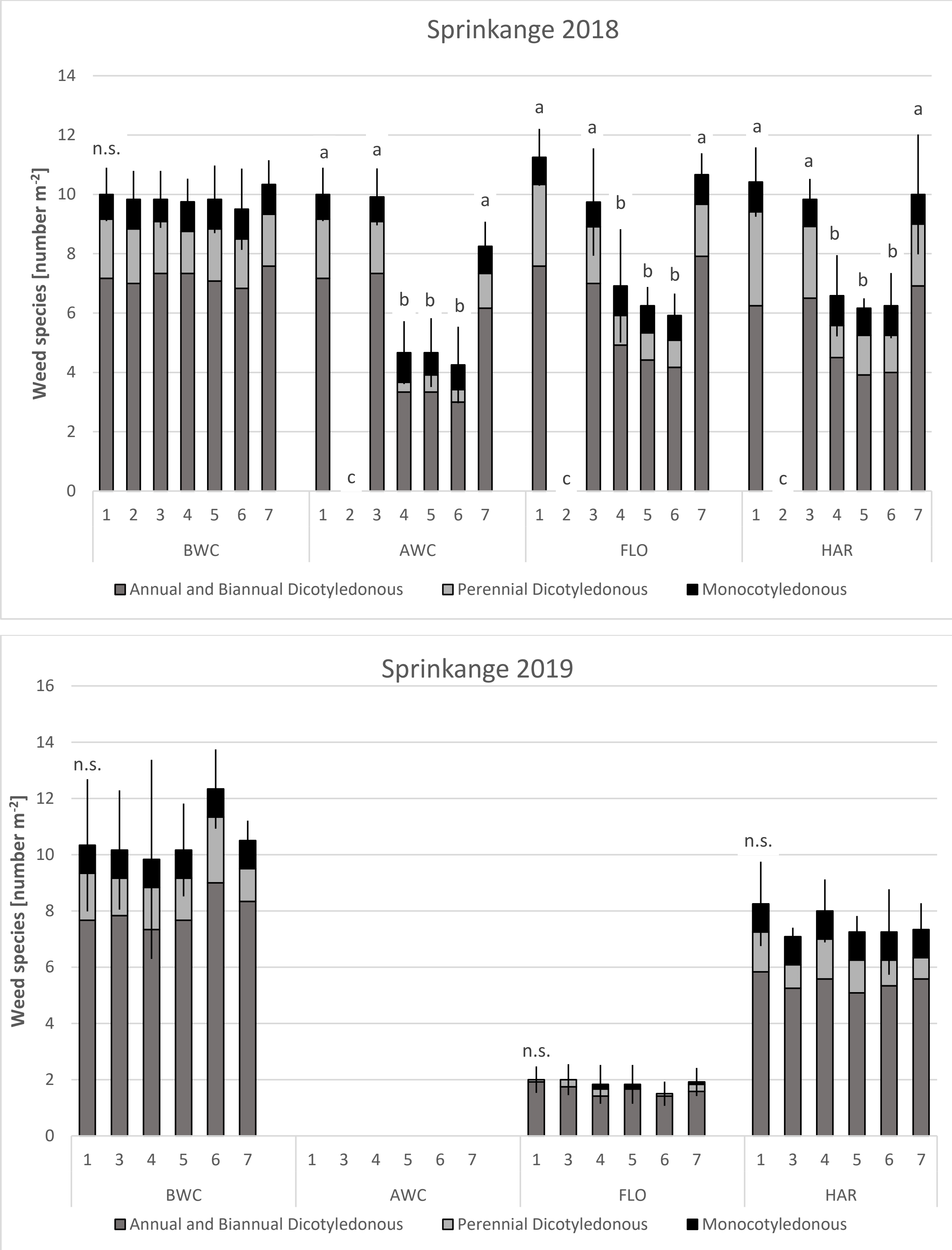


Figure 47: Average values of the number of weed species within each ecological group (Annual and biannual dicotyledonous, Perennial dicotyledonous, Monocotyledonous) for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for BWC, AWC, FLO and HAR, for Sprinkange 2018 (on top) and Sprinkange 2019 (at the bottom). Bars indicate standard deviation of the total number of weed species for each treatment. Letters on top of the bars indicate significant variances between treatments at p≤0.05.

Table 39: List of weed species per ecological group and total number of weed species for each site and experiment year, identified during the growing period of soybean (from BWC until HAR). Species in Bold were common for each site and experiment year. Letters within parenthesis indicate species recorded on the red list of the vascular plants of Luxembourg (Colling 2005), NT: Near Threatened, R: Extremely rare, VU: Vulnerable.

Weed species Botanical names	Hostert		Manternach		Sprinkange	
	2018	2019	2018	2019	2018	2019
Annual and Biannual dicotyledonous	**23**	**27**	**17**	**26**	**21**	**19**
Amaranthus blitum						✓
Amaranthus retroflexus				✓		
Anagallis arvensis	✓	✓	✓	✓	✓	✓
Anchusa officinalis		✓				
Atriplex L.						✓
Brassicaceae					✓	
Camelina sativa	✓		✓	✓		
Campanula rapunculus		✓				
Capsella bursa-pastoris	✓	✓	✓	✓	✓	✓
Centaurea cyanus (VU)	✓	✓				
Chenopodium album	✓	✓	✓	✓	✓	✓
Euphorbia cyparissias	✓	✓		✓		
Fagopyrum esculentum	✓					
Fumaria officinalis	✓	✓	✓	✓	✓	✓
Galeopsis tetrahit	✓	✓				
Galium aparine					✓	✓
Geranium dissectum		✓				
Geranium rotundifolium (R)		✓		✓		
Glycine max	✓	✓	✓	✓		
Lactuca serriola					✓	✓
Lamium amplexicaule	✓	✓	✓	✓	✓	✓
Lapana communis		✓				
Myosotis arvensis	✓	✓	✓	✓	✓	✓
Papaver rhoeas (NT)	✓	✓	✓	✓	✓	✓
Persicaria lapathifolia	✓			✓	✓	✓
Phacilia tanacetefolia				✓		
Polygonum aviculare	✓	✓	✓	✓	✓	✓
Raphanus raphanistrum				✓		
Senecio Vulgaris				✓		
Sinapis arvensis	✓	✓		✓	✓	✓
Solanum nigrum				✓		
Stellaria media	✓	✓	✓	✓	✓	✓
Thlaspi arvense	✓	✓	✓		✓	
Trifolium Spec.	✓	✓	✓	✓	✓	✓
Tripleurospermum inodorum	✓	✓	✓	✓	✓	✓
Unidentified	✓	✓	✓	✓	✓	
Valerianella locusta		✓				
Veronica agrestis	✓	✓	✓	✓	✓	✓
Vicia Spec.	✓	✓	✓	✓	✓	✓
Viola arvensis		✓		✓	✓	
Perennial dicotyledonous	**7**	**8**	**5**	**6**	**9**	**6**
Allium spec.	✓					
Calystegia sepium					✓	
Cirsium arvense	✓	✓	✓	✓	✓	✓
Cirsum oleraceum					✓	
Equisetum arvense	✓					
Galium verum					✓	
Plantago major	✓	✓	✓	✓	✓	✓
Polygonum convolvulus	✓	✓	✓	✓	✓	✓
Ranunculus repens		✓	✓	✓	✓	✓
Rumex obtusifolius	✓	✓	✓	✓	✓	✓
Sonchus arvensis		✓		✓		✓
Taraxacum sect. Ruderalia	✓	✓			✓	
Urtica dioica		✓				
Monocotyledonous	**3**	**2**	**4**	**2**	**2**	**1**
Avena sativa					✓	
Elymus repens	✓	✓	✓			
Lolium perenne				✓		
Phleum pratense	✓		✓			
Poa annua			✓			
Poaceae	✓	✓	✓	✓	✓	✓
Total	**33**	**37**	**26**	**34**	**32**	**26**

4.5.2 Species abundance

The abundance of weed species in terms of weed individuals' number is shown in Table 40 for Hostert18, Table 41 for Hostert19, Table 42 for Manternach18, Table 43 for Manternach19, Table 44 for Sprinaknge18 and Table 45 for Sprinkange19.

In Hostert18, for BWC, weed individuals from ABD species represented at least 99 % of the abundance of all species. *Fumaria officinalis* (28 to 45 %) was the most abundant species followed by, *Sinapis arvensis, Lamium amplexicaule* and *Thalspi arvense*. For AWC and at FLO, *Fumaria officinalis* and *Sinapis arvensis* remained predominant while, the abundance of *Lamium amplexicaule* and *Thalspi arvense* decreased but, *Chenopodium album* became more abundant at FLO. At HAR, *Sinapis arvensis* (40 to 62 %) and *Chenopodium album* (19 to 36 %) were WS with the most abundant number of individuals.

In Manternach18, for BWC, ABD weeds had an abundance varying from 83 to 92 %. *Myosotis arvensis* (39 to 54 %), *Chenopodium album* (6 to 21 %) and *Trifolium spec.* (6 to 25 %) are at this time the most abundant species. They remained the most abundant WS for AWC even though, most of the weeds have been eliminated by weed control. At FLO, the weed community has regrown but with more diverse species. Therefore, *Thlaspi arvense* (7 to 45 %), *Poa annua* (14 to 30 %) and *Elymus repens* (29 to 51 %) became the most abundant WS. At FLO, 30 to 68 % of WS were ABD and 31 to 66 % were M. At HAR, the fraction of ABD (16 to 29 %) further decreased while, PD represented 14 to 52 % of the population of weeds. Grass species (25 to 67 %) and *Plantago major* (13 to 51 %) were the most abundant species.

In Sprinkange18, although PD and M WS became more dominant in time, respectively 11-28 % and 10-34 % at HAR, ABD WS were predominant from BWC (78 to 88 %) until HAR (55-71 %). For BWC, two species had a high abundance: *Stellaria media* (23-38 %) and *Lamium amplexicaule* (17-29 %). These two species remained the most abundant for AWC. At FLO, *Stellaria media* still dominated (25-38 %) while, *Lamium amplexicaule* became less abundant (5-13 %) and other species, such like *Tripleurospermum inodorum* (5-17 %), *Veronica agrestis* (5-17 %) and undetermined grass species (9-24 %) were becoming more abundant. At HAR, although the abundance of grasses tended to be higher in hoed treatments than in harrowed ones, *Stellaria media* (9-32 %), *Veronica agrestis* (13-26 %) and grass species (10-34 %) were the most dominant species.

In Hostert19, the abundancy of ABD species was predominant over PD or M weed species all along the assessment period. The abundance of ABD species varied between 97 % and 100 % from BWC to HAR. For BWC, the most abundant weeds were *Viscia spec.* (39-65 %) and *Fumaria officinalis* (5-26 %). They remained the most abundant for AWC. At FLO, *Fumaria officinalis* (11-30 %), *Lamium amplexicaule* (8-20 %) and *Viscia spec.* (23-32 %) were more abundant in treatments $t.4_{hoe}$, $t.5_{hoe+}$ and $t.6_{comb}$ than in harrowed ones while, *Capsella bursa-pastoris* (13-20 %) and *Tripleurospermum inodorum* (30 %) were predominant in $t.3_{har}$ and $t.7_{mix}$. At HAR, *Fumaria officinalis, Thlaspi arvense* and *Veronica agrestis* dominated in t.4_{hoe}, t.5_{hoe+} and t.$6_{comb,}$ in comparison to *Myosotis arvensis* and *Viola arvensis* in treatments t.1_{neg}, t.3_{har} and t.7_{mix}.

In Manternach19, even though the abundance of PD weeds for FLO in treatments t.4_{hoe} and t.5_{hoe+} was over 50 %, globally, the most abundant ecological group was ABD weeds. For BWC, were counted, 76 to 92 % of ABD, 6 to 18 % of PD and 2 to 11 % of M weed individuals. *Lamium amplexicaule* (28-46 %) and *Veronica agrestis* (22-34 %) were the most abundant species and remained predominant for AWC. At FLO, the distribution changed, *Veronica agrestis* had an abundance of 14 to 38 %, *Lamium amplexicaule* of 9 to 24 % and *Polygonum convolvulus* of 14 to 50 %. In treatments t.4_{hoe} and t.6_{comb}, *Polygonum convolvulus* was more abundant than in other treatment while less *Veronica agrestis* grew. Although the abundance of *Polygonum convolvulus* decreased (4-25 %), *Veronica agrestis* (28-34 %) tended to be more abundant in harrowed treatments while *Lamium amplexicaule* (26-40 %) dominated in hoed ones.

In Sprinkange19, for BWC, ABD weeds had an abundancy of 61 to 79 %, PD of 1 to 4 % and M of 18 to 36 %. The most abundant species were *Tripleurospermum inodorum* (14-46 %), *Sinapis arvensis* (4-37 %) and *Persicaria lapathifolia* (8-17 %) for ABD species and, undetermined grass species (18-36 %) for M weeds. No data for AWC has been collected. At FLO, only the most abundant species have been identified but the number of individuals were not counted. At HAR, each growing weed species was recorded but not the corresponding number of individuals.

Globally, the abundance of annual and biannual dicotyledonous weeds tended to be predominant, (abundance > 50 %) for BWC across all experiment sites. Later in the cropping cycle, at FLO and HAR, the abundance of ABD often decreased while, the proportion of PD and M species increased, except in Hostert18 and Hostert19. PD and/or M species became predominant at FLO and/or at HAR particularly in Manternach18 (especially grasses and *Plantago major*), Manternach19 (*Polygonum convolvulus* particularly in t.4_{hoe} and t.6_{comb}) and Sprinkange19 (i.a. *Chenopodium album, Plantago major, Polygonum convolvulus, Rumex obtusifolius*). While 2 to 4 species were very abundant BWC, these species often remained dominant over time unless late growing ABD, PD or M species developed and became very abundant. At FLO, most problematic species identified were *Chenopodium album, Fumaria officinals* and *Sinapis arvensis* in Hostert18, *Poa annua* and *Elymus repens* in Manternach18, *Tripleurospermum inodorum, Veronica agrestis* and grasses in Sprinkange18, *Viscia spec.* and *Tripleurospermum inodorum* in Hostert19, *Veronica agrestis* and *Polygonum convolvulus* in Manternach19 and *Persicaria lapathifolia* and *Tripleurospermum inodorum* in Sprinaknge19. Problematic species at HAR were *Chenopodium album* and *Sinapis arvensis* in Hostert18, grasses and *Plantago major* in Manternach18, *Veronica agrestis* and grasses in Sprinkange18, *Veronica agrestis* in Hostert 2019, *Polygonum convolvulus* in Manternach 2019 and *Tripleurospermum inodorum* Mechanical weeding tended to increase the abundancy of these species while the less abundant ones tended to be more easily eliminated. Some differences of abundance between treatments were visible at FLO and at HAR especially in Hostert19 and Manternach19 where two mechanical weeding runs were performed.

Table 40: Mean number of weed individuals (number m^{-2}) per weed species for each ecological group for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for Hostert 2018. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group.

Hostert 2018	BWC													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	1.0	0%	0.0	0%
Camelina sativa	0.0	0%	0.0	0%	0.0	0%	5.3	1%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Centaurea cyanus	1.2	0%	1.5	0%	0.8	0%	1.3	0%	1.0	0%	4.0	1%	1.2	0%
Chenopodium album	40.8	10%	29.3	7%	27.7	6%	33.5	7%	32.0	6%	49.5	11%	28.2	6%
Euphorbia cyparissias	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fagopyrum esculentum	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fumaria officinalis	142.5	35%	166.3	38%	216.2	45%	151.7	33%	232.0	42%	127.8	28%	201.7	42%
Galeopsis tetrahit	2.3	1%	1.0	0%	6.5	1%	9.7	2%	2.7	0%	9.2	2%	2.0	0%
Glycine max	0.0	0%	0.0	0%	2.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	52.8	13%	58.2	13%	50.0	10%	66.7	15%	66.8	12%	61.2	14%	46.0	9%
Myosotis arvensis	0.0	0%	0.0	0%	0.7	0%	0.0	0%	0.0	0%	0.0	0%	5.0	1%
Papaver rhoeas	11.8	3%	11.7	3%	15.5	3%	15.3	3%	14.7	3%	17.3	4%	8.8	2%
Persicaria lapathifolia	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	54.8	13%	64.2	15%	80.8	17%	62.2	14%	93.3	17%	53.5	12%	66.3	14%
Stellaria media	1.8	0%	2.2	0%	0.5	0%	1.3	0%	0.8	0%	1.8	0%	1.5	0%
Thlaspi arvense	50.5	12%	59.2	14%	35.7	7%	64.7	14%	71.0	13%	73.7	16%	83.3	17%
Trifolium Spec.	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Tripleurospermum inodorum	15.7	4%	10.8	2%	8.5	2%	5.5	1%	11.7	2%	17.0	4%	6.7	1%
Unidentified	0.3	0%	0.0	0%	0.3	0%	1.0	0%	0.5	0%	0.0	0%	1.5	0%
Veronica agrestis	2.3	1%	4.2	1%	8.7	2%	4.0	1%	6.5	1%	3.2	1%	2.5	1%
Vicia spec.	29.2	7%	22.8	5%	18.2	4%	30.5	7%	15.5	3%	29.3	6%	24.2	5%
Total	**406.2**	**99%**	**431.5**	**100%**	**472.2**	**99%**	**452.8**	**99%**	**548.5**	**99%**	**448.5**	**99%**	**478.8**	**99%**
Perennial dicotyledonous														
Allium spec.	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.5	0%	0.0	0%
Cirsium arvense	0.0	0%	0.0	0%	1.0	0%	0.7	0%	0.2	0%	0.0	0%	0.3	0%
Equisetum arvense	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	1.0	0%	0.0	0%
Plantago major	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	1.0	0%	2.0	0%	1.5	0%	1.5	0%	1.0	0%	2.2	0%	0.5	0%
Rumex obtusifolius	0.0	0%	0.0	0%	0.8	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**1.0**	**0%**	**2.0**	**0%**	**3.3**	**1%**	**2.2**	**0%**	**1.2**	**0%**	**3.7**	**1%**	**0.8**	**0%**
Monocotyledonous														
Elymus repens	0.0	0%	0.0	0%	2.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Phleum pratense	1.0	0%	0.0	0%	1.3	0%	1.3	0%	3.5	1%	0.0	0%	5.7	1%
Poaceae	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**1.2**	**0%**	**0.0**	**0%**	**3.5**	**1%**	**1.3**	**0%**	**3.5**	**1%**	**0.0**	**0%**	**5.7**	**1%**
Global total	408.3		433.5		479.0		456.3		553.2		452.2		485.3	

Hostert 2018	AWC													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.5	1%	0.0	0%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Centaurea cyanus	1.2	0%	0.0	/	0.2	0%	0.3	0%	0.0	0%	0.2	0%	0.2	0%
Chenopodium album	40.8	10%	0.0	/	10.8	6%	9.5	8%	5.0	5%	8.0	10%	12.3	6%
Euphorbia cyparissias	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fagopyrum esculentum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fumaria officinalis	142.5	35%	0.0	/	77.7	40%	41.3	34%	46.0	42%	28.3	36%	76.2	37%
Galeopsis tetrahit	2.3	1%	0.0	/	1.2	1%	3.0	2%	1.2	1%	3.7	5%	0.7	0%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	52.8	13%	0.0	/	13.7	7%	12.7	11%	9.0	8%	4.7	6%	8.5	4%
Myosotis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.8	0%
Papaver rhoeas	11.8	3%	0.0	/	3.8	2%	2.2	2%	2.5	2%	1.7	2%	2.8	1%
Persicaria lapathifolia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	54.8	13%	0.0	/	64.3	33%	27.2	23%	28.3	26%	14.2	18%	56.8	28%
Stellaria media	1.8	0%	0.0	/	1.0	1%	0.2	0%	0.5	0%	0.2	0%	0.3	0%
Thlaspi arvense	50.5	12%	0.0	/	14.2	7%	15.3	13%	9.0	8%	11.3	14%	37.8	18%
Trifolium Spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.3	0%	0.0	0%	0.2	0%
Tripleurospermum inodorum	15.7	4%	0.0	/	0.7	0%	0.5	0%	0.3	0%	1.5	2%	0.5	0%
Unidentified	0.3	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	2.3	1%	0.0	/	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Vicia spec.	29.2	7%	0.0	/	3.0	2%	7.2	6%	5.3	5%	4.5	6%	4.8	2%
Total	**406.2**	**99%**	**0.0**	**/**	**190.5**	**98%**	**119.3**	**99%**	**107.7**	**98%**	**78.8**	**99%**	**202.0**	**98%**
Perennial dicotyledonous														
Allium spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Cirsium arvense	0.0	0%	0.0	/	0.5	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Equisetum arvense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	1.0	0%	0.0	/	0.8	0%	0.5	0%	0.0	0%	0.3	0%	0.2	0%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**1.0**	**0%**	**0.0**	**/**	**1.3**	**1%**	**0.5**	**0%**	**0.0**	**0%**	**0.3**	**0%**	**0.3**	**0%**
Monocotyledonous														
Elymus repens	0.0	0%	0.0	/	2.2	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Phleum pratense	1.0	0%	0.0	/	1.2	1%	0.7	1%	2.0	2%	0.2	0%	3.0	1%
Poaceae	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**1.2**	**0%**	**0.0**	**/**	**3.3**	**2%**	**0.7**	**1%**	**2.0**	**2%**	**0.2**	**0%**	**3.0**	**1%**
Global total	408.3		0.0		195.2		120.5		109.7		79.3		205.3	

Hostert 2018	FLO													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	2.0	1%	0.0	/	1.3	1%	1.2	1%	0.8	1%	0.5	1%	1.7	1%
Centaurea cyanus	1.3	1%	0.0	/	0.3	0%	0.3	0%	0.3	0%	0.7	1%	0.7	0%
Chenopodium album	41.3	19%	0.0	/	13.7	9%	18.0	16%	14.0	11%	12.2	12%	17.7	9%
Euphorbia cyparissias	1.2	1%	0.0	/	0.8	1%	0.5	0%	0.3	0%	0.2	0%	1.0	1%
Fagopyrum esculentum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fumaria officinalis	74.3	35%	0.0	/	45.3	31%	47.0	41%	47.0	37%	36.3	37%	87.3	45%
Galeopsis tetrahit	0.5	0%	0.0	/	1.5	1%	1.7	1%	1.2	1%	5.3	5%	1.8	1%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	13.5	6%	0.0	/	9.3	6%	12.2	11%	9.8	8%	8.7	9%	12.3	6%
Myosotis arvensis	0.5	0%	0.0	/	0.5	0%	0.3	0%	0.2	0%	0.0	0%	0.2	0%
Papaver rhoeas	2.2	1%	0.0	/	1.5	1%	0.5	0%	0.5	0%	1.7	2%	1.5	1%
Persicaria lapathifolia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	56.5	27%	0.0	/	62.3	43%	23.5	21%	36.8	29%	18.7	19%	55.5	28%
Stellaria media	0.5	0%	0.0	/	0.3	0%	0.0	0%	2.3	2%	1.8	2%	0.8	0%
Thlaspi arvense	0.0	0%	0.0	/	0.0	0%	0.5	0%	1.2	1%	0.8	1%	0.3	0%
Trifolium Spec.	0.2	0%	0.0	/	0.0	0%	0.3	0%	0.2	0%	0.3	0%	1.0	1%
Tripleurospermum inodorum	11.3	5%	0.0	/	2.3	2%	2.5	2%	1.2	1%	4.5	5%	2.2	1%
Unidentified	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Veronica agrestis	0.0	0%	0.0	/	0.2	0%	0.2	0%	0.0	0%	1.5	2%	0.2	0%
Vicia spec.	4.8	2%	0.0	/	2.7	2%	4.0	3%	3.7	3%	3.5	4%	3.2	2%
Total	**210.2**	**99%**	**0.0**	**/**	**142.2**	**97%**	**112.7**	**98%**	**119.7**	**94%**	**96.7**	**99%**	**187.5**	**96%**
Perennial dicotyledonous														
Allium spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Cirsium arvense	0.0	0%	0.0	/	0.5	0%	0.0	0%	0.3	0%	0.0	0%	0.2	0%
Equisetum arvense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	1.5	1%	0.0	/	1.2	1%	1.8	2%	2.2	2%	0.8	1%	0.3	0%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%
Total	**1.5**	**1%**	**0.0**	**/**	**1.7**	**1%**	**1.8**	**2%**	**2.5**	**2%**	**1.0**	**1%**	**0.5**	**0%**
Monocotyledonous														
Elymus repens	0.3	0%	0.0	/	2.8	2%	0.0	0%	5.3	4%	0.0	0%	7.3	4%
Phleum pratense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Poaceae	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**0.3**	**0%**	**0.0**	**/**	**2.8**	**2%**	**0.0**	**0%**	**5.3**	**4%**	**0.0**	**0%**	**7.3**	**4%**
Global total	212.0		0.0		146.7		114.5		127.5		97.7		195.3	

Hostert 2018	HAR													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	1%	0.0	0%
Capsella bursa-pastoris	0.2	0%	0.0	/	0.2	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%
Centaurea cyanus	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.7	1%
Chenopodium album	35.5	36%	0.0	/	11.5	17%	11.2	27%	7.7	20%	10.8	36%	16.5	20%
Euphorbia cyparissias	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fagopyrum esculentum	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.3	0%
Fumaria officinalis	4.0	4%	0.0	/	5.7	8%	2.0	5%	0.5	1%	1.2	4%	5.0	6%
Galeopsis tetrahit	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Glycine max	0.5	1%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Lamium amplexicaule	0.0	0%	0.0	/	0.0	0%	0.5	1%	0.3	1%	0.2	1%	0.2	0%
Myosotis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Papaver rhoeas	0.3	0%	0.0	/	0.2	0%	0.3	1%	0.3	1%	0.0	0%	0.0	0%
Persicaria lapathifolia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	0.0	0%	0.0	/	0.0	0%	1.5	4%	0.0	0%	0.0	0%	0.3	0%
Sinapis arvensis	51.2	52%	0.0	/	43.2	62%	23.0	55%	22.7	59%	13.0	43%	48.3	60%
Stellaria media	0.0	0%	0.0	/	0.0	0%	0.2	0%	0.3	1%	0.0	0%	0.0	0%
Thlaspi arvense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Trifolium Spec.	0.8	1%	0.0	/	0.0	0%	0.2	0%	0.0	0%	0.7	2%	0.5	1%
Tripleurospermum inodorum	2.3	2%	0.0	/	1.3	2%	0.3	1%	1.0	3%	1.5	5%	2.5	3%
Unidentified	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	0.0	0%	0.0	/	0.2	0%	0.2	0%	0.5	1%	0.3	1%	0.8	1%
Vicia spec.	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**95.2**	**96%**	**0.0**	**/**	**62.7**	**90%**	**39.5**	**94%**	**33.5**	**87%**	**27.8**	**91%**	**75.5**	**93%**
Perennial dicotyledonous														
Allium spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Cirsium arvense	0.0	0%	0.0	/	0.7	1%	0.0	0%	0.3	1%	0.8	3%	0.0	0%
Equisetum arvense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Plantago major	0.0	0%	0.0	/	0.5	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	3.0	3%	0.0	/	3.0	4%	2.0	5%	0.8	2%	1.3	4%	1.2	1%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**3.0**	**3%**	**0.0**	**/**	**4.2**	**6%**	**2.0**	**5%**	**1.2**	**3%**	**2.2**	**7%**	**1.2**	**1%**
Monocotyledonous														
Elymus repens	0.5	1%	0.0	/	0.3	0%	0.0	0%	0.0	0%	0.0	0%	1.0	1%
Phleum pratense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Poaceae	0.5	1%	0.0	/	2.3	3%	0.3	1%	3.8	10%	0.5	2%	3.3	4%
Total	**1.0**	**1%**	**0.0**	**/**	**2.7**	**4%**	**0.3**	**1%**	**3.8**	**10%**	**0.5**	**2%**	**4.3**	**5%**
Global total	99.2		0.0		69.5		41.8		38.5		30.5		81.0	

Table 41: Mean number of weed individuals (number m^{-2}) per weed species for each ecological group for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for Hostert 2018. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group. Red frames show variations in abundance according to hoed and harrowed treatments.

Hostert 2019	BWC														AWC													
	1		2		3		4		5		6		7		1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous																												
Anagallis arvensis	0.8	1%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.8	1%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anchusa officinalis	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Campanula rapunculus	0.0	0%	0.3	0%	0.0	0%	0.7	1%	1.0	1%	0.3	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	1%	0.0	0%
Capsella bursa-pastoris	0.5	0%	0.0	0%	0.5	1%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.5	0%	0.0	/	0.3	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Centaurea cyanus	3.0	3%	1.7	1%	2.0	2%	1.3	1%	2.3	2%	2.0	2%	1.5	2%	3.0	3%	0.0	/	1.7	4%	0.5	2%	0.5	2%	0.5	2%	0.8	2%
Chenopodium album	0.3	0%	2.5	2%	1.7	2%	1.2	1%	0.8	1%	0.8	1%	0.8	1%	0.3	0%	0.0	/	0.3	1%	0.7	3%	0.2	1%	0.5	2%	0.5	1%
Euphorbia cyparissias	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	10.5	13%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	1.8	3%
Fumaria officinalis	5.7	5%	8.8	7%	10.5	11%	19.2	18%	5.5	5%	25.8	26%	5.0	6%	5.7	5%	0.0	/	6.3	14%	6.7	29%	2.5	8%	8.5	34%	3.5	7%
Galeopsis tetrahit	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Geranium dissectum	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Geranium rotundifolium	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Glycine max	0.2	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.2	0%	0.0	0%	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	6.8	6%	12.5	10%	3.7	4%	12.2	12%	13.2	12%	7.7	8%	3.7	4%	6.8	6%	0.0	/	2.3	5%	2.5	11%	3.3	11%	2.5	10%	2.7	5%
Lapana communis	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Myosotis arvensis	1.3	1%	1.2	1%	1.5	2%	0.2	0%	0.3	0%	0.8	1%	0.5	1%	1.3	1%	0.0	/	0.5	1%	0.8	4%	0.2	1%	0.0	0%	0.0	0%
Papaver rhoeas	3.5	3%	5.7	5%	1.8	2%	3.0	3%	2.0	2%	1.7	2%	2.0	2%	3.5	3%	0.0	/	0.7	1%	0.7	3%	0.3	1%	0.0	0%	0.7	1%
Polygonum aviculare	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	0.3	0%	0.2	0%	0.2	0%	0.0	0%	0.2	0%	0.2	0%	0.0	0%	0.3	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.2	1%	0.0	0%
Stellaria media	1.5	1%	2.5	2%	2.2	2%	1.7	2%	2.7	2%	1.0	1%	0.8	1%	1.5	1%	0.0	/	0.3	1%	0.0	0%	0.0	0%	0.2	1%	0.3	1%
Thlaspi arvense	5.3	5%	13.0	11%	9.2	10%	15.8	15%	10.2	9%	9.7	10%	2.2	3%	5.3	5%	0.0	/	4.0	9%	1.3	6%	1.8	6%	1.2	5%	1.0	2%
Trifolium Spec.	0.5	0%	0.2	0%	0.0	0%	0.5	0%	0.3	0%	0.2	0%	0.0	0%	0.5	0%	0.0	/	0.0	0%	0.0	0%	0.2	1%	0.0	0%	0.5	1%
Tripleurospermum inodorum	5.5	5%	10.7	9%	8.3	9%	4.3	4%	4.3	4%	5.5	6%	4.3	5%	5.5	5%	0.0	/	4.7	10%	0.2	1%	1.0	3%	0.3	1%	2.2	4%
Unidentified	0.0	0%	0.0	0%	0.0	0%	0.3	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Valerianella locusta	0.3	0%	3.8	3%	0.3	0%	1.7	2%	0.3	0%	0.5	1%	0.0	0%	0.3	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	2.2	2%	2.5	2%	0.2	0%	1.5	1%	2.3	2%	1.0	1%	0.5	1%	2.2	2%	0.0	/	0.5	1%	0.5	2%	0.7	2%	0.3	1%	1.3	3%
Vicia Spec.	70.3	65%	55.0	45%	48.3	53%	40.7	39%	65.5	58%	40.5	41%	50.0	61%	70.3	65%	0.0	/	24.2	52%	9.3	40%	18.2	61%	10.3	42%	37.2	70%
Viola arvensis	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Total	**108.2**	**99%**	**120.7**	**99%**	**90.3**	**98%**	**104.7**	**99%**	**111.2**	**99%**	**97.8**	**99%**	**82.0**	**100%**	**108.2**	**99%**	**0.0**	**/**	**46.2**	**99%**	**23.2**	**100%**	**28.8**	**97%**	**24.7**	**99%**	**52.7**	**100%**
Perennial dicotyledonous																												
Cirsium arvense	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Plantago major	0.0	0%	0.7	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	0.8	1%	0.3	0%	0.8	1%	0.2	0%	1.2	1%	0.3	0%	0.2	0%	0.8	1%	0.0	/	0.7	1%	0.0	0%	0.3	1%	0.2	1%	0.0	0%
Ranunculus repens	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.2	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	1%	0.0	0%	0.0	0%
Sonchus arvensis	0.0	0%	0.2	0%	0.7	1%	0.5	0%	0.0	0%	0.3	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	1%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Urtica dioica	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**0.8**	**1%**	**1.2**	**1%**	**1.5**	**2%**	**0.8**	**1%**	**1.5**	**1%**	**0.7**	**1%**	**0.3**	**0%**	**0.8**	**1%**	**0.0**	**/**	**0.7**	**1%**	**0.0**	**0%**	**0.7**	**2%**	**0.2**	**1%**	**0.0**	**0%**
Monocotyledonous																												
Elymus repens	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Poaceae	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.2	0%	0.2	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	1%	0.0	0%	0.2	0%
Total	**0.0**	**0%**	**0.2**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.2**	**0%**	**0.3**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**/**	**0.0**	**0%**	**0.0**	**0%**	**0.2**	**1%**	**0.0**	**0%**	**0.2**	**0%**
Global total	109.0		122.0		91.8		105.5		112.8		98.8		82.3		109.0		0.0		46.8		23.2		29.7		24.8		52.8	

Hostert 2019	FLO														HAR													
	1		2		3		4		5		6		7		1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous																												
Anagallis arvensis	0.2	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anchusa officinalis	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Campanula rapunculus	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	26.5	15%	0.0	/	24.5	20%	1.7	6%	0.2	1%	0.5	5%	13.2	13%	1.3	3%	0.0	/	1.5	4%	1.5	5%	0.3	2%	0.2	2%	0.8	2%
Centaurea cyanus	1.7	1%	0.0	/	1.3	1%	0.3	1%	1.2	8%	0.0	0%	2.0	2%	1.8	4%	0.0	/	0.5	1%	0.0	0%	0.3	2%	0.0	0%	1.2	3%
Chenopodium album	1.2	1%	0.0	/	2.2	2%	0.8	3%	0.2	1%	0.0	0%	3.2	3%	0.7	1%	0.0	/	1.3	4%	0.2	1%	0.2	1%	0.0	0%	2.0	6%
Euphorbia cyparissias	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fumaria officinalis	6.7	4%	0.0	/	8.2	7%	4.5	16%	1.7	11%	3.3	30%	5.0	5%	0.2	0%	0.0	/	1.8	5%	8.8	27%	2.0	11%	0.2	2%	1.0	3%
Galeopsis tetrahit	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Geranium dissectum	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Geranium rotundifolium	0.8	0%	0.0	/	0.5	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.8	2%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.3	4%	0.0	0%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.2	1%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	11.5	6%	0.0	/	7.0	6%	4.7	16%	2.8	20%	0.8	8%	5.7	6%	0.2	0%	0.0	/	0.0	0%	0.3	1%	2.7	14%	0.0	0%	0.0	0%
Lapana communis	0.0	0%	0.0	/	0.2	0%	0.2	1%	0.2	1%	0.2	2%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Myosotis arvensis	1.8	1%	0.0	/	0.7	1%	0.2	1%	0.0	0%	0.0	0%	0.5	0%	20.0	40%	0.0	/	17.8	51%	6.0	18%	3.5	18%	2.0	24%	13.3	39%
Papaver rhoeas	10.0	6%	0.0	/	4.3	3%	1.0	3%	0.2	1%	0.2	2%	2.0	2%	0.8	2%	0.0	/	0.0	0%	0.3	1%	2.0	11%	0.8	10%	0.0	0%
Polygonum aviculare	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.7	1%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.5	1%
Sinapis arvensis	0.5	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	2%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stellaria media	2.2	1%	0.0	/	0.8	1%	0.3	1%	0.2	1%	0.0	0%	1.3	1%	0.5	1%	0.0	/	0.0	0%	0.3	1%	0.2	1%	0.3	4%	0.5	1%
Thlaspi arvense	6.8	4%	0.0	/	5.0	4%	0.8	3%	0.3	2%	0.2	2%	2.0	2%	1.7	3%	0.0	/	1.0	3%	5.7	17%	1.7	9%	0.7	8%	1.5	4%
Trifolium Spec.	1.2	1%	0.0	/	0.7	1%	0.2	1%	0.0	0%	0.0	0%	0.5	0%	0.0	0%	0.0	/	0.2	0%	0.2	1%	0.0	0%	0.0	0%	0.2	0%
Tripleurospermum inodorum	56.5	32%	0.0	/	37.3	30%	4.2	14%	1.8	13%	1.8	17%	31.2	30%	2.2	4%	0.0	/	0.3	1%	0.3	1%	0.0	0%	0.0	0%	2.2	6%
Unidentified	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Valerianella locusta	2.0	1%	0.0	/	0.7	1%	1.3	5%	0.2	1%	0.2	2%	0.3	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	13.7	8%	0.0	/	5.2	4%	1.5	5%	0.2	1%	0.3	3%	3.8	4%	11.3	23%	0.0	/	5.3	15%	7.5	23%	5.3	28%	1.8	22%	6.0	18%
Vicia Spec.	27.5	15%	0.0	/	17.0	14%	6.7	23%	4.7	32%	3.0	27%	26.5	26%	0.5	1%	0.0	/	0.2	0%	0.5	2%	0.3	2%	1.8	22%	0.0	0%
Viola arvensis	5.8	3%	0.0	/	6.3	5%	0.2	1%	0.7	5%	0.3	3%	4.7	5%	5.7	11%	0.0	/	4.0	11%	1.0	3%	0.2	1%	0.3	4%	4.5	13%
Total	**176.7**	**99%**	**0.0**	**/**	**122.3**	**99%**	**28.5**	**99%**	**14.3**	**99%**	**11.0**	**100%**	**102.2**	**100%**	**48.5**	**98%**	**0.0**	**/**	**34.3**	**98%**	**32.8**	**99%**	**18.7**	**98%**	**8.5**	**100%**	**33.7**	**100%**
Perennial dicotyledonous																												
Cirsium arvense	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.2	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.3	1%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	0.8	0%	0.0	/	1.3	1%	0.0	0%	0.2	1%	0.0	0%	0.2	0%	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.2	1%	0.0	0%	0.0	0%
Ranunculus repens	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.5	0%	0.0	/	0.2	0%	0.2	1%	0.0	0%	0.0	0%	0.0	0%	0.3	1%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sonchus arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Taraxacum sect. Ruderalia	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Urtica dioica	0.0	0%	0.0	/	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**1.5**	**1%**	**0.0**	**/**	**1.7**	**1%**	**0.3**	**1%**	**0.2**	**1%**	**0.0**	**0%**	**0.2**	**0%**	**0.3**	**1%**	**0.0**	**/**	**0.2**	**0%**	**0.3**	**1%**	**0.2**	**1%**	**0.0**	**0%**	**0.0**	**0%**
Monocotyledonous																												
Elymus repens	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Poaceae	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.8	2%	0.0	/	0.5	1%	0.0	0%	0.2	1%	0.0	0%	0.2	0%
Total	**0.0**	**0%**	**0.0**	**/**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.2**	**0%**	**0.8**	**2%**	**0.0**	**/**	**0.5**	**1%**	**0.0**	**0%**	**0.2**	**1%**	**0.0**	**0%**	**0.2**	**0%**
Global total	178.2		0.0		124.0		28.8		14.5		11.0		102.5		49.7		0.0		35.0		33.2		19.0		8.5		33.8	

Table 42: Mean number of weed individuals (number m⁻²) per weed species for each ecological group for each treatment t.1neg (1), t.2pos (2), t.3har (3), t.4hoe (4), t.5hoe+ (5), t.6comb (6) and t.7mix (7), for Manternach 2018. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group.

Manternach 2018	BWC							AWC						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Annual and Biannual dicotyledonous														
Anagalis arvensis	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Camelina sativa	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Capsella bursa-pastoris	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Chenopodium album	4.3 17%	3.7 17%	3.0 17%	3.3 17%	4.0 21%	2.8 18%	2.0 6%	4.3 17%	0.0 /	1.0 32%	0.3 11%	0.3 15%	0.2 7%	0.0 0%
Fumaria officinalis	0.5 2%	0.2 1%	0.8 5%	0.5 3%	0.3 2%	0.2 1%	0.5 1%	0.5 2%	0.0 /	0.5 16%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Glycine max	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Lamium amplexicaule	3.0 12%	2.8 13%	0.8 5%	1.7 8%	1.8 10%	1.3 9%	3.5 10%	3.0 12%	0.0 /	0.2 5%	0.8 28%	0.5 23%	0.3 14%	0.0 0%
Tripleurospermum inodorum	1.0 4%	0.0 0%	0.3 2%	2.0 10%	1.2 6%	0.3 2%	2.0 6%	1.0 4%	0.0 /	0.0 0%	0.2 6%	0.0 0%	0.0 0%	0.0 0%
Myosotis arvensis	10.0 39%	6.5 30%	9.8 54%	5.7 28%	4.7 25%	4.0 26%	14.3 40%	10.0 39%	0.0 /	0.5 16%	0.5 17%	0.5 23%	0.7 29%	0.2 50%
Papaver rhoeas	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Polygonum aviculare	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 1%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Stellaria media	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Thlaspi arvense	0.5 2%	1.3 6%	0.8 5%	0.8 4%	1.5 8%	1.7 11%	3.2 9%	0.5 2%	0.0 /	0.2 5%	0.2 6%	0.0 0%	0.2 7%	0.2 50%
Trifolium Spec.	2.3 9%	5.5 25%	1.0 6%	3.7 18%	1.8 10%	3.3 21%	5.7 16%	2.3 9%	0.0 /	0.5 16%	0.7 22%	0.3 15%	0.7 29%	0.0 0%
Unidentified	0.2 1%	0.0 0%	0.0 0%	0.2 1%	0.0 0%	0.2 1%	0.0 0%	0.2 1%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.2 7%	0.0 0%
Veronica agrestis	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Vicia Spec.	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Total	**21.8 86%**	**20.0 92%**	**16.7 92%**	**17.8 89%**	**15.5 83%**	**13.8 88%**	**31.3 87%**	**21.8 86%**	**0.0 /**	**2.8 89%**	**2.7 89%**	**1.7 77%**	**2.2 93%**	**0.3 100%**
Perennial dicotyledonous														
Cirsium arvense	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Plantago major	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.3 2%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Polygonum convolvulus	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Ranunculus repens	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Rumex obtusifolius	0.5 2%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 1%	0.0 0%	0.5 2%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.2 7%	0.0 0%
Total	**0.5 2%**	**0.0 0%**	**0.0 0%**	**0.0 0%**	**0.0 0%**	**0.5 3%**	**0.0 0%**	**0.5 2%**	**0.0 /**	**0.0 0%**	**0.0 0%**	**0.0 0%**	**0.2 7%**	**0.0 0%**
Monocotyledonous														
Elymus repens	0.0 0%	0.7 3%	0.2 1%	0.0 0%	0.2 1%	0.3 2%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Phleum pratense	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Poa annua	3.0 12%	1.2 5%	1.3 7%	2.2 11%	3.0 16%	1.0 6%	4.5 13%	3.0 12%	0.0 /	0.3 11%	0.3 11%	0.5 23%	0.0 0%	0.0 0%
Poaceae	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Total	**3.0 12%**	**1.8 8%**	**1.5 8%**	**2.2 11%**	**3.2 17%**	**1.3 9%**	**4.5 13%**	**3.0 12%**	**0.0 /**	**0.3 11%**	**0.3 11%**	**0.5 23%**	**0.0 0%**	**0.0 0%**
Global total	25.3	21.8	18.2	20.0	18.7	15.7	35.83	25.3	0.0	3.2	3.0	2.2	2.3	0.3

Manternach 2018	FLO							HAR						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Annual and Biannual dicotyledonous														
Anagalis arvensis	0.7 0%	0.0 /	0.5 1%	0.5 1%	1.3 2%	0.7 1%	0.2 0%	2.0 2%	0.0 /	1.8 2%	0.3 1%	0.7 1%	0.0 0%	0.7 1%
Camelina sativa	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	13.8 17%
Capsella bursa-pastoris	10.7 8%	0.0 /	2.2 3%	1.5 2%	0.5 1%	2.3 3%	1.8 4%	0.2 0%	0.0 /	0.5 1%	0.8 2%	0.8 1%	0.5 1%	0.3 0%
Chenopodium album	5.3 4%	0.0 /	1.7 3%	3.0 4%	0.7 1%	0.8 1%	1.3 3%	5.2 5%	0.0 /	1.8 2%	3.0 5%	1.3 2%	0.8 2%	1.2 1%
Fumaria officinalis	1.2 1%	0.0 /	1.7 3%	0.0 0%	0.2 0%	0.7 1%	0.3 1%	0.2 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Glycine max	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0 /	0.5 1%	0.0 0%	0.2 0%	1.3 3%	1.8 2%
Lamium amplexicaule	5.0 4%	0.0 /	0.7 1%	1.3 2%	1.2 2%	1.0 1%	1.5 3%	1.5 1%	0.0 /	2.7 3%	0.5 1%	0.7 1%	0.7 1%	2.0 2%
Tripleurospermum inodorum	1.5 1%	0.0 /	0.2 0%	1.2 2%	0.7 1%	0.2 0%	0.8 2%	0.5 0%	0.0 /	0.0 0%	0.3 1%	1.3 2%	0.2 0%	0.0 0%
Myosotis arvensis	0.2 0%	0.0 /	0.5 1%	5.5 8%	1.3 2%	0.3 0%	0.8 2%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0 0%
Papaver rhoeas	0.2 0%	0.0 /	0.2 0%	0.3 0%	0.0 0%	0.2 0%	0.3 1%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Polygonum aviculare	0.0 0%	0.0 /	0.0 0%	0.2 0%	0.0 0%	1.5 2%	0.0 0%	1.2 1%	0.0 /	1.7 2%	0.8 2%	0.3 1%	3.0 6%	1.5 2%
Stellaria media	2.5 2%	0.0 /	2.2 3%	1.5 2%	4.5 7%	2.8 4%	1.7 4%	0.2 0%	0.0 /	0.7 1%	0.0 0%	1.7 3%	0.7 1%	0.5 1%
Thlaspi arvense	10.0 7%	0.0 /	17.0 27%	26.7 37%	29.8 45%	25.8 37%	20.8 44%	4.2 4%	0.0 /	4.2 5%	0.5 1%	0.0 0%	0.0 0%	0.0 0%
Trifolium Spec.	1.3 1%	0.0 /	0.7 1%	1.8 3%	0.8 1%	0.5 1%	0.0 0%	0.0 0%	0.0 /	0.5 1%	0.2 0%	1.5 2%	0.3 1%	0.3 0%
Unidentified	0.2 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.2 0%	4.8 4%	0.0 /	3.5 4%	0.0 0%	1.8 3%	1.5 3%	1.5 2%
Veronica agrestis	2.7 2%	0.0 /	1.7 3%	0.7 1%	2.0 3%	2.0 3%	2.5 5%	0.3 0%	0.0 /	0.3 0%	1.8 3%	2.2 3%	0.7 1%	0.0 0%
Vicia Spec.	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.7 1%	0.0 0%	0.0 0%	0.0 0%
Total	**41.3 30%**	**0.0 /**	**29.0 46%**	**44.2 61%**	**43.0 65%**	**39.0 56%**	**32.3 68%**	**20.3 19%**	**0.0 /**	**18.2 22%**	**9.0 16%**	**12.5 20%**	**9.8 21%**	**23.7 29%**
Perennial dicotyledonous														
Cirsium arvense	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%
Plantago major	4.8 4%	0.0 /	3.7 6%	1.0 1%	2.0 3%	3.5 5%	0.5 1%	14.0 13%	0.0 /	23.7 29%	28.5 51%	31.0 49%	19.3 42%	37.0 45%
Polygonum convolvulus	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0	0.3 0%	0.0 0%	0.0 0%	0.3 1%	0.0 0%
Ranunculus repens	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.5 1%	0.0 0%	0.0 0%
Rumex obtusifolius	1.0 1%	0.0 /	0.0 0%	0.0 0%	0.2 0%	0.8 1%	0.0 0%	1.2 1%	0.0 /	0.2 0%	0.2 0%	0.7 1%	1.2 3%	0.3 0%
Total	**5.8 4%**	**0.0 /**	**3.7 6%**	**1.0 1%**	**2.2 3%**	**4.3 6%**	**0.5 1%**	**15.3 14%**	**0.0 /**	**24.3 29%**	**28.7 52%**	**32.2 50%**	**20.8 45%**	**37.5 46%**
Monocotyledonous														
Elymus repens	53.3 39%	0.0 /	16.8 27%	10.8 15%	9.0 14%	5.3 8%	7.8 16%	0.7 1%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%
Phleum pratense	0.7 0%	0.0	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Poa annua	35.8 26%	0.0 /	13.5 21%	15.8 22%	11.8 18%	21.2 30%	6.8 14%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Poaceae	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	72.8 67%	0.0 /	40.2 49%	17.8 32%	19.2 30%	15.8 34%	20.7 25%
Total	**89.8 66%**	**0.0 /**	**30.5 48%**	**26.7 37%**	**20.8 32%**	**26.5 38%**	**14.7 31%**	**73.5 67%**	**0.0 /**	**40.2 49%**	**17.8 32%**	**19.2 30%**	**15.8 34%**	**20.8 25%**
Global total	137.0	0.0	63.2	71.8	66.0	69.8	47.50	109.2	0.0	82.7	55.5	63.8	46.5	82.0

Table 43: Mean number of weed individuals (number m^{-2}) per weed species for each ecological group for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for Manternach 2019. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group.

Manternach 2019	BWC													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Amaranthus retroflexus	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anagallis arvensis	0.0	0%	0.2	0%	3.7	4%	14.2	12%	0.2	0%	1.7	2%	2.5	3%
Camelina sativa	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.5	1%
Chenopodium album	10.3	9%	7.5	6%	4.5	5%	4.3	4%	3.5	4%	7.8	7%	6.5	7%
Euphorbia cyparissias	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Fumaria officinalis	0.2	0%	0.0	0%	0.2	0%	1.8	2%	0.2	0%	0.3	0%	0.3	0%
Geranium rotundifolium	0.5	0%	0.5	0%	0.3	0%	0.3	0%	1.0	1%	0.5	0%	0.0	0%
Glycine max	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Lamium amplexicaule	55.7	46%	40.5	34%	33.5	37%	35.8	30%	26.2	33%	30.7	28%	30.8	32%
Myosotis arvensis	3.5	3%	7.2	6%	4.2	5%	6.7	6%	2.8	4%	7.2	6%	7.0	7%
Papaver rhoeas	0.2	0%	0.2	0%	0.0	0%	0.0	0%	0.2	0%	0.2	0%	0.7	1%
Persicaria lapathifolia	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Phacilia tanacetefolia	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Polygonum aviculare	1.2	1%	0.3	0%	1.0	1%	1.5	1%	0.3	0%	1.8	2%	0.7	1%
Raphanus raphanistrum	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Senecio Vulgaris	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	6.2	5%	0.2	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%
Solanum nigrum	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.3	0%	0.2	0%	0.0	0%
Stellaria media	5.3	4%	8.0	7%	3.7	4%	6.3	5%	4.3	5%	7.8	7%	7.0	7%
Trifolium Spec.	0.2	0%	0.0	0%	0.2	0%	0.2	0%	0.2	0%	0.5	0%	0.0	0%
Tripleurospermum inodorum	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.2	0%	0.0	0%
Unidentified	0.5	0%	0.2	0%	0.0	0%	0.7	1%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	26.3	22%	26.0	22%	29.3	33%	35.5	30%	25.2	32%	37.5	34%	18.3	19%
Vicia Spec.	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Viola arvensis	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**110.5**	**92%**	**91.0**	**76%**	**81.0**	**90%**	**107.5**	**90%**	**65.0**	**82%**	**96.3**	**87%**	**74.5**	**78%**
Perennial dicotyledonous														
Cirsium arvense	2.8	2%	16.2	14%	2.7	3%	0.3	0%	0.7	1%	0.7	1%	1.7	2%
Plantago major	0.0	0%	0.8	1%	0.3	0%	3.7	3%	1.7	2%	1.5	1%	0.5	1%
Polygonum convolvulus	4.5	4%	4.3	4%	2.8	3%	3.7	3%	7.5	9%	3.2	3%	8.2	9%
Ranunculus repens	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Sonchus arvensis	0.0	0%	0.0	0%	0.0	0%	2.0	2%	1.2	1%	1.7	2%	0.0	0%
Total	**7.3**	**6%**	**21.3**	**18%**	**5.8**	**6%**	**9.7**	**8%**	**11.2**	**14%**	**7.0**	**6%**	**10.3**	**11%**
Monocotyledonous														
Lolium perenne	1.2	1%	2.2	2%	2.3	3%	0.3	0%	0.3	0%	0.3	0%	9.2	10%
Poaceae	0.8	1%	4.5	4%	0.8	1%	4.3	4%	4.3	5%	8.8	8%	1.7	2%
Total	**2.0**	**2%**	**6.7**	**6%**	**3.2**	**4%**	**4.7**	**4%**	**4.7**	**6%**	**9.2**	**8%**	**10.8**	**11%**
Global total	119.8		119.0		90.0		119.8		79.7		110.8		95.7	

Manternach 2019	AWC													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Amaranthus retroflexus	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anagallis arvensis	0.0	0%	0.0	/	6.2	12%	0.0	0%	0.2	1%	0.2	1%	3.0	7%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Chenopodium album	10.3	9%	0.0	/	1.8	4%	0.7	6%	0.2	1%	1.5	9%	4.5	11%
Euphorbia cyparissias	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Fumaria officinalis	0.2	0%	0.0	/	0.3	1%	0.0	0%	0.0	0%	0.0	0%	0.5	1%
Geranium rotundifolium	0.5	0%	0.0	/	0.2	0%	0.2	1%	0.2	1%	0.0	0%	0.0	0%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.2	1%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	55.7	46%	0.0	/	13.2	26%	4.3	39%	3.8	31%	4.8	29%	9.3	22%
Myosotis arvensis	3.5	3%	0.0	/	3.2	6%	0.0	0%	0.8	7%	1.3	8%	1.3	3%
Papaver rhoeas	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.5	1%
Persicaria lapathifolia	0.0	0%	0.0	/	0.3	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Phacilia tanacetefolia	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	1.2	1%	0.0	/	0.5	1%	0.7	6%	0.3	3%	0.5	3%	0.8	2%
Raphanus raphanistrum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Senecio Vulgaris	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	6.2	5%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Solanum nigrum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stellaria media	5.3	4%	0.0	/	2.2	4%	1.0	9%	0.7	5%	1.0	6%	2.0	5%
Trifolium Spec.	0.2	0%	0.0	/	0.3	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Tripleurospermum inodorum	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Unidentified	0.5	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	26.3	22%	0.0	/	15.7	31%	2.2	19%	2.8	23%	3.3	20%	8.3	20%
Vicia Spec.	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.8	5%	0.0	0%
Viola arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**110.5**	**92%**	**0.0**	**/**	**43.8**	**87%**	**9.2**	**82%**	**9.0**	**72%**	**13.5**	**81%**	**30.5**	**71%**
Perennial dicotyledonous														
Cirsium arvense	2.8	2%	0.0	/	3.2	6%	0.0	0%	0.0	0%	0.2	1%	1.0	2%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum convolvulus	4.5	4%	0.0	/	1.8	4%	1.0	9%	3.2	25%	1.7	10%	5.3	13%
Ranunculus repens	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sonchus arvensis	0.0	0%	0.0	/	0.0	0%	0.7	6%	0.0	0%	0.7	4%	0.0	0%
Total	**7.3**	**6%**	**0.0**	**/**	**5.0**	**10%**	**1.7**	**15%**	**3.2**	**25%**	**2.5**	**15%**	**6.3**	**15%**
Monocotyledonous														
Lolium perenne	1.2	1%	0.0	/	1.0	2%	0.0	0%	0.0	0%	0.0	0%	4.8	11%
Poaceae	0.8	1%	0.0	/	0.8	2%	1.0	9%	0.3	3%	1.3	8%	1.0	2%
Total	**2.0**	**2%**	**0.0**	**/**	**1.8**	**4%**	**1.0**	**9%**	**0.3**	**3%**	**1.3**	**8%**	**5.8**	**14%**
Global total	119.8		0.0		50.7		11.2		12.5		16.7		42.7	

Manternach 2019	FLO													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Amaranthus retroflexus	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anagallis arvensis	0.0	0%	0.0	/	0.0	0%	0.3	2%	0.0	0%	0.2	1%	1.2	4%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.3	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Chenopodium album	9.8	14%	0.0	/	2.2	14%	0.2	1%	0.3	3%	0.7	5%	4.7	14%
Euphorbia cyparissias	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	1%
Fumaria officinalis	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.2	1%	0.3	1%
Geranium rotundifolium	0.3	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	15.2	22%	0.0	/	2.3	15%	2.7	17%	1.2	9%	1.7	13%	4.3	13%
Myosotis arvensis	6.0	9%	0.0	/	0.0	0%	0.2	1%	0.0	0%	0.3	3%	1.2	4%
Papaver rhoeas	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Persicaria lapathifolia	0.0	0%	0.0	/	0.5	3%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Phacilia tanacetefolia	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	2.2	3%	0.0	/	0.5	3%	0.5	3%	0.3	3%	0.3	3%	0.5	2%
Raphanus raphanistrum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Senecio Vulgaris	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Solanum nigrum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stellaria media	1.8	3%	0.0	/	0.5	3%	1.2	8%	0.7	5%	1.2	9%	2.7	8%
Trifolium Spec.	0.2	0%	0.0	/	0.2	1%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Tripleurospermum inodorum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Unidentified	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	20.8	31%	0.0	/	5.8	38%	2.2	14%	2.5	20%	4.3	35%	6.3	19%
Vicia Spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Viola arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	1%	0.0	0%	0.0	0%
Total	**57.3**	**84%**	**0.0**	**/**	**12.0**	**78%**	**7.2**	**46%**	**5.2**	**42%**	**8.8**	**71%**	**21.3**	**64%**
Perennial dicotyledonous														
Cirsium arvense	1.0	1%	0.0	/	1.0	7%	0.5	3%	0.8	7%	0.5	4%	0.7	2%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.3	3%	0.0	0%
Polygonum convolvulus	8.3	12%	0.0	/	2.3	15%	6.8	44%	6.2	50%	2.3	19%	6.8	21%
Ranunculus repens	0.3	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sonchus arvensis	0.3	0%	0.0	/	0.0	0%	0.8	5%	0.3	3%	1.3	11%	0.0	0%
Total	**10.0**	**15%**	**0.0**	**/**	**3.3**	**22%**	**8.2**	**53%**	**7.3**	**59%**	**4.5**	**36%**	**7.5**	**23%**
Monocotyledonous														
Lolium perenne	0.5	1%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	4.2	13%
Poaceae	0.5	1%	0.0	/	0.0	0%	1.0	6%	0.2	1%	0.5	4%	0.3	1%
Total	**1.0**	**1%**	**0.0**	**/**	**0.0**	**0%**	**1.0**	**6%**	**0.2**	**1%**	**0.5**	**4%**	**4.5**	**14%**
Global total	68.0		0.0		15.3		15.5		12.3		12.5		33.3	

Manternach 2019	HAR													
	1		2		3		4		5		6		7	
Annual and Biannual dicotyledonous														
Amaranthus retroflexus	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Anagallis arvensis	0.0	0%	0.0	/	0.3	2%	0.5	2%	0.3	1%	0.5	2%	1.5	4%
Camelina sativa	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Capsella bursa-pastoris	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Chenopodium album	10.0	19%	0.0	/	1.3	6%	1.2	4%	0.2	0%	1.0	4%	4.3	12%
Euphorbia cyparissias	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.2	0%
Fumaria officinalis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.8	3%	0.0	0%
Geranium rotundifolium	0.5	1%	0.0	/	0.8	4%	0.5	2%	2.2	5%	0.2	1%	0.0	0%
Glycine max	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Lamium amplexicaule	0.3	1%	0.0	/	3.2	14%	11.3	40%	15.5	39%	7.2	26%	3.5	10%
Myosotis arvensis	4.3	8%	0.0	/	0.0	0%	0.5	2%	0.2	0%	0.3	1%	0.8	2%
Papaver rhoeas	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.3	1%	0.0	0%	0.0	0%
Persicaria lapathifolia	0.0	0%	0.0	/	0.3	2%	0.0	0%	0.0	0%	0.0	0%	0.3	1%
Phacilia tanacetefolia	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Polygonum aviculare	2.8	5%	0.0	/	1.2	5%	1.2	4%	0.2	0%	1.5	5%	1.2	3%
Raphanus raphanistrum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Senecio Vulgaris	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sinapis arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.2	0%	0.0	0%	0.0	0%
Solanum nigrum	0.2	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stellaria media	0.5	1%	0.0	/	0.8	4%	1.8	6%	0.3	1%	0.8	3%	0.8	2%
Trifolium Spec.	0.0	0%	0.0	/	0.5	2%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Tripleurospermum inodorum	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Unidentified	0.0	0%	0.0	/	0.0	0%	0.2	1%	0.0	0%	0.0	0%	0.0	0%
Veronica agrestis	28.3	53%	0.0	/	7.5	34%	5.0	18%	8.7	22%	7.5	27%	10.2	28%
Vicia Spec.	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Viola arvensis	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Total	**47.5**	**90%**	**0.0**	**/**	**16.0**	**72%**	**22.2**	**78%**	**28.0**	**71%**	**19.8**	**73%**	**22.8**	**63%**
Perennial dicotyledonous														
Cirsium arvense	1.7	3%	0.0	/	3.8	17%	0.5	2%	2.0	5%	0.3	1%	0.5	1%
Plantago major	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.5	2%	0.0	0%
Polygonum convolvulus	2.3	4%	0.0	/	2.2	10%	4.8	17%	9.7	24%	6.5	24%	9.0	25%
Ranunculus repens	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Rumex obtusifolius	0.0	0%	0.0	/	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Sonchus arvensis	0.0	0%	0.0	/	0.0	0%	0.2	1%	0.2	0%	0.8	3%	0.0	0%
Total	**4.0**	**8%**	**0.0**	**/**	**6.0**	**27%**	**5.5**	**19%**	**11.8**	**30%**	**8.2**	**30%**	**9.5**	**26%**
Monocotyledonous														
Lolium perenne	0.7	1%	0.0	/	0.2	1%	0.0	0%	0.0	0%	0.0	0%	3.5	10%
Poaceae	0.8	2%	0.0	/	0.0	0%	0.8	3%	0.0	0%	0.2	1%	0.3	1%
Total	**1.5**	**3%**	**0.0**	**/**	**0.2**	**1%**	**0.8**	**3%**	**0.0**	**0%**	**0.2**	**1%**	**3.8**	**11%**
Global total	53.0		0.0		22.2		28.3		39.7		27.3		36.2	

Table 44: Mean number of weed individuals (number m-2) per weed species for each ecological group for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for Sprinkange 2018. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group.

Sprinkange 2018	BWC							AWC						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Brassicaceae	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Capsella bursa-pastoris	0.5 1%	1.7 1%	1.8 1%	1.7 1%	2.3 2%	0.3 0%	1.7 1%	0.5 1%	0.0 /	1.8 1%	0.0 0%	0.2 1%	0.0 0%	0.3 0%
Chenopodium album	0.2 0%	0.5 0%	0.2 0%	0.5 0%	0.2 0%	0.2 0%	1.0 1%	0.2 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.5 0%
Fumaria officinalis	0.0 0%	0.0 0%	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Galium aparine	0.2 0%	0.5 0%	0.2 0%	0.5 0%	0.0 0%	0.5 0%	0.2 0%	0.2 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.2 1%	0.2 0%
Lactuca serriola	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Lamium amplexicaule	26.2 29%	33.2 28%	34.2 26%	20.2 17%	24.0 22%	24.2 16%	36.3 21%	26.2 29%	0.0 /	34.2 26%	4.0 13%	7.2 28%	4.2 15%	31.5 29%
Myosotis arvensis	3.3 4%	4.8 4%	2.3 2%	2.5 2%	2.7 2%	2.3 2%	2.5 1%	3.3 4%	0.0 /	2.3 2%	0.0 0%	0.0 0%	0.2 1%	1.7 2%
Papaver rhoeas	0.5 1%	0.0 0%	1.2 1%	0.3 0%	0.0 0%	0.2 0%	0.3 0%	0.5 1%	0.0 /	1.2 1%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Persicaria lapathifolia	0.7 1%	0.3 0%	0.7 1%	0.2 0%	1.3 1%	1.0 1%	0.7 0%	0.7 1%	0.0 /	0.7 1%	0.0 0%	0.5 2%	0.5 2%	0.8 1%
Polygonum aviculare	2.3 3%	1.8 2%	0.7 1%	1.7 1%	3.3 3%	1.7 1%	1.5 1%	2.3 3%	0.0 /	0.7 1%	0.0 0%	0.2 1%	0.2 1%	0.7 1%
Sinapis arvensis	4.0 4%	4.0 3%	4.8 4%	8.0 7%	5.7 5%	10.3 7%	5.8 3%	4.0 4%	0.0 /	4.8 4%	0.0 0%	2.3 9%	2.7 10%	5.2 5%
Stellaria media	21.8 24%	35.3 29%	50.3 38%	30.7 26%	24.8 23%	49.0 32%	59.7 35%	21.8 24%	0.0 /	50.3 38%	18.0 57%	8.8 35%	9.2 33%	32.3 30%
Thlaspi arvense	0.5 1%	0.0 0%	0.3 0%	0.5 0%	0.0 0%	0.0 0%	0.0 0%	0.5 1%	0.0 /	0.3 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Trifolium Spec.	0.2 0%	0.3 0%	0.3 0%	0.3 0%	0.2 0%	0.0 0%	0.5 0%	0.2 0%	0.0 /	0.3 0%	0.0 0%	0.0 0%	0.0 0%	0.3 0%
Tripleurospermum inodorum	10.0 11%	9.7 8%	10.8 8%	11.8 10%	9.7 9%	7.5 5%	20.2 12%	10.0 11%	0.0 /	10.8 8%	4.0 13%	0.7 3%	0.7 2%	12.8 12%
Unidentified	1.2 1%	0.5 0%	0.0 0%	0.3 0%	0.0 0%	0.2 0%	1.5 1%	1.2 1%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Veronica agrestis	7.3 8%	9.0 8%	7.0 5%	11.2 9%	8.7 8%	23.7 15%	19.8 12%	7.3 8%	0.0 /	7.0 5%	0.0 0%	0.2 1%	3.5 13%	5.0 5%
Vicia Spec.	0.0 0%	0.3 0%	0.0 0%	3.0 3%	1.2 1%	0.2 0%	0.3 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%
Viola arvensis	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Total	**78.8 86%**	**102.0 85%**	**115.0 88%**	**93.3 78%**	**84.0 79%**	**121.2 79%**	**152.0 88%**	**78.8 86%**	**0.0 /**	**115.0 87%**	**26.0 83%**	**20.0 78%**	**21.2 76%**	**91.5 85%**
Perennial dicotyledonous														
Calystegia sepium	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Cirsium arvense	0.3 0%	0.8 1%	0.8 1%	0.8 1%	0.5 0%	0.3 0%	0.0 0%	0.3 0%	0.0 /	0.8 1%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Cirsum oleraceum	0.3 0%	0.2 0%	0.0 0%	0.0 0%	0.7 1%	0.0 0%	0.2 0%	0.3 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	1.0 1%
Galium verum	0.2 0%	0.2 0%	0.3 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%	0.0 /	0.3 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Plantago major	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.3 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%
Polygonum convolvulus	2.8 3%	2.2 2%	2.3 2%	1.5 1%	1.7 2%	4.5 3%	2.2 1%	2.8 3%	0.0 /	2.3 2%	0.7 2%	0.7 3%	0.3 1%	1.0 1%
Ranunculus repens	0.7 1%	0.0 0%	0.2 0%	0.3 0%	0.2 0%	0.2 0%	0.2 0%	0.7 1%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.2 0%
Rumex obtusifolius	2.7 3%	3.5 3%	3.8 3%	9.2 8%	5.5 5%	5.7 4%	2.8 2%	2.7 3%	0.0 /	3.8 3%	0.3 1%	0.7 3%	0.8 3%	1.8 2%
Taraxacum sect. Ruderalia	0.0 0%	0.0 0%	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Total	**7.2 8%**	**6.8 6%**	**7.7 6%**	**11.8 10%**	**8.5 8%**	**10.7 7%**	**5.7 3%**	**7.2 8%**	**0.0 /**	**7.7 6%**	**1.0 3%**	**1.3 5%**	**1.2 4%**	**4.2 4%**
Monocotyledonous														
Avena sativa	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Poaceae	5.5 6%	11.0 9%	8.7 7%	14.5 12%	14.5 14%	21.3 14%	14.7 9%	5.5 6%	0.0 /	9.5 7%	4.3 14%	4.2 16%	5.7 20%	12.3 11%
Total	**5.5 6%**	**11.0 9%**	**8.7 7%**	**14.5 12%**	**14.5 14%**	**21.3 14%**	**14.7 9%**	**5.5 6%**	**0.0 /**	**9.5 7%**	**4.3 14%**	**4.2 16%**	**5.7 20%**	**12.3 11%**
Global total	91.5	119.8	131.3	119.7	107.0	153.2	172.3	91.5	0.0	132.2	31.3	25.5	28.0	108.0

Sprinkange 2018	FLO							HAR						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Annual and Biannual dicotyledonous														
Anagallis arvensis	0.0 0%	0.0 /	0.4 0%	0.2 0%	0.0 0%	0.5 1%	0.7 1%	0.2 0%	0.0 /	1.3 1%	0.0 0%	0.0 0%	0.0 0%	0.5 0%
Brassicaceae	0.2 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Capsella bursa-pastoris	1.2 1%	0.0 /	4.2 4%	0.7 2%	0.5 1%	0.0 0%	0.5 1%	1.2 2%	0.0 /	1.2 1%	0.2 0%	0.0 0%	0.2 0%	0.2 0%
Chenopodium album	0.2 0%	0.0 /	0.5 0%	0.3 1%	0.0 0%	0.0 0%	1.0 1%	0.3 0%	0.0 /	0.0 0%	0.2 0%	0.0 0%	0.2 0%	0.5 0%
Fumaria officinalis	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Galium aparine	0.7 1%	0.0 /	0.4 0%	0.2 0%	0.0 0%	0.5 1%	0.5 1%	0.0 0%	0.0 /	0.0 0%	0.2 0%	0.0 0%	0.0 0%	0.0 0%
Lactuca serriola	0.2 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Lamium amplexicaule	7.5 9%	0.0 /	15.3 13%	5.5 14%	1.8 5%	3.2 9%	6.3 6%	0.2 0%	0.0 /	0.2 0%	2.0 5%	0.5 1%	0.3 1%	0.0 0%
Myosotis arvensis	1.7 2%	0.0 /	2.9 3%	0.8 2%	0.3 1%	0.0 0%	0.8 1%	1.3 2%	0.0 /	0.8 1%	0.7 2%	0.0 0%	0.0 0%	1.8 2%
Papaver rhoeas	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Persicaria lapathifolia	1.3 2%	0.0 /	2.0 2%	0.0 0%	0.7 2%	0.8 2%	1.8 2%	0.5 1%	0.0 /	1.5 2%	0.2 0%	0.7 2%	1.0 2%	1.5 1%
Polygonum aviculare	1.0 1%	0.0 /	0.9 1%	0.5 1%	0.3 1%	0.2 0%	1.7 2%	2.7 4%	0.0 /	2.0 2%	0.8 2%	1.0 3%	0.8 2%	2.5 2%
Sinapis arvensis	4.2 5%	0.0 /	4.5 4%	2.7 7%	2.2 6%	2.8 8%	6.8 7%	2.8 4%	0.0 /	2.2 2%	2.2 5%	1.7 5%	1.8 4%	4.3 4%
Stellaria media	20.3 25%	0.0 /	38.4 34%	15.2 38%	11.3 34%	10.7 31%	25.2 25%	7.0 9%	0.0 /	21.5 23%	14.2 32%	7.3 21%	9.2 20%	24.0 23%
Thlaspi arvense	0.2 0%	0.0 /	0.5 0%	0.3 1%	0.0 0%	0.2 0%	0.2 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Trifolium Spec.	1.5 2%	0.0 /	0.4 0%	0.3 1%	0.0 0%	0.0 0%	0.7 1%	2.0 3%	0.0 /	2.3 2%	0.5 1%	0.2 0%	0.2 0%	0.3 0%
Tripleurospermum inodorum	9.8 12%	0.0 /	13.6 12%	2.5 6%	1.7 5%	0.2 0%	16.7 17%	6.5 9%	0.0 /	10.7 11%	2.8 6%	1.2 3%	0.8 2%	13.3 13%
Unidentified	1.2 1%	0.0 /	0.5 0%	0.2 0%	0.0 0%	0.0 0%	0.5 1%	1.7 2%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	2.3 2%
Veronica agrestis	10.8 13%	0.0 /	9.1 8%	1.8 5%	5.7 17%	4.2 12%	13.5 14%	19.3 26%	0.0 /	18.0 19%	5.8 13%	7.0 20%	9.8 22%	21.8 21%
Vicia Spec.	0.2 0%	0.0 /	0.0 0%	0.2 0%	0.7 2%	0.3 1%	0.2 0%	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.7 2%	0.5 1%	0.5 0%
Viola arvensis	0.2 0%	0.0 /	0.2 0%	0.2 0%	0.0 0%	0.0 0%	0.3 0%	1.3 2%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.7 1%
Total	**62.2 76%**	**0.0 /**	**94.2 83%**	**31.5 78%**	**25.2 75%**	**23.5 68%**	**77.3 78%**	**47.0 64%**	**0.0 /**	**62.0 66%**	**29.7 68%**	**20.2 58%**	**24.8 55%**	**74.3 71%**
Perennial dicotyledonous														
Calystegia sepium	0.0 0%	0.0 /	0.5 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Cirsium arvense	0.8 1%	0.0 /	0.5 0%	0.0 0%	0.0 0%	0.0 0%	0.8 1%	0.5 1%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.3 0%
Cirsum oleraceum	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.3 0%
Galium verum	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Plantago major	5.3 7%	0.0 /	1.1 1%	0.5 1%	0.7 2%	0.5 1%	2.0 2%	10.0 14%	0.0 /	6.7 7%	0.5 1%	1.0 3%	0.8 2%	8.7 8%
Polygonum convolvulus	3.7 4%	0.0 /	2.4 2%	0.8 2%	0.8 2%	0.5 1%	3.0 3%	5.3 7%	0.0 /	7.2 8%	3.0 7%	1.7 5%	1.8 4%	3.2 3%
Ranunculus repens	0.7 1%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.3 0%	0.0 /	0.2 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Rumex obtusifolius	1.5 2%	0.0 /	2.2 2%	1.3 3%	1.3 4%	2.0 6%	3.0 3%	4.5 6%	0.0 /	4.7 5%	1.5 3%	1.7 5%	2.3 5%	3.5 3%
Taraxacum sect. Ruderalia	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%
Total	**12.0 15%**	**0.0 /**	**6.9 6%**	**2.7 7%**	**2.8 8%**	**3.0 9%**	**8.8 9%**	**20.7 28%**	**0.0 /**	**19.0 20%**	**5.0 11%**	**4.3 13%**	**5.0 11%**	**16.0 15%**
Monocotyledonous														
Avena sativa	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 0%	0.0 /	0.0 0%	0.0 0%	0.2 0%	0.0 0%	0.0 0%
Poaceae	7.7 9%	0.0 /	12.7 11%	6.5 16%	5.7 17%	8.3 24%	14.3 14%	7.7 10%	0.0 /	14.2 15%	9.0 21%	9.8 29%	15.3 34%	15.2 15%
Total	**7.7 9%**	**0.0 /**	**12.7 11%**	**6.5 16%**	**5.7 17%**	**8.3 24%**	**14.3 14%**	**7.7 10%**	**0.0 /**	**14.2 15%**	**9.0 21%**	**10.0 29%**	**15.3 34%**	**15.2 15%**
Global total	81.7	0.0	113.3	40.3	33.7	34.3	99.5	73.8	0.0	93.8	43.7	34.5	45.2	104.3

Table 45: Mean number of weed individuals (number m-2) per weed species for each ecological group for each treatment t.1neg (1), t.2pos (2), t.3har (3), t.4hoe (4), t.5hoe+ (5), t.6comb (6) and t.7mix (7), for Sprinkange 2019. Total number of individuals per ecological group and treatments are indicated, as well as, the abundancy (%) of each weed species and each ecological group. At FLO and HAR weeds have not been counted, only the species have been recorded (at FLO only the most abundant).

Sprinkange 2019	BWC												AWC					
	1		3		4		5		6		7		1	3	4	5	6	7
Annual and Biannual dicotyledonous																		
Amaranthus blitum	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.7	0%	1.7	0%	NA	NA	NA	NA	NA	NA
Anagallis arvensis	0.0	0%	1.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Atriplex L.	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Capsella bursa-pastoris	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.7	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Chenopodium album	1.0	0%	5.0	1%	0.3	0%	0.3	0%	2.0	0%	1.0	0%	NA	NA	NA	NA	NA	NA
Fumaria officinalis	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Galium aparine	0.3	0%	0.0	0%	1.0	0%	0.0	0%	0.0	0%	1.0	0%	NA	NA	NA	NA	NA	NA
Lactuca serriola	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.3	0%	NA	NA	NA	NA	NA	NA
Lamium amplexicaule	2.0	0%	3.7	1%	0.7	0%	3.7	1%	11.7	2%	7.3	2%	NA	NA	NA	NA	NA	NA
Myosotis arvensis	4.3	1%	0.0	0%	2.7	1%	0.7	0%	1.0	0%	0.7	0%	NA	NA	NA	NA	NA	NA
Papaver rhoeas	0.0	0%	0.3	0%	0.3	0%	0.3	0%	0.7	0%	0.3	0%	NA	NA	NA	NA	NA	NA
Persicaria lapathifolia	33.7	8%	32.3	8%	39.3	11%	59.7	17%	62.3	13%	39.7	8%	NA	NA	NA	NA	NA	NA
Polygonum aviculare	5.3	1%	0.0	0%	3.0	1%	1.7	0%	6.7	1%	1.7	0%	NA	NA	NA	NA	NA	NA
Sinapis arvensis	107.0	26%	78.7	21%	138.7	37%	20.7	6%	20.0	4%	20.0	4%	NA	NA	NA	NA	NA	NA
Stellaria media	13.7	3%	10.0	3%	8.3	2%	5.7	2%	12.7	3%	7.0	1%	NA	NA	NA	NA	NA	NA
Trifolium Spec.	8.3	2%	11.0	3%	11.0	3%	5.3	1%	5.0	1%	10.7	2%	NA	NA	NA	NA	NA	NA
Tripleurospermum inodorum	59.0	14%	101.3	27%	67.7	18%	82.0	23%	216.0	46%	214.7	44%	NA	NA	NA	NA	NA	NA
Veronica agrestis	16.0	4%	8.7	2%	4.0	1%	48.0	13%	33.3	7%	11.7	2%	NA	NA	NA	NA	NA	NA
Vicia Spec.	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Total	**250.7**	**61%**	**252.0**	**66%**	**277.0**	**74%**	**228.0**	**63%**	**372.7**	**79%**	**317.7**	**65%**						
Perennial dicotyledonous																		
Cirsium arvense	0.0	0%	0.0	0%	0.0	0%	0.0	0%	9.3	2%	0.0	0%	NA	NA	NA	NA	NA	NA
Plantago major	1.3	0%	0.7	0%	1.3	0%	0.7	0%	0.7	0%	1.0	0%	NA	NA	NA	NA	NA	NA
Polygonum convolvulus	8.3	2%	0.0	0%	3.0	1%	13.3	4%	3.3	1%	1.0	0%	NA	NA	NA	NA	NA	NA
Ranunculus repens	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	NA	NA	NA	NA	NA	NA
Rumex obtusifolius	1.3	0%	1.7	0%	2.3	1%	0.7	0%	0.7	0%	1.7	0%	NA	NA	NA	NA	NA	NA
Sonchus arvensis	1.3	0%	1.0	0%	0.7	0%	0.0	0%	3.0	1%	0.3	0%	NA	NA	NA	NA	NA	NA
Total	**12.3**	**3%**	**3.3**	**1%**	**7.3**	**2%**	**14.7**	**4%**	**17.0**	**4%**	**4.0**	**1%**						
Monocotyledonous																		
Poaceae	146.3	36%	128.0	33%	88.7	24%	118.7	33%	84.0	18%	166.7	34%	NA	NA	NA	NA	NA	NA
Total	**146.3**	**36%**	**128.0**	**33%**	**88.7**	**24%**	**118.7**	**33%**	**84.0**	**18%**	**166.7**	**34%**						
Global total	408.0		382.3		372.3		361.3		470.7		488.0							

Sprinkange 2019	FLO												HAR											
	1		3		4		5		6		7		1		3		4		5		6		7	
Annual and Biannual dicotyledonous																								
Amaranthus blitum																								
Anagallis arvensis													x								x			
Atriplex L.													x		x				X		x		x	
Capsella bursa-pastoris																								
Chenopodium album			x						x				x		x		x		X		x		x	
Fumaria officinalis																								
Galium aparine													x											
Lactuca serriola																			X					
Lamium amplexicaule							x										X		X		x			
Myosotis arvensis																								
Papaver rhoeas																								
Persicaria lapathifolia	x		x		x		x		x		x		x		x		X		X		x		x	
Polygonum aviculare													x		x		X		X		x		x	
Sinapis arvensis	x				x		x						x		x		X		X		x		x	
Stellaria media													x		x		X		X		x		x	
Trifolium Spec.													x		x		X		X		x		x	
Tripleurospermum inodorum	x		x		x		x		x		x		x		x		x		X		x		x	
Veronica agrestis													x		x		X		X		x		x	
Vicia Spec.													x						X					
Total	**3.0**	**75%**	**3.0**	**100%**	**3.0**	**100%**	**4.0**	**100%**	**3.0**	**100%**	**2.0**	**100%**	**12.0**	**71%**	**9.0**	**64%**	**9.0**	**60%**	**12.0**	**75%**	**11.0**	**69%**	**9.0**	**69%**
Perennial dicotyledonous																								
Cirsium arvense													x		x		X				x		x	
Plantago major													x		x		X		X		x		x	
Polygonum convolvulus													x		x		X		X		x			
Ranunculus repens																	X							
Rumex obtusifolius			x		x						x		x		x		X		X		x		x	
Sonchus arvensis	x		x		x				x															
Total	**1.0**	**25%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**4.0**	**24%**	**4.0**	**29%**	**5.0**	**33%**	**3.0**	**19%**	**4.0**	**25%**	**3.0**	**23%**
Monocotyledonous																								
Poaceae					x		x				x		x		x		X		X		x		x	
Total	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**0.0**	**0%**	**1.0**	**6%**	**1.0**	**7%**	**1.0**	**7%**	**1.0**	**6%**	**1.0**	**6%**	**1.0**	**8%**
Global total	4.0		3.0		3.0		4.0		3.0		2.0		17.0		14.0		15.0		16.0		16.0		13.0	

4.5.3 Shannon index

The Shannon index values express the abundance and evenness of the weed species and reflect the level of biodiversity. Shannon index maximum values reflect the theoretical value which could be reached when each species counts the same number of individuals. Equitability ratios show the distance between the Shannon index and its maximum. An equitability ratio of 1 indicates the complete evenness of species. Taking an example, in one treatment are 1 *Rumex*, 7 *Lamium* and 16 *Myosotis*, Shannon index is 0.8 for a Shannon maximum of 1.1 and an equitability of 0.6, this means that each species is not equally present: there are more *Lamium* than *Rumex* and more *Myosotis* than *Lamium*. In the case where are 10 *Rumex*, 10 *Lamium* and 10 *Myosotis*, Shannon index is 1.1 and equals Shannon index maximum (1.1) and equitability is 1.0, so that each species has the same number of individuals and is equally present.

For Hostert18 (see Figure 48), globally the Shannon index values and associated Shannon index maximum tended to decrease in time until HAR while, the equitability ratios remained stable. For BWC, Shannon index values were homogenous between treatments with a mean of 1.8 (Shannon index maximum: 2.4, Equitability: 0.7). For AWC, low diversity losses were observable for treatments $t.3_{har}$ to $t.7_{mix}$ which had a Shannon index ranging between 1.3 and 1.6, accompanied by a decrease of the Shannon index maximum ranging between 1.8 and 2.0 for these treatments while the equitability was not much affected. At FLO, while no more weed control has been performed, the diversity parameters reflected a small increase of their values (Shannon index: 1.5, Shannon index maximum: 2.1, Equitability: 0.7, on average). At HAR, the diversity of weeds was lower for all treatments than for BWC, AWC or FLO (Shannon index: 1.0, Shannon index maximum: 1.4, Equitability: 0.7).

For Manternach18 (see Figure 49), the diversity of weeds given by the Shannon index (1.2, Shannon index maximum: 1.3, Equitability: 0.8, on average) was homogenous between treatments for BWC. The discrepancy between the Shannon index and its theoretical maximum was very low for each treatment, illustrated by the high values of the equitability ratio. For AWC, all values are very low and close to zero for the Shannon index and maximum. Almost all weeds were destroyed by mechanical weeding. At FLO, while no more weed control was performed, weed communities have regrown. The Shannon index equals 1.3 in each treatment, except the positive control. The Shannon index maxima were higher than BWC and attained 2.1 in $t.1_{neg}$, for treatments $t.3_{har}$ to $t.7_{mix}$ it represented an average of 1.7. The equitability was lower than AWC but at the same level than BWC for each treatment. At HAR, the values of the diversity index tended to slightly decreased, also for the negative control. For $t.3_{har}$ to $t.7_{mix}$, the Shannon index varied between 1.0 and 1.2, the Shannon index maximum between 1.1 and 1.4 and the equitability ratio between 0.7 and 0.8.

For Sprinkange18 (see Figure 50), variations of the Shannon index during the assessment period were not big. Due to significant variations between treatments, the Shannon index were not homogenous for BWC even though the diversity varied between 1.7 and 1.9 (Shannon maximum: 2.2-

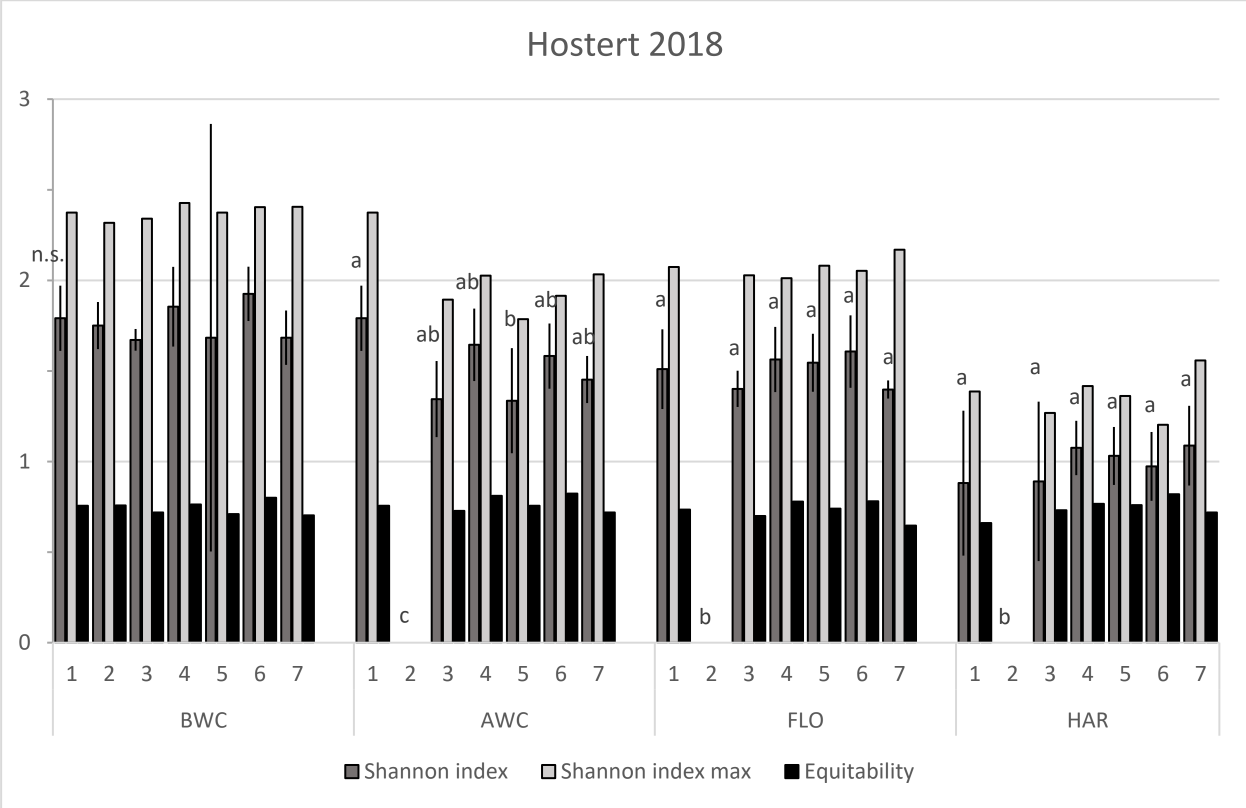
2.3, Equitability: 0.7-0.8). For AWC, the use of the hoe in treatments t.4_{hoe}, t.5_{hoe+} and t.6_{comb} significantly reduced the most the Shannon index (1.2-1.4) for a theoretical maximum of 1.4-1.5 and an equitability ratio of 0.9 on average. While no further weed controls were performed at FLO, the diversity of weeds increased. Treatments t.5_{hoe+} and t.6_{comb} kept having significant lower Shannon index (1.5 for each) than other treatments. At HAR, even though the Shannon index, maximum and equitability remained stable, the diversity was significantly lower in treatments t.4_{hoe} (1.6), t.5_{hoe+} (1.5) and t.6_{comb} (1.5).

For Hostert19 (see Figure 48), for BWC the diversity of weed was homogeneous for all treatments. It ranged between 1.0 and 1.6, the Shannon index maximum from 1.7 to 2.3 and the equitability ratio from 0.5 to 0.7. For AWC, the Shannon index decreased in particular for treatments t.4_{hoe} and t.6_{comb} with a Shannon index of 0.8 and 0.9 respectively and theoretical maximum of 1.0 and 1.1. The machines have also impacted the diversity by decreasing the Shannon index theoretical maxima. In comparison to AWC, at FLO, most of the Shannon index, and maximum were higher for all treatments. Only in treatment t.6_{comb} the diversity has lowered more. Its Shannon index was lower than others (0.8), as well as the Shannon index maximum (0.9) while, the equitability reached a ratio of 0.9. In treatment t.5_{hoe+}, a decrease of the Shannon index maximum, from 1.4 down to 1.2, was observable at FLO although the Shannon index remained stable (1.1). The probable loss of species has created a better distribution between remaining species therefore, the equitability ratio augmented from 0.7 to 0.9. At HAR, the lowest Shannon index is 0.8 for treatment t.6_{comb} (Shannon maximum: 0.8, Equitability: 0.9).

For Manternach19 (see Figure 49), for BWC, Shannon index values were homogenous for each treatment and reached a mean of 1.4. The Shannon index theoretical maximum was 1.9 on average, leading to an equitability ratio of 0.7. For AWC, the diversity has been reduced for weeded treatments, in particular for treatments t.4_{hoe}, t.5_{hoe+} and t.6_{comb}. In treatment t.5_{hoe+}, the Shannon index of 0.7 (Shannon maximum of 0.8 and Equitability of 0.9) is significantly lower than in other treatments. At FLO, after a second weeding run, Shannon index values of 0.8 and 0.6 in treatments t.3_{har} and t.5_{hoe+}, respectively, were significantly lower than in other treatments. For these treatments, the equitability has become higher and reached 0.9 while the theoretical maxim values were low (0.9 and 1.0 respectively. At HAR, there the diversity was homogenous across weeded treatments and the negative control (t.1_{neg}), which has a lower Shannon index than at FLO while other remained about at the same level than at FLO. The average Shannon index value equals 1.0, for a Shannon index maximum of 1.3 and an equitability ratio of 0.8.

For Sprinkange19 (see Figure 50), the calculation of the Shannon index was only possible for BWC. In all treatments the Shannon index was homogenous with, an average of 1.6. The Shannon index maximum attained 2.3 on average and the equitability ratio was of 0.7.

Globally, the effects of mechanical weed control performances are visible for AWC, FLO and until HAR, except in the case of Hostert18 and Manternach18. Mechanical runs contributed to a decrease of the diversity of weeds in the respective treatments. In most of the cases, lower diversity was present in hoed treatments than in harrowed ones, excepted in Manternach for both years the harrow in $t.3_{har}$ also reduced significantly the Shannon index. Shannon indexes and associated theoretical maximum were reduced, in comparison to the negative control. Nevertheless, the entire weed community was never eliminated, allowing some species to establish and grow. The lower the diversity was, higher the equitability between species was.



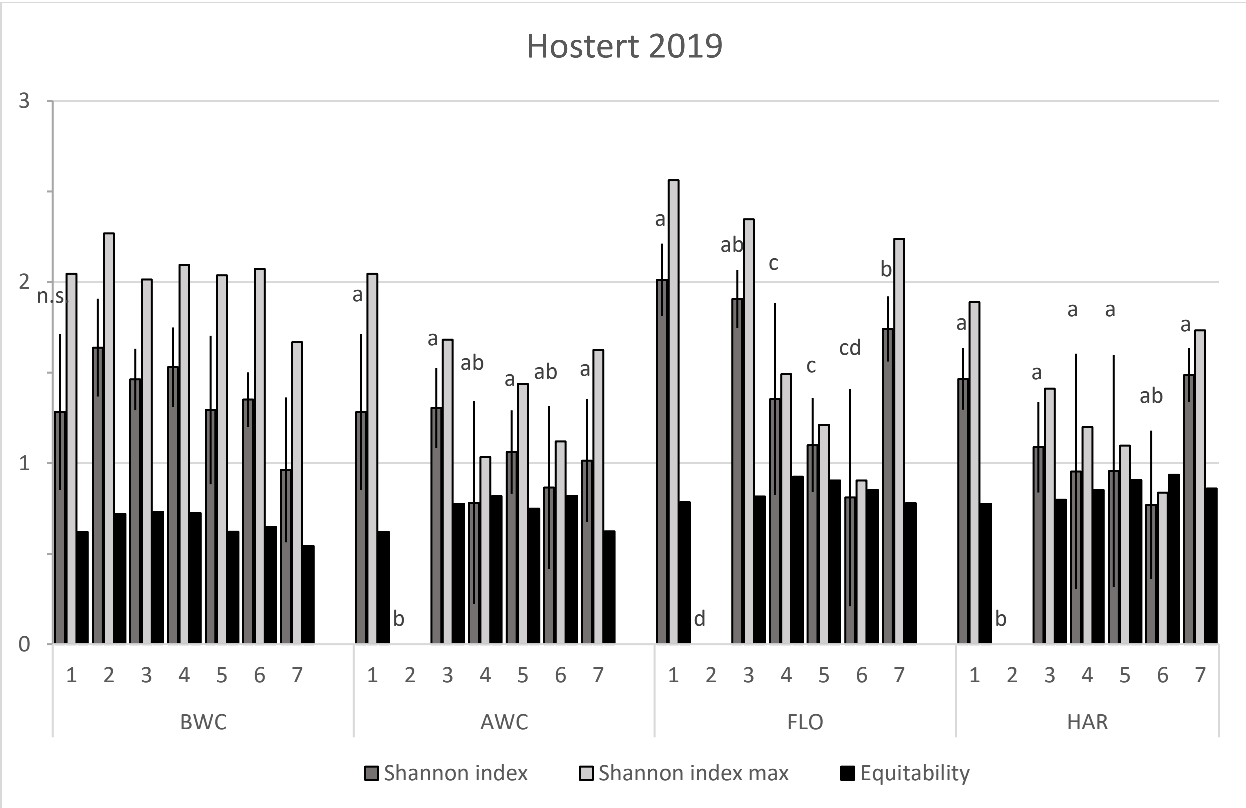


Figure 48: Average values of the Shannon index, the Shannon index theoretical maximum and the equitability ratio for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Hostert 2018 (on top) and Hostert 2019 (at the bottom). Bars indicate standard deviation of the Shannon index. Letters on top of the bars indicate significant variances between treatments at $p \leq 0.05$.

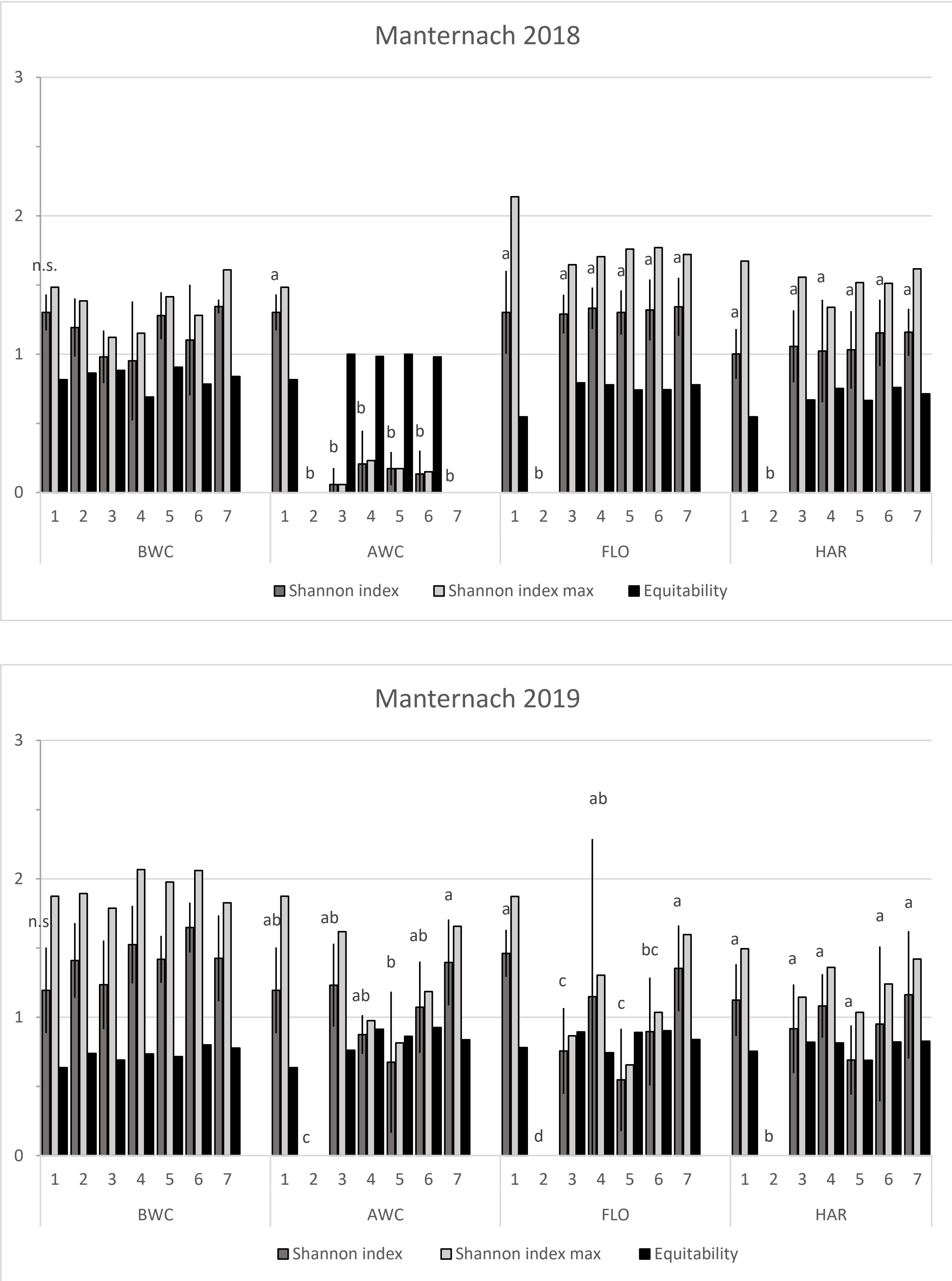
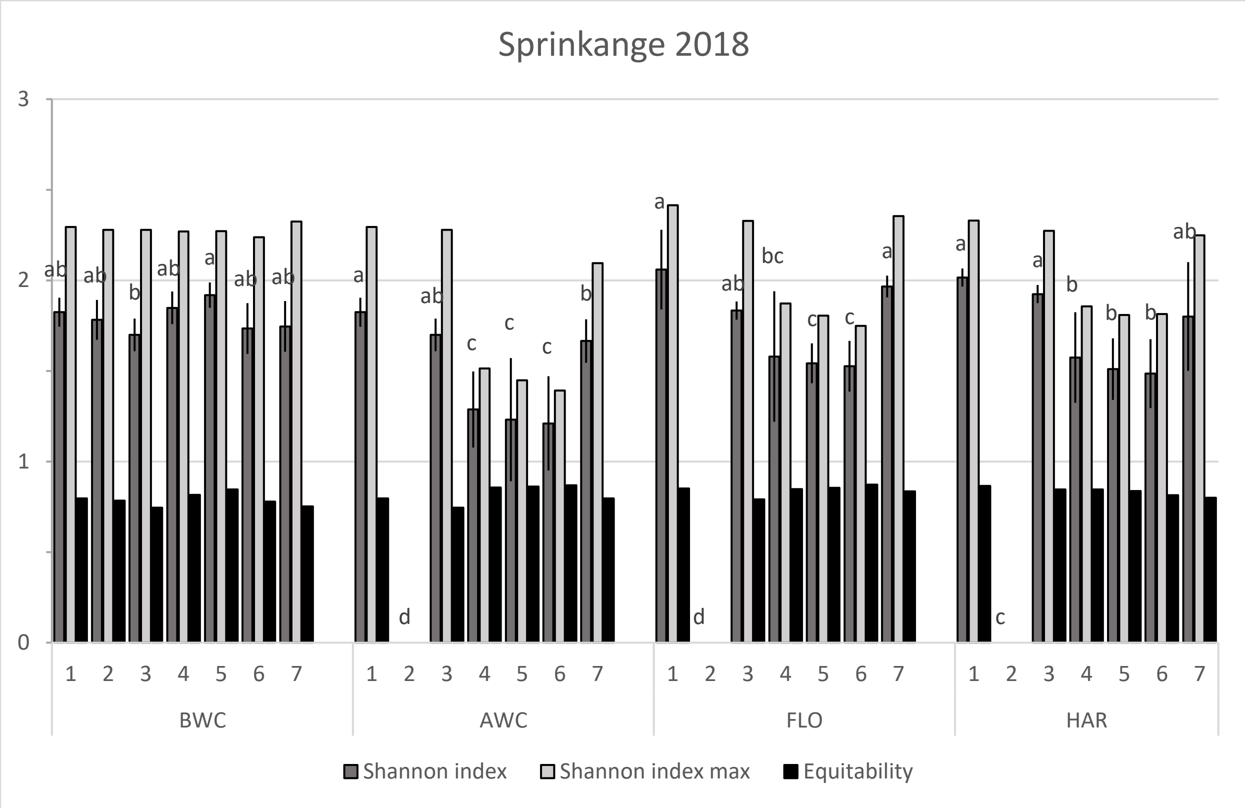


Figure 49: Average values of the Shannon index, the Shannon index theoretical maximum and the equitability ratio for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for BWC, AWC, FLO and HAR, for Manternach 2018 (on top) and Manternach 2019 (at the bottom). Bars indicate standard deviation of the Shannon index. Letters on top of the bars indicate significant variances between treatments at p≤0.05.



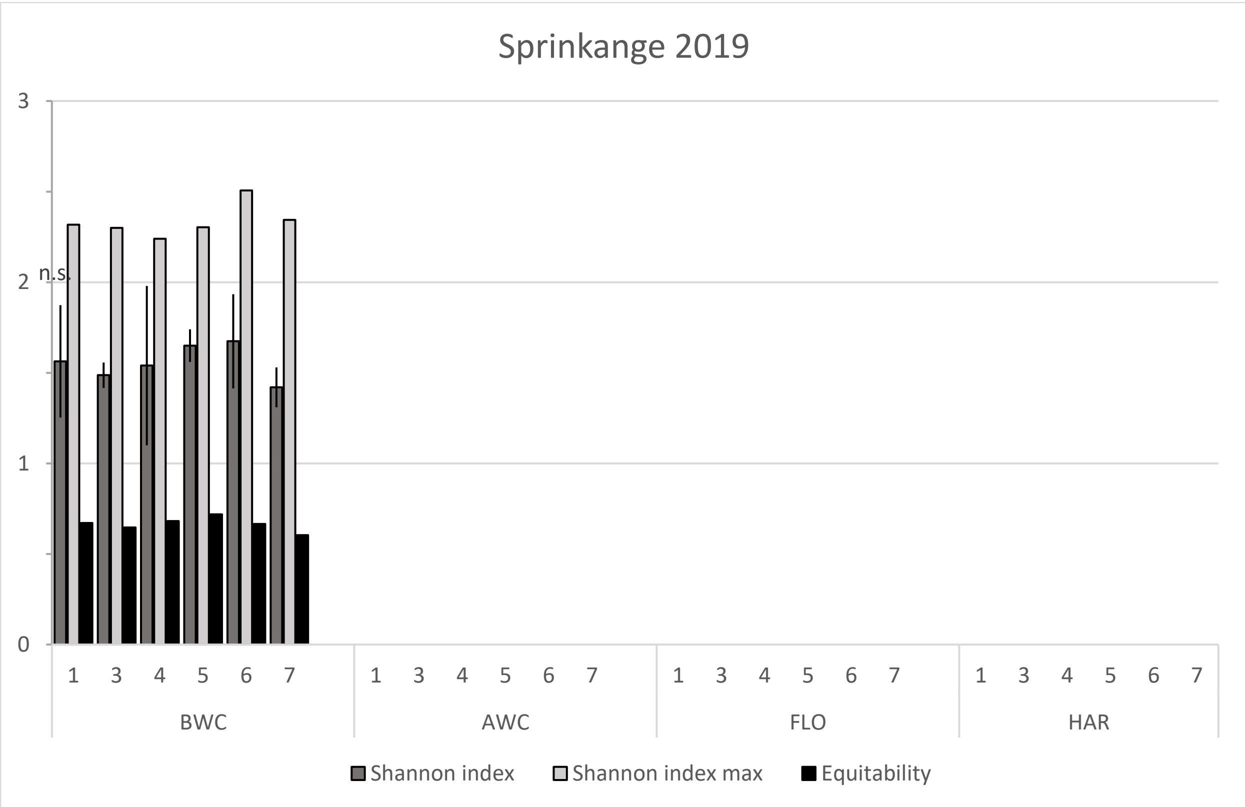


Figure 50: Average values of the Shannon index, the Shannon index theoretical maximum and the equitability ratio for each treatment t.1$_{neg}$ (1), t.2$_{pos}$ (2), t.3$_{har}$ (3), t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5), t.6$_{comb}$ (6) and t.7$_{mix}$ (7), for BWC, AWC, FLO and HAR, for Sprinkange 2018 (on top) and Sprinkange 2019 (at the bottom). Bars indicate standard deviation of the Shannon index. Letters on top of the bars indicate significant variances between treatments at p≤0.05.

4.6. Geospatial data analysis

4.6.1 Vegetations indices

For each site and date different Vegetation indices were derived from the multispectral data. An example is shown in Figure 51.

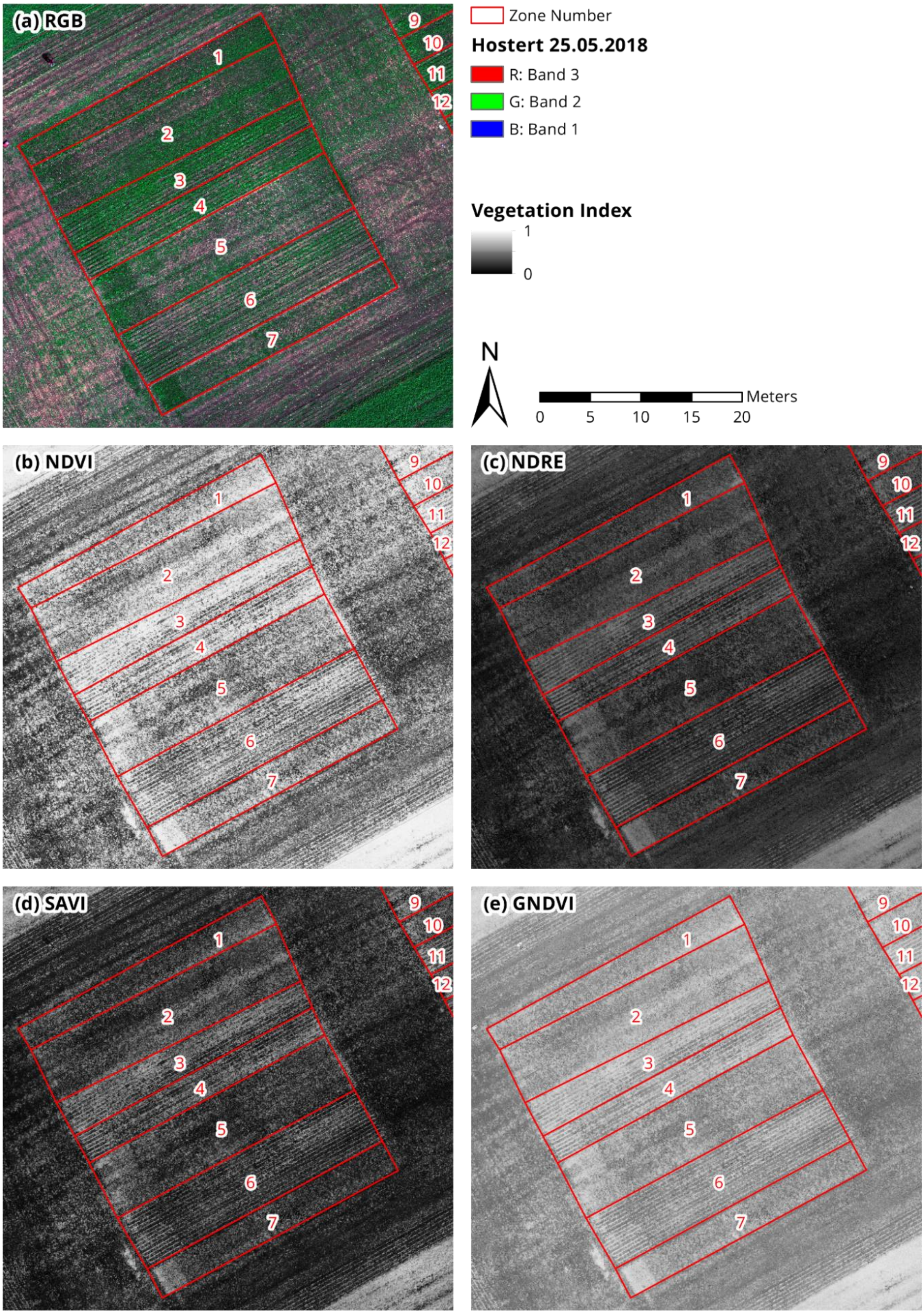


Figure 51: Vegetation Indices for Hostert (25.05.2018). (a) RGB Orthomosaic, (b) NDVI ,(c) NDRE, (d) SAVI,(e) GNDVI.

It is clearly noticeable that different indices provide different contrast and are more or less sensitive to spatial patterns. At first sight, NDVI is higher in contrast and that NDRE and SAVI present lower values in general.

4.6.2 Vegetation classification

Vegetation classification provides a high-resolution binary mask of vegetation and soil pixels. Considering these results on different dates provides information about canopy development (3.6.3). Figure 52 shows an exemplary plot of a vegetation classification. A visual comparison of the binary mask and the source high resolution RGB-orthophoto serves as validation

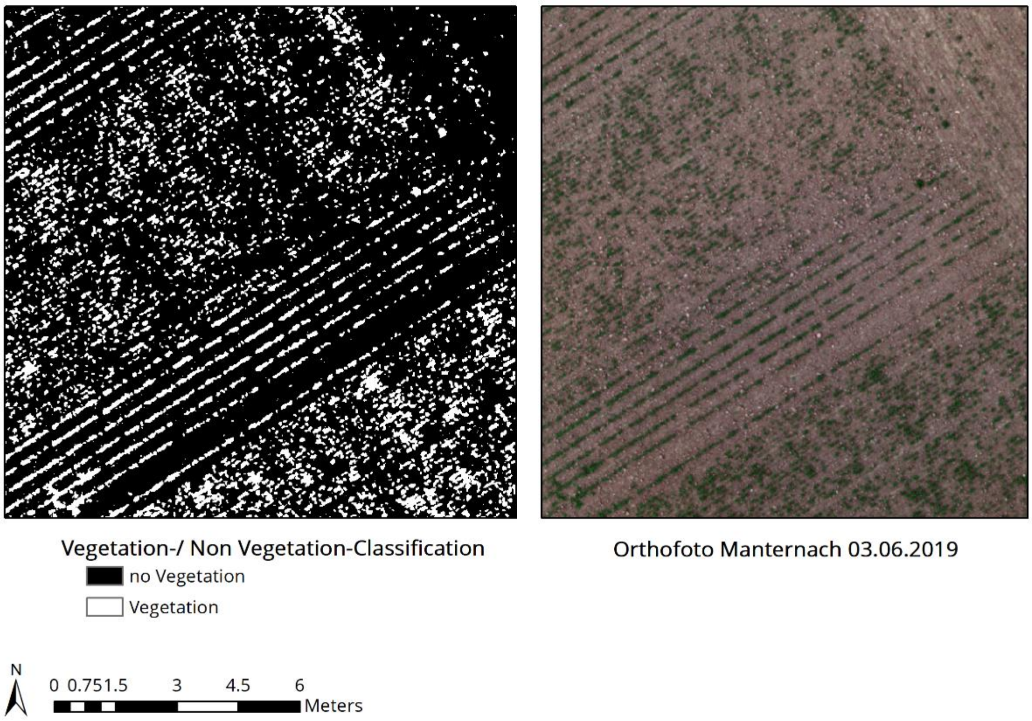


Figure 52: Vegetation classification of the site: Manternach on 03.06.2019.

4.6.3 Time series analysis

Besides the absolute parameters like plant height, vegetation cover or photosynthetic activity, the temporal signatures of vegetation indices of the soybean test plot are additional UAV-based datasets. These parameters often reveal relative patterns that can be correlated to temporal signatures of plant physiology.

Figure 53 and Figure 54 show vegetation cover time series for Manternach19 and Sprinkange18. In Manternach19, the image-based vegetation cover shows an increase from BWC to AWC as well as an increase from AWC to FLO. This is not exactly similar to the manually detected vegetation cover, where the BWC and AWC valuer are nearly identical.

In Sprinkange19, the image-based vegetation cover as well as the in-situ soybean cover, show an increase from AWC to FLO and a decrease from FLO to HAR. The absolute values for the image-based numbers are higher in general at AWC and FLO and partially higher at HAR.

The increase in vegetation cover from BWC over AWC to FLO correlates with the development of green leaves and a lateral growth of soybeans plants. The decrease in vegetation cover does not depict a geometric decrease of the plant size but is more an indication of senescent leaves.

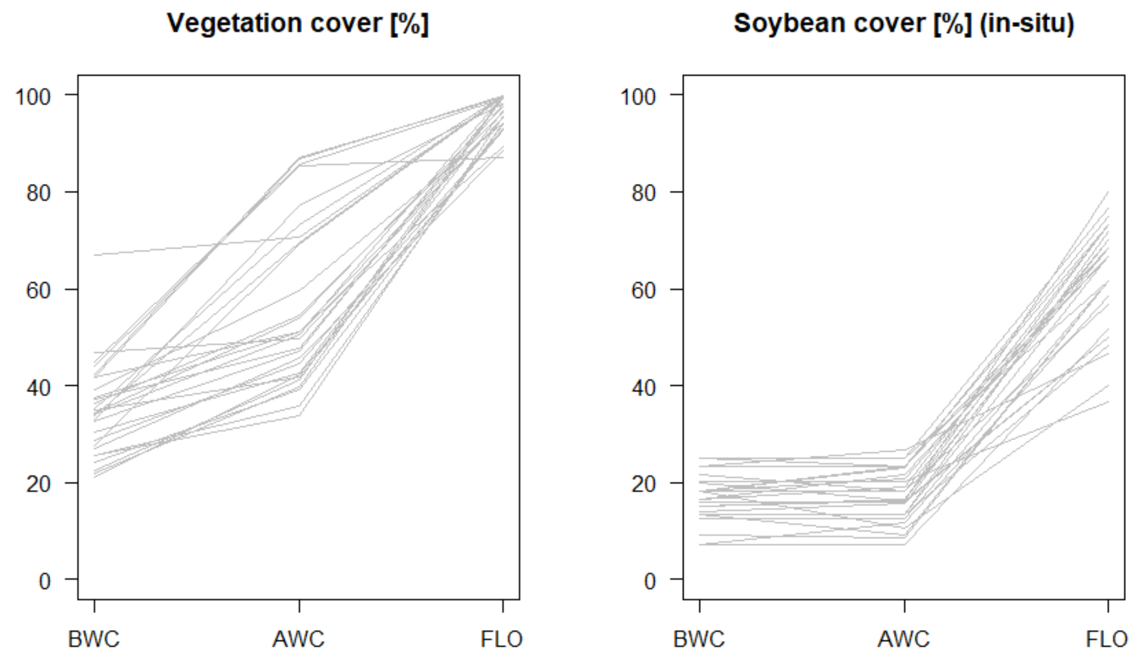


Figure 53: Vegetation cover in Manternach 2019. Left: Image based, Right: in-situ. (BWC=Before Weed Control, AWC=After Weed Control, FLO = Flowering).

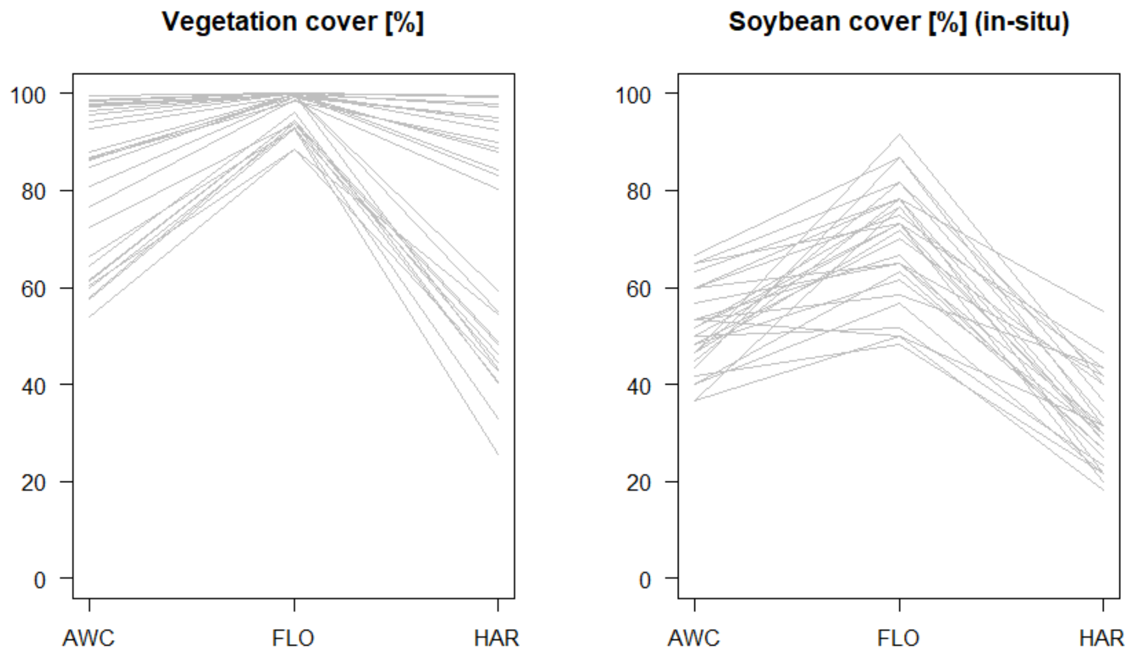


Figure 54: Vegetation cover in Sprinkange 2018. Left: Image based, Right: in-situ. (AWC=After Weed Control, FLO = Flowering, HAR = Harvest).

4.6.4 Supervised Classification

The supervised classifications RF and SVM show similar performances. Discrimination of vegetation and bare earth achieve Overall Accuracies (OA) of >92 % (see Table 46).

Table 46: Overall accuracies (OA) of supervised classifcations (Random Forest (RF); Support Vector Machine (SVM)).

Dataset	Classifier	OA [%]
Sprinkange 2018	RF	81.73
Sprinkange 2018	SVM	85.81
Sprinkange 2019	RF	92.45
Sprinkange 2019	SVM	92.13
Manternach 2018	RF	75.88
Manternach 2018	SVM	72.34
Manternach 2019	RF	89.13
Manternach 2019	SVM	88.74
Hostert 2018	RF	67.23
Hostert 2018	SVM	54.99
Hostert 2019	RF	88.67
Hostert 2019	SVM	78.08

A visual check of the classified images confirms these results. A discrimination of soybean and weeds is not possible because no training data was collected in the fields. A supervised classification was performed using training points from the image data. Here, only flowering weeds could be used (see Figure 55).

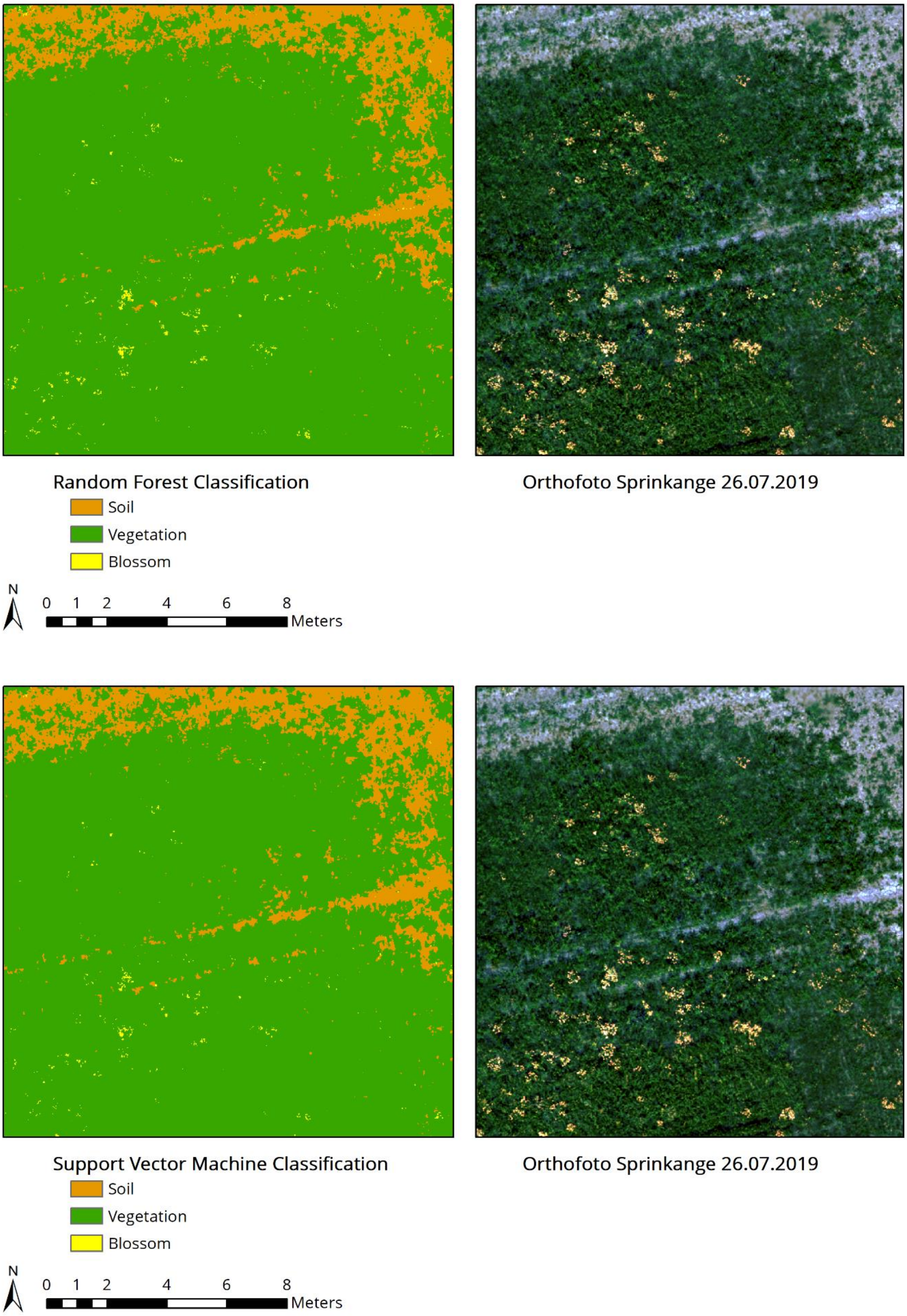


Figure 55: Comparison of Random Forest (top) and Support Vector Machine (bottom) classification in Sprinkange 2019.

4.6.5 Zonal statistics

Figure 56 and Figure 57 depict the vegetation cover for the site Hostert in the years 2018 and 2019. The vegetation density is derived by setting the number of vegetation pixel into relation to the non-vegetation (ground) pixel. Figure 58 and Figure 59 depict the vegetation cover for the site Manternach in the years 2018 and 2019. Figure 60 and Figure 61 depict the vegetation cove for the site Sprinkange in the years 2018 and 2019.

Special attention is needed for the differentiation between different treatments: The image-based canopy cover is directly linked to phenology which again is directly linked to seeding or plant densities (Amanullah et al., 2009). This only allows the comparison of canopy cover dataset from one date at one single site, because plant phenology is inconsistent due to differing environmental conditions and dates of data collection.

Although a statistical test is not permitted, spatial patterns can be recognized by visual control for early development stages (BWC and AWC).

Multiple patterns can optically be recognized (see Figure 52):

- Sowing pattern: due the interrow-spacing (narrow =12.5 cm or wide = 37.5 cm)
- Seeding errors: due to mechanical clogging within the seed drill
- Inhomogeneities: due to soil or terrain inhomogeneities and speed/acceleration inhomogeneities
- Weed occurances

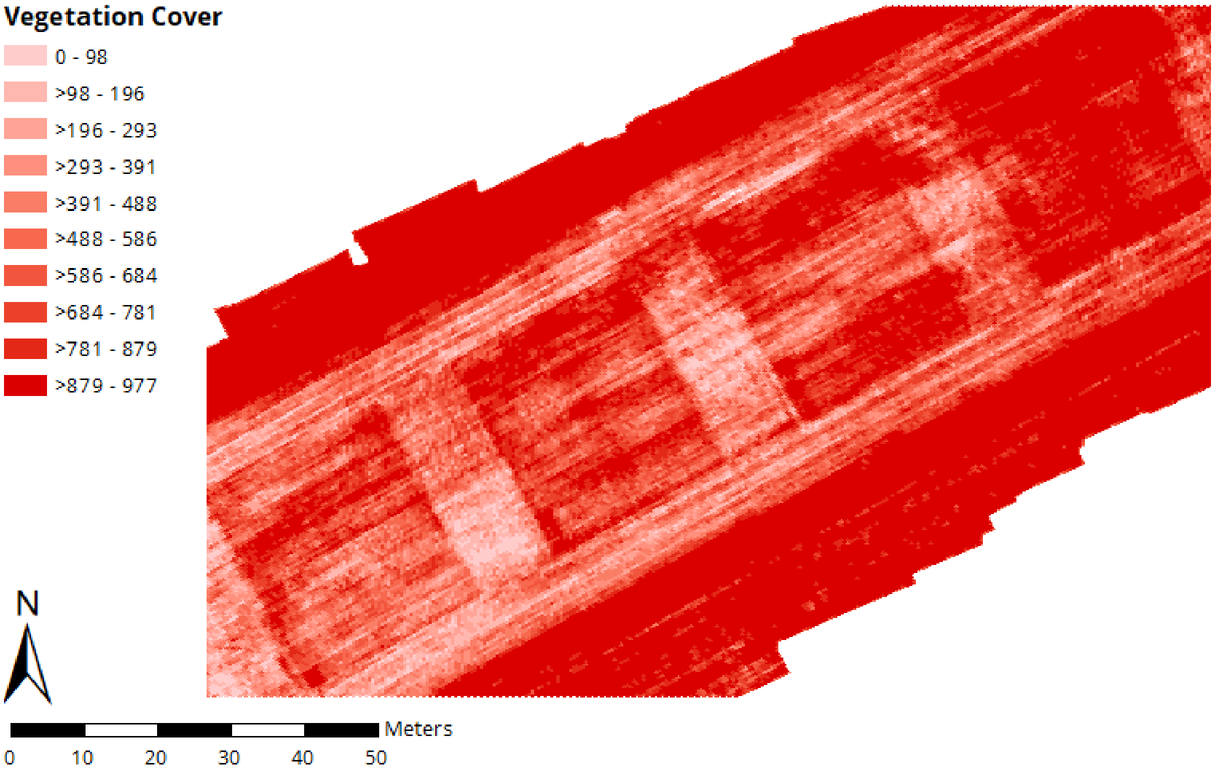


Figure 56: Zonal statistics for vegetation cover in Hostert (25.05.2018).

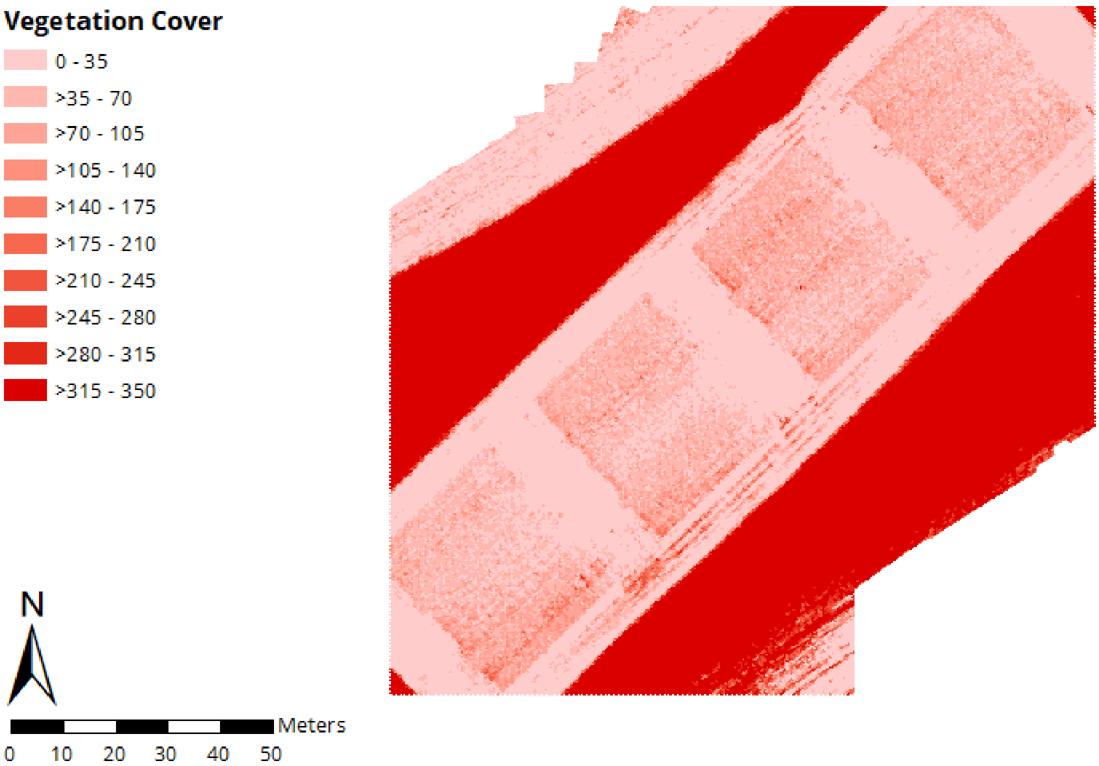


Figure 57: Zonal statistics for vegetation cover in Hostert (14.06.2019).

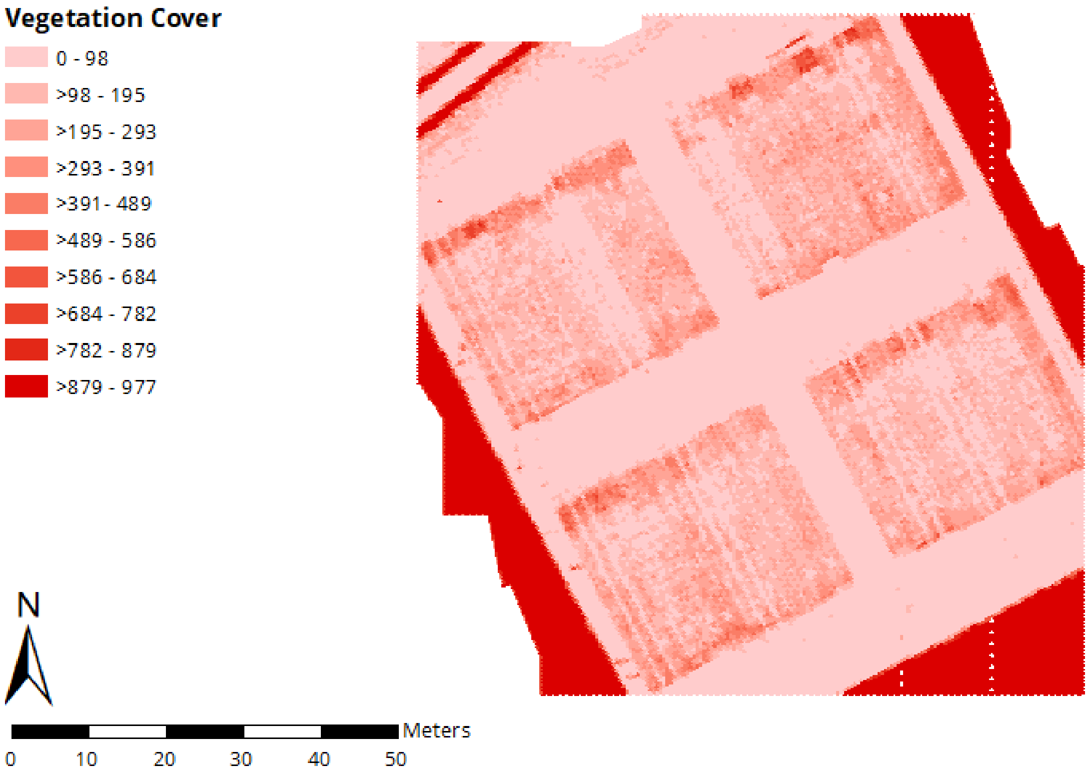


Figure 58: Zonal statistics for vegetation cover in Manternach (18.05.2018).

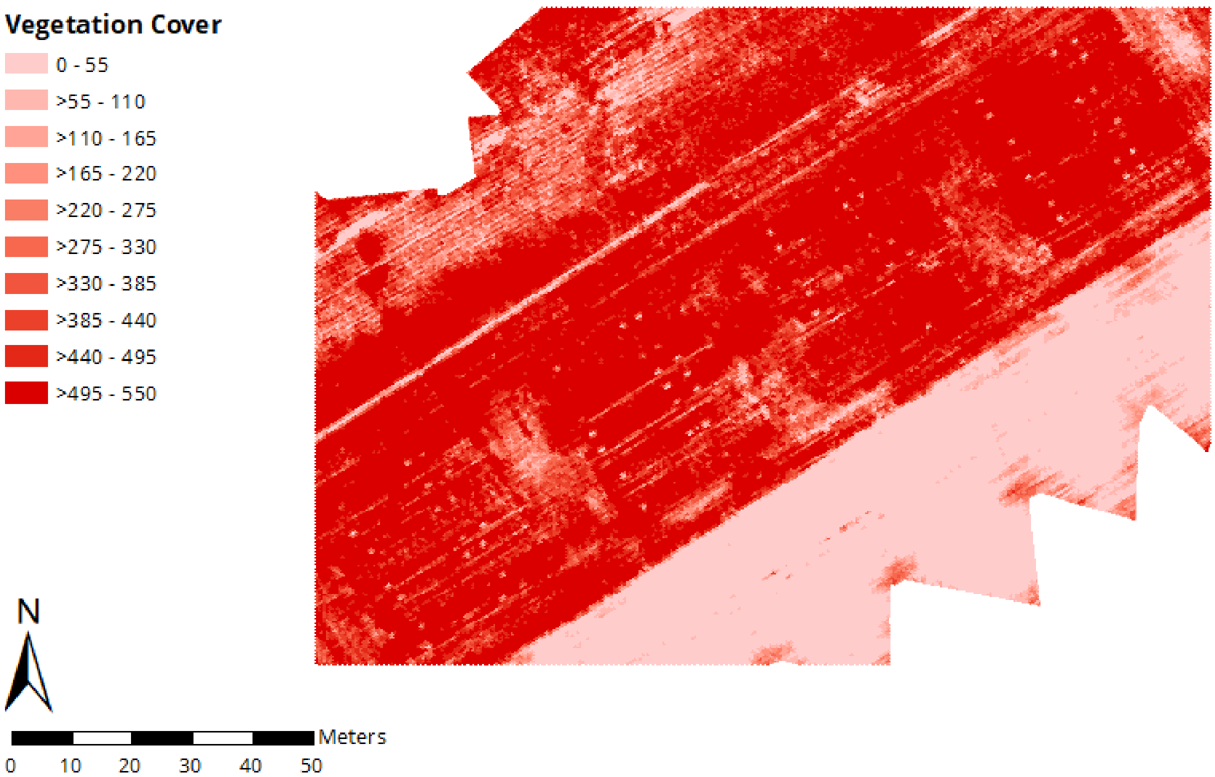


Figure 59: Zonal statistics for vegetation cover in Manternach (09.07.2019).

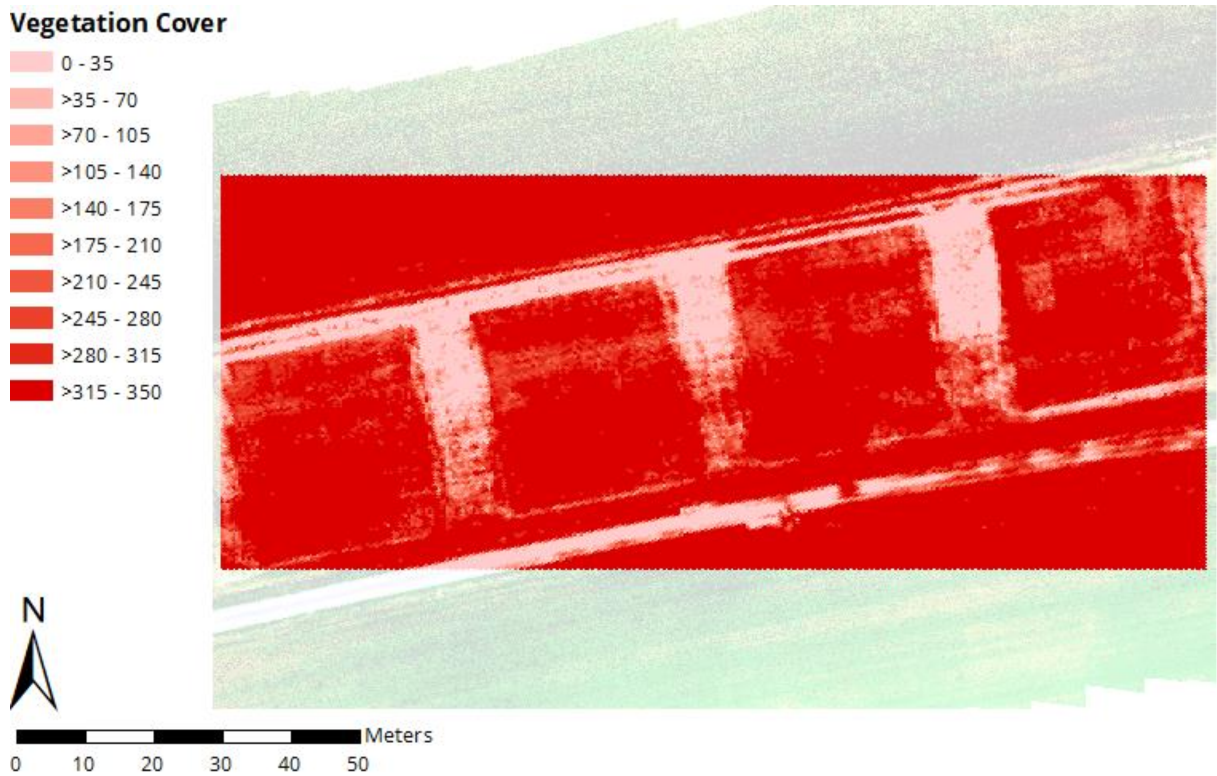


Figure 60: Zonal statistics for vegetation cover in Sprinkange (21.06.2018).

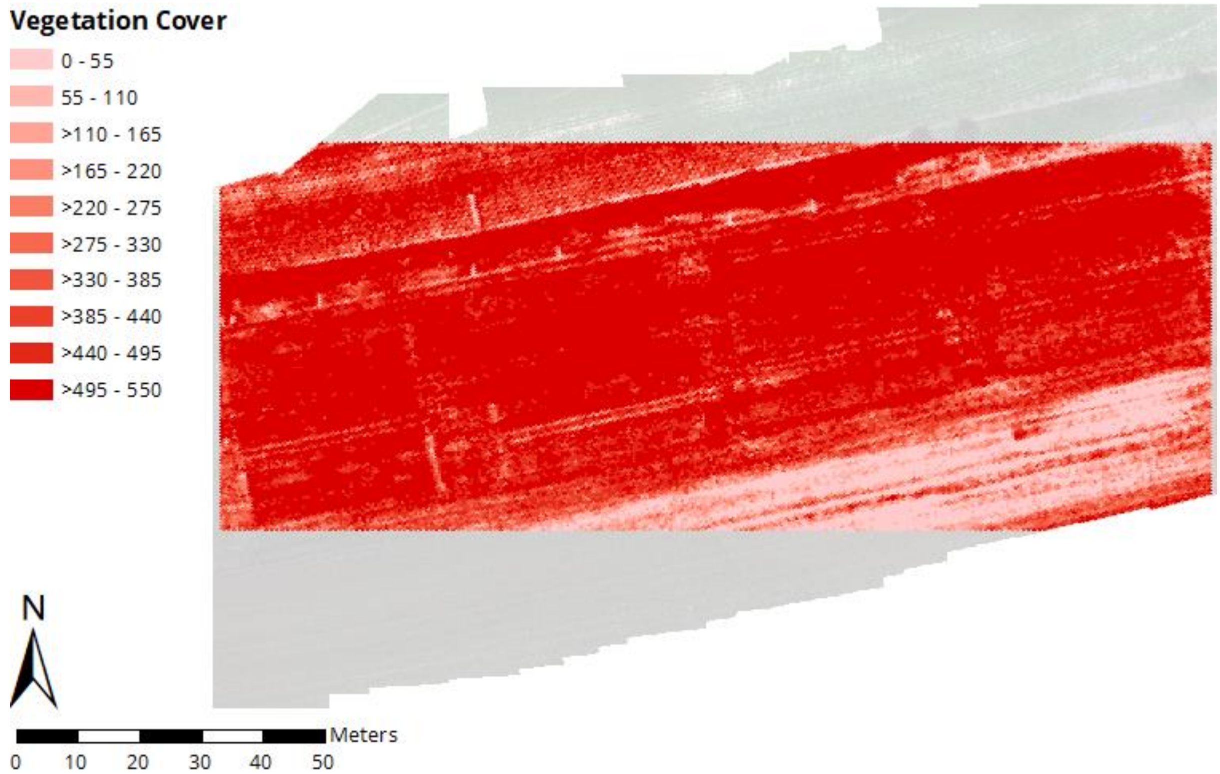


Figure 61: Zonal statistics for vegetation cover in Sprinkange (26.07.2019).

5. On-farm field experiment in Bettendorf

Accompanying the exact-field trials at the three study sites, an on-farm field experiment was carried out in 2018 and 2019 at the agricultural study sites of the LTA in Bettendorf. This area was managed independently by the students of the LTA in consultation with the teaching staff and soybean experts of IBLA was thus used for teaching and demonstration purposes. The aim of this part within the LeguTec project was the immediate transfer of the gained soybean cultivation knowledge to the students of the LTA agricultural school in Luxembourg.

In this on-farm experiment, practical lessons took place regularly. During the summer semester, the students calculated the field emergence, determined the weeds present, the development stages of the soybean plants and compared the various weed control measures. Immediately after the summer holidays in autumn, the 12th grade students harvested the ripe soybeans with a combine harvester in order to determine yield parameters of the individual varieties. The results were then discussed within teaching units.

5.1 Materials and methods on-farm experiment

Each year, a test plot for the hoe was installed to adjust the machine before the single runs within the experiment (A). In addition, the field was divided into 12.5 cm row spacing (B) and 37.5 cm row spacing (C). (see Figure 62).

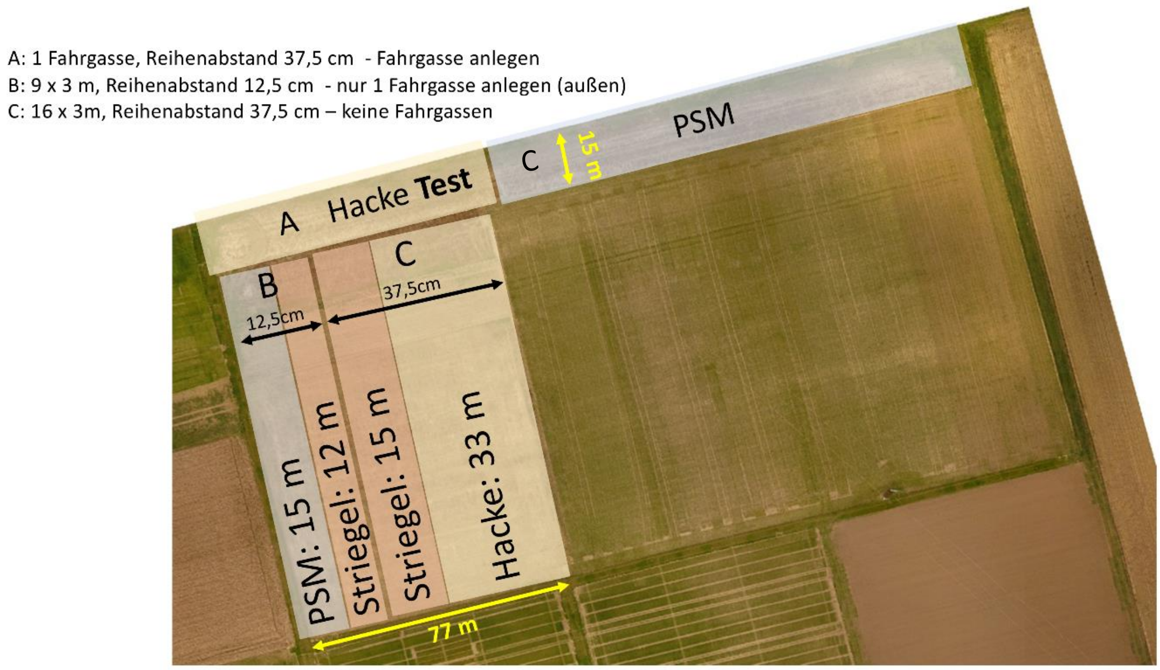


Figure 62: Experimental design of on-farm study site Bettendorf in 2019.

The on-farm field trial in Bettendorf consisted of the following treatments: a) two hoeing runs, b) one run combination of harrow and hoe plus finder weeder, c) one run combination of harrow and hoe, d) one harrowing run, e) one hoeing run plus one hoeing and finger weeder, and f) chemical weed control in row spacing of 12.5 cm and g) chemical weed control in row spacing 37.5 cm. The sequences of the treatments are shown in Figure 63.

	Unkrautregulierungs-Maßnahme
13 x 3 m Reihenabstand: 37,5 cm	Hacke - Einstellungen
	Hacke - Einstellungen
	Hacke - Einstellungen
	Hacke - Einstellungen
	Hacke - Einstellungen
	Hacke
	Hacke
	Hacke + Fingerhacke
	Hacke + Fingerhacke
	Striegel + Hacke + Fingerhacke
	Striegel + Hacke + Fingerhacke
	Striegel + Hacke
	Striegel + Hacke
4 x 3 m Reihenabstand: 12,5 cm	Striegel
	Striegel
	chemischer PS
	chemischer PS
7 x 3m Reihenabstand: 37,5 cm	chemischer PS
	chemischer PS
	Striegel + Hacke (70 m) / chemischer PS (70 m)
	Striegel + Hacke (70 m) / chemischer PS (70 m)
	Hacke (70 m) / chemischer PS (70 m)
	Hacke (70 m) / chemischer PS (70 m)
	Hacke (70 m) / chemischer PS (70 m)

	Unkrautregulierungs-Maßnahme
16 x 3 m Reihenabstand: 37,5 cm	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Hacke
	Striegel
	Striegel
	Striegel
	Striegel
	Striegel
9 x 3 m Reihenabstand: 12,5 cm	Striegel
	Striegel
	Striegel
	Striegel
	chemischer PS
	chemischer PS
	chemischer PS
	chemischer PS
	chemischer PS

Figure 63: Detailed overview of single treatments in 2018 (left) and 2019 (right).

The hoe and its finger weeder applications were the same used within the exact-field trials. For harrowing, a Treffler precision tine harrow was used. Both the machines were provided by Wolff-Weyland S.A..

Figure 64: Harrow (left), hoe (middle) and harvest (right) at the on-farm field trial in Bettendorf (Source: LTA).

Sowing took place the 20th of April in 2018 and the 02nd of May in 2019. During the vegetation period, weeds present in the plots were determined as well as BBCH development stages of the culture. Harvest took place in 2018 on the 12th of September and in 2019 on the 20th of September. At harvest 2018 several parameters like soybean yield, moisture content, thousand kernel weight and hectoliter weight were recorded. Within the lessons, the results were discussed and evaluated by the students.

In 2019, only an overall yield calculation could be done due to irregular field emergence and high weed pressure on all the plots.

Table 47 provides an overview of the Bettendorf study sites in 2018 and 2019, the characteristics and data on the treatments carried out, the assessment dates and further important key figures.

Table 47: Key figures of the on-farm study site in Bettendorf as well as data of the work steps carried out in 2018 and 2019. Temperature and precipitation are given as a 7-year average.

LeguTec		Bettendorf (LTA)	Bettendorf (LTA)
Study site	**Year of investigation**	**2018**	**2019**
	FLIK number	P0893423 (Plot 1)	P0893423 (Plot 2)
	area field (ha)	1.05	1.47
	m a.s.l.	188	188
	Ø-Temp (°C)	9.7	9.7
	Ø-precipitation ∑ (mm)	849	849
	CHU (crop heat unit)	2740.3	2740.3
	Soil type	valley soils	valley soils
	Soil parameter		
	soil extraction date	Jan.18	Jan.19
	pH (CaCl2)	7.4	7.3
	K_2O (mg/100 g tr. Boden)	12.5	15
	P_2O_5 (mg/100 g tr. Boden)	15.5	14
	Mg (mg/100 g tr. Boden)	24	26
	Na (mg/100 g tr. Boden)	1	2
	Nmin (kg Nitrat-N/ha)		
	previous crop	winter grain	Spring barley/Winter wheat
	intercrop		
Primary cultivation	**Plough**	20.03.	March/April 2019
Fertilizer	**Liming date**	-	-
	Amount of lime (kg)	-	-
	Phosphorus date	11.04.	-
	Amount of phosphorus (kg)	100	-
Sowing	**False seed-bed**	13.04.	-
	Inoculation + sowing	20.04.	02.05.
	Inoculant	Biodoz Soja	Rizoliq Top S
	Seed rate (seeds/m²)	65	
	Sowing camelina	-	-
	Amount of camelina (kg/ha)	-	-
Mechanical weed control	**Blind harrowing**	- no blind-harrowing possible	- no blind-harrowing possible
	Harrowing 1	09.05.	03.06. (BBCH 13)
	Hoeing 1		03.06. (BBCH 13)
	Harrowing 2	-	-
	Hoeing 2	30.05. (BBCH 13)	
Chemical	**Pulsar 40**	0.5 l/ha at 28.05.	0.5 l/ha at 13.06
	Harmony SX	7.5 g/ha at 28.05.	7.5 g/ha at 13.06.
Harvest	**Harvest date**	12.09. (BBCH 99)	20.09.

5.2 Results on-farm experiment

During the vegetation period the occurrence of the following weed species was detected by the students: *Galium aparine*, *Polygonum aviculare*, *Lamium amplexicaule*, *Veronica agrestis*, *Viola arvensis*, *Polygonum convolvulus*, *Rumex obtusifolius* and gras species. *Chenopodium album* mainly occurred in very high density within the chemically treated plots.

At harvest 2018, some of the pods were not yet all riped in the subplots with a row spacing of 12.5 cm. The chemically treated plot showed high weed infestation. Results of soybean yields for each treatment are given in Figure 65.

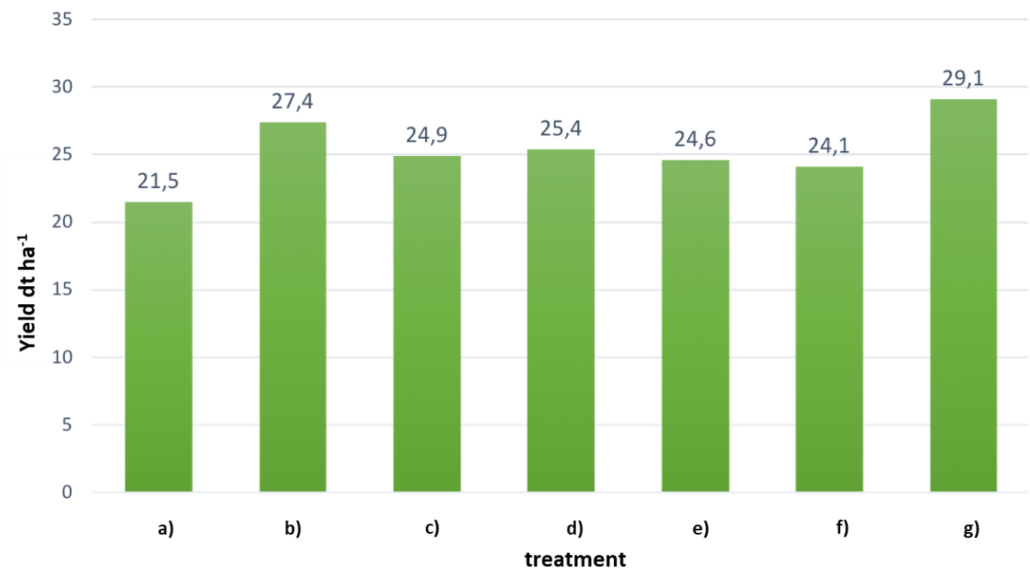


Figure 65: Soybean yield [dt ha^{-1}] in 2018 at study site Bettendorf of the seven treatments a) two hoeing runs, b) one run combination of harrow and hoe plus finder weeder, c) one run combination of harrow and hoe, d) one harrowing run, e) one hoeing run plus one hoeing and finger weeder, and f) chemical weed control in row spacing of 12.5 cm and g) chemical weed control in row spacing 37.5 cm.

Highest yields were found in the mechanically treated plot with one harrowing run followed by one hoeing run with finger weeder applications amounting 27.4 dt ha^{-1} and in the chemically treated plot with 37.5 cm row spacing amounting 29.1 dt h^{-1}. The lowest yield was observed in the chemically treated plot with row spacing of 12.5 cm amounting 24.1 dt ha^{-1} and in the mechanically treated plot with two single hoeing runs amounts to 21.5 dt ha^{-1}. In 2019 an overall yield of 25.0 dt ha^{-1} was determined. An evaluation of the individual treatments was not possible during this year, because the field emergence was irregular and the weed pressure within the plots was very high.

6. Discussion

In order to determine the performance of the weed regulation methods, grain yield is an important parameter. Grain yields were rather low in both project years and were lower than the production potential for this area. Highest yields amounted to 16.2 dt ha^{-1} in 2018 and 19.9 dt ha^{-1} in 2019 on average. Putting these yields into relation, the results of the national variety field trials showed higher yields in both years. Average grain yield for variety Merlin in Luxembourg was 23.9 dt ha^{-1} in 2018 and 27.8 dt ha^{-1} in 2019 (Keßler, 2018; Heidt, 2019). Comparing with neighbour cultivation regions average grain yield of variety Merlin in Rhineland-Palatinate, Germany was 26.1 dt ha^{-1} in 2017 (Anderl et al., 2018) and in Nord Pas de Calais, France was 19.6 dt ha^{-1} in 2016 (Chambres d'agriculture des Hauts de France, 2016). Limited grain yields could be explained by site features varying in soil and weather conditions. Hostert18 and Sprinkange19 suffered from high weed infestation from the beginning of the vegetation period. Both Manternach sites were characterized by the lowest annual precipitation and were the driest locations. Hostert19 was suffering from high precipitation during the harvest period, that made it impossible for soybeans to ripen properly and for harvesting in time. Heavy soils were typical for the Sprinkange study sites that tend to delay in drying up or becoming crusted, being a challenge for mechanical weed control (Bernet et al., 2016). Only few agricultural sites are perfectly suitable for soybean cultivation in Luxembourg. Therefore, yields had to be maximised on the sites given within the project. The study on hand shows that also for Luxembourg, the biggest challenge identified in organic soybean cultivation is the competition with weeds that need to be well controlled to reach adequate yields (FIBL, 2016; Hamilton et al., 2014). It was shown that soybean yields were significantly influenced by mechanical weed treatments. Higher yields generally resulted from hoeing treatments compared to harrowing treatments. Yields were similar with hoeing and hand-weeding, as well as with harrowing and no-weed control. Regarding the latter, same was observed by Kunz et al. (2015). Within hoeing treatments, yields were similar no matter if finger-weeding was applied or not. This is in accordance with Pannacci et al. (2018), who observed no differences in yield within different hoeing devices. On sites with low weed pressure (Manternach18) yields were similar and hence not affected by treatment; harrow was shown here as an equally alternative method.

Different parameters that influence soybean grain yield have been worked out. According to Vollmann et al. (2010), high weed density in a soybean crop usually causes yield losses, reduced harvesting efficiency, increased moisture and damaged or diseased seed subsequently generating significant economic losses. In the present study, weed occurrence parameters showed high negative correlations with yield indicating yield to reflect the efficacy of weed control. Calculated weed control efficiencies reflect the status of weeds before and after the first run of weed control. Highest weed cover reduction of up to 82 % on average was reached with hoeing. Insufficient weed control was found for harrowing with e.g. less than 20 % at Sprinkange18 and Hostert19. This is in accordance with Pannacci et al. (2018) who also found simple hoeing to be most effective on weeds, although hoeing did not effectively control weeds in the row. They also described significant less efficiencies in harrowing, due to the low efficacy against grasses and taller weeds. Conversely, Weber et al. (2016) found no significant differences between hoeing and harrowing but observed a tendency towards insufficient weed control with harrowing explained by inter alia high weed occurrence. The success in controlling weed is in turn depending on weed pressure present on the site (Weber et al., 2016). Sites with low weed pressure, in this study Matnernach18, seemed to be controlled with a similar efficiency by hoe and harrow. Here, any mechanical option chosen is better than doing no weed control. Where weed pressure was already high after emergence, the efficiency was unsatisfactory for the treatments. This was found, for example, at Hostert18, where harrowing had reduced weed cover only by 25 % on average, statistically similar with no weed control, and hoeing only by 52 % on average. Manual weeding, that showed highest weed control efficiencies, could not be seen as an option common in practice due to its low profitability and operability. The application of finger weeders generally resulted in no differences regarding weed control success in comparison to single use of hoe after the first run; but this was different on one site: Weed control efficiency of finger-weeding was higher at Sprinkange18 compared to single use of duck-foot shares. The strengths of the rubber fingers must be selected according to the soil conditions (Hatzenbichler, 2015). In our field experiment yellow finger weeder attachments were selected for medium and hard soil, while also orange coloured ones were available for soft and sandy soil. The missing success at the remaining sites could be explained by the wrong choice of the attachments for these sites or, especially at Hostert18, by high weed pressure. An individual adaptation by each farmer on each field under consideration of soil conditions and plant development is essential to successfully implement finger-weeding and minimize plant damages (Dierauer, 2017), but requires considerable experience.

Shortly before flowering, weed control was terminated. When comparing the presence of weeds in each treatment with the negative control plots AWC and at FLO (WCI_{cover}), a trend was seen with regard to the number of mechanical runs. Where only one mechanical run was performed, the effects of weed control decreased until flowering, indicating new weeds had been established. Plants were really small when the first run had been done and weeds took the advantage on open space occupation between the rows that offered ideal conditions for new weed infestation as described by Pousset (2016). Harrowing twice slightly increased weed control success compared to non-weeding but still remains lower compared to hoeing once. Hoeing twice also tended to slightly increase success. Statements on finger-weeding performances in the second run (with previous single hoeing) are again difficult to make since site conditions seemed to have different influences on their success. The finger-weeding could only have a slight impact since no differences in weed occurrences (cover, biomass and density) were observed in combination with the hoeing treatments at flowering ($t.4_{hoe}$ and $t.5_{hoe+}$). Weed occurrence at flowering again showed higher amounts after harrowing compared to hoeing. This observation is in accordance with Kunz et al. (2015). In cases of high weed infestation, even no differences of harrowing with the non-treated plots were found indicating the failure of harrowing under high weed pressure.

Bernet et al. (2016) describe the ability of soybeans to compensate the exposure to stress (drought, mechanical and environmental stress) during the vegetative growing phase. Drought stress creates changes in growth dynamics like plant height (Board et al., 2016). Soybean stand height at flowering was measured in this study and lower heights were observed with harrowing compared to hoeing. According to Board et al. (2017) drought stress during the vegetative phase has adverse effects on plant heights, since plant height reflects the root depths and hence the plant's future potential for obtaining water. Since weed occurrence was higher in harrowing, the competition for water was higher. When plants were damaged by environmental causes or by mechanical treatments, they have to compensate first the damages by putting energy into new biomass formation before going on with the vegetative growth (Bernet et al., 2016). Soybeans being exposed to stress from mechanical treatments were investigated while focusing on the plant damages. In this study it appeared that harrowed treatments contained more damaged plants than hoed ones. Plants were either slightly damaged and recovered with delay or were completely destroyed. The latter was mainly observed with hoeing. Soybean plant losses were highest in harrowing with more than 20 % plant losses and even 35 % at Hostert18. A study performed by Jobst et al. (2012) showed plant losses of up to 20 % on average with harrow, that goes well in accordance with the observations in this study. Plant losses again promote new weed infestation within the newly appeared bare soils, referring to the higher weed occurrence at flowering within harrowing and thus increased water stress. Hoeing methods did not reduce soybean plant numbers compared to hand-weeding. Kunz et al. (2015) confirm the conclusion that managing weeds with hoeing was observed to have a better selectivity than with harrowing.

At Hostert19 environmental stress was caused by a hail event interrupting soybean growth at BBCH 12. Our observations match with Bernet et al. (2016) who described the ability of soybean plants to compensate hail damages during the vegetative development without any disadvantages in yield but slightly delayed growth while building up new biomass. However due to the inhomogeneous and finally delayed ripening, harvesting at Hostert19 was not possible.

The appearance of the first flowers determines the beginning of generative growth and the period, where most water is needed by the plant (Bachteler, 2017). Lack of precipitation and heat waves in 2019 were observed on all the sites. Water stress at flowering resulted in competition for water between weeds and soybean. At the treatments with high weed infestation, mainly the harrowing plots in this study, the competition for water was higher resulting in increased water stress for soybeans. Additionally, the competition for nutrients on sides with higher weed occurrence is higher according to Pousset (2016) and does so in the harrowing plots in our study. Together with the fact, that plant stand height of the harrowed treatments was lower compared to the hoed ones, aggravate the situation of drought stress for the harrowed treatments.

Board et al. (2017) described a reduced photosynthetic rate due to drought stress at flowering. Since no significant differences in chlorophyll content were observed in the LeguTec study within the mechanical treatments, it can be concluded that all treatments were affected in the similar way by drought. Average chlorophyll contents at flowering ranged between 338 µmol m^{-2} and 410 µmol m^{-2} in 2018 and between 448 µmol m^{-2} and 508 µmol m^{-2} in 2019. Thompson et al. (2016) described chlorophyll contents of soybean at flowering ranging between 300 µmol m^{-2} and 330 µmol m^{-2}. The measured chlorophyll contents in this study were therefore on average in 2018 and above average in 2019 compared to Thompson et al. (1996). Photosynthetic rate is the yield-determining parameter at flowering (Bard et al., 2017) and missing differences indicate no differences of the treatments in this growing state. The differences in yield observed in this study might therefore be a result of water deficit starting in the vegetative growth and continuing in the generative growth. Investigated yield structure showed high positive correlation between pods per plant and grain yield. While the number of pods per plants are determined within the pod formation period, the water deficit during this period observed on all the sites, had high negative influences on yield. According to Board et al. (2017), yield loss is the double within this period compared to the following seed filling period. Further studies showed the pod formation period as the most drought prone period (Board et al., 2016).

Further yield parameters are essential at harvest. High weed cover at harvest makes it difficult for the combine harvester to harvest properly (Bernet et al., 2016). Harrowing treatments showed much higher weed cover similar to the negative control plot. First pod height is essential for harvesting to avoid cutting losses at mechanical harvest. It is necessary that the first pod has a large distance to the soil surface to minimise soybean yield losses as the lowest pods may remain on the field when the cutting unit is not able to reach the lowest pods. According to Tkachuk (2019) a minimum pod height of 12 cm measured as the distance from the soil to the lowest pod-bearing node, is recommended to prevent stubble loss at the cutter bar. First pod height is depending on genetic structure of the soybean cultivar, the level of precipitation and the cultivation technology (Sobko, 2019). First pod heights were lower in 2019 than in 2018, while in 2019 for all mechanical treatments pod height was less than 11 cm. In 2018 all hoeing treatment showed heights above 12 cm. Higher temperatures and less precipitation during vegetative growing in 2019 might have been responsible for the limited pod heights. Another factor affecting height in harrowing were direct mechanical impacts on the plants. The non-selectivity of the single tines while using a harrow lead to an S-shape of plants, observed immediately after harrowing. Hence, the size of the whole plant was reduced mechanically due to compression of the whole plant. In general, hoeing tended to increase first pod height, while harrowing seemed to decrease first pod height. Therefore, it was shown, that cultivation technology in form of mechanical weed treatments, is responsible for different pod heights in this study (mechanical influence).

Besides grain yield, protein content is mainly essential for soybean valence. Protein contents were in all treatments above the average of 36 % for soybeans grown in our geographically region (Bellof, 2014) and ranged around 40 %. In Luxembourg, similar protein contents were observed in the last years of soybean field trials, too, indicating above average protein contents and high-quality soybeans (Zimmer et al., 2016a; Heidt, 2020, Keßler et al., 2019). An exception in this study was Sprinkange18, characterized by protein contents ranging only around 30 %. This can be easily explained by the missing inoculation when soybean was reseeded. Nitrogen fixation plays an important role in protein formation in soybeans. Soybeans were delivered pre-inoculated by the manufacturer. Nevertheless, these low amounts clearly demonstrate the insufficient pre-inoculation. Same was found by Zimmer et al. (2016c) who observed inoculation significantly influencing protein content and protein yield. Recknagel et al. (2015) reported that the pre-inoculated seeds have repeatedly shown considerable weaknesses in recent years in practice, especially under unfavourable conditions such as prolonged drought, wetness or cold.

The diversity of weeds that has been observed in this study reflect common values for arable fields and organic farming. Edesi et al. (2012) indicated that the Shannon index is rarely exceeding 2.0 in arable fields. In this study, Shannon indexes often remained above 1.0, except in Manternach18 where the low weed pressure from the beginning allows a very high weed control efficiency and attained a maximum of 2.0. In the Czech Republic Tyšer et al. (2008) have found higher Shannon indexes in organic agriculture (from 1.26 to 2.23) than in conventional farming (from 0.27 to 1.34) in winter cereals and root crops. In diverse crop rotations in the USA Wortman et al. (2010) have also found higher Shannon index values of soil seed banks in organic farming (from 0.78 to 1.06) than in conventional farming (from 0.66 to 0.76). These findings confirm that the range of values of the Shannon index, found in this study, are in line with other values in organic agriculture. A meta-analysis conducted by Bengtsson et al. (2005), revealing that species richness in organic farming is on average 30 % higher than in conventional farming, reported that the Shannon index is often close to the species richness, which is valuable for the present results showing small differences between the Shannon index and the Shannon index maximum. In Hostert19, the Shannon index ranged between 0.8 and 2.0 and the maximum associated to these values from 1.0 and 2.6, as an example.

In the present study, the species richness varied between 26 to 37 weed species identified along the growing cycle of soybean and 30 % of them were in common for each of the study sites. This shows that the diversity of weed is site-specific and that the diversity is mainly explained by the major number of low abundant species which are not common to each site. The classification of the species in ecological groups has revealed usual findings in the way that annual and biannual dicotyledonous species are generally the most abundant, in terms of species and number of individuals, in comparison to perennial dicotyledonous and monocotyledonous weeds species (de la Fuente et al., 1999, Gabriel et al., 2006, Tyšer et al., 2008). Romero et al. (2007) reported that, under organic farming, broad-leaved, insect-pollinated and legume weeds were more abundant than in conventional farming. In agroecosystems, weed species are affected mainly by crop rotations (Lutman et al., 2009), which are often longer in organic farming (Barbieri et al., 2017, Zimmer et al., 2016b). The regular presence of perennial crops (grassland, alfalfa) in organic crop rotations is mainly enhancing the diversity of weeds (Henckel et al., 2015, Wortman et al., 2010). As demonstrated by Schumacher et al. (2018) most of the species are not very frequent (abundancy < 10 %) which leads to the dominance of only few species in arable land (de la Fuente et al., 1999, Dessaint et al.,2001). In fact, the present results have shown that two to four species, for instance *Lamium amplexicaule, Veronica agrestis* and later *Polygonum convolvulus* in Manternach19, were dominant at each assessment time and that often the most dominant species at the beginning of the experiment remained dominant until the end, except of special cases where late emerging or perennial species grew (*Chenopodium album, Polygonum convolvulus*). It has been found that the most abundant species were in most cases different across each site. Guay (2012) mentioned that when a community is diverse, it is more likely that species with low abundancy are eliminated while, species with a high number of individuals have lower chance to be completely removed. This explains why the number of annual and biannual species were globally more reduced than other ecological groups. However, annual and biannual dicotyledonous weeds remained most of the time the most abundant weeds in terms of number of individuals. Perennial dicotyledonous and monocotyledonous were not often the most abundant but this does not mean that they do not affect the crop. Species like *Cirsium arvense, Elymus repens, Polygonom convolvulus or Rumex obtisifolius* are plants present in low density but who can develop a lot of biomass or highly cover the soil and are competitive towards the crop. The presence of three weed species registered on the red list of vascular plants in Luxembourg (Colling, 2005) strengthens the role of diversity conservation of organic farming. *Centaurea cyanus* (vulnerable) has been identified in Hostert 18 and in Hostert19, *Geranium rotundifolium* (extremely rare) has been found in Hostert19 and in Manternach19 and *Papaver rhoeas* (near threatened) grew in all experiments. Rare weed species are commonly found to be more abundant in organic fields (Gabriel et al., 2006, Romero et al., 2007, Rydberg and Milberg, 2000). Rotches-Ribalta et al. (2015) specified that the occurrence of rare species is often higher in fields that are under organic farming for a long time and in rotations with a high presence of winter cereals and is mainly due to the low level of fertilization and the large diversity of seeds remaining in the soil seed bank. Nevertheless, rare weed species are often occurring at low frequencies (Hyrvönen and Salonen, 2002) and are more vulnerable to climate change which is favorable to non-specific weeds and invasive species (Schumacher et al., 2018).

Six of the most abundant species at flowering and at harvest of soybean, remaining after the weed control program, have been classified to be the most harmful to the crop (direct competition) or problematic at harvest (indirect harmfulness): *Chenopodium album, Elymus repens, Persicaria lapathifolia, Polygonum convolvulus, Tripleurospermum inodorum* and *Viscia spec* (Arino et al., 2012, Infloweb.fr). According to Arino et al. (2012) the best way to control these species is an early weed control such as false seedbed as well as an alternance of harrowing and hoeing. *Chenopodium album,* which is often present at high density in spring/summer crop, has a high competition ability towards the crop and creates problems at harvest (increased humidity in the harvest) (Arino et al., 2012). In the study on hand, either no differences were found between harrowed and hoed treatments, or there were more *Chenopodium album* remaining in harrowed plots, but its abundance was always higher in the negative control. *Elymus repens*, often growing in compacted soils and in long-term grass cultivations, is directly competitive towards the crop due to allelopathy but is sensible to droughts (Arino et al. 2012). *Elymus repens* grew mainly in Manternach18 after the last weeding due to high precipitations in the negative control and in harrowed treatments. *Persicaria lapathifolia,* growing at high densities in summer crops mainly in loamy-clayish soils (Infloweb.fr), is mainly problematic at harvest (increased humidity in the harvest) (Arino et al., 2012). In Sprinkange19, where no false seedbed and no pre-emergence could be performed, *Persicaria lapathifolia* grew abundantly and was found from the start of soybean emergence on. *Polygonum convolvulus* is mediumly harmful but tends to twist around the crop. Harrowing tends to better control this species than hoeing (Arino et al., 2012), which was the case in Manternach19 AWC and at FLO whereas in Sprinkange 18 no differences could be seen between treatments. *Tripleurospermum inodorum* is very frequent and at high density is problematic by increasing the humidity in the harvest (Arino et al., 2012). In the study, *Tripleurospermum inodorum*, which has a great emergence potential in crusted soils (Infloweb.fr), was less abundant in treatments with a false seed bed than others only in Manternach18 and also less abundant in hoed treatments in Hostert19 and in Sprinkange18. *Viscia spec.,* mediumly harmful towards the corp, can be found locally at high density in particular in rotations with a high presence of winter cereals and the use of farmer seeds, here only very abundant in Hostert18 and Hostert19 (Infloweb.fr). Although a better soil preparation was performed in Hostert19 than in Hostert18, the abundance of *Viscia spec.* was higher in 2019. In Hostert19, the hoe controlled better the vetches than harrowing, while no differences were observable between the techniques in Hostert18. Thus, in general false seedbed and hoeing seems to control these problematic weed species better than harrowing.

Mechanic weed control has a negative impact on weed diversity by lowering the number of individuals and the number of species until the last performed run. Nevertheless, weeds are never completely all eliminated which allows some species to further develop and pursue their life cycle. Weed control efficiency is one of the parameters that explains why weeds are globally more present and more diverse under organic farming than under conventional agriculture (Lutman et al., 2009). Although Rydberg and Milberg (2000) and Marshall et al. (2003) underlined that there are generally less nitrophilous weed species under organic farming than in conventional and that they might be less competitive towards the crop, weeds should be maintained at a controlled rate which is a compromise between the ecological services they bring and the competition they cause to the crop (Chauvel et al., 2018. Henckel et al., 2015). Lower intensity of weed control often lead to an increase of the most problematic weeds (Marshall et al., 2003). Conversely, Marshall et al. (2003) stated weeds provide diversity, ecosystem functions and support many species so that weed elimination negatively affects different natural processes i.e. nutrient cycles, soil processes and trophic interactions. In fact, the abundance of weeds and species were differently reduced according to the different mechanical methods used and to the weed control efficiency. Hoeing alone or in combination with pre-emergence blind harrowing and/or finger weeder generally reduced the most the diversity of weeds in comparison to the performance of pre- and post-emergence harrowing. In the trial, the diversity of weeds shown by the Shannon index was often close to the positive control (weed-free) for hoed treatments while closer to the negative control for harrowed treatments. Variations in the composition of weed communities between hoed and harrowed treatments have been observable, in particular after the performance of two runs of mechanical weed control. On the one hand, the abundance of the ecological groups could differ: monocotyledonous weeds were more abundant in hoed treatments while perennial dicotyledonous were more predominant in harrowed treatments in the case of Sprinkange18. According to Bond and Grundy (2001), variations of dominating ecological groups or species reflect well the different spectrum of action between the hoe and the harrow. On the other hand, the most abundant species switched between hoeing and harrowing methods so that, in Hostert19, as an example, *Fumaria officinalis, Lamium amplexicaule* and *Viscia spec.* dominated at flowering in hoed treatments while *Capsella bursa-pastoris* and *Tripleurospermum inodorum* were more abundant in harrowed ones. Such differences between the techniques might be due to the fact that mechanical weeding aims to maintain specific assemblages (Marshall et al., 2003) and to different factors such as the growing stage of soybean and weeds, the original weed pressure (low or high), the soil type and structure, the machine adjustments, the field management history and weather (Bond and Grundy, 2001, de la Fuente, 1999, Gunsolus et al., 1990, Henckel et al., 2015, Weber, 2016).

Variations of weed occurrences, that resulted from different mechanical treatments, influenced the drought stress of the soybean plants. Water deficit was finally the main yield limiting factor in the study on hand. That is also why intercropping with camelina was not successfully tested in this study. Lack of rain after sowing of camelina resulted in bad or even no emergence.

The advantages of mechanical weed control with the hoe instead of harrow pointed out in this study are only valid under the consideration of an appropriate field management. When this management is not performed rigorously and weed infestation is already high after emergence, the best mechanical weed control device will not be able to successfully work and yield losses are certain. Soil management adapted to the site conditions and a wide crop rotation to indirectly control weeds in advance, is essential. The differences resulted from soil management were observed in Hostert18 and Sprinkange19, where an adequate management and continuous support by IBLA advisors lead to improved soybean cultivation. An appropriate soil management must start already in autumn with the choice of the site. According to the LeguTec study and others (Heidt, 2018, 2019; Stoll et al., 2015; Wilbois, 2015; Zimmer et al., 2015; Zimmer et al., 2016a, c) the following suggestions for soybean cultivation were derived for Luxembourg: Soil management should include ploughing in autumn (or in early spring), followed by a freezing catch crop for water storage, nutrient fixation and weed suppression; timely tillage before sowing and the setting of a false seed bed. Soybean inoculation right before sowing is unavoidable. Blind harrowing is recommended in literature (Bernet et al., 2016) as pre-weeding procedure but it has to be selected carefully. In the present study, blind harrowed treatments did not differ in weed cover after soybean emergence and hence no positive effect of blind-harrowing could be derived. But when the site is suffering from drought after emergence, blind-harrowing can also have negative effects as was monitored in Sprinkange18 where weed cover after soybean emergence was higher in the blind-harrowed plots. These effects can be explained by stimulating nitrogen mobilization and weeds profiting by nitrogen supply due to the faster growth compared to soybean (Bernet et al., 2016). Additionally, mechanical treatments have to be selected carefully, as also found in this study, when focusing on finger-weeding. It seemed that neither blind-harrowing nor finger-weeding resulted in advantageous conditions and grain yield. Not only when choosing finger-weeding but also when choosing single hoe with duck-foot shares, an exact adjustment of the machine is necessary as well as the right choice of the finger weeder strengths. A person experienced in hoeing should drive the machine to avoid plant losses. When a camera control unit is used, special attention has to be paid. Especially with high weed pressure, no differentiation between soybean and weed might be possible as observed in this study. When weed infestation is low and soybeans are recognized by the camera, this device might help on uneven grounds since it adapts immediately to changing levels.

Regarding remote sensing techniques and geospatial data analyses a high-quality data acquisition is fundamental to vegetation analysis. The choice of the acquisition date is always a trade-off between the optimal date in relation to phenology and meteorological conditions. In this study, a high-quality data acquisition was declared as highest priority. Non-optimal illumination conditions due to haze, overcast or even precipitation have a significant impact on image radiometry that cannot be corrected by atmospheric correction. Inhomogeneities in radiometry would add further uncertainties to the experimental setup. As a conclusion, if applicable, perfect meteorological conditions where prioritized to timing of data acquisition.

The uncertainties in the experimental setup have significant impacts on the outcome of data analysis. Especially when combining datasets from differing sources, uncertainties often limit the potential of the results. In this study, three main sources of uncertainties were identified: First source of uncertainty was a non-synchronous data collection in a dynamic experiment. While UAV data acquisition can be understood as a temporal snapshot, in situ data collection is a very time-consuming task. On the one hand, in-situ data collection is timed by the crop phenology, time-consuming and not very sensitive to meteorological conditions. As, on the other hand, UAV data acquisition is timed to meteorological conditions, there is the potential that the two datasets could be temporally distant up to 10 days. Second source of uncertainty identified was the fact, that subjective in-situ data collection adds further fuzziness to the data and reduces the potential analysis to qualitative findings. And finally, inhomogeneities in the experimental setup that are not considered for data analysis add uncertainties and fuzziness to the data. In this study, the main inhomogeneities are probably related to terrain (slope, aspect, and curvature), soil inhomogeneities (clay, skeleton), and seeding (clogging, acceleration and speed). The differences in terrain and slope can cause differing meteorological conditions such as wind exposure, surface runoff and solar irradiation. Inhomogeneities in the soil could be related to soil compaction, differences in soil skeleton and grain size distribution. These parameters have a direct impact in the development of roots and the availability of water and nutrients and therefore, also a direct impact on the temporal as well as on the absolute development of plants. While in the collection of in-situ data, obvious inhomogeneities can be compensated, this is not the case for remote sensing data, aggregating up to plot level. Thus, in this study in-situ data collection remains the more reliable method.

The use of vegetation indices is a common approach for phenotyping, especially for parameters like biomass and photosynthetic activity. Here, the choice of a well-suited vegetation index is mandatory depending on the parameter that needs to be monitored. In this study, a variety of broad-band indices that can be collected using commercial sensors were tested. Critical point is the saturation of indices at high vegetation density or high biomass values. This causes that suitability of vegetation indices changes between early and later phenological development stages.

Image classification is a very important step in data processing. The differentiation between soil crop and weeds is mandatory for further analysis. Within the LeguTec project, three different classifiers were applied and tested. Shortly, results showed that differentiation between weeds and crops are only feasible with satisfying results when weeds show phenological characteristics like blossoms. To discriminate soil and vegetation, simple approaches like vegetation index thresholding provide excellent results. For the classification of crops and weeds, Support Vector Machines and Random Forest models were setup. While the soil-vegetation discrimination provides excellent results, the weed classification is not consistent and only performs adequately at blossom of certain weed species. Here, an increase in geometric resolution as well as an increase in spectral resolution would improve the results of the image classification but would also recede the practical applicability as data collection would become very time intensive and require very sophisticated sensors. Once again it was confirmed that in-situ detection is still the proven method for agricultural field trials.

Time series analysis is the most frequent type of application for remote sensing data when monitoring vegetation. The temporal dimension of phenology releases significant quantities of information that cannot be derived from one single dataset. On a large scale, satellites like Sentinel 2 or Modis provide data at high temporal resolution but are limited in their use for phenotyping. Here on a small-scale experimental setup, UAVs have many advantages but also the drawback, that data collection is labour intensive and expensive compared to satellite data. It has been shown that phenology parameters like photosynthetic activity, canopy cover can in general be derived from UAV data and that time series of these parameters follow the expected course. But the differences were too small to be able to discriminate the different treatments based on image time series.

Agronomic results of the exact field trials were confirmed in the on-farm field trials in Bettendorf, also resulting in a better performance of the hoeing treatments in comparison to harrowing with regard to grain yield. The grain yields of the on-farm field trials, that reached up to 27 dt ha^{-1}, were higher than in the exact field trials. The ability of reaching high yields and the provided information during the field visits and events organised during the project years resulted in an increased interest of farmers for soybean cultivation. A few organic farmers started successfully cultivating soybean in 2019 in cooperation with Bio Ovo S.A. and the advisory service of IBLA. It was confirmed that a continuous consultancy offered for farmers is necessary to successfully cultivate soybeans. Soybean cultivation in Luxembourg is still facing the challenge of missing further processing steps of drying, cleaning and toasting that have to be implemented to be able to handle larger quantities and in order to indicate price adaptions to the higher production costs. The average market price for organic soybeans between 2015 and 2019 was 82.52 € dt^{-1} (incl. 10 % TVA), while for conventional soybean the average market price was 38.42 € dt^{-1} (incl. 10 % TVA) (Lfl, 2020). Market prices alone are not enough to evaluate the economic profitability of local soybean cultivation. A detailed economic evaluation is still missing, and was not part of the LeguTec project, but is being assessed for Luxembourgish on-farm soybean cultivation in a present master thesis at University of Hohenheim in collaboration with IBLA.

For future investigations, where information on weed infestation is needed, the reduction of the recorded weed parameters might be taken into consideration to reduce time and costs. The LeguTec study showed high correlation between weed density, weed cover and weed biomass. Weed cover is the most cost and time efficient detection method and showed similar results like the time-consuming weed biomass or density detection. A combination of detecting the main weed species appearing on the sites with weed cover estimations still deliver high quality results. For studies on biodiversity and species abundance it is still recommended to detect each number and species to be able to make significant conclusions. The experimental design taken as basis in LeguTec has proven itself. The right choice was made regarding the number of study sites and replications. The only factor that needs to be changed in future studies is the number of observation years. To be able to perform an overall statistical analysis combining years and sites, a minimum of three years is required. It is recommended at this point to increase the number of observation years in future studies.

7. Conclusions and Outlook

Mechanical weed control in soybean cultivation showed a high weed control efficiency. In the study years, where water stress was the main limiting factor, higher yields generally resulted from hoeing treatments compared to harrowing treatments. Yields were similar with hoeing and hand-weeding; as well as with harrowing and no-weed control. Grain yield was not affected significantly by blind-harrowing. No significant differences in soybean yields were found for the hoeing treatments ($t.4_{hoe}$; $t.5_{hoe+}$; $t.6_{comp}$), thus the finger weeder had no influence on the performance of the hoeing method. Hoeing was observed to have a better selectivity towards weeds than harrowing. Higher water stress, due to higher plant losses and damages, resulted in higher weed infestation and thus higher water competition of soybeans and weeds occurred in harrowing compared to hoeing treatments. Intercropping of camelina was shown not to be suitable for Luxembourg, especially during the dry study years. It was observed that rigorous field management in regards to weed suppression throughout the whole crop rotation is the key factor to maximizing soybean yield. The efficiency of any treatment was low, when weed infestation was already high after soybean emergence. Where low weed infestation was found, any of the treatments were applicable.

Across all sites, 59 weed species were identified with a dominant share of annual and biannual dicotyledonous species. The diversity of weeds, shown by the Shannon index, tended to be reduced by mechanical weed control but weeds were never completely eliminated. In general, hoeing impacted more negatively the diversity than harrowing. *Chenopodium album, Elymus repens, Persicaria lapathifolia, Polygonum convolvulus, Tripleurospermum inodorum* and *Viscia spec* have been identified as the most problematic weeds, being competitive towards soybean or causing nuisance at harvest.

High resolution remote sensing techniques present a variety of valuable tools for monitoring experimental setups. But practical remote sensing methods offer only limited advantages compared to in-situ assessment methods, being the first choice for quantitative data collection in a scientific framework. From a remote sensing point of view, and from a precision agriculture point of view, a follow up of the LeguTec project could pursue the setting up of a plant growth model for soybean. This would allow to predict the development of the crop also in terms of competition with weeds. This tool could serve as a decision support system for farmers, as it would be able to predict the development of soybean for a period of up to two weeks and thus allow better decision making in terms of mechanical weed control.

The high number of visitors at field visits demonstrated the high interest of farmers in soybean cultivation. The dissemination of the gained information helped to start successfully cultivating soybeans. It was confirmed that a continuous consultancy to guide farmers in the new cultivar soybean is crucial.

Further research and continuous practical experience are needed for successful soybean cultivation in Luxembourg, despite the knowledge already obtained. Precision farming technologies for mechanical weed control, like new automatic row guidance systems for inter-row hoeing, are constantly being developed and need to be tested in practice. The hoe can be controlled by camera, as intended in the LeguTec project. Since this device seemed not to work properly in the pre-tests of the present study and therefore was not used, further trials are needed to truly test the benefit from this technology. The changing climate conditions, already observed within the last years, require an adaptation in cultivation and alternative cultivation concepts. Newly developed and existing soybean varieties have to be tested continuously on the national level to follow the suitability of the changing climate conditions. The traditional variety Merlin might no longer be up to date, as other early ripening varieties showed higher yields in the last two years. Alternative cultivation methods like intercropping or direct drilling of soybean were only little researched with no clear results. Soybean cultivation for human consumption might be interesting for Luxembourgish sites, since the requirement of a high protein content is already met. The changing vegetation cycle forces to rethink about the right time for sowing and hoeing; an adequate soil management was observed to be most important in controlling weeds. Here, complementary studies with further practical relevance are necessary. The complex topic of weed regulation methods must continue to be a focus also with regard to the aim of reducing herbicides in conventional farming. Furthermore, continuous on-farm field trials and the support of advisors specialized in soybean cultivation are needed to gain further expertise to reach a successful establishment of national soybean cultivation.

Incentives from public authorities are essential to promote national soybean production and thus protein autarky. Although the Luxembourgish government has committed itself to increase national protein autarky by signing the European Soya declaration in 2017, further political incentives e.g. including soybean into the legume subsidy or the implementation of processing infrastructures have to be discussed. Such incentives and measures should all form part of a future holistic protein strategy for Luxembourg.

8. Outcomes and dissemination

The main focus of the project LeguTec lies on the communication and transfer of the results into the practice to the farmers and interested public mainly in Luxembourg and the Greater Region on the one hand and to scientists on the other hand. Exchanges with experts on the field of soybean cultivation and networking play an important role to reach the goal of improving and increasing protein production in Luxembourg. The following overview of the activities carried out during the project years highlight the great interest of the public in regional soybean cultivation.

8. 1. Activities during the project years

8.1.1 Activities and knowledge network carried out in 2018

The LeguTec logo and a first roll-up were designed by the project partner Wolff-Weyland S.A. at the start of the project. The practical execution of the experiments, the drafting of the assessments and the experimental plan took place in consultation with experts of the *Research Institute for Biological Agriculture Switzerland (FIBL)* and the *Department of Ecological Agricultural Sciences* of the University of Kassel. Expert opinions were also obtained at the Soybean Conference in Rastatt, which took place the 6th and 7th of December 2017. This conference was also used as a contact point for IBLA, for further training in the field of soybean and to gain insight into current and similar soybean projects. An exchange of views and advice on the project design made it possible to come into contact with experts and build up a network. This also resulted in IBLA's membership in the German Soybean Promotion Association (*Deutscher Sojaförderring e.V.*).

After a large part of the preparation and planning had been carried out at the end of 2017 and beginning of 2018, the project LeguTec could start with the internally organized kick-off meeting of the individual partners. The kick-off meeting on 16.02.2018 was attended by representatives of the partners Geocoptix GmbH, Wolff-Weyland S.A., LTA and IBLA as well as the farmers involved in the project to discuss joint agreements, fine-tuning and clarification of responsibilities. On the agenda was the signature of the "Contrat d'étude" by the project partners as well as the signature of the agreement between partner farmers and IBLA.

The following information material and promotional activities have subsequently been produced for the project to date:

- a project leaflet (see Appendix 37),
- specially designed snack soybeans as a giveaway for the project (see Appendix 38),
- a poster with a brief description of the project (see Appendix 39),
- information signs on each of the test fields, as the sites are easily accessible and located along cycle paths.

The article "Soybean made in Luxembourg" was published on 12th of January 2018 in the column Kloertext of the Letzebuerger Journal (see Appendix 39). The project was presented to experts at a colloquium at the University of Kassel, Department of Organic Agriculture in Witzenhausen on 19th of February 2018. Practical suggestions for the experimental design resulted from the subsequent discussion. The project was presented to the public for the first time as part of the conference “Legume Day” on the 2nd of March 2018 in Ettelbrück, organized by IBLA.

On the 8th of June 2018 IBLA together with the LeguTec project partners organized an official field visit on the LeguTec study site at the organic farm Mehlen in Manternach. A large audience of more than 200 visitors, among them Her Royal Highness the Hereditary Grand Duchess, as well as the Minister of Agriculture Mr. Fernand Etgen, the President of the Oeuvre Nationale de Secours Grande-Duchesse Charlotte Mr. Pierre Bley, and a large number of farmers and other interested parties were able to inform themselves about the project and the status of the weed control methods. The audience was led past various stations and informed about the project details by the project partners. The students of the agricultural school were involved in the field inspection and presented the test site Bettendorf (see Figure 66). With this event LeguTec met with great public interest. A large number of articles in regional magazines (Allianz, Alcovit), radio reports (including RTL and radio100,7) and a TV report on RTL confirm this (see Appendix 41).

Figure 66: Official field visit at the study site Mehlen in Manternach.

The project was also in the focus of the IBLA stand at *Foire Agricole Ettelbrück*. With an exhibition of the hoeing technique used in the project, poster information materials as well as the demonstration of the drones by Geocoptix GmbH the visitors could inform themselves. As a special guest we could welcome His Highness the Grand Duke on the IBLA stand, where he informed himself about the LeguTec project. A children's studio, to which various school classes were able to register, provided playful knowledge about the chicken and linked its feeding with the soybean and thus with the LeguTec project. The photographer Nikos Zompolas chosed the project LeguTec for a competition of the association Etika and accompanied the IBLA team during the vegetation period with the work on the three study sites. The photos shown in Appendix 42 were the first results of his work. A postcard from Etika with brief information about the project as well as a picture during the assessment in Hostert is the result of this competition (see Appendix 43).

As part of a field visit to organic soybean cultivation in Wallonia, Belgium, on 21st of September in Nalinnes, an exchange of experiences took place with the local specialists (forfarmes, SCAR, BioWallonie, Wallonie research CRA-W and Province de Liège Agriculture). At the "Semaine de la machine agricole", which was organized by the project partner Wolff-Weyland S.A. (18.10.-22.10.2018), the project content as well as first results were presented to the public on an information desk.

8.1.2 Activities carried out in 2019

The Luxembourgish Legume Day yearly organized by IBLA took place the 8th of February 2019 in Ettelbrück. In the focus of soybean cultivation, more than 100 interested participants informed themselves about the possibility of cultivating soybean in Luxembourg. As a main part, first results of the project LeguTec were presented hand in hand with the project partners Geocoptix GmbH and some students of the agricultural school.

As an essential part as well in 2019 the official field visit took place on 20.06.2019 at the study site in Hostert, which, as in the previous year, aroused great public interest. More than 100 farmers and other interested parties informed themselves about the progress of the project. The machines used in the trial were demonstrated and a flight demonstration with the drone was conducted by the Geocoptix GmbH team (see Figure 67).

Figure 67: Official field visit in 2019 at the study site Hostert.

A further activity carried out within the framework of the project was the official field visit of the demonstration fields in Bettendorf on June 14, 2019, during which the soybean on-farm field trial was explained with the help of the agricultural students.

A list of media contributions of the LeguTec project published during the years 2019 and 2020 are shown in Appendix 41 including the corresponding links.

8.2 Conference participation and publication

The first results gained in the first project year 2018 were presented on 17th and 18th of October 2018 at the legume conference "2e Rencontres Francophones sur les Légumineuses" in Toulouse in the form of a poster presentation. Further results were presented also on a poster at the Soybean Conference 2018, which took place on 23rd to 24th of October in Würzburg, Germany as well as at the international conference ICOAS 2018 (6th International Conference on Organic Agriculture Sciences) from 7th to 8th of November 2018 in Eisenstadt, Austria (see Appendix 44). The first publications from the mentioned participations in international conferences and meetings are listed below:

> ***Leimbrock, L.; Rock, G.; Diederich, R.; Krier, R.; Reiland, G; Stoll, E.; Zimmer, S. (2018). LeguTec – Mechanical weed control in soybean cultivation in Luxembourg. ICOAS, 7.-8. November 2018, Eisenstadt, Austria. Book of Abstracts, p. 80.***
>
> ***Leimbrock, L.; Altmann, G.; Rock, G.; Diederich, R.; Krier, R.; Reiland, G; Stoll, E.; Zimmer, S. (2018). Désherbage mécanique dans la culture du soja bio au Luxembourg. RFL2, 17.-18. Oktober 2018, Toulouse, France. Livre des Résumés, p. 215.***

From 2019 on, conference contributions at two international scientific conferences, the 15th Science Conference on Organic Agriculture in Kassel, Germany and the EGU General Assembly 2020 in Vienna, Austria (see Appendix 45) took place. Two further contributions were planned for the Organic World Congress 2020 in May 2020. The submitted abstracts were accepted for presentation to the committee. However, due to COVID-19 the conference had to be postponed to 2021. Two more conference contributions for the World Soybean Research Conference 11 in Novi Sad, Serbia and for the RFL 3 ("3e Rencontres Francophones sur les Légumineuses") were postponed to 2021 due to the same reason. It is planned to present the final project results at these conferences as well.

The following scientific publications resulted from the conference participations in 2019 and 2020:

> ***Leimbrock, L., Rock, G., Diederich, R., Krier, R., Reiland, G., Stoll, E., Zimmer, S. (2019). LeguTec – mechanische Beikrautregulierung im Sojaanbau in Luxemburg. 15. Wissenschaftstagung Ökologischer Landbau, Kassel, Germany. 06.-08. March 2019, p. 84.***
>
> ***Richard, D., Leimbrock, L., Rock, G., Diederich, R., Reiland, G., and Zimmer, S. (2020). Effects of mechanical weed control in organic soybean cultivation on weed biomass and diversity in Luxembourg, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-7564, https://doi.org/10.5194/egusphere-egu2020-7564, 2020.***

Richard, D., Zimmer, S., Naudin, C., Leimbrock, L. (2020). Impact of different mechanical weed control methods on weed communities, in organic soybean cultivation, in Luxembourg. Organic World Congress 2020, Rennes, France. Accepted for poster presentation, postponed to 2021.

Leimbrock, L., Rock, G., Reiland, G., Richard, D., Zimmer, S. (2020). Effects of mechanical weed control in organic soybean cultivation on yield and weed biomass in Luxembourg. Organic World Congress 2020, Rennes, France. Accepted for oral presentation, postponed to 2021.

In cooperation with IBLA and ESA - École Supérieure d'Agricultures d'Angers, France, a master thesis on a sub-topic on herb composition was successfully written under the following title by David Richard

Richard, D. (2019). Evaluation of the success of different weed control methods and their consequences on weed communities, in organic soybean cultivation in Luxembourg. Master Thesis. ESA - École Supérieure d'Agricultures d'Angers, France.

respectively written in French language as the following thesis

Richard, D. (2019). Evaluer le succès de différentes méthodes de désherbage mécanique et leurs effets sur les communautés adventices, pour la culture du soja en agriculture biologique au Luxembourg. Master Thesis. ESA - École Supérieure d'Agricultures d'Angers, France.

During the project year 2020, which is dedicated to data evaluation and publication, an article was also published in the international journal Organic Agriculture published by Springer Verlag (see Appendix 46) titled follows

Richard, D.; Leimbrock-Rosch, L.; Keßler, S.; Zimmer, S.; Stoll, E. (2020). Impact of different mechanical weed control methods on weed communities in organic soybean cultivation in Luxembourg. Org. Agr. doi.org: 10.1007/s13165-020-00296-1.

A further scientific article including the results of this final report is planned to be submitted by the end of this year.

8.3 Initiatives and perspectives

The good cooperation between the project partners and especially with the farmers involved enables a practical experiment procedure. Flexible planning and spontaneous, weather-related assignments worked without any problems. The great interest on the part of the public and the farmers shows the topicality of the project and confirms the implementation of the project in soybean culture.

The increased interest in regional soybean cultivation due to the LeguTec project prompted Bio-OVO to launch a new project in 2019 with a three years duriation. BIO-OVO is an eggs producer association and has set itself the goal of increasing its protein self-sufficiency by increasing the proportion of soya in its feed rations from regional sources. Together with the project partners IBLA, SCAR Scrl, Wolff-Weyland S.A., Lycée Technique Agricole (LTA) and Piet van Luijk Sàrl, a conclusive concept for national soybean production was developed: From the accompaniment and advice of the seed, mechanical weed control (required technology) over the harvest up to the cleaning, drying, storage, preparation and further processing in the feed rations for the BIO-OVO laying hens (see Figure 68).

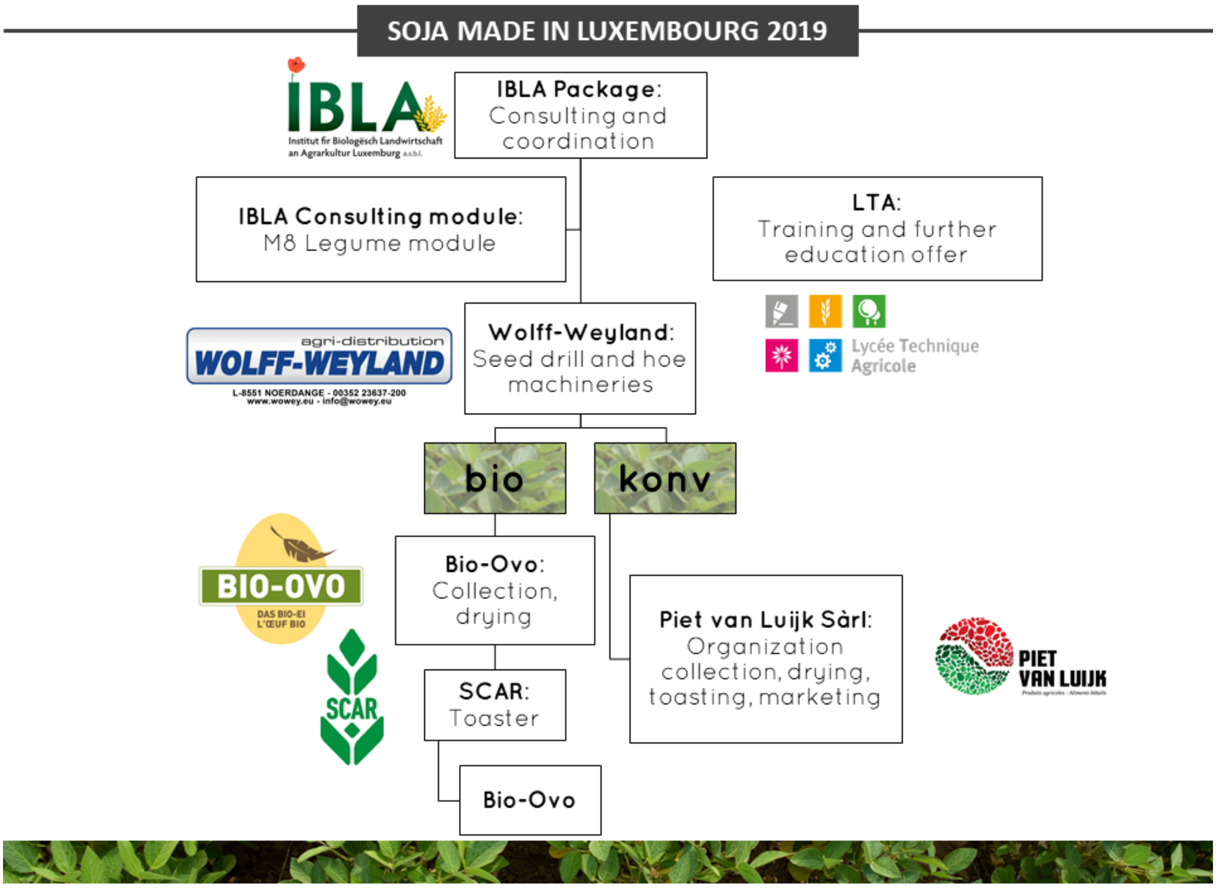


Figure 68: Overview of the new project of Bio-OVO, which was developed from the increased public interest in the context of LeguTec.

During the first project year 2019 five farmers started cultivating organic soybean on an overall area of 12 ha. The gained experience within LeguTec was used by IBLA in advising the farmers and accompanying them throughout the soybean production cycle. Highest yields were obtained amounting up to 23.2 dt ha^{-1}. In 2020 the cultivated area slightly increased. Until now, only organic soybean cultivation was chosen by the farmers. Mechanical weed control performed well mainly with the use of a hoe. Due to the small quantity further processing is still difficult. High costs resulted from soybean cleaning, drying and transportation. Due to the small quantities, spontaneous solutions within the further processing had to be found e.g. mobile dryer that can deal with small amounts of harvested soybeans. If quantities would increase it would be easier to move to fixed places for drying and cleaning so that the machines (e.g. dryer) are operated with the minimum quantity they need to run. Nevertheless, the demand for organic EU - soybean is high and the market price remains stable. Average market price for organic soybeans between 2015 and 2019 was 82.52 € dt^{-1} (incl. 10 % TVA), while for conventional soybean an average market price of 38.42 € dt^{-1} (incl. 10 % TVA) was given (Lfl, 2020). It is intended to meet the high interest from farmers for soybean cultivation and to increase the organic soybean production in the coming years.

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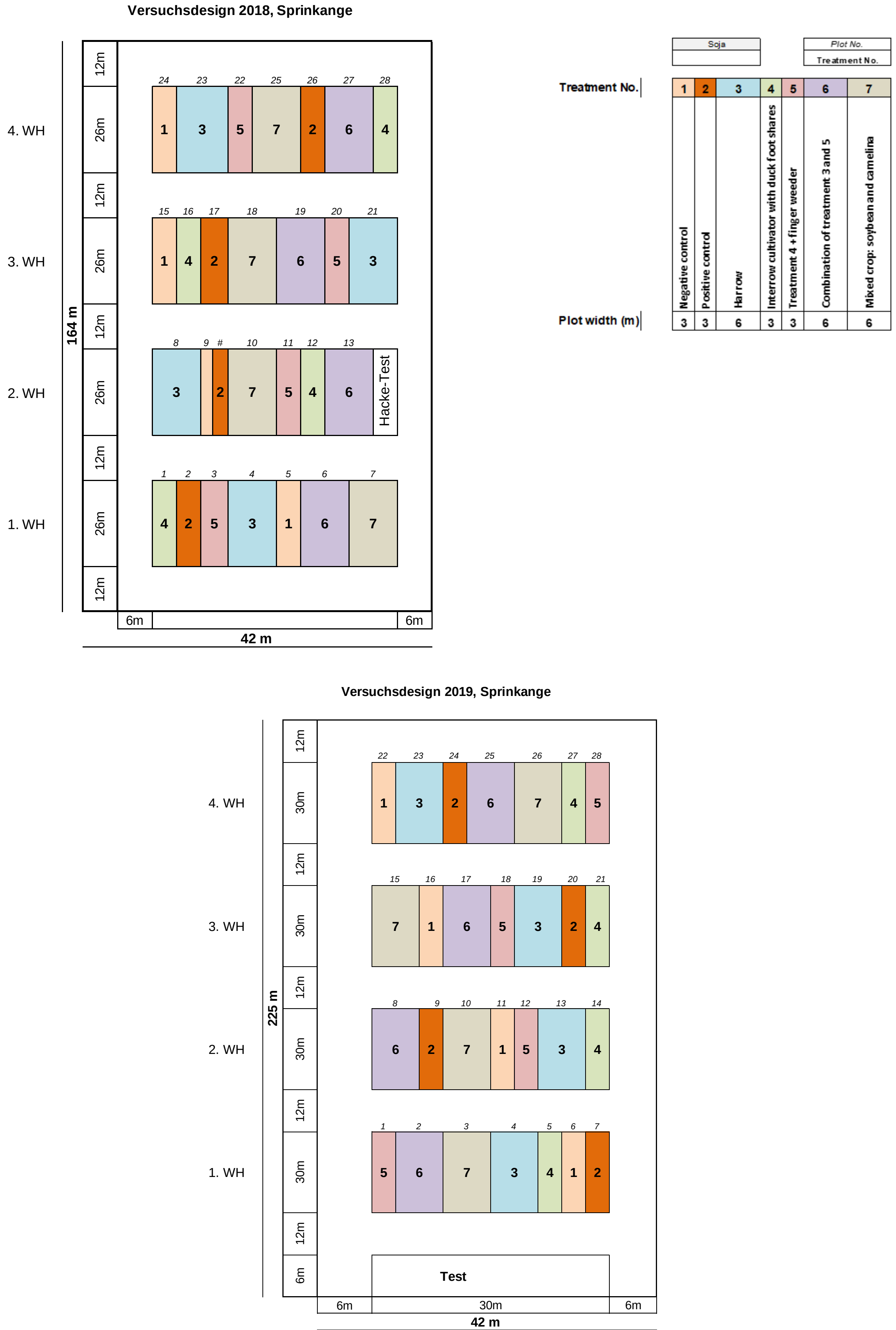
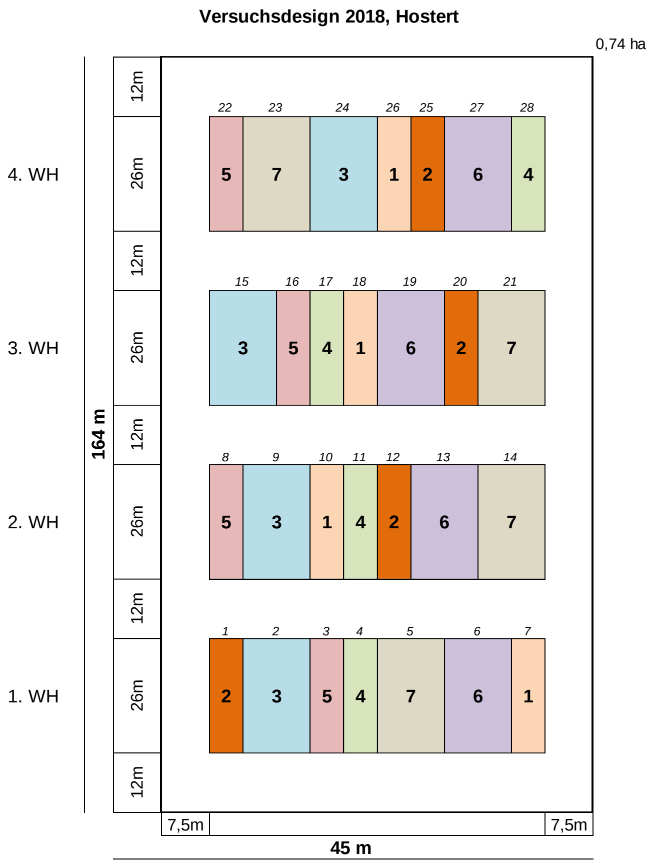
Appendix

Appendix 1: Experimental design of the study site Sprinkange for the years 2018 (upper) and 2019 (lower). Numbers within the plots indicate the treatment according to the legend (upper right).



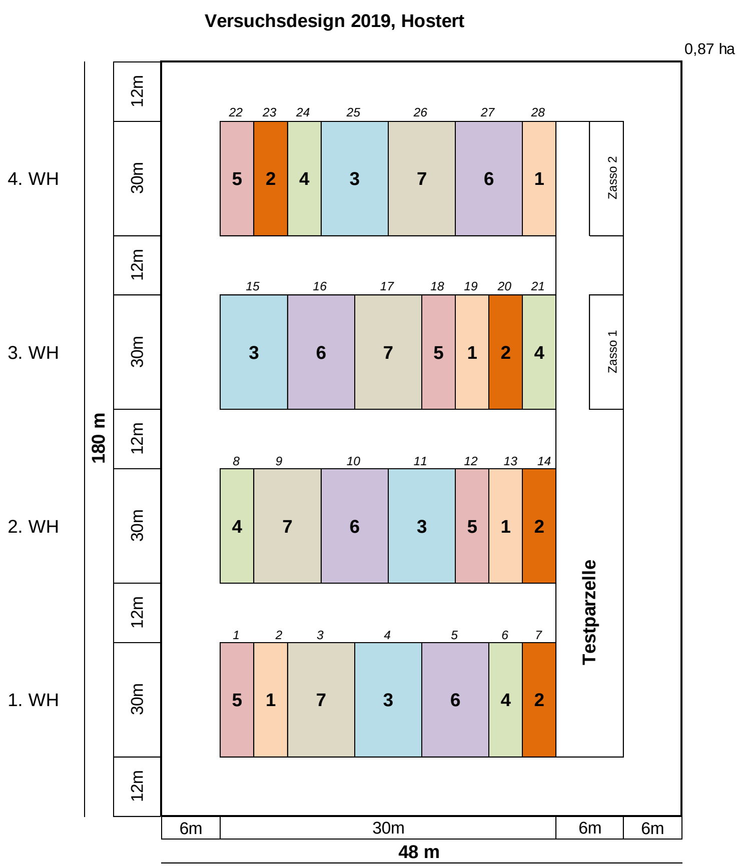
Appendix 2: Experimental design of the study site Sprinkange for the years 2018 (upper) and 2019 (lower). Numbers within the plots indicate the treatment according to the legend (upper right).



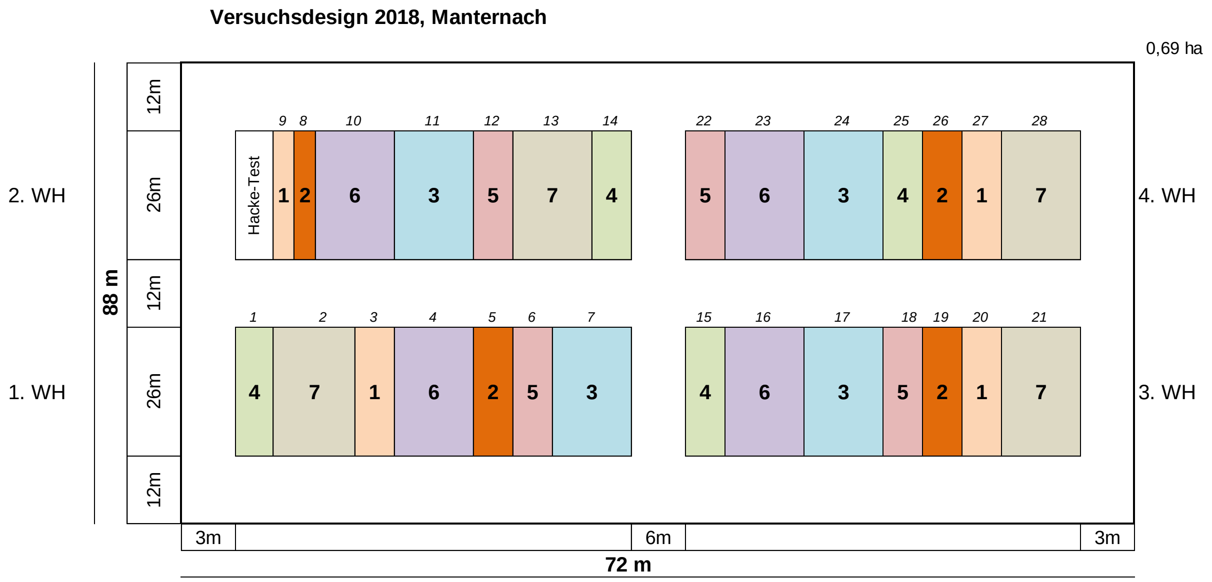
Soja

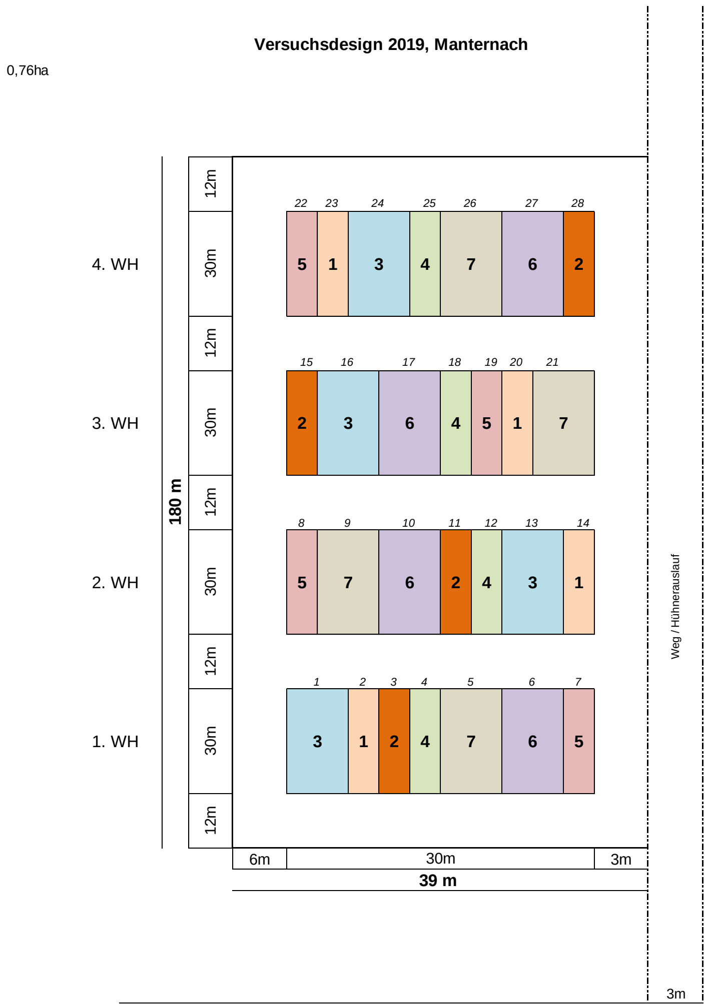
Plot No.
Treatment No.

Treatment No.	1	2	3	4	5	6	7
	Negative control	Positive control	Harrow	Interrow cultivator with duck foot shares	Treatment 4 + finger weeder	Combination of treatment 3 and 5	Mixed crop: soybean and camelina
Plot width (m)	3	3	6	3	3	6	6



Appendix 3: Experimental design of the study site Sprinkange for the years 2018 (upper) and 2019 (lower). Numbers within the plots indicate the treatment according to the legend (middle).





Soja	Plot No.
	Treatment No.

Treatment No.	1	2	3	4	5	6	7
	Negative control	Positive control	Harrow	Interrow cultivator with duck foot shares	Treatment 4 + finger weeder	Combination of treatment 3 and 5	Mixed crop: soybean and camelina
Plot width (m)	3	3	6	3	3	6	6

Appendix 4: BBCH stages of soybean (Glycine max. Merr. L) (Munger et al., 1997).

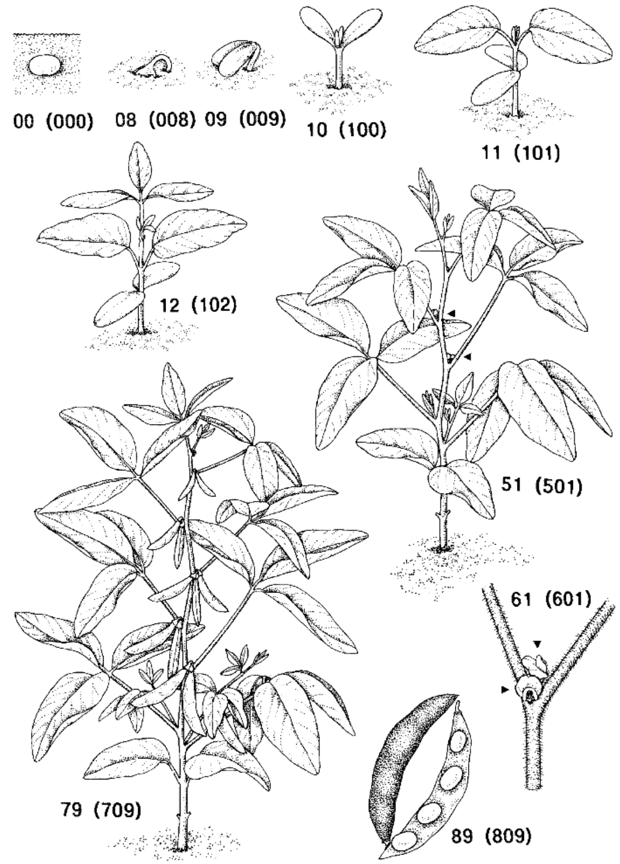
Sojabohne Munger et al., 1997

BBCH-Codierung der phänologischen Entwicklungsstadien der Sojabohne
(*Glycine max* L. Merr.)

Code		Beschreibung
2- und 3stellig		
Makrostadium 0: Keimung		
00	000	Trockener Samen
01	001	Beginn der Samenquellung
03	003	Ende der Samenquellung
05	005	Keimwurzel aus Samen ausgetreten
06	006	Streckung der Keimwurzel
07	007	Hypokotyl mit Keimblättern hat Samenschale durchbrochen
08	008	Hypokotyl erreicht die Bodenoberfläche. Keimblätter noch im Boden
09	009	Auflaufen: Hypokotyl mit Keimblättern durchbricht Bodenoberfläche («cracking stage»)
2- und 3stellig		
Makrostadium 1: Blattentwicklung (Hauptspross)		
10	100	Keimblätter voll entfaltet
11	101	Erstes Laubblattpaar am ersten Nodium entfaltet
12	102	Laubblatt am 2. Nodium entfaltet
13	103	Laubblatt am 3. Nodium entfaltet
1 .	10 .	Stadien fortlaufend bis ...
19	109	Laubblatt am 9. Nodium entfaltet[1]
	110	Laubblatt am 10. Nodium entfaltet[1]
	111	Laubblatt am 11. Nodium entfaltet[1]
	112	Laubblatt am 12. Nodium entfaltet[1]
	113	Laubblatt am 13. Nodium entfaltet[1]
	11 .	Stadien fortlaufend bis ...
	119	Laubblatt am 19. Nodium entfaltet[1]

[1] Die Seitentriebentwicklung kann früher beginnen; in diesem Fall auf Makrostadium 2 übergehen

Sojabohne



Appendix 5: BBCH stages of soybean (Glycine max. Merr. L) (Munger et al., 1997).

Sojabohne Munger et al., 1997

BBCH-Codierung der phänologischen Entwicklungsstadien der Sojabohne

Code		Beschreibung
2- und 3stellig		
Makrostadium 2: Entwicklung von Seitensprossen		
21	201	Erster Seitenspross sichtbar
22	202	2. Seitenspross erster Ordnung sichtbar
23	203	3. Seitenspross erster Ordnung sichtbar
2 .	20 .	Stadien fortlaufend bis ...
29	209	9 oder mehr Seitensprosse erster Ordnung sichtbar (2stellig) 9. Seitenspross erster Ordnung sichtbar (3stellig)
	210	10. Seitenspross erster Ordnung sichtbar
	221	Erster Seitenspross zweiter Ordnung sichtbar
	22 .	Stadien fortlaufend bis...
	229	9. Seitenspross zweiter Ordnung sichtbar
	2N1	Erster Seitenspross N-ter Ordnung sichtbar
	2N9	9. Seitenspross N-ter Ordnung sichtbar
2- und 3stellig		
Makrostadium 4: Entwicklung vegetativer Pflanzenteile Ernteprodukt		
49	409	Erntefähige vegetative Pflanzenteile haben endgültige Grösse erreicht (Schnittgut von Soja zur Verfütterung)
2- und 3stellig		
Makrostadium 5: Entwicklung der Blütenanlagen		
51	501	Erste Blütenknospen sichtbar
55	505	Erste Blütenknospen gestreckt
59	509	Erste Blütenblätter sichtbar; Blüten noch geschlossen

Sojabohne Munger et al., 1997

BBCH-Codierung der phänologischen Entwicklungsstadien der Sojabohne

Code		Beschreibung
2- und 3stellig		
Makrostadium 6: Blüte		
60	600	Erste Blüten vereinzelt im Bestand offen
61	601	Beginn der Blüte: 10% der Blüten offen[3] Beginn der Blüte[4]
62	602	20% der Blüte offen[3]
63	603	30% der Blüten offen[3]
64	604	40% der Blüten offen[3]
65	605	Vollblüte: 50% der Blüten offen[3] Hauptblüte[4]
66	606	60 % der Blüten offen[3]
67	607	Abgehende Blüte[3]
69	609	Ende der Blüte: erste Hülsen sichtbar (ca. 5 mm lang)
2- und 3stellig		
Makrostadium 7: Frucht- und Samenentwicklung		
70	700	Erste Hülsen haben endgültige Länge erreicht (15–20 mm)
71	701	10% der Hülsen haben endgültige Länge erreicht (15–20 mm)[3] Beginn der Hülsenentwicklung[4]
72	702	20% der Hülsen haben endgültige Länge erreicht (15–20 mm)[3] Beginn der Hülsenfüllung[4]
73	703	30% der Hülsen haben endgültige Länge erreicht (15–20 mm)[3] Beginn der Hülsenfüllung[4]
74	704	40% der Hülsen haben endgültige Länge erreicht (15–20 mm)[3] Beginn der Hülsenfüllung[4]
75	705	50% der Hülsen haben endgültige Länge erreicht (15–20 mm)[3] Hauptphase der Hülsenentwicklung; fortschreitende Hülsenfüllung[4]
77	707	70% der Hülsen haben endgültige Länge erreicht (15–20 mm); fortgeschrittene Hülsenfüllung.[3] Fortgeschrittene Hülsenfüllung[4]
79	709	Fast alle Hülsen haben endgültige Grösse erreicht (15–20 mm); Samen füllt die Hülse aus[3, 4]

[3] Für die determinanten Sorten
[4] Für die nicht-determinanten Sorten

Appendix 6: BBCH stages of soybean (Glycine max. Merr. L) (Munger et al., 1997).

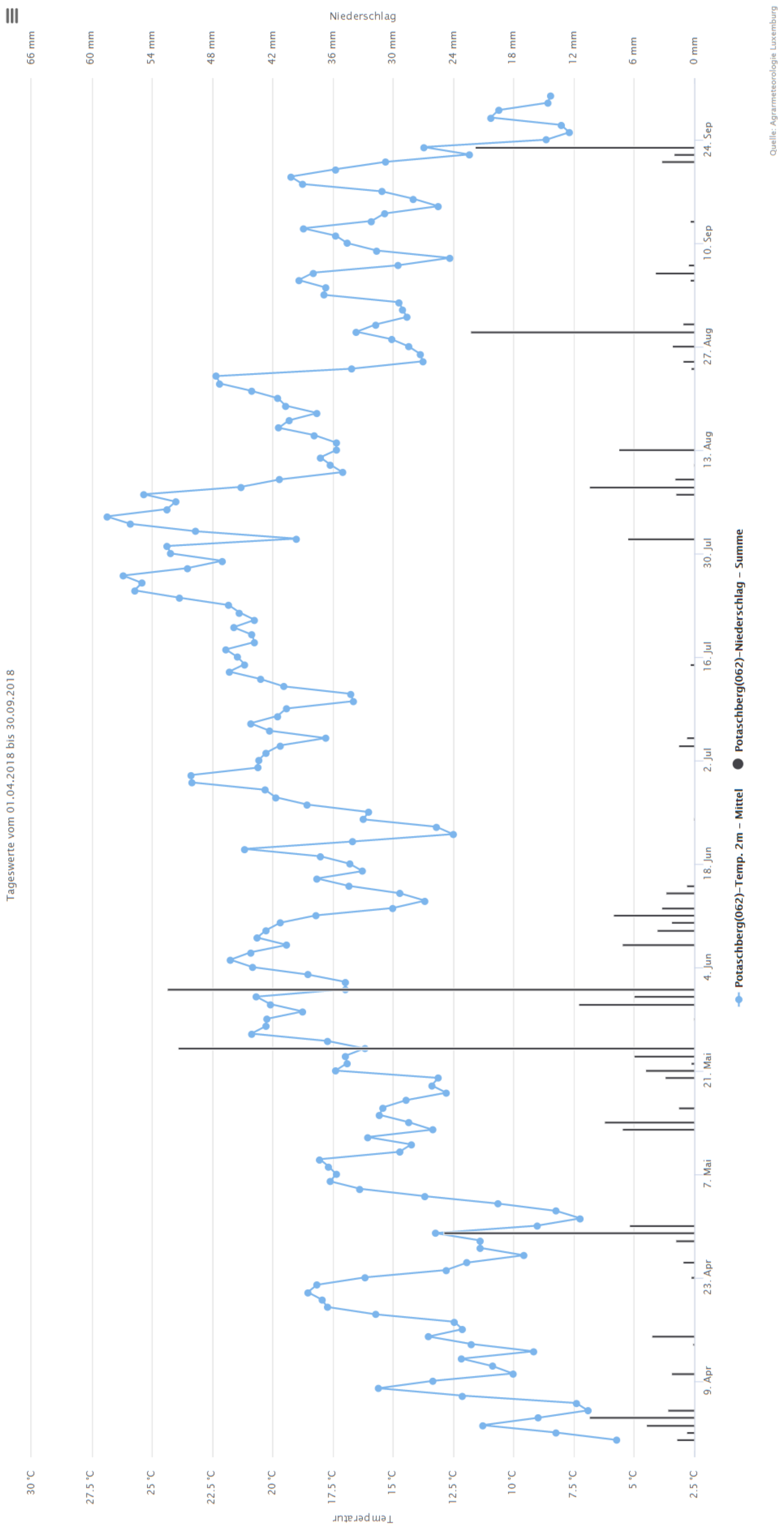
Sojabohne Munger et al., 1997

BBCH-Codierung der phänologischen Entwicklungsstadien der Sojabohne

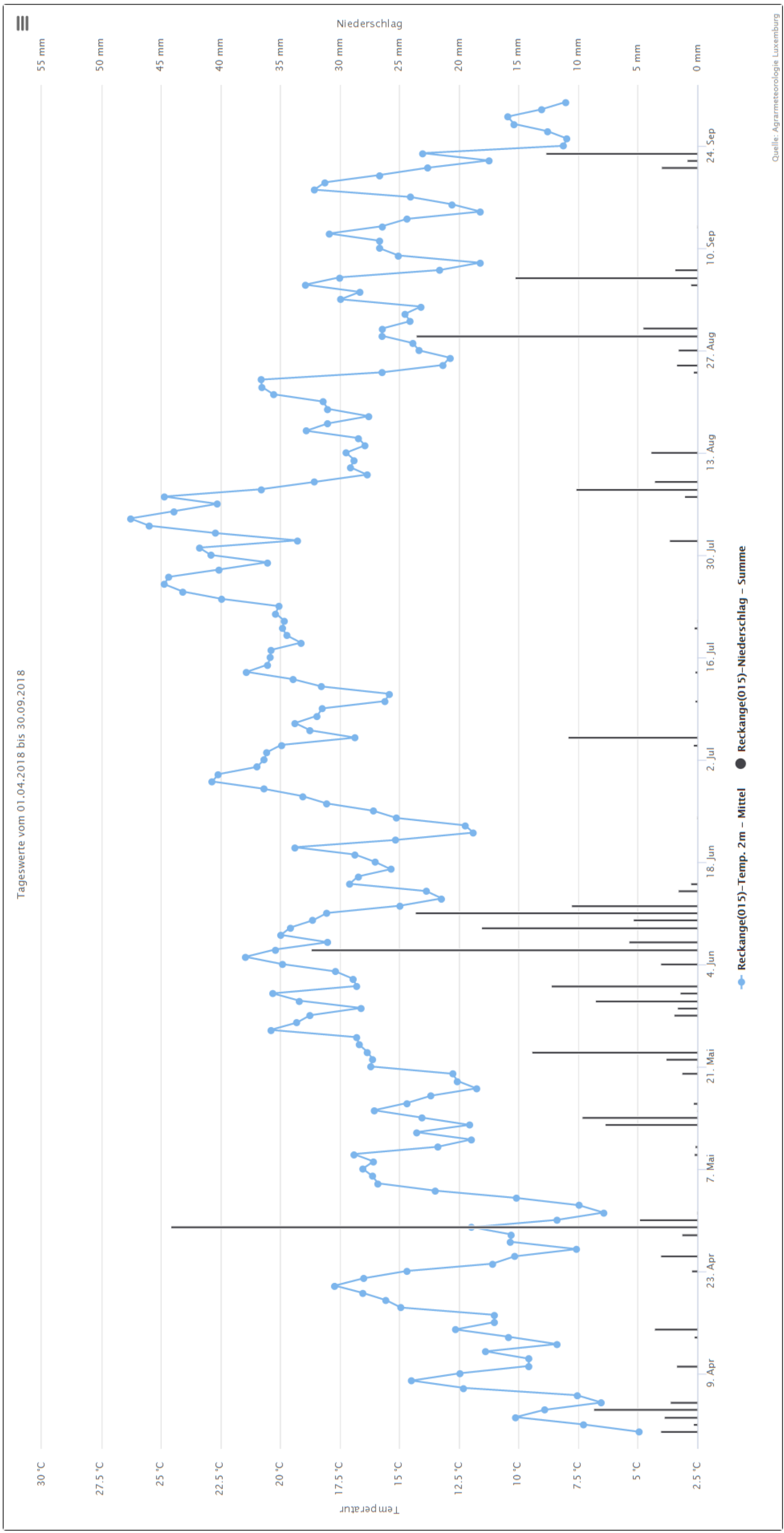
Code		Beschreibung
2- und 3stellig		
Makrostadium 8: Frucht- und Samenreife		
80	800	Erste Hülsen reif, Samen haben endgültige Farbe und sind hart und trocken
81	801	Beginn der Reife: 10% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart.[3] Beginn der Hülsen- und Samenreife[4]
82	802	20% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
83	803	30% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
84	804	40% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
85	805	Fortschreitende Reife: 50% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart.[3] Hauptphase der Hülsen- und Samenreife[4]
86	806	60% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
87	807	70% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
88	808	80% der Hülsen reif; Samen haben endgültige Farbe und sind trocken und hart[3]
89	809	Vollreife: alle Hülsen sind reif; Samen haben endgültige Farbe und sind trocken und hart (Erntereife)[3] Mehrzahl der Hülsen sind reif; Samen haben endgültige Farbe und sind trocken und hart[4]
2- und 3stellig		
Makrostadium 9: Absterben		
91	901	10% der Blätter sind verfärbt oder abgefallen
92	902	20% der Blätter sind verfärbt oder abgefallen
93	903	30% der Blätter sind verfärbt oder abgefallen
94	904	40% der Blätter sind verfärbt oder abgefallen
95	905	50% der Blätter sind verfärbt oder abgefallen
96	906	60% der Blätter sind verfärbt oder abgefallen
97	907	Fast alle oberirdischen Pflanzenteile trocken
99	909	Erntegut

[3] Für die determinanten Sorten
[4] Für die nicht-determinanten Sorten

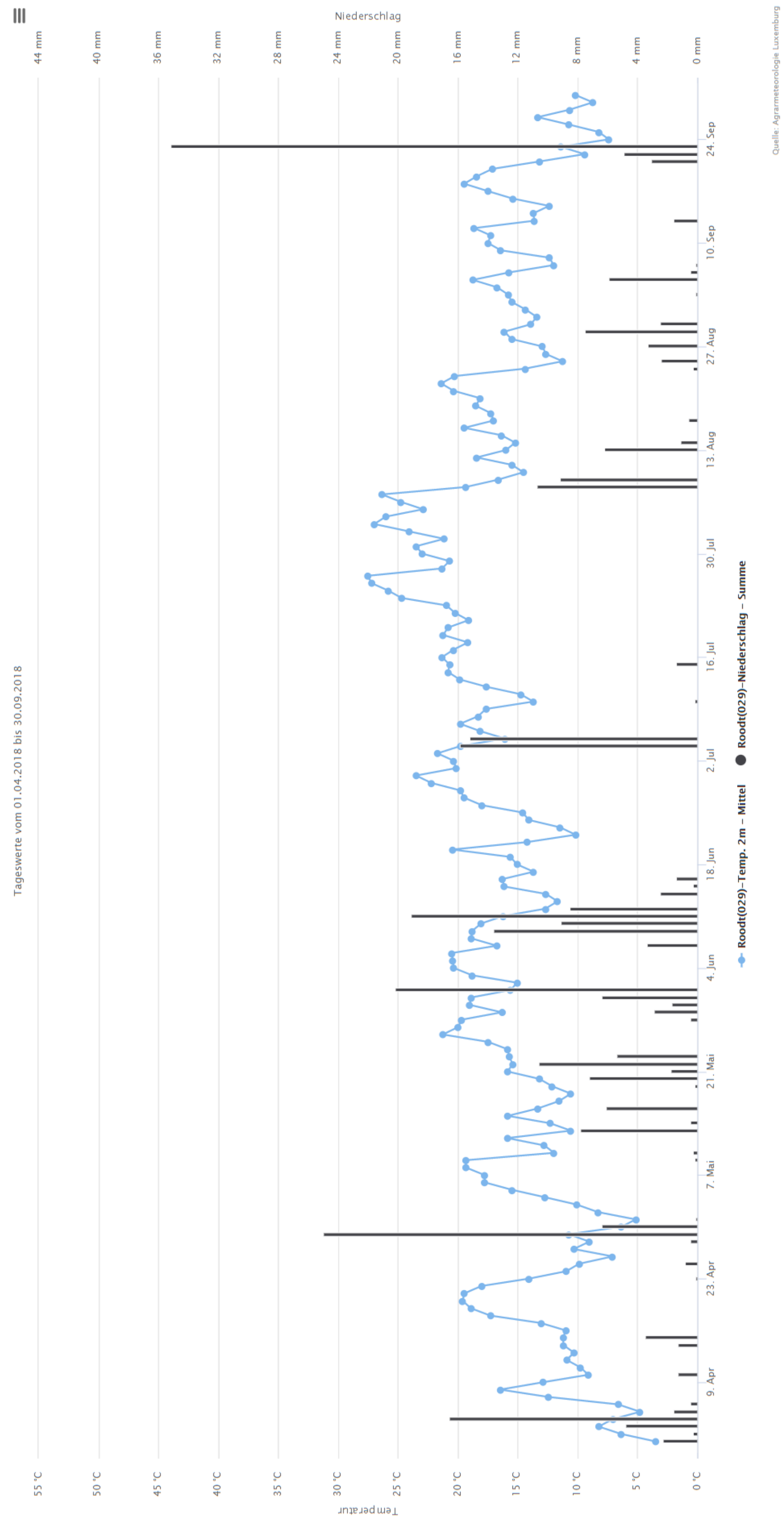
Appendix 7: Daily mean temperature (blue line) and precipitation (black bars) of weather station Potaschbierg, representative for study site Manternach in 2018 (agrimeteo.lu).



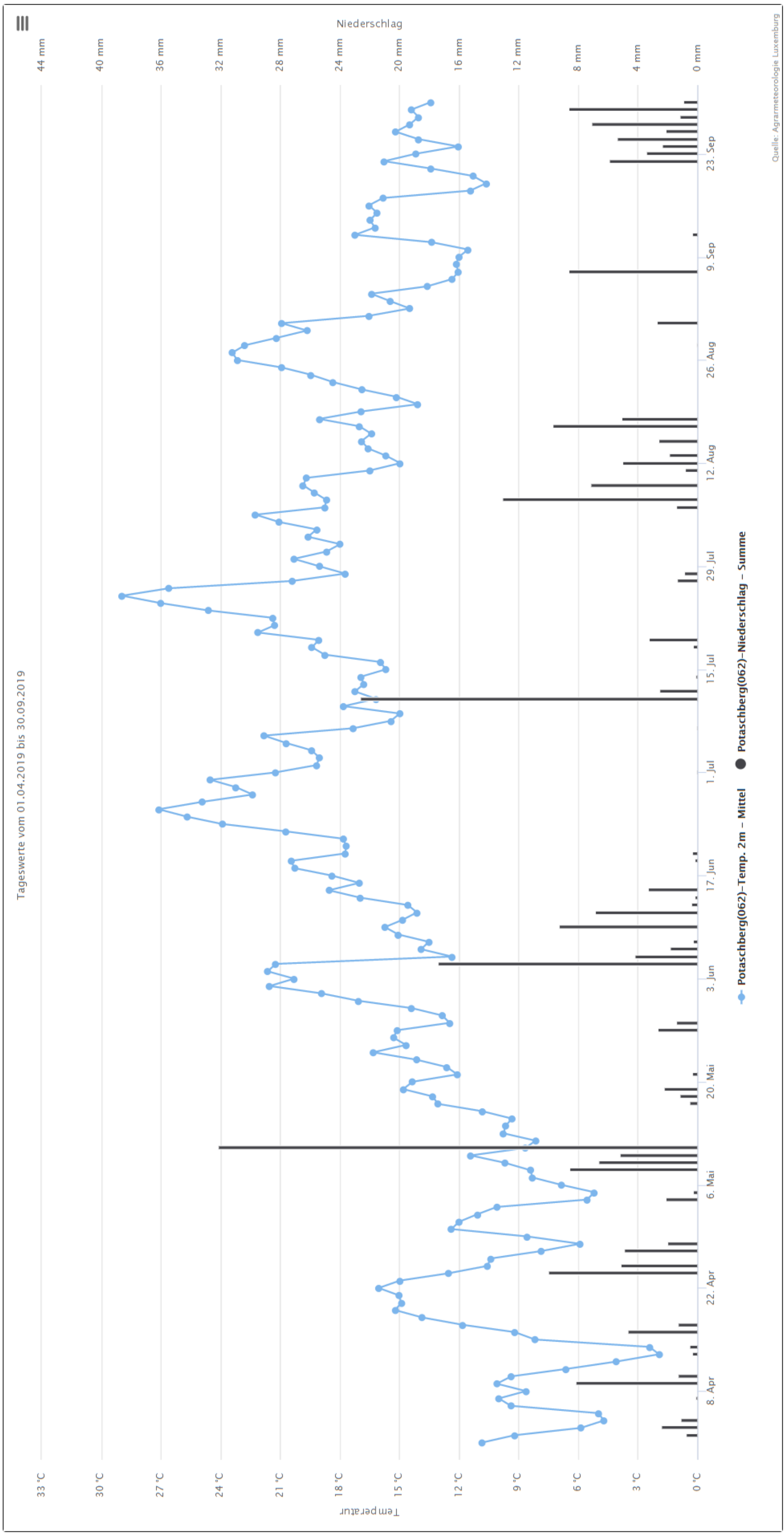
Appendix 8: Daily mean temperature (blue line) and precipitation (black bars) of weather station Reckange, representative for study site Sprinkange in 2018 (agrimeteo.lu).



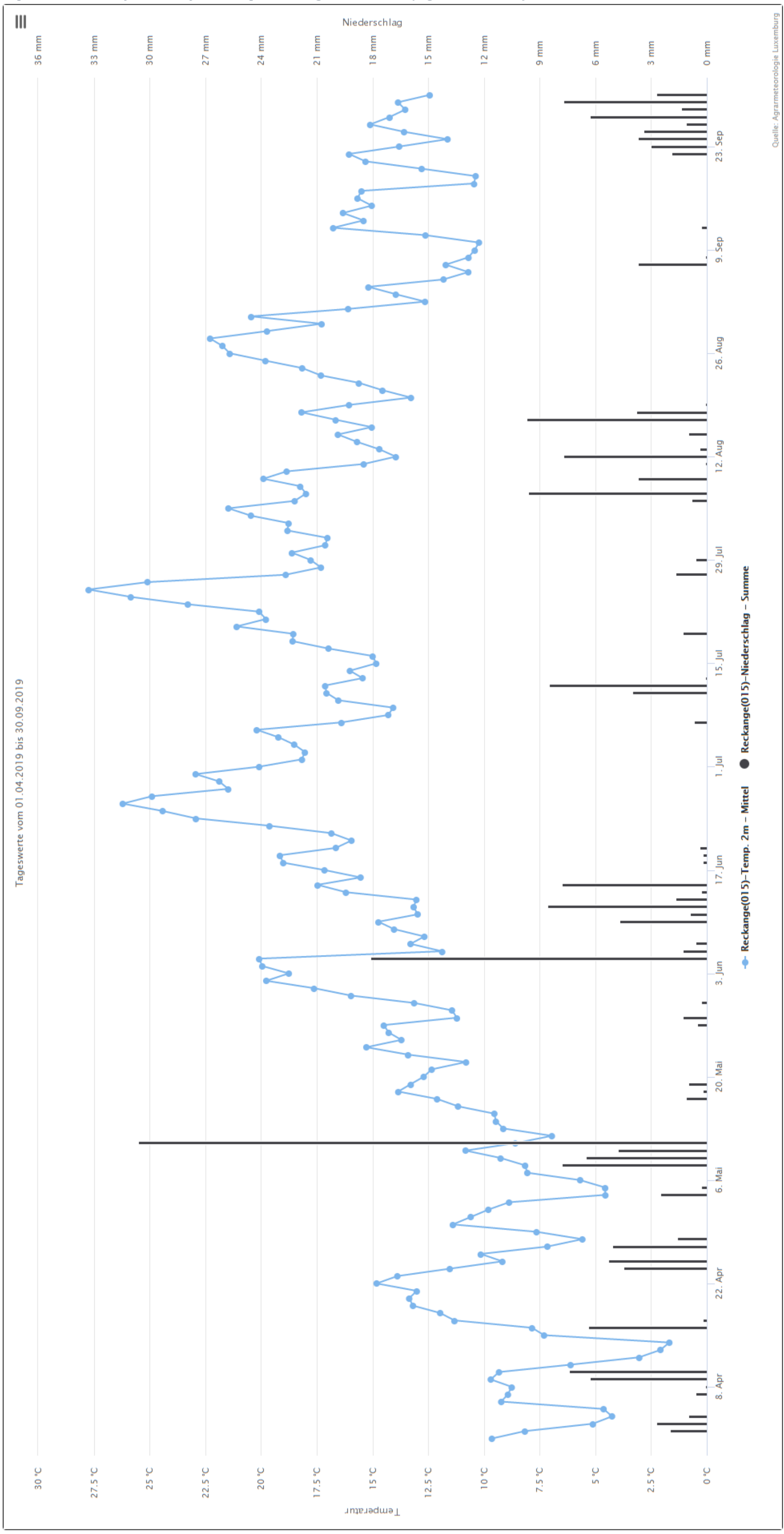
Appendix 9: Daily mean temperature (blue line) and precipitation (black bars) of weather station Roodt, representative for study site Hostert in 2018 (agrimeteo.lu).



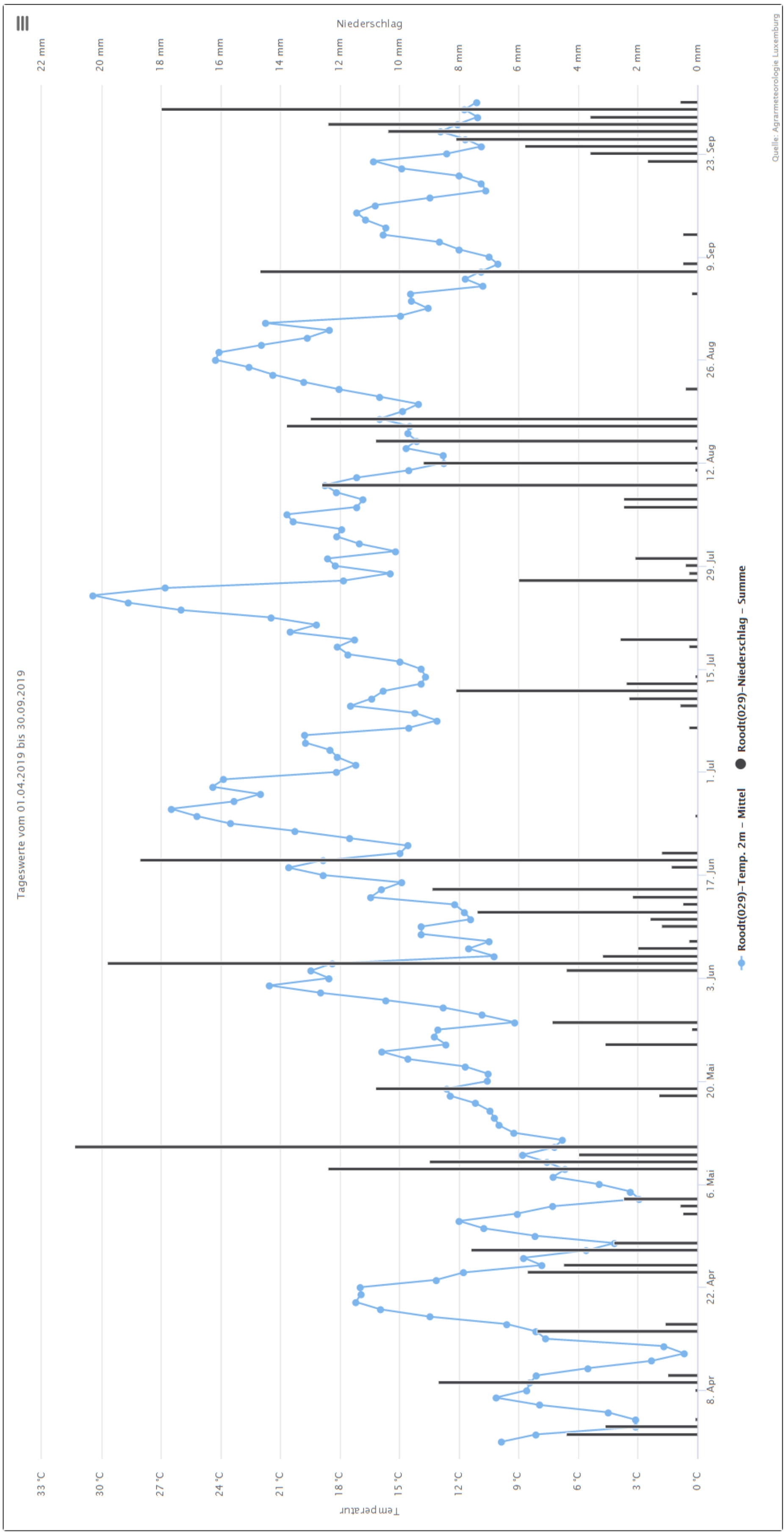
Appendix 10: Daily mean temperature (blue line) and precipitation (black bars) of weather station Potaschbierg, representative for study site Manternach in 2019 (agrimeteo.lu).



Appendix 11: Daily mean temperature (blue line) and precipitation (black bars) of weather station Reckange, representative for study site Sprinkange in 2019 (agrimeteo.lu).



Appendix 12: Daily mean temperature (blue line) and precipitation (black bars) of weather station Roodt, representative for study site Hostert in 2019 (agrimeteo.lu).



Appendix 13: Braun-Blanquet abundance-dominance scale (according to Braun-Blanquet, 1932).

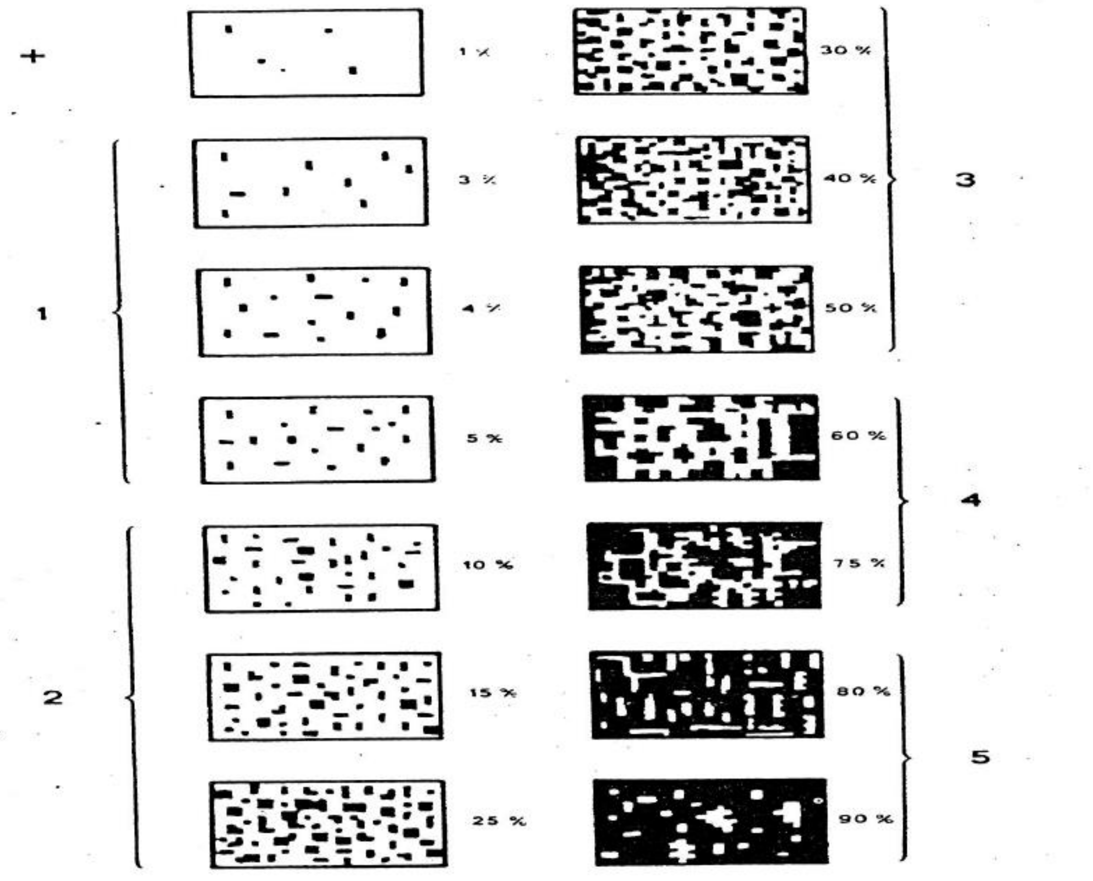
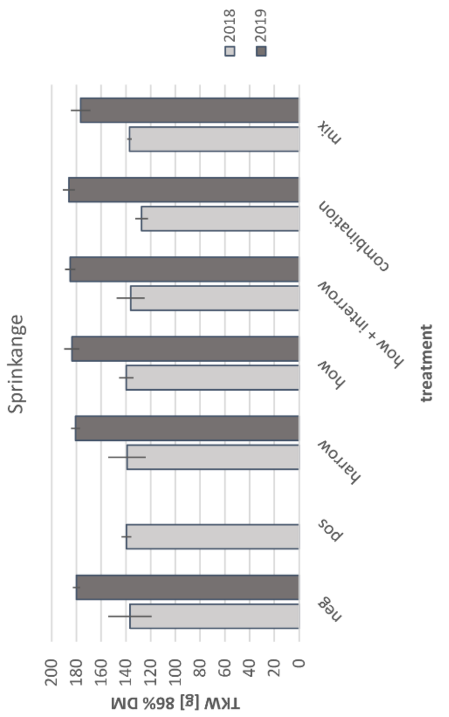


Fig. 2.19 - Modelli per una stima delle percentuali di abbondanza-dominanza secondo il metodo di Braun-Blanquet.

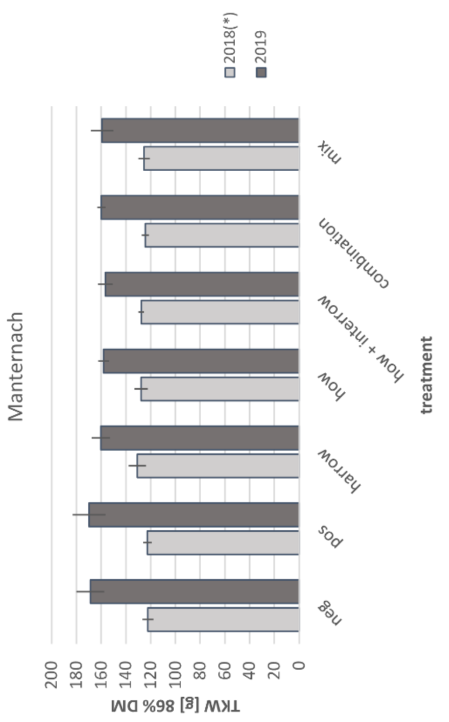
Figure 2. Reference pictures for estimating per cent weed cover by visual assessment. Weeds are represented by black areas. Codes outside parentheses are the corresponding values of the Braun-Blanquet abundance-dominance scale.

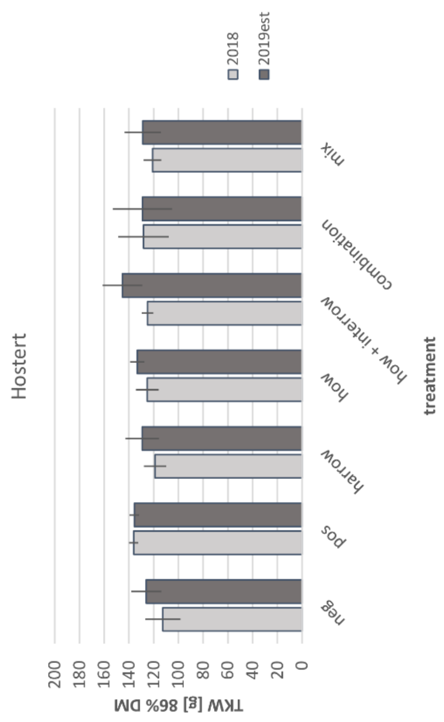
Appendix 14: Mean thousand kernel weight [g] at 86 % dry matter of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey's test and Fisher's test (ANOVA p≤0.1) (*).

TKW [g] 86 % DM



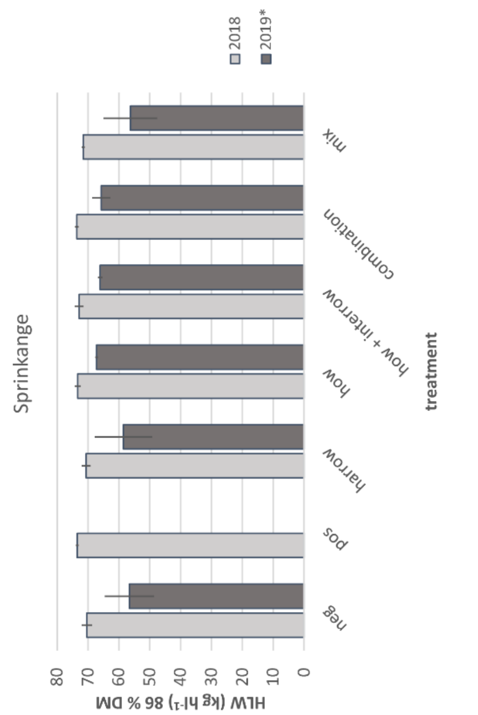
Treatment	TCW (g) 86% DM										
	Manternach				Sprinkange				Hostert		
	2018(*)		2019		2018		2019		2018		2019est
t.1 neg	122.3	b	168.8	n.s.	136.7	n.s.	180.0	n.s.	112.6	n.s.	NA
t.2 pos	122.6	b	169.8		139.6		-		136.1		
t.3 harrow	130.8	a	160.3		139.1		180.7		118.9		
t.4 how	127.8	ab	158.1		139.7		183.7		125.1		
t.5 how + interrow	127.6	ab	156.6		136.2		185.0		125.0		
t.6 combination	124.3	b	159.8		127.3		186.1		128.2		
t.7 mix	125.4	ab	159.3		137.1		176.6		120.9		



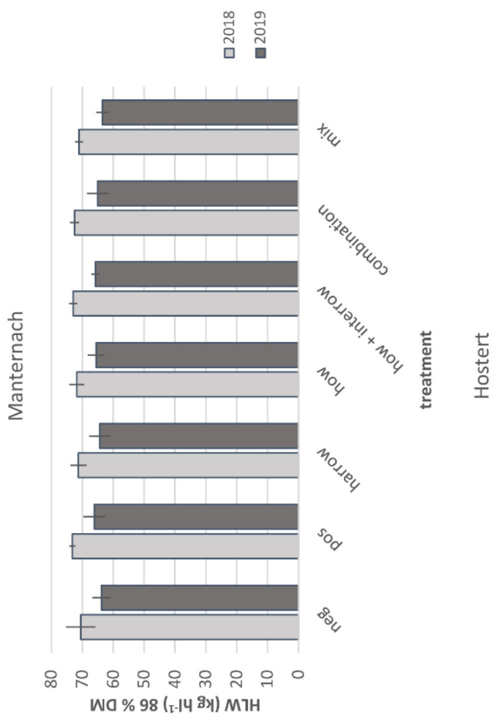


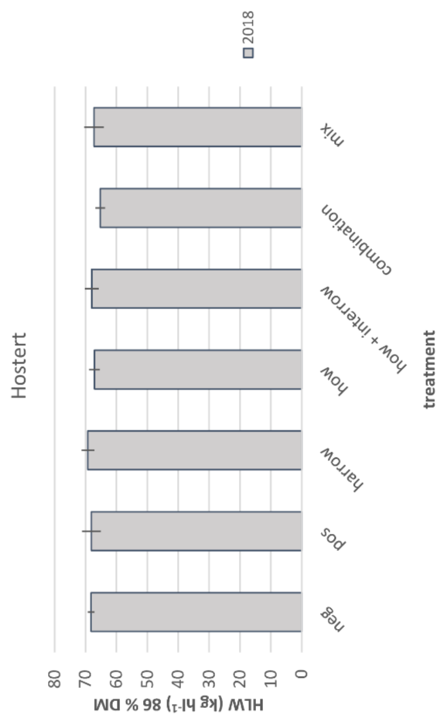
*Appendix 15: Mean hectoliter weight [kg hl-1] at 86 % dry matter of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey's test and Fisher's test *.*

HLW [kg hl-1] 86 % DM



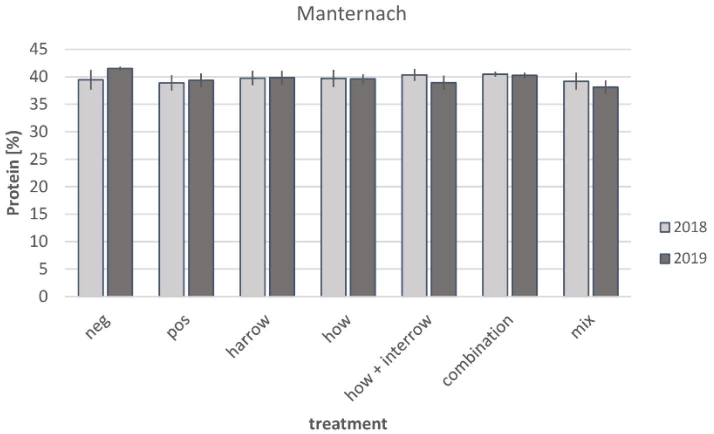
Treatment	HLW (kg/hl) 86 % DM									
	Manternach				Sprinkange				Hostert	
	2018		2019		2018		2019*		2018	2019
t.1 neg	70.6	n.s.	63.8	n.s.	70.4	c	56.6	bc	68.2	n.s. NA
t.2 pos	73.2		66.1		73.5	ab	-		68.1	
t.3 harrow	71.3		64.4		70.7	bc	58.6	abc	69.2	
t.4 how	71.8		65.5		73.3	ab	67.2	a	67.1	
t.5 how + interrow	73.0		65.7		72.8	abc	66.1	ab	67.9	
t.6 combination	72.5		65.0		73.6	a	65.7	abc	65.2	
t.7 mix	71.1		63.5		71.5	abc	56.3	c	67.3	

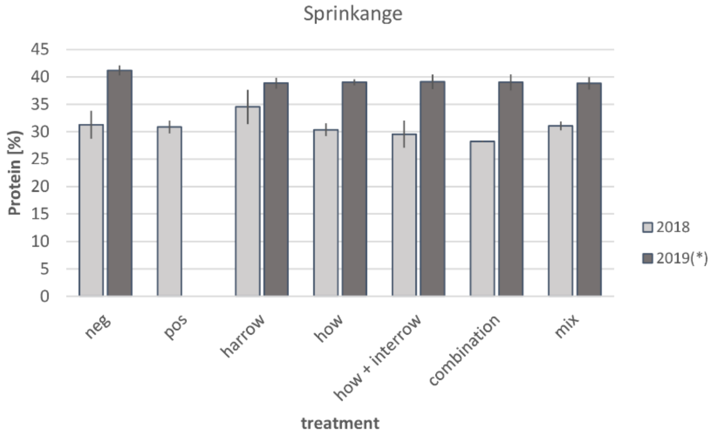


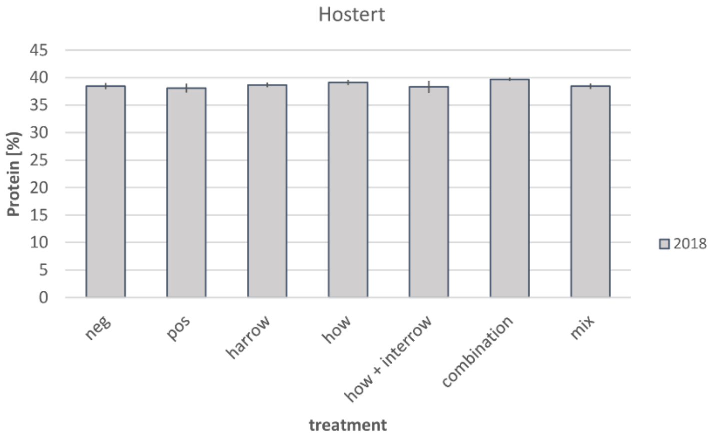


Appendix 16: Mean protein contents [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.5 according to Tukey-test and Fisher's test (but ANOVA p≤0.1) (*).

Protein(%)



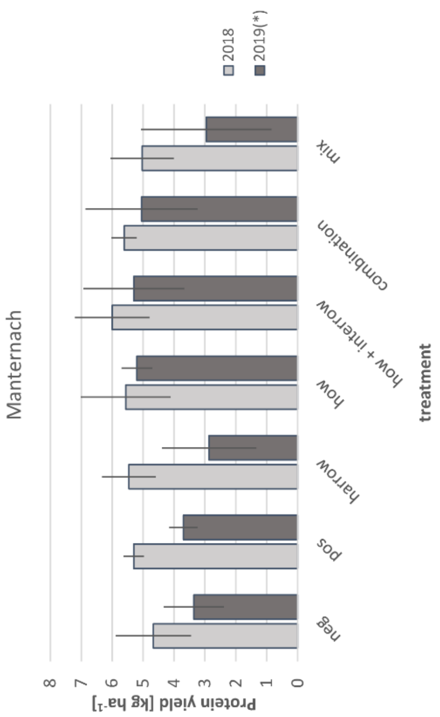


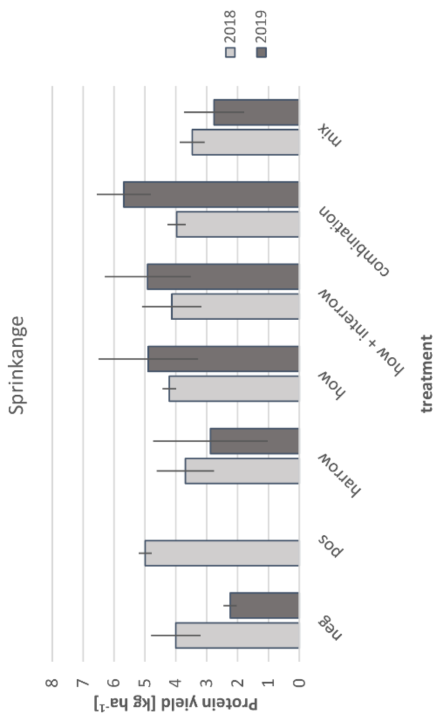


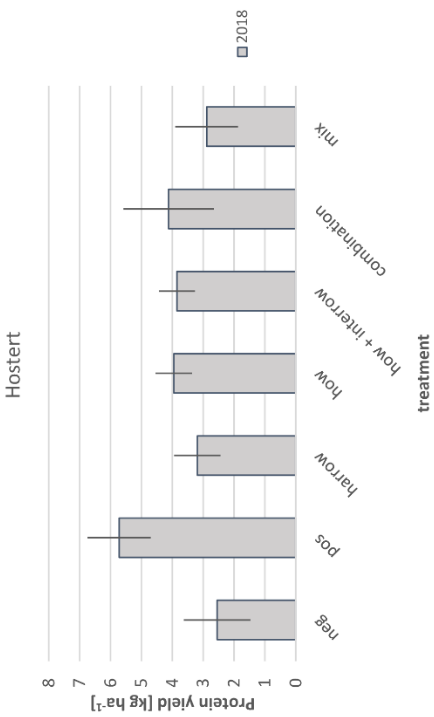
		Protein [%]											
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019		2018		2019(*)		2018		2019	
t.1	neg	39.5	n.s.	41.5	a	31.3	ab	41.2	a	38.5	ab	NA	
t.2	pos	38.9		39.4	ab	30.9	ab	-		38.1	b		
t.3	harrow	39.8		39.9	ab	34.5	a	38.9	b	38.7	ab		
t.4	how	39.7		39.6	b	30.4	ab	39.0	b	39.2	ab		
t.5	how + interrow	40.4		39.0	b	29.6	b	39.1	b	38.3	ab		
t.6	combination	40.5		40.3	ab	28.3	b	39.0	b	39.7	a		
t.7	mix	39.2		38.1	ab	31.1	ab	38.8	b	38.4	ab		

Appendix 17: Mean protein yield [kg ha⁻¹] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test or Fisher's test but with ANOVA p≤0.1 (*).

Protein yield [kg ha⁻¹]



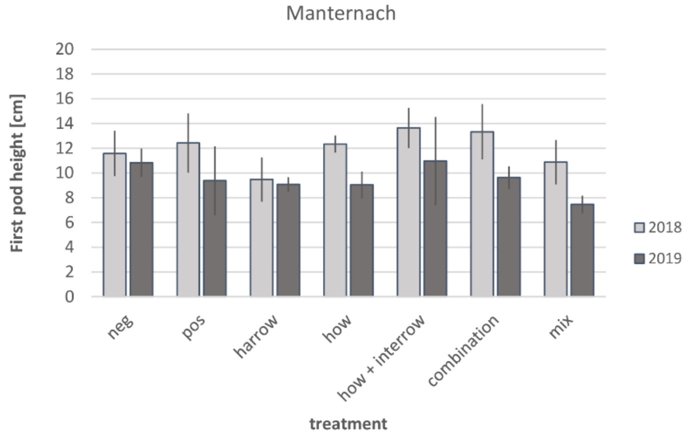


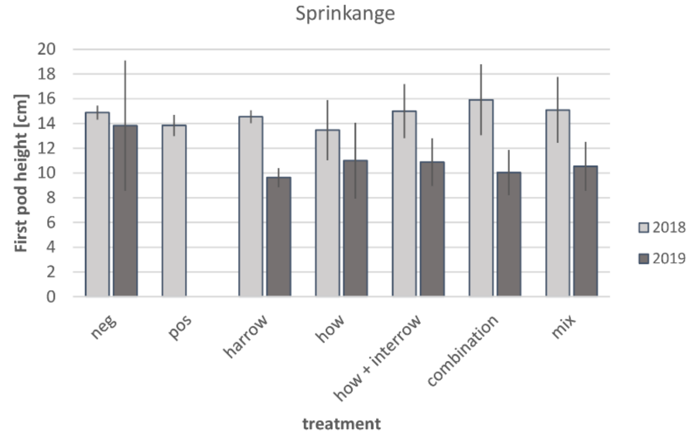


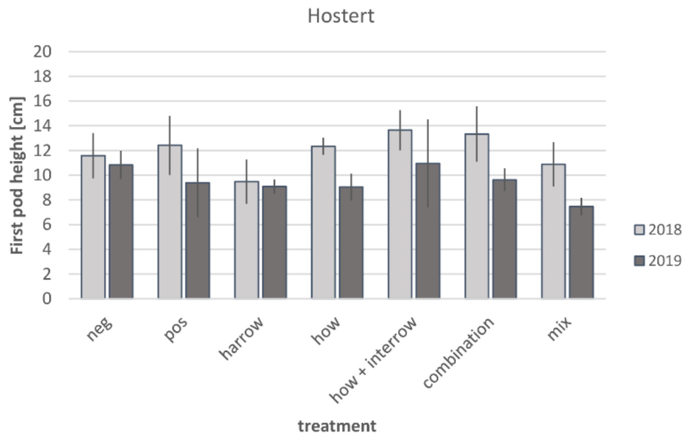
Treatment	Protein yield (kg/ha)										
	Manternach				Sprinkange				Hostert		
	2018		2019(*)		2018		2019		2018		2019
t.1 neg	4.7	n.s.	3.4	abc	4.0	n.s.	2.2	c	2.6	b	NA
t.2 pos	5.3		3.7	abc	5.0		-		5.7	a	
t.3 harrow	5.5		2.9	c	3.7		2.9	bc	3.2	b	
t.4 how	5.6		5.2	ab	4.2		4.9	ab	4.0	ab	
t.5 how + interrow	6.0		5.3	a	4.1		4.9	ab	3.9	ab	
t.6 combination	5.6		5.1	abc	4.0		5.7	a	4.1	ab	
t.7 mix	5.0		3.0	bc	3.5		2.8	bc	2.9	b	

Appendix 18: *Mean soybean first pod heights [cm] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test.*

First pod height [cm]



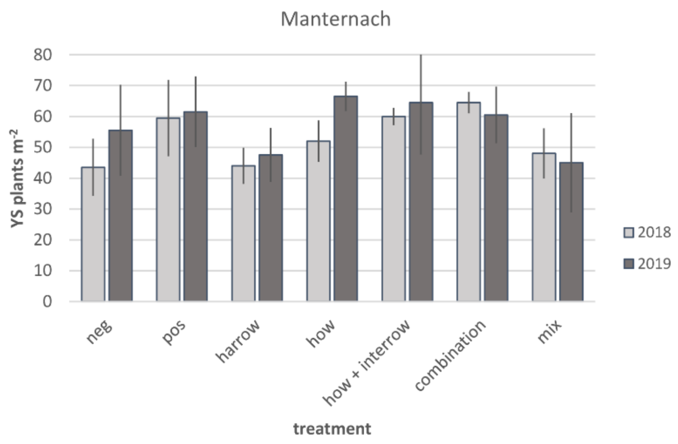


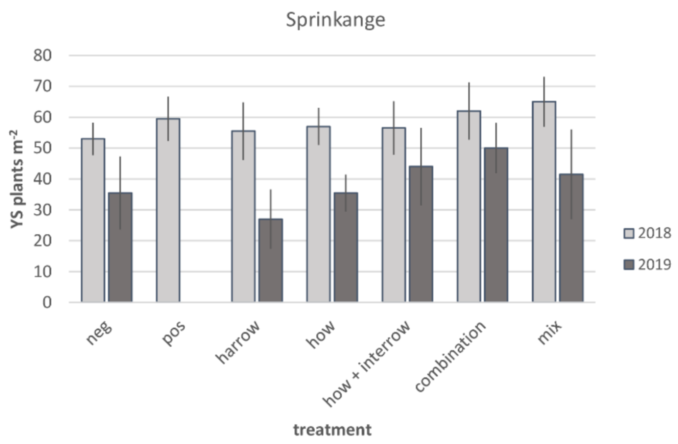


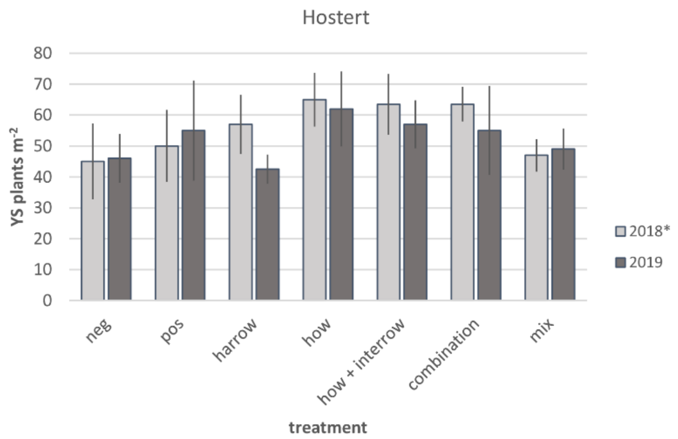
		First pod height [cm]											
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019		2018		2019		2018		2019	
t.1	neg	11.6	ab	10.8	n.s.	14.9	n.s.	13.8	n.s.	17.3	a	10.1	n.s.
t.2	pos	12.4	ab	9.4		13.8		-		9.6	b	11.8	
t.3	harrow	9.5	b	9.1		14.5		9.6		15.0	ab	9.5	
t.4	how	12.3	ab	9.0		13.5		11.0		15.7	ab	10.4	
t.5	how + interrow	13.6	a	11.0		15.0		10.9		13.8	ab	11.1	
t.6	combination	13.3	a	9.6		15.9		10.0		13.0	ab	9.9	
t.7	mix	10.9	ab	7.5		15.1		10.5		14.9	ab	10.4	

*Appendix 19: Mean number of soybean plants [plants m^{-2}] within the YS detection at HAR of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test or Fisher's test *.*

YS plants m^{-2}



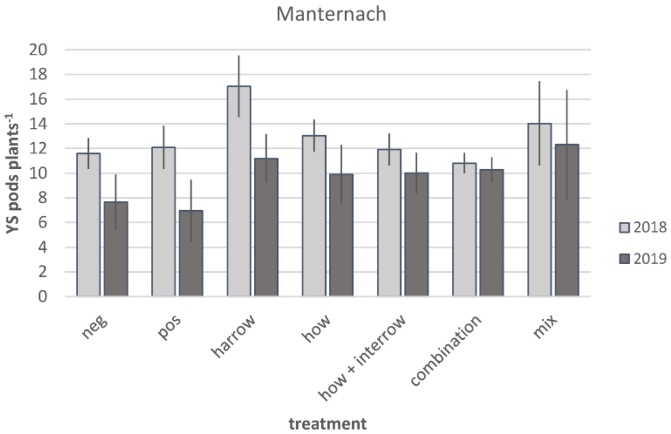


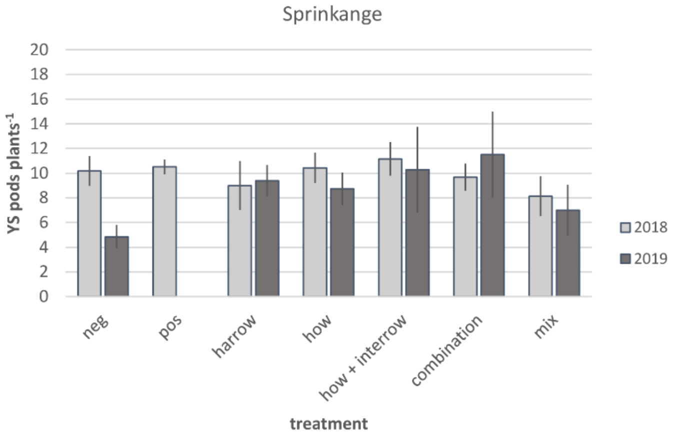


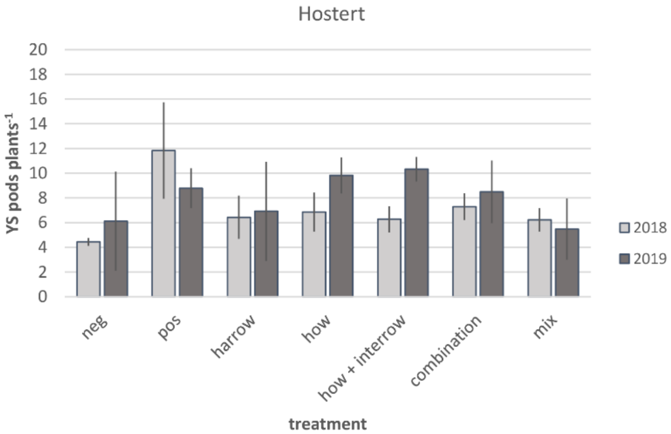
	YS plants m^{-2}											
	Manternach				Sprinkange				Hostert			
Treatment	2018		2019		2018		2019		2018*		2019	
t.1 neg	43.5	b	55.5	n.s.	53.0	b	35.5	n.s.	45.0	c	46.0	n.s.
t.2 pos	59.5	ab	61.5		59.5	ab	-		50.0	bc	55.0	
t.3 harrow	44.0	b	47.5		55.5	ab	27.0		57.0	abc	42.5	
t.4 how	52.0	ab	66.5		57.0	ab	35.5		65.0	a	62.0	
t.5 how + interrow	60.0	ab	64.5		56.5	ab	44.0		63.5	ab	57.0	
t.6 combination	64.5	a	60.5		62.0	ab	50.0		63.5	ab	55.0	
t.7 mix	48.0	ab	45.0		65.0	a	41.5		47.0	c	49.0	

*Appendix 20: Mean number of pods per plant taken within YS determinations of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test, according to Fisher's test * and Fisher's test but with ANOVA p≤0.1 (*).*

YS pods plant-1



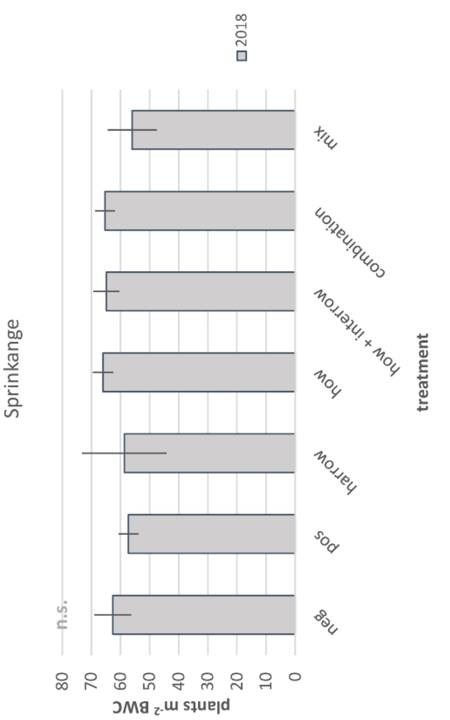




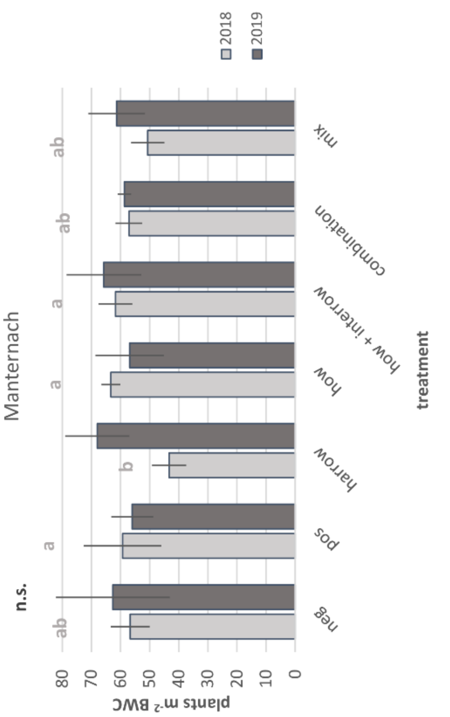
		YS pods plant^{-1}											
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019		2018(*)		2019		2018		2019*	
t.1	neg	11.6	b	7.7	n.s.	10.2	ab	4.8	b	4.4	b	6.1	cd
t.2	pos	12.1	b	7.0		10.5	ab	-		11.8	a	8.8	abc
t.3	harrow	17.0	a	11.2		9.0	bc	9.4	ab	6.4	b	6.9	bcd
t.4	how	13.0	ab	9.9		10.4	ab	8.7	ab	6.9	b	9.8	ab
t.5	how + interrow	11.9	b	10.0		11.2	a	10.3	a	6.3	b	10.3	a
t.6	combination	10.8	b	10.3		9.7	abc	11.5	a	7.3	b	8.5	abcd
t.7	mix	14.0	ab	12.3		8.1	c	7.0	ab	6.2	b	5.5	d

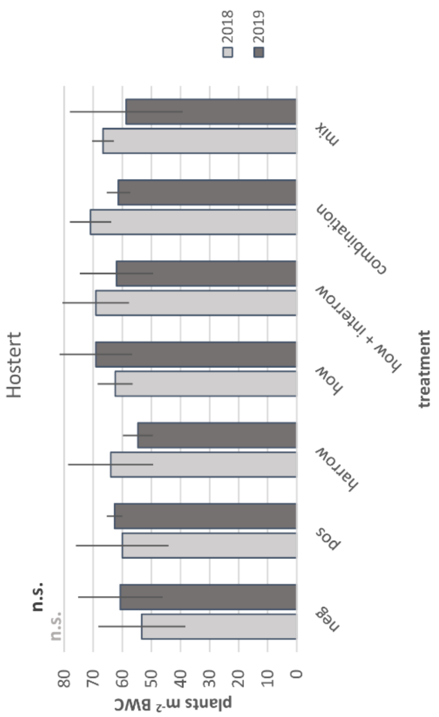
Appendix 21: Mean soybean plant density BWC (plants m^{-2}) of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test.

Plants m^{-2} BWC



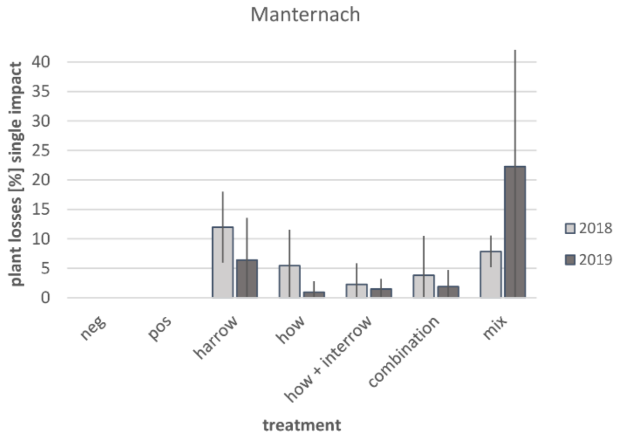
Treatment	plants m^{-2} BWC										
	Manternach				Sprinkange			Hostert			
	2018		2019		2018		2019	2018		2019	
t.1 neg	56.7	ab	62.7	n.s.	62.7	n.s.	NA	53.3	n.s.	60.7	n.s.
t.2 pos	59.3	a	56.0		57.3			60.0		62.7	
t.3 harrow	43.3	b	68.0		58.7			64.0		54.7	
t.4 how	63.3	a	56.9		66.0			62.5		69.1	
t.5 how + interrow	61.8	a	65.8		64.9			69.1		62.0	
t.6 combination	57.1	ab	58.7		65.3			70.9		61.3	
t.7 mix	50.7	ab	61.3		56.0			66.7		58.7	

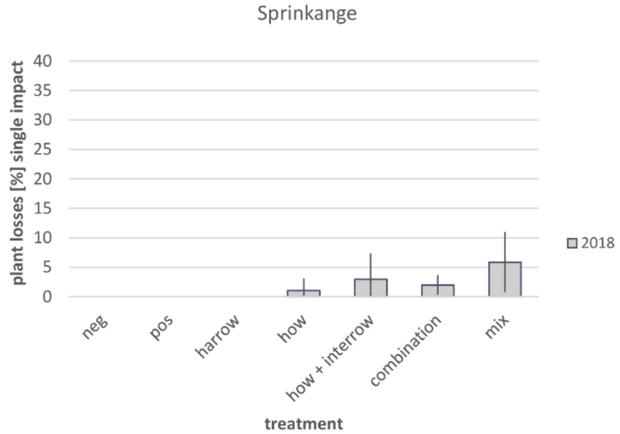


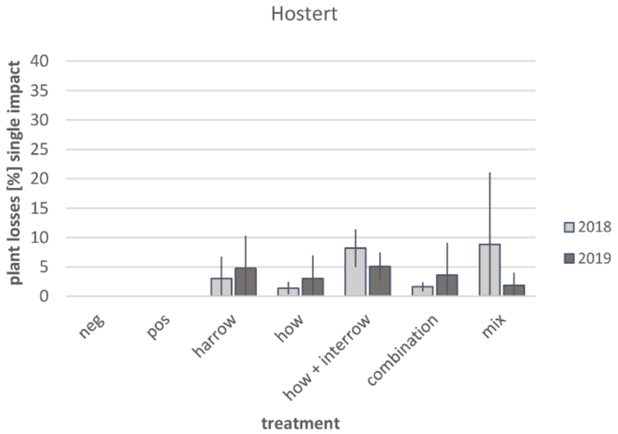


Appendix 22: Mean plant losses [%] single impact of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and Fisher's test but with ANOVA p≤0.1 (*) and Fisher's test with Kruskal-Wallis test but p≤0.1 (**).

Soybean plant losses$_{single\ impact}$ [%]



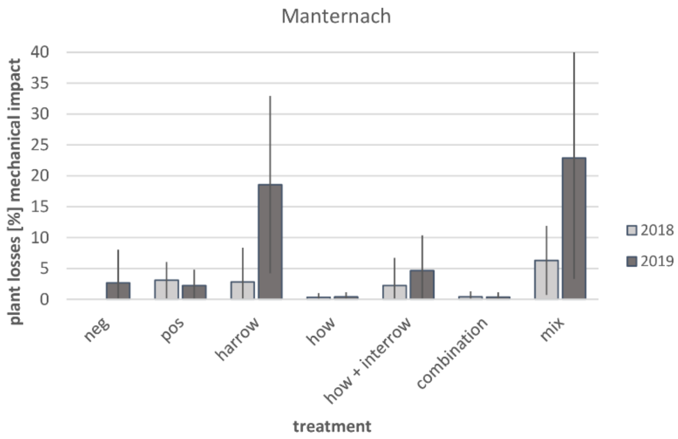


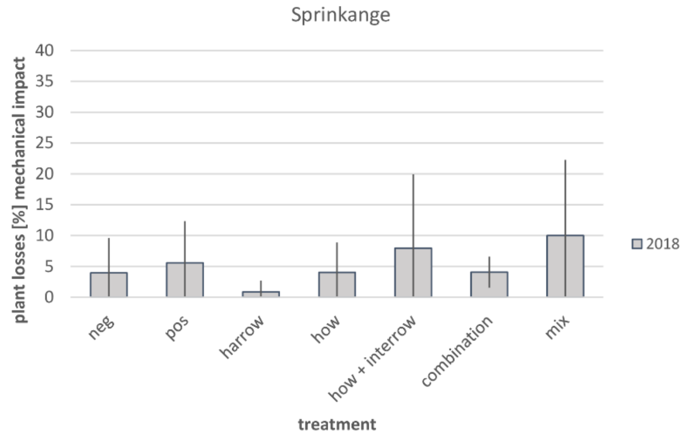


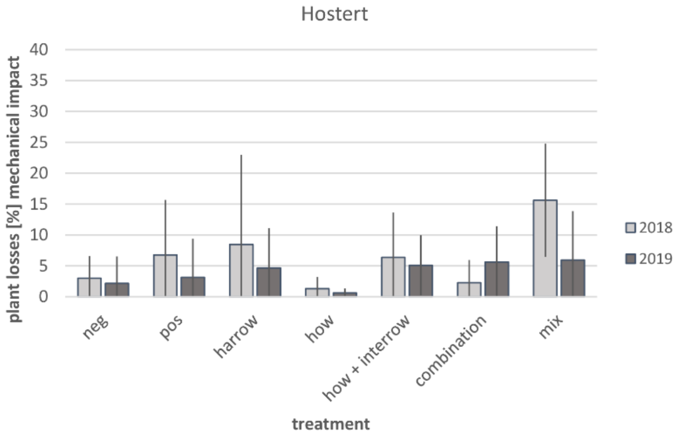
		plant losses [%] single impact											
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019(**)		2018(*)		2019		2018(*)		2019	
t.1	neg	0.0	a	0.0	a	0.0	a	NA		0.0	a	0.0	n.s.
t.2	pos	0.0	a	0.0	a	0.0	a			0.0	a	0.0	
t.3	harrow	12.0	b	6.4	bc	-				3.0	abc	4.8	
t.4	how	5.5	ab	0.9	ab	1.0	a			1.4	ab	3.0	
t.5	how + interrow	2.3	ab	1.5	abc	3.0	ab			8.2	bc	5.1	
t.6	combination	3.8	ab	1.9	abc	2.0	ab			1.6	ab	3.6	
t.7	mix	7.9	ab	22.3	c	5.9	b			8.8	c	1.9	

Appendix 23: Plant losses [%] of the mechanical impact from BWC and FLO for in 2019. Common letters indicate no significantly differences at p≤0.5 according to Tukey's test and Fisher's test.*

Soybean plant losses$_{\text{mechanical impact}}$ [%]



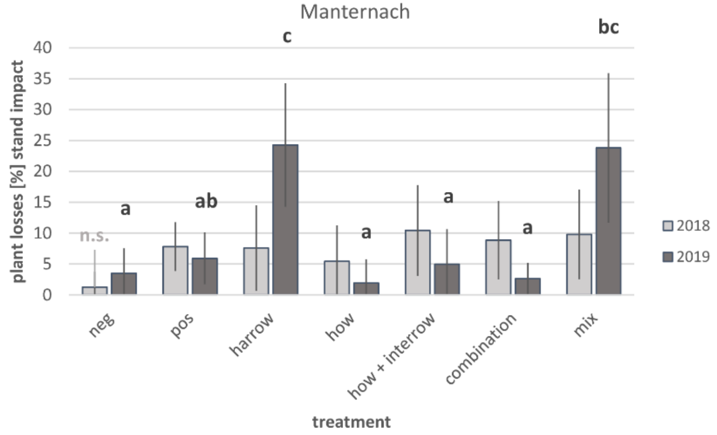


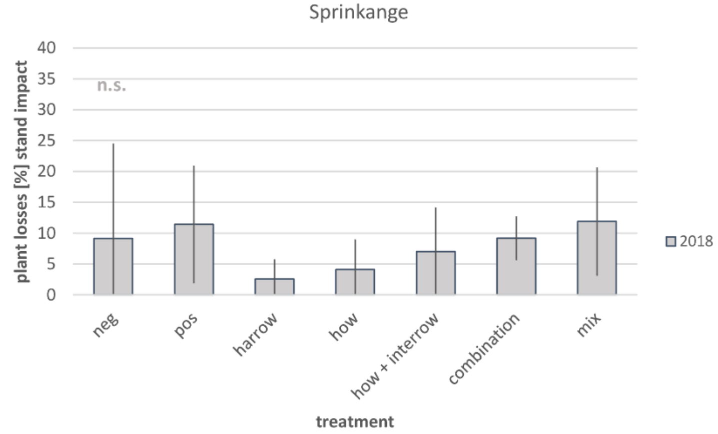


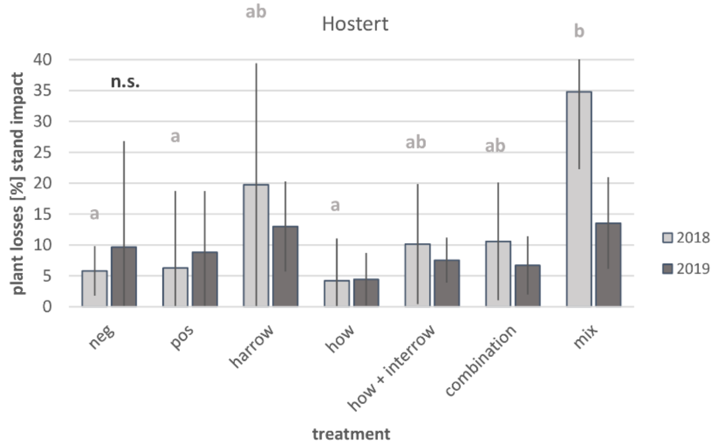
		plant losses [%] mechanical impact											
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019*		2018		2019		2018		2019	
t.1	neg	0.0	n.s.	2.7	a	4.0	n.s.	NA		3.0	n.s.	2.2	n.s.
t.2	pos	3.1		2.2	ab	5.6				6.8		3.1	
t.3	harrow	2.8		18.6	bc	0.9				8.5		4.7	
t.4	how	0.3		0.4	a	4.0				1.3		0.6	
t.5	how + interrow	2.2		4.6	abc	7.9				6.4		5.1	
t.6	combination	0.4		0.4	a	4.1				2.3		5.6	
t.7	mix	6.3		22.9	c	10.0				15.6		6.0	

*Appendix 24: Mean plant losses [%] stand impact of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and according to Fisher's test as post-hoc for Kruskal-Wallis **.*

Soybean plant losses$_{\text{stand impact}}$ [%]



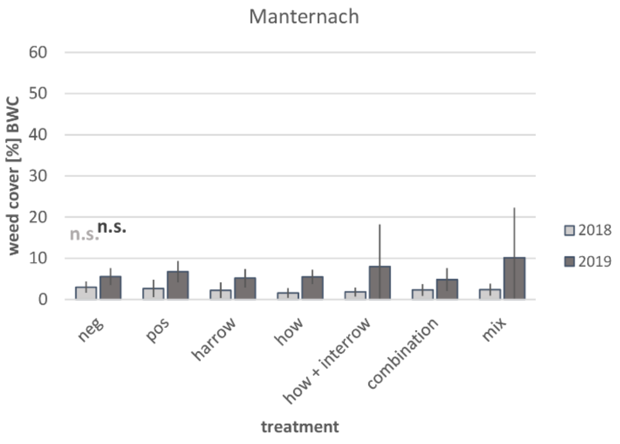


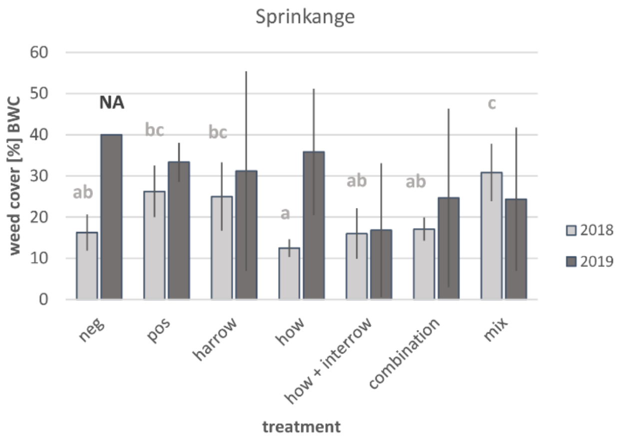


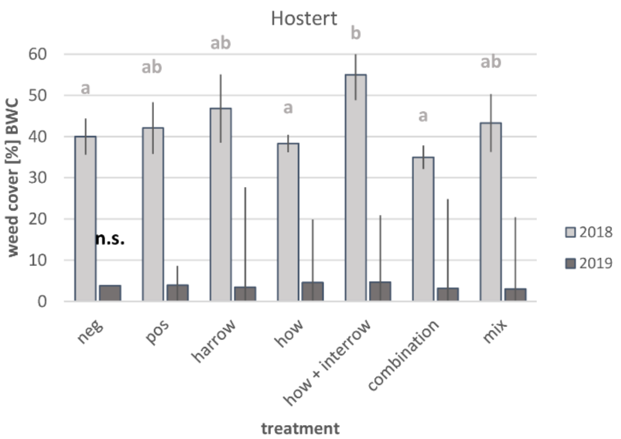
		plant losses [%] stand impact												
		Manternach				Sprinkange				Hostert			
Treatment		2018		2019**		2018		2019		2018		2019	
t.1	neg	1.3	n.s.	3.5	a	9.1	n.s.	NA		5.8	a	9.7	n.s.
t.2	pos	7.8		5.9	ab	11.4		n=2		6.3	a	8.8	
t.3	harrow	7.6		24.3	c	2.6				19.7	ab	13.0	
t.4	how	5.5		1.9	a	4.1				4.2	a	4.4	
t.5	how + interrow	10.4		5.0	a	7.0				10.2	ab	7.5	
t.6	combination	8.9		2.6	a	9.2				10.6	ab	6.7	
t.7	mix	9.8		23.8	bc	11.9				34.8	b	13.5	

Appendix 25: Mean weed cover [%] of the different treatments for the three study sites and both the project years. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and Fisher's test but with ANOVA p≤0.1 (*). NA indicates no statistical testing due to low sampling size of n=2.

Weed cover BWC







	weed cover [g] BWC											
	Manternach				Sprinkange				Hostert			
Treatment	2018		2019		2018		2019		2018(*)		2019	
t.1 neg	3.0	n.s.	5.6	n.s.	16.3	ab	40.0	NA	40.0	a	3.8	n.s.
t.2 pos	2.7		6.8		26.3	bc	33.33		42.1	ab	3.9	
t.3 harrow	2.3		5.2		25.0	bc	31.2		46.8	ab	3.4	
t.4 how	1.6		5.5		12.5	a	35.8		38.3	a	4.6	
t.5 how + interrow	1.8		8.0		16.0	ab	16.8		55.0	b	4.7	
t.6 combination	2.3		4.8		17.1	ab	24.7		35.0	a	3.2	
t.7 mix	2.4		10.2		30.8	c	24.3		43.3	ab	3.0	

Appendix 26: Correlation table of Pearson correlation and Spreaman correlation (blue) of Manternach18. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Manternach18 r-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	1.00	0.93	-0.05	-0.88	-0.08	0.22	-0.70	-0.26	0.89	0.91	-0.77	0.06	0.19	-0.81	-0.42	-0.74	-0.01	-0.71	-0.15	-0.53	-0.24	0.05	-0.41	-0.89	-0.92	0.88	0.77
weed biomass [g] HAR	0.93	1.00	-0.32	-0.68	-0.18	0.32	0.07	-0.14	0.75	0.75	-0.54	0.32	-0.21	-0.32	-0.36	-0.64	0.07	-0.29	-0.04	-0.29	-0.36	-0.07	-0.46	-0.64	-0.50	0.64	0.86
soybean biomass [g] FLO	-0.05	-0.32	1.00	0.03	0.96	0.93	-0.26	-0.70	-0.82	-0.33	-0.39	0.84	-0.69	0.18	-0.40	0.42	0.10	0.20	0.78	0.50	-0.75	0.87	-0.11	-0.09	-0.17	0.17	-0.09
chl [µmol m-2]	-0.88	-0.68	0.03	1.00	0.04	-0.29	0.57	0.30	-0.68	-0.68	0.75	-0.11	-0.02	0.55	0.36	0.48	-0.36	0.41	-0.06	0.22	0.37	0.15	0.23	0.81	0.86	-0.87	-0.76
plants m-2 BWC	-0.08	-0.18	0.96	0.04	1.00	0.92	-0.10	-0.76	-0.75	-0.33	-0.38	0.94	-0.79	0.27	-0.39	0.52	0.15	0.29	0.87	0.58	-0.80	0.80	-0.19	-0.06	-0.12	0.13	-0.10
plants m-2 AWC	0.22	0.32	0.93	-0.29	0.92	1.00	-0.39	-0.74	-0.18	-0.09	-0.67	0.91	-0.76	0.09	-0.38	0.26	0.29	0.16	0.78	0.39	-0.79	0.75	-0.12	-0.27	-0.43	0.47	0.21
plant losses stand impact	-0.70	0.07	-0.26	0.57	-0.10	-0.39	1.00	0.31	-0.18	-0.51	0.72	-0.04	-0.20	0.69	0.34	0.58	0.27	0.66	0.21	0.55	0.12	-0.46	0.28	0.62	0.86	-0.67	-0.39
plant losses single impact	-0.26	-0.14	-0.70	0.30	-0.76	-0.74	0.31	1.00	0.22	0.05	0.41	-0.71	0.37	0.16	0.81	-0.38	0.09	0.14	-0.71	-0.43	0.88	-0.59	0.70	0.52	0.46	-0.21	0.14
weed cover [%] FLO	0.89	0.75	-0.82	-0.68	-0.75	-0.18	-0.18	0.22	1.00	0.89	-0.29	-0.29	0.39	-0.61	-0.18	-0.89	0.04	-0.54	-0.57	-0.64	0.00	-0.50	-0.21	-0.46	-0.32	0.36	0.61
weed cover [%] HAR	0.91	0.75	-0.33	-0.68	-0.33	-0.09	-0.51	0.05	0.89	1.00	-0.58	-0.14	0.33	-0.80	-0.19	-0.88	-0.13	-0.73	-0.41	-0.73	0.08	-0.12	-0.32	-0.72	-0.73	0.74	0.76
WCE cov	-0.77	-0.54	-0.39	0.75	-0.38	-0.67	0.72	0.41	-0.29	-0.58	1.00	-0.52	0.38	0.36	0.18	0.43	-0.28	0.25	-0.21	0.30	0.38	-0.37	0.12	0.57	0.87	-0.93	-0.75
Height [cm] FLO	0.06	0.32	0.84	-0.11	0.94	0.91	-0.04	-0.71	-0.29	-0.14	-0.52	1.00	-0.89	0.28	-0.30	0.42	0.33	0.34	0.88	0.51	-0.77	0.64	-0.16	-0.11	-0.21	0.30	0.13
HEB Index	0.19	-0.21	-0.69	-0.02	-0.79	-0.76	-0.20	0.37	0.39	0.33	0.38	-0.89	1.00	-0.63	-0.13	-0.51	-0.62	-0.70	-0.81	-0.56	0.52	-0.39	-0.27	-0.26	-0.06	-0.19	-0.16
Yield [dt ha-1]	-0.81	-0.32	0.18	0.55	0.27	0.09	0.69	0.16	-0.61	-0.80	0.36	0.28	-0.63	1.00	0.56	0.76	0.53	0.99	0.43	0.64	0.04	-0.12	0.60	0.85	0.72	-0.50	-0.36
TKW [g]	-0.42	-0.36	-0.40	0.36	-0.39	-0.38	0.34	0.81	-0.18	-0.19	0.18	-0.30	-0.13	0.56	1.00	-0.08	0.37	0.56	-0.38	-0.23	0.75	-0.41	0.86	0.77	0.46	-0.16	0.12
HLW [kg hl-1]	-0.74	-0.64	0.42	0.48	0.52	0.26	0.58	-0.38	-0.89	-0.88	0.43	0.42	-0.51	0.76	-0.08	1.00	0.21	0.71	0.70	0.90	-0.41	0.12	0.01	0.48	0.57	-0.62	-0.69
Protein content [%]	-0.01	0.07	0.10	-0.36	0.15	0.29	0.27	0.09	0.04	-0.13	-0.28	0.33	-0.62	0.53	0.37	0.21	1.00	0.66	0.45	0.42	-0.23	-0.33	0.60	0.16	0.03	0.35	0.49
Protein yield [kg ha-1]	-0.71	-0.29	0.20	0.41	0.29	0.16	0.66	0.14	-0.54	-0.73	0.25	0.34	-0.70	0.99	0.56	0.71	0.66	1.00	0.49	0.65	-0.03	-0.15	0.63	0.77	0.63	-0.36	-0.21
First pod height [cm]	-0.15	-0.04	0.78	-0.06	0.87	0.78	0.21	-0.71	-0.57	-0.41	-0.21	0.88	-0.81	0.43	-0.38	0.70	0.45	0.49	1.00	0.85	-0.88	0.43	-0.13	-0.05	0.02	0.05	-0.09
YS plants m-2	-0.53	-0.29	0.50	0.22	0.58	0.39	0.55	-0.43	-0.64	-0.73	0.30	0.51	-0.56	0.64	-0.23	0.90	0.42	0.65	0.85	1.00	-0.64	0.10	0.03	0.24	0.44	-0.38	-0.42
YS pods plant-1	-0.24	-0.36	-0.75	0.37	-0.80	-0.79	0.12	0.88	0.00	0.08	0.38	-0.77	0.52	0.04	0.75	-0.41	-0.23	-0.03	-0.88	-0.64	1.00	-0.49	0.46	0.50	0.34	-0.29	-0.05
YS beans pods-1	0.05	-0.07	0.87	0.15	0.80	0.75	-0.46	-0.59	-0.50	-0.12	-0.37	0.64	-0.39	-0.12	-0.41	0.12	-0.33	-0.15	0.43	0.10	-0.49	1.00	-0.27	-0.15	-0.25	0.14	-0.14
YS TKW [g]	-0.41	-0.46	-0.11	0.23	-0.19	-0.12	0.28	0.70	-0.21	-0.32	0.12	-0.16	-0.27	0.60	0.86	0.01	0.60	0.63	-0.13	0.03	0.46	-0.27	1.00	0.68	0.44	-0.05	0.20
YS yield [dt ha-1]	-0.89	-0.64	-0.09	0.81	-0.06	-0.27	0.62	0.52	-0.46	-0.72	0.57	-0.11	-0.26	0.85	0.77	0.48	0.16	0.77	-0.05	0.24	0.50	-0.15	0.68	1.00	0.84	-0.67	-0.47
WCE dens	-0.43	-0.50	-0.14	0.64	-0.25	-0.79	0.54	0.18	-0.32	-0.32	0.96	-0.61	0.54	-0.11	0.11	0.43	-0.43	-0.07	-0.11	0.18	0.50	-0.21	-0.04	0.29	1.00	-0.96	-0.71
weeds m-2 FLO	0.88	0.64	0.17	-0.87	0.13	0.47	-0.67	-0.21	0.36	0.74	-0.93	0.30	-0.19	-0.50	-0.16	-0.62	0.35	-0.36	0.05	-0.38	-0.29	0.14	-0.05	-0.67	-0.87	1.00	0.91
weed species m-2 FLO	0.86	0.86	-0.18	-0.89	-0.04	0.46	0.00	-0.29	0.61	0.46	-0.68	0.46	-0.43	-0.11	-0.43	-0.43	0.43	0.00	0.25	0.00	-0.71	-0.14	-0.32	-0.71	-0.71	0.79	1.00

Manternach18 p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.003	0.911	0.009	0.866	0.641	0.080	0.574	0.007	0.004	0.045	0.896	0.686	0.026	0.345	0.057	0.980	0.072	0.746	0.223	0.608	0.917	0.359	0.007	0.337	0.008	0.014
weed biomass [g] HAR	0.003	0.000	0.482	0.094	0.702	0.482	0.879	0.758	0.052	0.052	0.215	0.482	0.645	0.482	0.432	0.119	0.879	0.535	0.939	0.535	0.432	0.879	0.294	0.119	0.253	0.119	0.014
soybean biomass [g] FLO	0.911	0.482	0.000	0.956	0.001	0.003	0.581	0.083	0.023	0.474	0.389	0.017	0.088	0.702	0.379	0.352	0.829	0.669	0.039	0.255	0.054	0.010	0.815	0.843	0.760	0.715	0.702
chl [µmol m-2]	0.009	0.094	0.956	0.000	0.929	0.525	0.185	0.507	0.094	0.094	0.054	0.808	0.961	0.203	0.429	0.272	0.424	0.357	0.891	0.631	0.414	0.755	0.614	0.029	0.119	0.010	0.007
plants m-2 BWC	0.866	0.702	0.001	0.929	0.000	0.003	0.831	0.049	0.052	0.476	0.406	0.002	0.034	0.559	0.383	0.234	0.743	0.522	0.010	0.173	0.033	0.031	0.691	0.892	0.589	0.778	0.939
plants m-2 AWC	0.641	0.482	0.003	0.525	0.003	0.000	0.391	0.058	0.702	0.846	0.098	0.005	0.049	0.846	0.407	0.572	0.524	0.731	0.039	0.393	0.036	0.051	0.797	0.562	0.036	0.284	0.294
plant losses stand impact	0.080	0.879	0.581	0.185	0.831	0.391	0.000	0.494	0.702	0.241	0.070	0.929	0.663	0.084	0.455	0.168	0.555	0.103	0.645	0.196	0.792	0.298	0.549	0.134	0.215	0.097	1.000
plant losses single impact	0.574	0.758	0.083	0.507	0.049	0.058	0.494	0.000	0.641	0.913	0.357	0.074	0.408	0.726	0.029	0.399	0.841	0.759	0.073	0.330	0.009	0.164	0.079	0.228	0.699	0.644	0.531
weed cover [%] FLO	0.007	0.052	0.023	0.094	0.052	0.702	0.702	0.641	0.000	0.007	0.535	0.535	0.383	0.148	0.702	0.007	0.939	0.215	0.180	0.119	1.000	0.253	0.645	0.294	0.482	0.432	0.148
weed cover [%] HAR	0.004	0.052	0.474	0.094	0.476	0.846	0.241	0.913	0.007	0.000	0.175	0.758	0.469	0.030	0.676	0.009	0.776	0.065	0.357	0.065	0.866	0.804	0.481	0.068	0.482	0.057	0.294
WCE cov	0.045	0.215	0.389	0.054	0.406	0.098	0.070	0.357	0.535	0.175	0.000	0.232	0.394	0.424	0.698	0.335	0.548	0.591	0.652	0.516	0.403	0.413	0.798	0.183	0.001	0.002	0.094
Height [cm] FLO	0.896	0.482	0.017	0.808	0.002	0.005	0.929	0.074	0.535	0.758	0.232	0.000	0.008	0.542	0.520	0.346	0.476	0.452	0.010	0.241	0.041	0.119	0.738	0.814	0.148	0.514	0.294
HEB Index	0.686	0.645	0.088	0.961	0.034	0.049	0.663	0.408	0.383	0.469	0.394	0.008	0.000	0.131	0.774	0.248	0.140	0.081	0.027	0.188	0.230	0.387	0.554	0.578	0.215	0.684	0.337
Yield [dt ha-1]	0.026	0.482	0.702	0.203	0.559	0.846	0.084	0.726	0.148	0.030	0.424	0.542	0.131	0.000	0.187	0.048	0.221	0.000	0.329	0.122	0.930	0.802	0.154	0.016	0.819	0.254	0.819
TKW [g]	0.345	0.432	0.379	0.429	0.383	0.407	0.455	0.029	0.702	0.676	0.698	0.520	0.774	0.187	0.000	0.868	0.420	0.192	0.394	0.614	0.053	0.361	0.014	0.042	0.819	0.726	0.337
HLW [kg hl-1]	0.057	0.119	0.352	0.272	0.234	0.572	0.168	0.399	0.007	0.009	0.335	0.346	0.248	0.048	0.868	0.000	0.645	0.072	0.081	0.006	0.361	0.794	0.976	0.271	0.337	0.136	0.337
Protein content [%]	0.980	0.879	0.829	0.424	0.743	0.524	0.555	0.841	0.939	0.776	0.548	0.476	0.140	0.221	0.420	0.645	0.000	0.106	0.308	0.342	0.623	0.465	0.156	0.730	0.337	0.448	0.337
Protein yield [kg ha-1]	0.072	0.535	0.669	0.357	0.522	0.731	0.103	0.759	0.215	0.065	0.591	0.452	0.081	0.000	0.192	0.072	0.106	0.000	0.262	0.113	0.955	0.756	0.126	0.042	0.879	0.424	1.000
First pod height [cm]	0.746	0.939	0.039	0.891	0.010	0.039	0.645	0.073	0.180	0.357	0.652	0.010	0.027	0.329	0.394	0.081	0.308	0.262	0.000	0.016	0.010	0.341	0.787	0.919	0.819	0.908	0.589
YS plants m-2	0.223	0.535	0.255	0.631	0.173	0.393	0.196	0.330	0.119	0.065	0.516	0.241	0.188	0.122	0.614	0.006	0.342	0.113	0.016	0.000	0.122	0.825	0.948	0.599	0.702	0.395	1.000
YS pods plant-1	0.608	0.432	0.054	0.414	0.033	0.036	0.792	0.009	1.000	0.866	0.403	0.041	0.230	0.930	0.053	0.361	0.623	0.955	0.010	0.122	0.000	0.262	0.297	0.249	0.253	0.532	0.071
YS beans pods-1	0.917	0.879	0.010	0.755	0.031	0.051	0.298	0.164	0.253	0.804	0.413	0.119	0.387	0.802	0.361	0.794	0.465	0.756	0.341	0.825	0.262	0.000	0.559	0.744	0.645	0.762	0.760
YS TKW [g]	0.359	0.294	0.815	0.614	0.691	0.797	0.549	0.079	0.645	0.481	0.798	0.738	0.554	0.154	0.014	0.976	0.156	0.126	0.787	0.948	0.297	0.559	0.000	0.095	0.939	0.916	0.482
YS yield [dt ha-1]	0.007	0.119	0.843	0.029	0.892	0.562	0.134	0.228	0.294	0.068	0.183	0.814	0.578	0.016	0.042	0.271	0.730	0.042	0.919	0.599	0.249	0.744	0.095	0.000	0.535	0.097	0.071
WCE dens	0.337	0.253	0.760	0.119	0.589	0.036	0.215	0.699	0.482	0.482	0.001	0.148	0.215	0.819	0.819	0.337	0.337	0.879	0.819	0.702	0.253	0.645	0.939	0.535	0.000	0.001	0.071
weeds m-2 FLO	0.008	0.119	0.715	0.010	0.778	0.284	0.097	0.644	0.432	0.057	0.002	0.514	0.684	0.254	0.726	0.136	0.448	0.424	0.908	0.395	0.532	0.762	0.916	0.097	0.001	0.000	0.036
weed species m-2 FLO	0.014	0.014	0.702	0.007	0.939	0.294	1.000	0.531	0.148	0.294	0.094	0.294	0.337	0.819	0.337	0.337	0.337	1.000	0.589	1.000	0.071	0.760	0.482	0.071	0.071	0.036	0.000

Appendix 27: Correlation table of Pearson correlation and Spreaman correlation (blue) of Sprinkange18. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Sprinkange18 r-values	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	1.00	0.96	-0.42	0.14	-0.52	-0.43	-0.11	0.44	1.00	0.97	-0.86	0.00	0.03	-0.94	0.11	-0.76	0.61	-0.86	0.21	0.18	-0.86	-0.65	0.15	-0.89	-0.78	0.95	0.83
weed biomass [g] HAR	0.96	1.00	-0.42	0.15	-0.39	-0.27	-0.15	0.33	0.98	0.98	-0.94	-0.07	0.14	-0.96	-0.29	-0.87	0.60	-0.88	0.31	-0.01	-0.76	-0.76	0.18	-0.96	-0.90	0.99	0.92
soybean biomass [g] FLO	-0.42	-0.42	1.00	0.77	-0.21	0.03	-0.23	-0.82	-0.42	-0.39	0.19	0.74	-0.60	0.38	0.54	0.04	0.45	0.73	-0.67	-0.51	0.43	0.24	0.54	0.46	0.10	-0.33	-0.52
chl [µmol m-2]	0.14	0.15	0.77	1.00	-0.63	-0.35	-0.02	-0.51	0.17	0.23	-0.36	0.79	-0.60	-0.08	0.43	-0.50	0.76	0.32	-0.53	-0.44	0.00	-0.13	0.69	0.01	-0.39	0.19	-0.04
plants m-2 BWC	-0.52	-0.39	-0.21	-0.63	1.00	0.90	-0.40	-0.20	-0.51	-0.51	0.35	-0.35	0.34	0.30	-0.14	0.38	-0.57	0.08	0.11	-0.37	0.62	-0.08	-0.10	0.19	0.28	-0.36	-0.03
plants m-2 AWC	-0.43	-0.27	0.03	-0.35	0.90	1.00	-0.54	-0.52	-0.41	-0.38	0.11	-0.10	0.08	0.18	-0.07	0.14	-0.28	0.09	-0.03	-0.60	0.53	-0.16	0.18	0.10	0.02	-0.19	0.08
plant losses stand impact	-0.11	-0.15	-0.23	-0.02	-0.40	-0.54	1.00	0.42	-0.07	-0.01	0.21	-0.22	0.07	0.37	-0.21	0.16	-0.46	0.20	0.32	0.58	-0.14	0.56	-0.42	0.33	0.28	-0.28	-0.28
plant losses single impact	0.44	0.33	-0.82	-0.51	-0.20	-0.52	0.42	1.00	0.41	0.35	-0.03	-0.53	0.46	-0.28	-0.41	0.07	-0.33	-0.53	0.43	0.74	-0.47	-0.07	-0.53	-0.29	0.09	0.21	0.25
weed cover [%] FLO	1.00	0.98	-0.42	0.17	-0.51	-0.41	-0.07	0.41	1.00	0.99	-0.89	0.00	0.04	-0.94	0.11	-0.81	0.60	-0.86	0.24	0.14	-0.84	-0.66	0.17	-0.90	-0.82	0.96	0.86
weed cover [%] HAR	0.97	0.98	-0.39	0.23	-0.51	-0.38	-0.01	0.35	0.99	1.00	-0.93	0.02	0.02	-0.91	0.09	-0.87	0.59	-0.82	0.25	0.06	-0.80	-0.67	0.22	-0.88	-0.87	0.96	0.87
WCE cov	-0.86	-0.94	0.19	-0.36	0.35	0.11	0.21	-0.03	-0.89	-0.93	1.00	-0.14	0.05	0.88	-0.07	0.97	-0.70	0.73	-0.16	0.27	0.61	0.78	-0.42	0.87	0.99	-0.95	-0.91
Height [cm] FLO	0.00	-0.07	0.74	0.79	-0.35	-0.10	-0.22	-0.53	0.00	0.02	-0.14	1.00	-0.91	0.08	0.93	-0.19	0.59	0.43	-0.92	-0.41	0.12	-0.05	0.88	0.23	-0.14	0.01	-0.14
HEB Index	0.03	0.14	-0.60	-0.60	0.34	0.08	0.07	0.46	0.04	0.02	0.05	-0.91	1.00	-0.17	-0.89	0.02	-0.42	-0.42	0.85	0.14	0.04	-0.20	-0.73	-0.33	0.01	0.06	0.20
Yield [dt ha-1]	-0.94	-0.96	0.38	-0.08	0.30	0.18	0.37	-0.28	-0.94	-0.91	0.88	0.08	-0.17	1.00	0.04	0.80	-0.64	0.91	-0.27	0.04	0.73	0.80	-0.16	0.98	0.85	-0.98	-0.90
TKW [g]	0.11	-0.29	0.54	0.43	-0.14	-0.07	-0.21	-0.41	0.11	0.09	-0.07	0.93	-0.89	0.04	1.00	-0.04	0.39	0.39	-0.89	-0.04	0.07	0.14	0.75	0.25	-0.07	0.11	0.00
HLW [kg hl-1]	-0.76	-0.87	0.04	-0.50	0.38	0.14	0.16	0.07	-0.81	-0.87	0.97	-0.19	0.02	0.80	-0.04	1.00	-0.72	0.59	-0.14	0.40	0.47	0.77	-0.47	0.80	0.98	-0.88	-0.82
Protein content [%]	0.61	0.60	0.45	0.76	-0.57	-0.28	-0.46	-0.33	0.60	0.59	-0.70	0.59	-0.42	-0.64	0.39	-0.72	1.00	-0.26	-0.35	-0.37	-0.41	-0.53	0.63	-0.53	-0.71	0.67	0.42
Protein yield [kg ha-1]	-0.86	-0.88	0.73	0.32	0.08	0.09	0.20	-0.53	-0.86	-0.82	0.73	0.43	-0.42	0.91	0.39	0.59	-0.26	1.00	-0.53	-0.18	0.72	0.69	0.15	0.93	0.67	-0.87	-0.90
First pod height [cm]	0.21	0.31	-0.67	-0.53	0.11	-0.03	0.32	0.43	0.24	0.25	-0.16	-0.92	0.85	-0.27	-0.89	-0.14	-0.35	-0.53	1.00	0.33	-0.31	-0.06	-0.77	-0.42	-0.17	0.23	0.32
YS plants m-2	0.18	-0.01	-0.51	-0.44	-0.37	-0.60	0.58	0.74	0.14	0.06	0.27	-0.41	0.14	0.04	-0.04	0.40	-0.37	-0.18	0.33	1.00	-0.55	0.51	-0.68	0.09	0.40	-0.08	-0.19
YS pods plant-1	-0.86	-0.76	0.43	0.00	0.62	0.53	-0.14	-0.47	-0.84	-0.80	0.61	0.12	0.04	0.73	0.07	0.47	-0.41	0.72	-0.31	-0.55	1.00	0.20	0.14	0.66	0.51	-0.74	-0.55
YS beans pods-1	-0.65	-0.76	0.24	-0.13	-0.08	-0.16	0.56	-0.07	-0.66	-0.67	0.78	-0.05	-0.20	0.80	0.14	0.77	-0.53	0.69	-0.06	0.51	0.20	1.00	-0.44	0.82	0.80	-0.78	-0.86
YS TKW [g]	0.15	0.18	0.54	0.69	-0.10	0.18	-0.42	-0.53	0.17	0.22	-0.42	0.88	-0.73	-0.16	0.75	-0.47	0.63	0.15	-0.77	-0.68	0.14	-0.44	1.00	-0.07	-0.44	0.26	0.24
YS yield [dt ha-1]	-0.89	-0.96	0.46	0.01	0.19	0.10	0.33	-0.29	-0.90	-0.88	0.87	0.23	-0.33	0.98	0.25	0.80	-0.53	0.93	-0.42	0.09	0.66	0.82	-0.07	1.00	0.86	-0.96	-0.93
WCE dens	-0.78	-0.90	0.10	-0.39	0.28	0.02	0.28	0.09	-0.82	-0.87	0.99	-0.14	0.01	0.85	-0.07	0.98	-0.71	0.67	-0.17	0.40	0.51	0.80	-0.44	0.86	1.00	-0.92	-0.88
weeds m-2 FLO	0.95	0.99	-0.33	0.19	-0.36	-0.19	-0.28	0.21	0.96	0.96	-0.95	0.01	0.06	-0.98	0.11	-0.88	0.67	-0.87	0.23	-0.08	-0.74	-0.78	0.26	-0.96	-0.92	1.00	0.92
weed species m-2 FLO	0.83	0.92	-0.52	-0.04	-0.03	0.08	-0.28	0.25	0.86	0.87	-0.91	-0.14	0.20	-0.90	0.00	-0.82	0.42	-0.90	0.32	-0.19	-0.55	-0.86	0.24	-0.93	-0.88	0.92	1.00

Sprinkange18 p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.001	0.346	0.761	0.234	0.336	0.817	0.323	0.000	0.000	0.014	0.993	0.942	0.001	0.819	0.047	0.149	0.013	0.651	0.703	0.014	0.111	0.748	0.007	0.038	0.001	0.020
weed biomass [g] HAR	0.001	0.000	0.351	0.744	0.384	0.558	0.750	0.475	0.000	0.000	0.002	0.887	0.769	0.001	0.535	0.010	0.157	0.008	0.495	0.981	0.049	0.047	0.696	0.001	0.006	0.000	0.003
soybean biomass [g] FLO	0.346	0.351	0.000	0.045	0.650	0.949	0.620	0.023	0.350	0.389	0.691	0.059	0.151	0.397	0.215	0.925	0.315	0.062	0.102	0.237	0.338	0.607	0.211	0.296	0.829	0.466	0.236
chl [µmol m-2]	0.761	0.744	0.045	0.000	0.130	0.437	0.959	0.239	0.721	0.622	0.433	0.034	0.159	0.864	0.337	0.251	0.050	0.488	0.218	0.317	0.998	0.774	0.087	0.989	0.384	0.688	0.933
plants m-2 BWC	0.234	0.384	0.650	0.130	0.000	0.005	0.375	0.675	0.240	0.244	0.445	0.436	0.456	0.517	0.760	0.396	0.179	0.872	0.817	0.412	0.137	0.864	0.828	0.687	0.545	0.428	0.946
plants m-2 AWC	0.336	0.558	0.949	0.437	0.005	0.000	0.213	0.228	0.364	0.406	0.816	0.836	0.872	0.699	0.878	0.757	0.548	0.851	0.955	0.158	0.217	0.731	0.695	0.830	0.967	0.679	0.861
plant losses stand impact	0.817	0.750	0.620	0.959	0.375	0.213	0.000	0.346	0.874	0.989	0.652	0.636	0.880	0.416	0.645	0.727	0.305	0.662	0.483	0.171	0.761	0.195	0.349	0.467	0.545	0.546	0.536
plant losses single impact	0.323	0.475	0.023	0.239	0.675	0.228	0.346	0.000	0.359	0.441	0.957	0.225	0.305	0.549	0.364	0.889	0.473	0.216	0.333	0.059	0.293	0.874	0.216	0.522	0.843	0.646	0.591
weed cover [%] FLO	0.000	0.000	0.350	0.721	0.240	0.364	0.874	0.359	0.000	0.000	0.007	0.993	0.939	0.002	0.819	0.029	0.152	0.014	0.611	0.766	0.017	0.103	0.716	0.006	0.024	0.001	0.014
weed cover [%] HAR	0.000	0.000	0.389	0.622	0.244	0.406	0.989	0.441	0.000	0.000	0.002	0.965	0.968	0.005	0.848	0.011	0.161	0.024	0.587	0.890	0.031	0.100	0.636	0.009	0.011	0.001	0.010
WCE cov	0.014	0.002	0.691	0.433	0.445	0.816	0.652	0.957	0.007	0.002	0.000	0.759	0.916	0.008	0.878	0.000	0.083	0.065	0.730	0.552	0.143	0.040	0.342	0.010	0.000	0.001	0.005
Height [cm] FLO	0.993	0.887	0.059	0.034	0.436	0.836	0.636	0.225	0.993	0.965	0.759	0.000	0.004	0.859	0.003	0.678	0.159	0.339	0.004	0.366	0.803	0.922	0.009	0.617	0.764	0.989	0.766
HEB Index	0.942	0.769	0.151	0.159	0.456	0.872	0.880	0.305	0.939	0.968	0.916	0.004	0.000	0.724	0.007	0.959	0.353	0.350	0.016	0.762	0.935	0.669	0.061	0.469	0.983	0.893	0.662
Yield [dt ha-1]	0.001	0.001	0.397	0.864	0.517	0.699	0.416	0.549	0.002	0.005	0.008	0.859	0.724	0.000	0.939	0.033	0.121	0.005	0.560	0.930	0.062	0.032	0.727	0.000	0.015	0.000	0.006
TKW [g]	0.819	0.535	0.215	0.337	0.760	0.878	0.645	0.364	0.819	0.848	0.878	0.003	0.007	0.939	0.000	0.939	0.383	0.383	0.007	0.939	0.879	0.760	0.052	0.589	0.878	0.819	1.000
HLW [kg hl-1]	0.047	0.010	0.925	0.251	0.396	0.757	0.727	0.889	0.029	0.011	0.000	0.678	0.959	0.033	0.939	0.000	0.066	0.161	0.769	0.376	0.290	0.042	0.292	0.030	0.000	0.010	0.024
Protein content [%]	0.149	0.157	0.315	0.050	0.179	0.548	0.305	0.473	0.152	0.161	0.083	0.159	0.353	0.121	0.383	0.066	0.000	0.578	0.435	0.408	0.362	0.216	0.132	0.217	0.073	0.098	0.348
Protein yield [kg ha-1]	0.013	0.008	0.062	0.488	0.872	0.851	0.662	0.216	0.014	0.024	0.065	0.339	0.350	0.005	0.383	0.161	0.578	0.000	0.223	0.698	0.069	0.088	0.755	0.002	0.099	0.012	0.007
First pod height [cm]	0.651	0.495	0.102	0.218	0.817	0.955	0.483	0.333	0.611	0.587	0.730	0.004	0.016	0.560	0.007	0.769	0.435	0.223	0.000	0.470	0.494	0.906	0.043	0.352	0.716	0.613	0.482
YS plants m-2	0.703	0.981	0.237	0.317	0.412	0.158	0.171	0.059	0.766	0.890	0.552	0.366	0.762	0.930	0.939	0.376	0.408	0.698	0.470	0.000	0.202	0.238	0.094	0.855	0.373	0.858	0.677
YS pods plant-1	0.014	0.049	0.338	0.998	0.137	0.217	0.761	0.293	0.017	0.031	0.143	0.803	0.935	0.062	0.879	0.290	0.362	0.069	0.494	0.202	0.000	0.674	0.759	0.109	0.243	0.055	0.196
YS beans pods-1	0.111	0.047	0.607	0.774	0.864	0.731	0.195	0.874	0.103	0.100	0.040	0.922	0.669	0.032	0.760	0.042	0.216	0.088	0.906	0.238	0.674	0.000	0.325	0.023	0.031	0.038	0.013
YS TKW [g]	0.748	0.696	0.211	0.087	0.828	0.695	0.349	0.216	0.716	0.636	0.342	0.009	0.061	0.727	0.052	0.292	0.132	0.755	0.043	0.094	0.759	0.325	0.000	0.883	0.317	0.577	0.604
YS yield [dt ha-1]	0.007	0.001	0.296	0.989	0.687	0.830	0.467	0.522	0.006	0.009	0.010	0.617	0.469	0.000	0.589	0.030	0.217	0.002	0.352	0.855	0.109	0.023	0.883	0.000	0.014	0.001	0.002
WCE dens	0.038	0.006	0.829	0.384	0.545	0.967	0.545	0.843	0.024	0.011	0.000	0.764	0.983	0.015	0.878	0.000	0.073	0.099	0.716	0.373	0.243	0.031	0.317	0.014	0.000	0.004	0.009
weeds m-2 FLO	0.001	0.000	0.466	0.688	0.428	0.679	0.546	0.646	0.001	0.001	0.001	0.989	0.893	0.000	0.819	0.010	0.098	0.012	0.613	0.858	0.055	0.038	0.577	0.001	0.004	0.000	0.003
weed species m-2 FLO	0.020	0.003	0.236	0.933	0.946	0.861	0.536	0.591	0.014	0.010	0.005	0.766	0.662	0.006	1.000	0.024	0.348	0.007	0.482	0.677	0.196	0.013	0.604	0.002	0.009	0.003	0.000

Appendix 28: Correlation table of Pearson correlation and Spreaman correlation (blue) of Hostert18. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Hostert18 r-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	1.00	1.00	-0.98	-0.06	-0.05	-0.14	0.30	0.30	0.94	1.00	-0.95	0.64	-0.80	-0.98	-0.94	0.09	0.21	-0.97	0.94	-0.05	-0.89	-0.36	-0.61	-0.94	-0.77	0.95	0.64
weed biomass [g] HAR	0.68	1.00	-0.68	0.07	-0.36	-0.43	-0.36	0.00	0.82	0.68	-0.75	0.75	-0.38	-0.75	-0.68	0.04	0.18	-0.75	0.89	-0.18	-0.79	-0.16	-0.32	-0.68	-0.82	0.75	0.54
soybean biomass [g] FLO	-0.98	-1.00	1.00	0.24	0.09	0.27	-0.42	-0.36	-0.97	-1.00	0.95	-0.64	0.76	0.99	0.96	-0.23	-0.07	0.99	-0.91	0.16	0.89	0.29	0.60	0.98	0.77	-0.96	-0.64
chl [µmol m-2]	-0.06	-0.46	0.24	1.00	0.31	0.75	-0.52	-0.18	-0.30	-0.46	0.20	0.18	-0.15	0.17	0.28	-0.82	0.69	0.22	-0.01	0.62	0.29	-0.11	-0.13	0.34	0.19	-0.19	-0.11
plants m-2 BWC	-0.05	-0.25	0.09	0.31	1.00	0.76	0.37	0.60	-0.23	-0.25	0.30	-0.36	-0.17	0.11	0.36	-0.51	0.44	0.15	-0.29	0.64	0.14	0.51	-0.64	0.24	0.62	-0.16	0.25
plants m-2 AWC	-0.14	-0.54	0.27	0.75	0.76	1.00	-0.27	0.06	-0.44	-0.54	0.39	-0.11	-0.03	0.28	0.44	-0.67	0.74	0.34	-0.24	0.92	0.54	0.07	-0.30	0.43	0.58	-0.36	-0.32
plant losses stand impact	0.30	0.18	-0.42	-0.52	0.37	-0.27	1.00	0.71	0.44	0.18	-0.33	-0.50	-0.50	-0.43	-0.26	0.06	-0.15	-0.44	0.14	-0.34	-0.14	0.45	-0.61	-0.40	-0.05	0.45	0.43
plant losses single impact	0.30	0.22	-0.36	-0.18	0.60	0.06	0.71	1.00	0.35	0.22	-0.13	-0.25	-0.26	-0.32	-0.13	0.03	-0.24	-0.33	0.11	0.07	-0.32	0.76	-0.84	-0.26	0.11	0.38	0.52
weed cover [%] FLO	0.94	0.93	-0.97	-0.30	-0.23	-0.44	0.44	0.35	1.00	0.93	-0.96	0.61	-0.73	-0.97	-0.96	0.29	-0.06	-0.98	0.92	-0.32	-0.89	-0.23	-0.54	-0.97	-0.83	0.98	0.68
weed cover [%] HAR	1.00	0.68	-1.00	-0.46	-0.25	-0.54	0.18	0.22	0.93	1.00	-0.86	0.64	-0.38	-0.96	-1.00	0.57	0.07	-0.96	0.79	-0.50	-0.89	-0.32	-0.11	-1.00	-0.93	0.96	0.64
WCE cov	-0.95	-0.86	0.95	0.20	0.30	0.39	-0.33	-0.13	-0.96	-0.86	1.00	-0.57	0.80	0.98	0.98	-0.18	-0.12	0.98	-0.95	0.30	0.79	0.47	0.42	0.97	0.88	-0.96	-0.64
Height [cm] FLO	0.64	0.75	-0.64	0.18	-0.36	-0.11	-0.50	-0.25	0.61	0.64	-0.57	1.00	-0.09	-0.54	-0.64	0.25	0.46	-0.54	0.89	0.09	-0.50	-0.65	0.07	-0.64	-0.61	0.54	0.14
HEB Index	-0.80	-0.38	0.76	-0.15	-0.17	-0.03	-0.50	-0.26	-0.73	-0.38	0.80	-0.09	1.00	0.84	0.68	0.39	-0.52	0.81	-0.73	0.07	0.45	0.29	0.64	0.72	0.56	-0.81	-0.70
Yield [dt ha-1]	-0.98	-0.96	0.99	0.17	0.11	0.28	-0.43	-0.32	-0.97	-0.96	0.98	-0.54	0.84	1.00	0.96	-0.12	-0.13	1.00	-0.92	0.21	0.96	0.32	0.59	0.97	0.81	-0.99	-0.79
TKW [g]	-0.94	-1.00	0.96	0.28	0.36	0.44	-0.26	-0.13	-0.96	-1.00	0.98	-0.64	0.68	0.96	1.00	-0.32	0.02	0.96	-0.93	0.33	0.89	0.46	0.36	0.98	0.91	-0.95	-0.64
HLW [kg hl-1]	0.09	0.57	-0.23	-0.82	-0.51	-0.67	0.06	0.03	0.29	0.57	-0.18	0.25	0.39	-0.12	-0.32	1.00	-0.74	-0.17	0.15	-0.37	-0.32	0.00	0.23	-0.30	-0.24	0.13	-0.04
Protein content [%]	0.21	0.07	-0.07	0.69	0.44	0.74	-0.15	-0.24	-0.06	0.07	-0.12	0.46	-0.52	-0.13	0.02	-0.74	1.00	-0.07	0.18	0.62	0.11	-0.42	-0.25	0.04	0.11	0.02	-0.04
Proteinyield [kg ha-1]	-0.97	-0.96	0.99	0.22	0.15	0.34	-0.44	-0.33	-0.98	-0.96	0.98	-0.54	0.81	1.00	0.96	-0.17	-0.07	1.00	-0.92	0.26	0.96	0.31	0.57	0.98	0.82	-0.99	-0.79
First pod height [cm]	0.94	0.79	-0.91	-0.01	-0.29	-0.24	0.14	0.11	0.92	0.79	-0.95	0.89	-0.73	-0.92	-0.93	0.15	0.18	-0.92	1.00	-0.09	-0.68	-0.44	-0.46	-0.88	-0.82	0.91	0.32
YS plants m-2	-0.05	-0.50	0.16	0.62	0.64	0.92	-0.34	0.07	-0.32	-0.50	0.30	0.09	0.07	0.21	0.33	-0.37	0.62	0.26	-0.09	1.00	0.52	0.06	-0.32	0.34	0.54	-0.31	-0.49
YS pods plant-1	-0.89	-0.79	0.89	0.29	0.14	0.54	-0.14	-0.32	-0.89	-0.89	0.79	-0.50	0.45	0.96	0.89	-0.32	0.11	0.96	-0.68	0.52	1.00	0.04	0.36	0.89	0.89	-0.96	-0.86
YS beans pods-1	-0.36	-0.32	0.29	-0.11	0.51	0.07	0.45	0.76	-0.23	-0.32	0.47	-0.65	0.29	0.32	0.46	0.00	-0.42	0.31	-0.44	0.06	0.04	1.00	-0.41	0.37	0.57	-0.23	0.13
YS TKW [g]	-0.61	-0.11	0.60	-0.13	-0.64	-0.30	-0.61	-0.84	-0.54	-0.11	0.42	0.07	0.64	0.59	0.36	0.23	-0.25	0.57	-0.46	-0.32	0.36	-0.41	1.00	0.45	0.06	-0.59	-0.54
YS yield [dt ha-1]	-0.94	-1.00	0.98	0.34	0.24	0.43	-0.40	-0.26	-0.97	-1.00	0.97	-0.64	0.72	0.97	0.98	-0.30	0.04	0.98	-0.88	0.34	0.89	0.37	0.45	1.00	0.86	-0.96	-0.64
WCE dens	-0.77	-0.93	0.77	0.19	0.62	0.58	-0.05	0.11	-0.83	-0.93	0.88	-0.61	0.56	0.81	0.91	-0.24	0.11	0.82	-0.82	0.54	0.89	0.57	0.06	0.86	1.00	-0.83	-0.68
weeds m-2 FLO	0.95	0.96	-0.96	-0.19	-0.16	-0.36	0.45	0.38	0.98	0.96	-0.96	0.54	-0.81	-0.99	-0.95	0.13	0.02	-0.99	0.91	-0.31	-0.96	-0.23	-0.59	-0.96	-0.83	1.00	0.79
weed species m-2 FLO	0.64	0.54	-0.64	-0.11	0.25	-0.32	0.43	0.52	0.68	0.64	-0.64	0.14	-0.70	-0.79	-0.64	-0.04	-0.04	-0.79	0.32	-0.49	-0.86	0.13	-0.54	-0.64	-0.68	0.79	1.00

Hostert18 p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.094	0.000	0.904	0.909	0.767	0.507	0.511	0.002	0.000	0.001	0.119	0.029	0.000	0.002	0.847	0.646	0.000	0.002	0.920	0.007	0.428	0.144	0.002	0.044	0.001	0.119
weed biomass [g] HAR	0.094	0.000	0.094	0.879	0.432	0.337	0.432	1.000	0.023	0.094	0.052	0.052	0.403	0.052	0.094	0.939	0.702	0.052	0.007	0.699	0.036	0.728	0.482	0.094	0.023	0.052	0.215
soybean biomass [g] FLO	0.000	0.094	0.000	0.602	0.850	0.557	0.352	0.428	0.000	0.000	0.001	0.119	0.048	0.000	0.001	0.614	0.879	0.000	0.004	0.734	0.007	0.521	0.157	0.000	0.044	0.000	0.119
chl [µmol m-2]	0.904	0.879	0.602	0.000	0.493	0.052	0.232	0.701	0.514	0.294	0.662	0.702	0.750	0.712	0.544	0.024	0.087	0.635	0.983	0.139	0.535	0.816	0.777	0.450	0.688	0.690	0.819
plants m-2 BWC	0.909	0.432	0.850	0.493	0.000	0.048	0.410	0.155	0.614	0.589	0.512	0.432	0.716	0.812	0.422	0.242	0.329	0.752	0.530	0.124	0.760	0.241	0.123	0.600	0.136	0.735	0.589
plants m-2 AWC	0.767	0.337	0.557	0.052	0.048	0.000	0.558	0.903	0.322	0.215	0.391	0.819	0.951	0.543	0.318	0.100	0.057	0.462	0.603	0.004	0.215	0.874	0.516	0.335	0.169	0.424	0.482
plant losses stand impact	0.507	0.432	0.352	0.232	0.410	0.558	0.000	0.075	0.318	0.702	0.472	0.253	0.258	0.338	0.581	0.893	0.750	0.321	0.769	0.457	0.760	0.312	0.149	0.370	0.919	0.314	0.337
plant losses single impact	0.511	1.000	0.428	0.701	0.155	0.903	0.075	0.000	0.441	0.641	0.783	0.585	0.574	0.484	0.773	0.951	0.604	0.471	0.812	0.886	0.478	0.049	0.018	0.572	0.811	0.406	0.229
weed cover [%] FLO	0.002	0.023	0.000	0.514	0.614	0.322	0.318	0.441	0.000	0.003	0.001	0.148	0.062	0.000	0.001	0.533	0.892	0.000	0.003	0.481	0.007	0.613	0.209	0.000	0.021	0.000	0.094
weed cover [%] HAR	0.000	0.094	0.000	0.294	0.589	0.215	0.702	0.641	0.003	0.000	0.014	0.119	0.403	0.001	0.000	0.180	0.879	0.001	0.036	0.248	0.007	0.478	0.819	0.000	0.003	0.001	0.119
WCE cov	0.001	0.052	0.001	0.662	0.512	0.391	0.472	0.783	0.001	0.014	0.000	0.180	0.031	0.000	0.000	0.704	0.803	0.000	0.001	0.506	0.036	0.290	0.353	0.000	0.008	0.001	0.119
Height [cm] FLO	0.119	0.052	0.119	0.702	0.432	0.819	0.253	0.585	0.148	0.119	0.180	0.000	0.848	0.215	0.119	0.589	0.294	0.215	0.007	0.848	0.253	0.115	0.879	0.119	0.148	0.215	0.760
HEB Index	0.029	0.403	0.048	0.750	0.716	0.951	0.258	0.574	0.062	0.403	0.031	0.848	0.000	0.019	0.094	0.390	0.234	0.027	0.064	0.877	0.310	0.535	0.125	0.069	0.188	0.028	0.078
Yield [dt ha-1]	0.000	0.052	0.000	0.712	0.812	0.543	0.338	0.484	0.000	0.001	0.000	0.215	0.019	0.000	0.001	0.796	0.781	0.000	0.003	0.645	0.001	0.478	0.166	0.000	0.028	0.000	0.036
TKW [g]	0.002	0.094	0.001	0.544	0.422	0.318	0.581	0.773	0.001	0.000	0.000	0.119	0.094	0.001	0.000	0.481	0.963	0.001	0.002	0.474	0.007	0.294	0.432	0.000	0.004	0.001	0.119
HLW [kg hl-1]	0.847	0.939	0.614	0.024	0.242	0.100	0.893	0.951	0.533	0.180	0.704	0.589	0.390	0.796	0.481	0.000	0.055	0.718	0.754	0.409	0.482	0.992	0.614	0.506	0.597	0.774	0.939
Protein content [%]	0.646	0.702	0.879	0.087	0.329	0.057	0.750	0.604	0.892	0.879	0.803	0.294	0.234	0.781	0.963	0.055	0.000	0.884	0.692	0.135	0.819	0.346	0.594	0.939	0.813	0.971	0.939
Proteinyield [kg ha-1]	0.000	0.052	0.000	0.635	0.752	0.462	0.321	0.471	0.000	0.001	0.000	0.215	0.027	0.000	0.001	0.718	0.884	0.000	0.004	0.568	0.001	0.505	0.183	0.000	0.023	0.000	0.036
First pod height [cm]	0.002	0.007	0.004	0.983	0.530	0.603	0.769	0.812	0.003	0.036	0.001	0.007	0.064	0.003	0.002	0.754	0.692	0.004	0.000	0.852	0.094	0.321	0.297	0.008	0.023	0.005	0.482
YS plants m-2	0.920	0.699	0.734	0.139	0.124	0.004	0.457	0.886	0.481	0.248	0.506	0.848	0.877	0.645	0.474	0.409	0.135	0.568	0.852	0.000	0.229	0.895	0.486	0.452	0.211	0.502	0.268
YS pods plant-1	0.007	0.036	0.007	0.535	0.760	0.215	0.760	0.478	0.007	0.007	0.036	0.253	0.310	0.001	0.007	0.482	0.819	0.001	0.094	0.229	0.000	0.939	0.432	0.007	0.007	0.001	0.014
YS beans pods-1	0.428	0.728	0.521	0.816	0.241	0.874	0.312	0.049	0.613	0.478	0.290	0.115	0.535	0.478	0.294	0.992	0.346	0.505	0.321	0.895	0.939	0.000	0.360	0.417	0.186	0.615	0.788
YS TKW [g]	0.144	0.482	0.157	0.777	0.123	0.516	0.149	0.018	0.209	0.819	0.353	0.879	0.125	0.166	0.432	0.614	0.594	0.183	0.297	0.486	0.432	0.360	0.000	0.314	0.895	0.166	0.215
YS yield [dt ha-1]	0.002	0.094	0.000	0.450	0.600	0.335	0.370	0.572	0.000	0.000	0.000	0.119	0.069	0.000	0.000	0.506	0.939	0.000	0.008	0.452	0.007	0.417	0.314	0.000	0.013	0.001	0.119
WCE dens	0.044	0.023	0.044	0.688	0.136	0.169	0.919	0.811	0.021	0.003	0.008	0.148	0.188	0.028	0.004	0.597	0.813	0.023	0.023	0.211	0.007	0.186	0.895	0.013	0.000	0.020	0.094
weeds m-2 FLO	0.001	0.052	0.000	0.690	0.735	0.424	0.314	0.406	0.000	0.001	0.001	0.215	0.028	0.000	0.001	0.774	0.971	0.000	0.005	0.502	0.001	0.615	0.166	0.001	0.020	0.000	0.036
weed species m-2 FLO	0.119	0.215	0.119	0.819	0.589	0.482	0.337	0.229	0.094	0.119	0.119	0.760	0.078	0.036	0.119	0.939	0.939	0.036	0.482	0.268	0.014	0.788	0.215	0.119	0.094	0.036	0.000

Appendix 29: Correlation table of Pearson correlation and Spreaman correlation (blue) of Manternach19. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Manternach19 r-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	1.00	0.93	0.04	0.09	0.37	0.01	-0.14	0.04	0.92	0.97	-0.88	-0.10	0.67	-0.40	0.04	-0.83	0.23	-0.39	0.02	-0.47	0.19	-0.75	0.00	-0.35	-0.85	0.94	0.92
weed biomass [g] HAR	0.93	1.00	-0.25	0.13	0.32	0.16	0.14	0.32	0.78	0.92	-0.95	0.00	0.40	-0.43	0.17	-0.85	0.52	-0.39	0.13	-0.45	0.08	-0.74	-0.10	-0.40	-0.92	0.97	0.95
soybean biomass [g] FLO	0.04	-0.25	1.00	-0.50	-0.21	0.64	-0.39	-0.95	-0.29	-0.11	0.21	0.39	-0.07	0.39	0.36	0.46	0.36	0.39	0.68	0.50	-0.93	-0.32	-0.11	-0.43	0.11	-0.14	-0.11
chl [µmol m-2]	0.09	0.13	-0.50	1.00	0.66	0.25	0.14	0.59	0.04	0.25	-0.30	-0.20	0.37	0.28	-0.77	-0.16	0.05	0.30	0.15	-0.08	0.64	0.32	-0.28	0.46	-0.11	-0.04	0.17
plants m-2 BWC	0.37	0.32	-0.21	0.66	1.00	0.11	0.46	0.43	0.26	0.50	-0.52	-0.60	0.56	-0.25	-0.31	-0.41	0.02	-0.25	0.24	-0.48	0.41	0.09	-0.73	-0.27	-0.51	0.23	0.18
plants m-2 AWC	0.01	0.16	0.64	0.25	0.11	1.00	-0.61	-0.52	-0.35	-0.07	-0.02	0.65	0.01	0.48	0.13	0.34	0.73	0.54	0.93	0.65	-0.55	-0.22	-0.28	-0.02	-0.18	0.20	0.03
plant losses stand impact	-0.14	0.14	-0.39	0.14	0.46	-0.61	1.00	0.47	0.07	0.29	-0.25	-1.00	0.05	-0.71	0.29	-0.25	-0.39	-0.71	-0.25	-0.68	0.43	0.14	-0.43	-0.54	-0.36	-0.11	-0.29
plant losses single impact	0.04	0.32	-0.95	0.59	0.43	-0.52	0.47	1.00	0.31	0.25	-0.36	-0.47	0.22	-0.38	-0.41	-0.52	-0.36	-0.38	-0.47	-0.58	0.99	0.41	-0.11	0.34	-0.29	0.14	0.11
weed cover [%] FLO	0.92	0.78	-0.29	0.04	0.26	-0.35	0.07	0.31	1.00	0.91	-0.77	-0.26	0.67	-0.43	-0.12	-0.86	-0.10	-0.44	-0.34	-0.60	0.43	-0.60	0.21	-0.17	-0.65	0.77	0.87
weed cover [%] HAR	0.97	0.92	-0.11	0.25	0.50	-0.07	0.29	0.25	0.91	1.00	-0.93	-0.23	0.65	-0.41	-0.09	-0.90	0.17	-0.40	-0.04	-0.59	0.37	-0.58	-0.12	-0.30	-0.84	0.88	0.92
WCE cov	-0.88	-0.95	0.21	-0.30	-0.52	-0.02	-0.25	-0.36	-0.77	-0.93	1.00	0.27	-0.41	0.55	-0.05	0.93	-0.42	0.52	-0.01	0.65	-0.28	0.58	0.25	0.41	0.93	-0.87	-0.88
Height [cm] FLO	-0.10	0.00	0.39	-0.20	-0.60	0.65	-1.00	-0.47	-0.26	-0.23	0.27	1.00	-0.20	0.68	0.13	0.45	0.41	0.72	0.53	0.84	-0.55	-0.22	0.35	0.31	0.22	0.09	0.07
HEB Index	0.67	0.40	-0.07	0.37	0.56	0.01	0.05	0.22	0.67	0.65	-0.41	-0.20	1.00	0.04	-0.47	-0.37	-0.26	0.02	0.06	-0.18	0.41	-0.31	0.01	0.07	-0.37	0.42	0.48
Yield [dt ha-1]	-0.40	-0.43	0.39	0.28	-0.25	0.48	-0.71	-0.38	-0.43	-0.41	0.55	0.68	0.04	1.00	-0.51	0.68	-0.12	1.00	0.41	0.85	-0.04	0.40	0.21	0.74	0.62	-0.42	-0.29
TKW [g]	0.04	0.17	0.36	-0.77	-0.31	0.13	0.29	-0.41	-0.12	-0.09	-0.05	0.13	-0.47	-0.51	1.00	-0.02	0.51	-0.48	0.21	-0.04	-0.82	-0.49	-0.15	-0.80	-0.33	0.31	-0.04
HLW [kg hl-1]	-0.83	-0.85	0.46	-0.16	-0.41	0.34	-0.25	-0.52	-0.86	-0.90	0.93	0.45	-0.37	0.68	-0.02	1.00	-0.14	0.67	0.33	0.83	-0.45	0.48	0.10	0.37	0.81	-0.76	-0.84
Protein content [%]	0.23	0.52	0.36	0.05	0.02	0.73	-0.39	-0.36	-0.10	0.17	-0.42	0.41	-0.26	-0.12	0.51	-0.14	1.00	-0.04	0.61	0.17	-0.55	-0.53	-0.24	-0.38	-0.57	0.52	0.34
Proteinyield [kg ha-1]	-0.39	-0.39	0.39	0.30	-0.25	0.54	-0.71	-0.38	-0.44	-0.40	0.52	0.72	0.02	1.00	-0.48	0.67	-0.04	1.00	0.45	0.87	-0.07	0.36	0.20	0.72	0.58	-0.38	-0.26
First pod height [cm]	0.02	0.13	0.68	0.15	0.24	0.93	-0.25	-0.47	-0.34	-0.04	-0.01	0.53	0.06	0.41	0.21	0.33	0.61	0.45	1.00	0.56	-0.59	-0.11	-0.53	-0.23	-0.20	0.20	-0.06
YS plants m-2	-0.47	-0.45	0.50	-0.08	-0.48	0.65	-0.68	-0.58	-0.60	-0.59	0.65	0.84	-0.18	0.85	-0.04	0.83	0.17	0.87	0.56	1.00	-0.52	0.12	0.26	0.45	0.55	-0.36	-0.39
YS pods plant-1	0.19	0.08	-0.93	0.64	0.41	-0.55	0.43	0.99	0.43	0.37	-0.28	-0.55	0.41	-0.04	-0.82	-0.45	-0.55	-0.07	-0.59	-0.52	1.00	0.36	0.09	0.48	0.03	-0.09	0.26
YS beans pods-1	-0.75	-0.74	-0.32	0.32	0.09	-0.22	0.14	0.41	-0.60	-0.58	0.58	-0.22	-0.31	0.40	-0.49	0.48	-0.53	0.36	-0.11	0.12	0.36	1.00	-0.28	0.44	0.72	-0.84	-0.71
YS TKW [g]	0.00	-0.10	-0.11	-0.28	-0.73	-0.28	-0.43	-0.11	0.21	-0.12	0.25	0.35	0.01	0.21	-0.15	0.10	-0.24	0.20	-0.53	0.26	0.09	-0.28	1.00	0.56	0.34	-0.07	0.17
YS yield [dt ha-1]	-0.35	-0.40	-0.43	0.46	-0.27	-0.02	-0.54	0.34	-0.17	-0.30	0.41	0.31	0.07	0.74	-0.80	0.37	-0.38	0.72	-0.23	0.45	0.48	0.44	0.56	1.00	0.64	-0.49	-0.12
WCE dens	-0.85	-0.92	0.11	-0.11	-0.51	-0.18	-0.36	-0.29	-0.65	-0.84	0.93	0.22	-0.37	0.62	-0.33	0.81	-0.57	0.58	-0.20	0.55	0.03	0.72	0.34	0.64	1.00	-0.91	-0.77
weeds m-2 FLO	0.94	0.97	-0.14	-0.04	0.23	0.20	-0.11	0.14	0.77	0.88	-0.87	0.09	0.42	-0.42	0.31	-0.76	0.52	-0.38	0.20	-0.36	-0.09	-0.84	-0.07	-0.49	-0.91	1.00	0.90
weed species m-2 FLO	0.92	0.95	-0.11	0.17	0.18	0.03	-0.29	0.11	0.87	0.92	-0.88	0.07	0.48	-0.29	-0.04	-0.84	0.34	-0.26	-0.06	-0.39	0.26	-0.71	0.17	-0.12	-0.77	0.90	1.00

Manternach19 p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.003	0.939	0.853	0.415	0.989	0.760	0.939	0.003	0.000	0.009	0.827	0.099	0.368	0.924	0.020	0.614	0.388	0.970	0.282	0.689	0.053	0.992	0.444	0.015	0.002	0.003
weed biomass [g] HAR	0.003	0.000	0.589	0.774	0.484	0.733	0.760	0.478	0.039	0.003	0.001	1.000	0.371	0.334	0.715	0.015	0.232	0.386	0.787	0.311	0.863	0.055	0.829	0.376	0.003	0.000	0.001
soybean biomass [g] FLO	0.939	0.589	0.000	0.253	0.645	0.119	0.383	0.001	0.535	0.819	0.645	0.383	0.877	0.383	0.432	0.294	0.432	0.383	0.094	0.253	0.003	0.482	0.819	0.337	0.819	0.760	0.819
chl [µmol m-2]	0.853	0.774	0.253	0.000	0.108	0.592	0.760	0.159	0.927	0.591	0.515	0.665	0.412	0.541	0.042	0.724	0.918	0.520	0.753	0.864	0.120	0.491	0.549	0.300	0.807	0.925	0.710
plants m-2 BWC	0.415	0.484	0.645	0.108	0.000	0.819	0.294	0.333	0.581	0.257	0.228	0.153	0.191	0.586	0.492	0.363	0.958	0.586	0.600	0.276	0.360	0.844	0.064	0.552	0.243	0.615	0.703
plants m-2 AWC	0.989	0.733	0.119	0.592	0.819	0.000	0.148	0.229	0.445	0.888	0.964	0.115	0.981	0.278	0.778	0.457	0.060	0.214	0.003	0.112	0.201	0.636	0.550	0.964	0.692	0.661	0.945
plant losses stand impact	0.760	0.760	0.383	0.760	0.294	0.148	0.000	0.289	0.879	0.535	0.589	0.000	0.908	0.071	0.535	0.589	0.383	0.071	0.589	0.094	0.337	0.760	0.337	0.215	0.432	0.819	0.535
plant losses single impact	0.939	0.478	0.001	0.159	0.333	0.229	0.289	0.000	0.504	0.585	0.427	0.289	0.635	0.403	0.355	0.229	0.427	0.403	0.289	0.175	0.000	0.355	0.818	0.452	0.531	0.758	0.818
weed cover [%] FLO	0.003	0.039	0.535	0.927	0.581	0.445	0.879	0.504	0.000	0.004	0.043	0.575	0.097	0.330	0.798	0.014	0.832	0.318	0.450	0.155	0.332	0.152	0.655	0.714	0.112	0.045	0.011
weed cover [%] HAR	0.000	0.003	0.819	0.591	0.257	0.888	0.535	0.585	0.004	0.000	0.002	0.623	0.112	0.355	0.848	0.005	0.709	0.370	0.940	0.164	0.420	0.171	0.796	0.517	0.018	0.009	0.004
WCE cov	0.009	0.001	0.645	0.515	0.228	0.964	0.589	0.427	0.043	0.002	0.000	0.553	0.358	0.198	0.907	0.002	0.349	0.232	0.982	0.113	0.541	0.173	0.593	0.363	0.002	0.010	0.009
Height [cm] FLO	0.827	1.000	0.383	0.665	0.153	0.115	0.000	0.289	0.575	0.623	0.553	0.000	0.667	0.090	0.773	0.310	0.355	0.068	0.224	0.017	0.201	0.641	0.436	0.501	0.639	0.847	0.889
HEB Index	0.099	0.371	0.877	0.412	0.191	0.981	0.908	0.635	0.097	0.112	0.358	0.667	0.000	0.925	0.288	0.418	0.566	0.965	0.905	0.698	0.358	0.498	0.985	0.881	0.414	0.349	0.279
Yield [dt ha-1]	0.368	0.334	0.383	0.541	0.586	0.278	0.071	0.403	0.330	0.355	0.198	0.090	0.925	0.000	0.240	0.094	0.795	0.000	0.360	0.015	0.934	0.371	0.654	0.058	0.136	0.353	0.528
TKW [g]	0.924	0.715	0.432	0.042	0.492	0.778	0.535	0.355	0.798	0.848	0.907	0.773	0.288	0.240	0.000	0.971	0.242	0.273	0.648	0.927	0.025	0.267	0.744	0.030	0.475	0.503	0.932
HLW [kg hl-1]	0.020	0.015	0.294	0.724	0.363	0.457	0.589	0.229	0.014	0.005	0.002	0.310	0.418	0.094	0.971	0.000	0.766	0.101	0.471	0.021	0.313	0.270	0.832	0.420	0.028	0.045	0.019
Protein content [%]	0.614	0.232	0.432	0.918	0.958	0.060	0.383	0.427	0.832	0.709	0.349	0.355	0.566	0.795	0.242	0.766	0.000	0.930	0.147	0.717	0.197	0.220	0.607	0.403	0.179	0.229	0.456
Proteinyield [kg ha-1]	0.388	0.386	0.383	0.520	0.586	0.214	0.071	0.403	0.318	0.370	0.232	0.068	0.965	0.000	0.273	0.101	0.930	0.000	0.306	0.011	0.875	0.421	0.673	0.067	0.171	0.402	0.572
First pod height [cm]	0.970	0.787	0.094	0.753	0.600	0.003	0.589	0.289	0.450	0.940	0.982	0.224	0.905	0.360	0.648	0.471	0.147	0.306	0.000	0.195	0.165	0.811	0.225	0.624	0.664	0.666	0.898
YS plants m-2	0.282	0.311	0.253	0.864	0.276	0.112	0.094	0.175	0.155	0.164	0.113	0.017	0.698	0.015	0.927	0.021	0.717	0.011	0.195	0.000	0.232	0.791	0.575	0.308	0.200	0.434	0.383
YS pods plant-1	0.689	0.863	0.003	0.120	0.360	0.201	0.337	0.000	0.332	0.420	0.541	0.201	0.358	0.934	0.025	0.313	0.197	0.875	0.165	0.232	0.000	0.431	0.847	0.270	0.948	0.842	0.577
YS beans pods-1	0.053	0.055	0.482	0.491	0.844	0.636	0.760	0.355	0.152	0.171	0.173	0.641	0.498	0.371	0.267	0.270	0.220	0.421	0.811	0.791	0.431	0.000	0.548	0.329	0.067	0.019	0.075
YS TKW [g]	0.992	0.829	0.819	0.549	0.064	0.550	0.337	0.818	0.655	0.796	0.593	0.436	0.985	0.654	0.744	0.832	0.607	0.673	0.225	0.575	0.847	0.548	0.000	0.195	0.456	0.880	0.714
YS yield [dt ha-1]	0.444	0.376	0.337	0.300	0.552	0.964	0.215	0.452	0.714	0.517	0.363	0.501	0.881	0.058	0.030	0.420	0.403	0.067	0.624	0.308	0.270	0.329	0.195	0.000	0.120	0.266	0.790
WCE dens	0.015	0.003	0.819	0.807	0.243	0.692	0.432	0.531	0.112	0.018	0.002	0.639	0.414	0.136	0.475	0.028	0.179	0.171	0.664	0.200	0.948	0.067	0.456	0.120	0.000	0.005	0.043
weeds m-2 FLO	0.002	0.000	0.760	0.925	0.615	0.661	0.819	0.758	0.045	0.009	0.010	0.847	0.349	0.353	0.503	0.045	0.229	0.402	0.666	0.434	0.842	0.019	0.880	0.266	0.005	0.000	0.005
weed species m-2 FLO	0.003	0.001	0.819	0.710	0.703	0.945	0.535	0.818	0.011	0.004	0.009	0.889	0.279	0.528	0.932	0.019	0.456	0.572	0.898	0.383	0.577	0.075	0.714	0.790	0.043	0.005	0.000

Appendix 30: Correlation table of Pearson correlation and Spreaman correlation (blue) of Sprinkange19. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Sprinkange19 r-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	weed cover [%] FLO	weed cover [%] HAR	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	weed species m-2 FLO
weed biomass [g] FLO	1.00	0.65	-0.48	0.25	-0.52	0.22	-0.26	0.62	0.74	-0.09	-0.66	-0.67	-0.30	-0.57	0.49	-0.65	0.63	-0.36	-0.55	-0.53	0.42	-0.57	0.63
weed biomass [g] HAR	0.65	1.00	-0.63	-0.49	0.18	0.31	-0.31	0.72	0.71	-0.35	-0.53	-0.67	-0.60	-0.55	0.37	-0.65	0.70	-0.16	-0.80	-0.80	0.60	-0.71	0.69
soybean biomass [g] FLO	-0.48	-0.63	1.00	0.52	0.18	0.36	0.09	-0.88	-0.94	0.37	0.72	0.89	0.79	0.75	-0.03	0.89	-0.57	0.73	0.92	0.65	-0.66	0.98	-0.86
chl [µmol m-2]	0.25	-0.49	0.52	1.00	-0.73	0.09	0.03	-0.50	-0.32	0.44	0.23	0.37	0.69	0.39	0.14	0.38	-0.24	-0.01	0.61	0.40	-0.28	0.46	-0.27
plants m-2 BWC	-0.52	0.18	0.18	-0.73	1.00	0.23	0.37	-0.03	-0.31	-0.33	0.26	0.18	-0.25	0.02	-0.43	0.17	-0.16	0.62	-0.02	-0.07	-0.13	0.20	-0.31
plants m-2 AWC	0.22	0.31	0.36	0.09	0.23	1.00	-0.43	-0.09	-0.17	0.54	-0.15	0.33	0.42	0.31	0.66	0.36	0.51	0.73	-0.01	0.23	-0.48	0.35	-0.40
plant losses stand impact	-0.26	-0.31	0.09	0.03	0.37	-0.43	1.00	-0.09	-0.14	-0.60	-0.09	0.03	-0.20	-0.43	-0.94	0.09	-0.83	0.12	0.26	-0.49	0.54	0.09	-0.12
weed cover [%] FLO	0.62	0.72	-0.88	-0.50	-0.03	-0.09	-0.09	1.00	0.94	-0.39	-0.88	-0.94	-0.84	-0.91	0.03	-0.93	0.66	-0.42	-0.95	-0.61	0.45	-0.88	0.70
weed cover [%] HAR	0.74	0.71	-0.94	-0.32	-0.31	-0.17	-0.14	0.94	1.00	-0.30	-0.85	-0.94	-0.73	-0.82	0.09	-0.93	0.69	-0.64	-0.92	-0.65	0.59	-0.95	0.85
Height [cm] FLO	-0.09	-0.35	0.37	0.44	-0.33	0.54	-0.60	-0.39	-0.30	1.00	-0.06	0.58	0.80	0.66	0.49	0.60	0.33	0.31	0.25	0.76	-0.70	0.45	-0.53
HEB Index	-0.66	-0.53	0.72	0.23	0.26	-0.15	-0.09	-0.88	-0.85	-0.06	1.00	0.74	0.50	0.70	0.14	0.72	-0.82	0.28	0.84	0.23	-0.08	0.68	-0.45
Yield [dt ha-1]	-0.67	-0.67	0.89	0.37	0.18	0.33	0.03	-0.94	-0.94	0.58	0.74	1.00	0.88	0.95	-0.09	1.00	-0.46	0.62	0.85	0.75	-0.66	0.93	-0.85
TKW [g]	-0.30	-0.60	0.79	0.69	-0.25	0.42	-0.20	-0.84	-0.73	0.80	0.50	0.88	1.00	0.90	0.26	0.89	-0.21	0.44	0.76	0.76	-0.65	0.81	-0.71
HLW [kg hl-1]	-0.57	-0.55	0.75	0.39	0.02	0.31	-0.43	-0.91	-0.82	0.66	0.70	0.95	0.90	1.00	0.37	0.95	-0.31	0.43	0.74	0.64	-0.50	0.78	-0.66
Protein content [%]	0.49	0.37	-0.03	0.14	-0.43	0.66	-0.94	0.03	0.09	0.49	0.14	-0.09	0.26	0.37	1.00	-0.03	0.77	0.03	-0.14	0.31	-0.43	-0.03	0.12
Protein yield [kg ha-1]	-0.65	-0.65	0.89	0.38	0.17	0.36	0.09	-0.93	-0.93	0.60	0.72	1.00	0.89	0.95	-0.03	1.00	-0.43	0.63	0.83	0.76	-0.68	0.92	-0.85
First pod height [cm]	0.63	0.70	-0.57	-0.24	-0.16	0.51	-0.83	0.66	0.69	0.33	-0.82	-0.46	-0.21	-0.31	0.77	-0.43	1.00	-0.10	-0.79	-0.23	0.08	-0.55	0.39
YS plants m-2	-0.36	-0.16	0.73	-0.01	0.62	0.73	0.12	-0.42	-0.64	0.31	0.28	0.62	0.44	0.43	0.03	0.63	-0.10	1.00	0.41	0.50	-0.72	0.74	-0.81
YS pods plant-1	-0.55	-0.80	0.92	0.61	-0.02	-0.01	0.26	-0.95	-0.92	0.25	0.84	0.85	0.76	0.74	-0.14	0.83	-0.79	0.41	1.00	0.61	-0.47	0.90	-0.72
YS beans pods-1	-0.53	-0.80	0.65	0.40	-0.07	0.23	-0.49	-0.61	-0.65	0.76	0.23	0.75	0.76	0.64	0.31	0.76	-0.23	0.50	0.61	1.00	-0.93	0.77	-0.88
YS TKW [g]	0.42	0.60	-0.66	-0.28	-0.13	-0.48	0.54	0.45	0.59	-0.70	-0.08	-0.66	-0.65	-0.50	-0.43	-0.68	0.08	-0.72	-0.47	-0.93	1.00	-0.76	0.92
YS yield [dt ha-1]	-0.57	-0.71	0.98	0.46	0.20	0.35	0.09	-0.88	-0.95	0.45	0.68	0.93	0.81	0.78	-0.03	0.92	-0.55	0.74	0.90	0.77	-0.76	1.00	-0.93
weed species m-2 FLO	0.63	0.69	-0.86	-0.27	-0.31	-0.40	-0.12	0.70	0.85	-0.53	-0.45	-0.85	-0.71	-0.66	0.12	-0.85	0.39	-0.81	-0.72	-0.88	0.92	-0.93	1.00

Sprinkange19 p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	weed cover [%] FLO	weed cover [%] HAR	Height [cm] FLO	HEB Index	Yield [dt ha-1]	TKW [g]	HLW [kg hl-1]	Protein content [%]	Protein yield [kg ha-1]	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.160	0.339	0.640	0.288	0.674	0.623	0.186	0.096	0.866	0.151	0.146	0.563	0.240	0.329	0.160	0.180	0.487	0.259	0.274	0.411	0.233	0.184
weed biomass [g] HAR	0.160	0.000	0.178	0.328	0.739	0.548	0.544	0.107	0.118	0.503	0.276	0.149	0.207	0.260	0.469	0.162	0.118	0.765	0.056	0.054	0.211	0.117	0.129
soybean biomass [g] FLO	0.339	0.178	0.000	0.288	0.736	0.478	0.872	0.021	0.006	0.470	0.107	0.017	0.060	0.089	0.957	0.018	0.233	0.102	0.010	0.159	0.157	0.000	0.027
chl [µmol m-2]	0.640	0.328	0.288	0.000	0.102	0.862	0.957	0.308	0.538	0.380	0.661	0.466	0.129	0.451	0.787	0.464	0.650	0.979	0.199	0.426	0.597	0.353	0.602
plants m-2 BWC	0.288	0.739	0.736	0.102	0.000	0.657	0.469	0.954	0.548	0.521	0.625	0.739	0.628	0.965	0.397	0.745	0.765	0.189	0.971	0.896	0.799	0.703	0.554
plants m-2 AWC	0.674	0.548	0.478	0.862	0.657	0.000	0.397	0.865	0.740	0.267	0.782	0.528	0.409	0.544	0.156	0.489	0.296	0.099	0.992	0.661	0.339	0.501	0.435
plant losses stand impact	0.623	0.544	0.872	0.957	0.469	0.397	0.000	0.872	0.787	0.208	0.872	0.957	0.704	0.397	0.005	0.872	0.042	0.827	0.623	0.329	0.266	0.872	0.827
weed cover [%] FLO	0.186	0.107	0.021	0.308	0.954	0.865	0.872	0.000	0.005	0.442	0.020	0.005	0.036	0.013	0.957	0.007	0.153	0.412	0.004	0.201	0.373	0.021	0.121
weed cover [%] HAR	0.096	0.118	0.006	0.538	0.548	0.740	0.787	0.005	0.000	0.564	0.031	0.005	0.097	0.046	0.872	0.006	0.128	0.167	0.009	0.163	0.222	0.003	0.034
Height [cm] FLO	0.866	0.503	0.470	0.380	0.521	0.267	0.208	0.442	0.564	0.000	0.906	0.232	0.057	0.158	0.329	0.209	0.527	0.545	0.628	0.082	0.122	0.367	0.275
HEB Index	0.151	0.276	0.107	0.661	0.625	0.782	0.872	0.020	0.031	0.906	0.000	0.092	0.315	0.123	0.787	0.107	0.045	0.588	0.036	0.659	0.876	0.137	0.374
Yield [dt ha-1]	0.146	0.149	0.017	0.466	0.739	0.528	0.957	0.005	0.005	0.232	0.092	0.000	0.020	0.004	0.872	0.000	0.354	0.187	0.033	0.086	0.151	0.008	0.033
TKW [g]	0.563	0.207	0.060	0.129	0.628	0.409	0.704	0.036	0.097	0.057	0.315	0.020	0.000	0.013	0.623	0.017	0.685	0.383	0.081	0.081	0.166	0.050	0.116
HLW [kg hl-1]	0.240	0.260	0.089	0.451	0.965	0.544	0.397	0.013	0.046	0.158	0.123	0.004	0.013	0.000	0.469	0.004	0.544	0.391	0.095	0.167	0.311	0.070	0.151
Protein content [%]	0.329	0.469	0.957	0.787	0.397	0.156	0.005	0.957	0.872	0.329	0.787	0.872	0.623	0.469	0.000	0.957	0.072	0.957	0.787	0.544	0.397	0.957	0.827
Protein yield [kg ha-1]	0.160	0.162	0.018	0.464	0.745	0.489	0.872	0.007	0.006	0.209	0.107	0.000	0.017	0.004	0.957	0.000	0.391	0.177	0.040	0.083	0.141	0.008	0.032
First pod height [cm]	0.180	0.118	0.233	0.650	0.765	0.296	0.042	0.153	0.128	0.527	0.045	0.354	0.685	0.544	0.072	0.391	0.000	0.855	0.064	0.658	0.885	0.255	0.449
YS plants m-2	0.487	0.765	0.102	0.979	0.189	0.099	0.827	0.412	0.167	0.545	0.588	0.187	0.383	0.391	0.957	0.177	0.855	0.000	0.414	0.318	0.104	0.091	0.050
YS pods plant-1	0.259	0.056	0.010	0.199	0.971	0.992	0.623	0.004	0.009	0.628	0.036	0.033	0.081	0.095	0.787	0.040	0.064	0.414	0.000	0.202	0.342	0.014	0.106
YS beans pods-1	0.274	0.054	0.159	0.426	0.896	0.661	0.329	0.201	0.163	0.082	0.659	0.086	0.081	0.167	0.544	0.083	0.658	0.318	0.202	0.000	0.007	0.075	0.021
YS TKW [g]	0.411	0.211	0.157	0.597	0.799	0.339	0.266	0.373	0.222	0.122	0.876	0.151	0.166	0.311	0.397	0.141	0.885	0.104	0.342	0.007	0.000	0.082	0.009
YS yield [dt ha-1]	0.233	0.117	0.000	0.353	0.703	0.501	0.872	0.021	0.003	0.367	0.137	0.008	0.050	0.070	0.957	0.008	0.255	0.091	0.014	0.075	0.082	0.000	0.007
weed species m-2 FLO	0.184	0.129	0.027	0.602	0.554	0.435	0.827	0.121	0.034	0.275	0.374	0.033	0.116	0.151	0.827	0.032	0.449	0.050	0.106	0.021	0.009	0.007	0.000

Appendix 31: Correlation table of Pearson correlation and Spreaman correlation (blue) of Hostert19. P-values are shown in the lower part (significant p values p≤0.05 are marked in red) and corresponding r- values are shown in the upper part.

Hostert19 r-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	1.00	0.86	-0.96	-0.14	-0.53	-0.24	0.66	-0.14	0.96	0.96	-0.93	-0.74	0.81	-0.56	-0.80	-0.87	-0.91	-0.66	-0.84	-0.98	0.98	0.96
weed biomass [g] HAR	0.86	1.00	-0.71	0.00	-0.46	0.07	0.32	0.11	0.96	0.93	-0.71	-0.45	0.54	-0.56	-0.49	-0.43	-0.82	-0.54	-0.36	-0.71	0.96	0.96
soybean biomass [g] FLO	-0.96	-0.71	1.00	0.21	0.66	0.43	-0.72	0.09	-0.90	-0.89	0.98	0.67	-0.75	0.56	0.83	0.86	0.89	0.57	0.88	0.97	-0.93	-0.90
chl [µmol m-2]	-0.14	0.00	0.21	1.00	-0.21	-0.25	-0.07	0.45	-0.07	0.07	0.21	-0.05	0.22	-0.58	-0.41	-0.04	0.32	-0.04	0.00	0.21	-0.07	-0.07
plants m-2 BWC	-0.53	-0.46	0.66	-0.21	1.00	0.93	-0.88	-0.24	-0.49	-0.48	0.66	0.70	-0.64	0.43	0.90	0.66	0.35	0.32	0.81	0.51	-0.53	-0.47
plants m-2 AWC	-0.24	0.07	0.43	-0.25	0.93	1.00	-0.78	-0.35	-0.16	-0.15	0.45	0.29	-0.38	0.29	0.68	0.46	0.07	0.11	0.62	0.22	-0.22	-0.18
plant losses stand impact	0.66	0.32	-0.72	-0.07	-0.88	-0.78	1.00	0.02	0.53	0.52	-0.68	-0.83	0.81	-0.26	-0.86	-0.82	-0.46	-0.38	-0.88	-0.57	0.62	0.57
plant losses single impact	-0.14	0.11	0.09	0.45	-0.24	-0.35	0.02	1.00	-0.05	-0.07	-0.11	0.35	-0.30	-0.66	-0.07	0.12	0.22	-0.08	0.08	0.10	-0.09	0.07
weed cover [%] FLO	0.96	0.96	-0.90	-0.07	-0.49	-0.16	0.53	-0.05	1.00	1.00	-0.90	-0.61	0.73	-0.63	-0.78	-0.74	-0.92	-0.61	-0.74	-0.97	0.99	0.97
weed cover [%] HAR	0.96	0.93	-0.89	0.07	-0.48	-0.15	0.52	-0.07	1.00	1.00	-0.88	-0.68	0.76	-0.63	-0.79	-0.75	-0.89	-0.65	-0.75	-0.96	0.99	0.96
WCE cov	-0.93	-0.71	0.98	0.21	0.66	0.45	-0.68	-0.11	-0.90	-0.88	1.00	0.67	-0.65	0.69	0.81	0.80	0.88	0.55	0.82	0.95	-0.91	-0.93
Height [cm] FLO	-0.74	-0.45	0.67	-0.05	0.70	0.29	-0.83	0.35	-0.61	-0.68	0.67	1.00	-0.97	0.34	0.84	0.95	0.63	0.81	0.92	0.67	-0.61	-0.61
HEB Index	0.81	0.54	-0.75	0.22	-0.64	-0.38	0.81	-0.30	0.73	0.76	-0.65	-0.97	1.00	-0.25	-0.86	-0.90	-0.58	-0.67	-0.91	-0.72	0.82	0.68
First pod height [cm]	-0.56	-0.56	0.56	-0.58	0.43	0.29	-0.26	-0.66	-0.63	-0.63	0.69	0.34	-0.25	1.00	0.53	0.47	0.42	0.66	0.46	0.61	-0.59	-0.69
YS plants m-2	-0.80	-0.49	0.83	-0.41	0.90	0.68	-0.86	-0.07	-0.78	-0.79	0.81	0.84	-0.86	0.53	1.00	0.83	0.60	0.57	0.93	0.76	-0.82	-0.74
YS pods plant-1	-0.87	-0.43	0.86	-0.04	0.66	0.46	-0.82	0.12	-0.74	-0.75	0.80	0.95	-0.90	0.47	0.83	1.00	0.63	0.79	0.97	0.80	-0.82	-0.76
YS beans pods-1	-0.91	-0.82	0.89	0.32	0.35	0.07	-0.46	0.22	-0.92	-0.89	0.88	0.63	-0.58	0.42	0.60	0.63	1.00	0.35	0.61	0.94	-0.90	-0.91
YS TKW [g]	-0.66	-0.54	0.57	-0.04	0.32	0.11	-0.38	-0.08	-0.61	-0.65	0.55	0.81	-0.67	0.66	0.57	0.79	0.35	1.00	0.70	0.61	-0.65	-0.61
YS yield [dt ha-1]	-0.84	-0.36	0.88	0.00	0.81	0.62	-0.88	0.08	-0.74	-0.75	0.82	0.92	-0.91	0.46	0.93	0.97	0.61	0.70	1.00	0.79	-0.81	-0.72
WCE dens	-0.98	-0.71	0.97	0.21	0.51	0.22	-0.57	0.10	-0.97	-0.96	0.95	0.67	-0.72	0.61	0.76	0.80	0.94	0.61	0.79	1.00	-0.97	-0.96
weeds m-2 FLO	0.98	0.96	-0.93	-0.07	-0.53	-0.22	0.62	-0.09	0.99	0.99	-0.91	-0.61	0.82	-0.59	-0.82	-0.82	-0.90	-0.65	-0.81	-0.97	1.00	0.97
weed species m-2 FLO	0.96	0.96	-0.90	-0.07	-0.47	-0.18	0.57	0.07	0.97	0.96	-0.93	-0.61	0.68	-0.69	-0.74	-0.76	-0.91	-0.61	-0.72	-0.96	0.97	1.00

p-value	weed biomass [g] FLO	weed biomass [g] HAR	soybean biomass [g] FLO	chl [µmol m-2]	plants m-2 BWC	plants m-2 AWC	plant losses stand impact	plant losses single impact	weed cover [%] FLO	weed cover [%] HAR	WCE cov	Height [cm] FLO	HEB Index	First pod height [cm]	YS plants m-2	YS pods plant-1	YS beans pods-1	YS TKW [g]	YS yield [dt ha-1]	WCE dens	weeds m-2 FLO	weed species m-2 FLO
weed biomass [g] FLO	0.000	0.014	0.001	0.760	0.222	0.599	0.110	0.769	0.001	0.001	0.002	0.058	0.028	0.190	0.032	0.010	0.004	0.106	0.017	0.000	0.000	0.001
weed biomass [g] HAR	0.014	0.000	0.071	1.000	0.294	0.879	0.482	0.818	0.001	0.003	0.071	0.310	0.210	0.193	0.268	0.337	0.023	0.215	0.432	0.071	0.001	0.001
soybean biomass [g] FLO	0.001	0.071	0.000	0.645	0.105	0.332	0.070	0.847	0.005	0.007	0.000	0.102	0.050	0.190	0.020	0.012	0.007	0.178	0.009	0.000	0.003	0.005
chl [µmol m-2]	0.760	1.000	0.645	0.000	0.645	0.589	0.879	0.310	0.879	0.879	0.645	0.908	0.641	0.175	0.355	0.939	0.482	0.939	1.000	0.645	0.879	0.879
plants m-2 BWC	0.222	0.294	0.105	0.645	0.000	0.003	0.010	0.599	0.269	0.276	0.105	0.078	0.122	0.340	0.006	0.109	0.448	0.485	0.027	0.247	0.217	0.288
plants m-2 AWC	0.599	0.879	0.332	0.589	0.003	0.000	0.040	0.445	0.732	0.756	0.308	0.531	0.402	0.534	0.094	0.297	0.875	0.808	0.134	0.630	0.643	0.697
plant losses stand impact	0.110	0.482	0.070	0.879	0.010	0.040	0.000	0.960	0.217	0.227	0.093	0.021	0.027	0.573	0.012	0.025	0.302	0.396	0.009	0.184	0.134	0.185
plant losses single impact	0.769	0.818	0.847	0.310	0.599	0.445	0.960	0.000	0.911	0.890	0.810	0.435	0.511	0.105	0.884	0.799	0.633	0.868	0.858	0.827	0.847	0.878
weed cover [%] FLO	0.001	0.001	0.005	0.879	0.269	0.732	0.217	0.911	0.000	0.000	0.006	0.144	0.060	0.131	0.038	0.058	0.004	0.149	0.059	0.000	0.000	0.000
weed cover [%] HAR	0.001	0.003	0.007	0.879	0.276	0.756	0.227	0.890	0.000	0.000	0.009	0.090	0.048	0.128	0.035	0.051	0.008	0.112	0.053	0.001	0.000	0.001
WCE cov	0.002	0.071	0.000	0.645	0.105	0.308	0.093	0.810	0.006	0.009	0.000	0.102	0.114	0.084	0.029	0.030	0.010	0.202	0.025	0.001	0.005	0.002
Height [cm] FLO	0.058	0.310	0.102	0.908	0.078	0.531	0.021	0.435	0.144	0.090	0.102	0.000	0.000	0.461	0.019	0.001	0.129	0.027	0.003	0.102	0.144	0.144
HEB Index	0.028	0.210	0.050	0.641	0.122	0.402	0.027	0.511	0.060	0.048	0.114	0.000	0.000	0.588	0.012	0.006	0.171	0.102	0.005	0.071	0.025	0.091
First pod height [cm]	0.190	0.193	0.190	0.175	0.340	0.534	0.573	0.105	0.131	0.128	0.084	0.461	0.588	0.000	0.224	0.289	0.344	0.110	0.295	0.145	0.161	0.088
YS plants m-2	0.032	0.268	0.020	0.355	0.006	0.094	0.012	0.884	0.038	0.035	0.029	0.019	0.012	0.224	0.000	0.021	0.154	0.178	0.003	0.047	0.023	0.059
YS pods plant-1	0.010	0.337	0.012	0.939	0.109	0.297	0.025	0.799	0.058	0.051	0.030	0.001	0.006	0.289	0.021	0.000	0.133	0.034	0.000	0.031	0.024	0.050
YS beans pods-1	0.004	0.023	0.007	0.482	0.448	0.875	0.302	0.633	0.004	0.008	0.010	0.129	0.171	0.344	0.154	0.133	0.000	0.440	0.148	0.002	0.006	0.004
YS TKW [g]	0.106	0.215	0.178	0.939	0.485	0.808	0.396	0.868	0.149	0.112	0.202	0.027	0.102	0.110	0.178	0.034	0.440	0.000	0.079	0.143	0.110	0.148
YS yield [dt ha-1]	0.017	0.432	0.009	1.000	0.027	0.134	0.009	0.858	0.059	0.053	0.025	0.003	0.005	0.295	0.003	0.000	0.148	0.079	0.000	0.035	0.027	0.068
WCE dens	0.000	0.071	0.000	0.645	0.247	0.630	0.184	0.827	0.000	0.001	0.001	0.102	0.071	0.145	0.047	0.031	0.002	0.143	0.035	0.000	0.000	0.001
weeds m-2 FLO	0.000	0.001	0.003	0.879	0.217	0.643	0.134	0.847	0.000	0.000	0.005	0.144	0.025	0.161	0.023	0.024	0.006	0.110	0.027	0.000	0.000	0.000
weed species m-2 FLO	0.001	0.001	0.005	0.879	0.288	0.697	0.185	0.878	0.000	0.001	0.002	0.144	0.091	0.088	0.059	0.050	0.004	0.148	0.068	0.001	0.000	0.000

Appendix 32: Mean number of weed individuals (number m^{-2}) and weed species (number m^{-2}), average values of the Shannon index, the Shannon index maximum and the equitability ratio for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Hostert 2018 and Hostert 2019. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's HSD test or to Tukey's LSD test + and to Fisher's test with preceded Kruskal-Wallis test ++.

Hostert	Weed individuals [number m^{-2}]							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018++	2019
$t.1_{neg}$	408.3 n.s.	109.0 n.s.	408.3 a	109.0 a	212.0 a	178.5 a	99.2 a	49.7 a
$t.2_{pos}$	433.5	122.0	0.0 c	0.0 c	0.0 d	0.0 c	0.0 d	0.0 b
$t.3_{har}$	479.0	91.8	195.2 b	46.8 b	146.7 abc	124.0 ab	69.5 ab	35.0 ab
$t.4_{hoe}$	456.3	105.5	120.5 bc	23.2 bc	114.5 c	28.8 c	41.8 bc	33.2 ab
$t.5_{hoe+}$	553.2	112.8	109.7 bc	29.7 bc	127.5 bc	14.5 c	38.5 bc	19.0 ab
$t.6_{comb}$	452.2	98.8	79.3 bc	24.8 bc	97.7 c	11.0 c	30.5 cd	8.5 ab
$t.7_{mix}$	485.3	82.3	205.3 b	52.8 b	195.3 ab	102.5 b	81.0 ab	33.8 ab
p-value	0.49	0.72	5.18e-06***	9.53e-06***	6.82e-07***	4.04e-08***	0.01	0.02*

Hostert	Weed species [number m-2]							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	10.8 n.s.	7.9 n.s.	10.8 a	7.9 a	8.3 a	13.1 a	4.5 a	6.8 a
$t.2_{pos}$	10.3	9.9	0.0 c	0.0 c	0.0 b	0.0 c	0.0 b	0.0 c
$t.3_{har}$	10.7	7.7	7.2 b	5.8 ab	7.9 a	10.6 a	4.3 a	4.6 ab
$t.4_{hoe}$	11.4	8.4	7.7 ab	3.3 b	7.6 a	5.5 b	4.3 a	4.3 ab
$t.5_{hoe+}$	10.8	8.0	6.4 b	4.6 b	8.2 a	3.8 b	4.0 a	3.5 ab
$t.6_{comb}$	11.2	8.2	7.0 b	3.6 b	7.9 a	2.8 bc	3.8 a	2.5 bc
$t.7_{mix}$	11.2	6.0	7.8 ab	5.3 ab	8.8 a	9.6 a	5.1 a	5.8 ab
p-value	0.89	0.14	3.55E-07 ***	1.36E-05 ***	6.42E-08 ***	3.86E-09 ***	2.35E-03 **	0.00 ***

Hostert	Shannon index							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	1.8 n.s.	1.3 n.s.	1.8 a	1.3 a	1.5 a	2.0 a	0.9 a	1.5 a
$t.2_{pos}$	1.8	1.6	0.0 c	0.0 b	0.0 b	0.0 d	0.0 b	0.0 b
$t.3_{har}$	1.7	1.5	1.3 ab	1.3 a	1.4 a	1.9 ab	0.9 a	1.1 a
$t.4_{hoe}$	1.9	1.5	1.6 ab	0.8 ab	1.6 a	1.4 c	1.1 a	1.0 a
$t.5_{hoe+}$	1.7	1.3	1.3 b	1.1 a	1.5 a	1.1 c	1.0 a	1.0 a
$t.6_{comb}$	1.9	1.4	1.6 ab	0.9 ab	1.6 a	0.8 cd	1.0 a	0.8 ab
$t.7_{mix}$	1.7	1.0	1.5 ab	1.0 a	1.4 a	1.7 b	1.1 a	1.5 a
p-value	0.16	0.07	2.22E-09 ***	1.98E-03 **	2.54E-11 ***	1.80E-06 ***	1.20E-04 ***	1.79E-04 ***

Hostert	Shannon index maximum							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	2.4	2.0	2.4	2.0	2.1	2.6	1.4	1.9
$t.2_{pos}$	2.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0
$t.3_{har}$	2.3	2.0	1.9	1.7	2.0	2.3	1.3	1.4
$t.4_{hoe}$	2.4	2.1	2.0	1.0	2.0	1.5	1.4	1.2
$t.5_{hoe+}$	2.4	2.0	1.8	1.4	2.1	1.2	1.4	1.1
$t.6_{comb}$	2.4	2.1	1.9	1.1	2.1	0.9	1.2	0.8
$t.7_{mix}$	2.4	1.7	2.0	1.6	2.2	2.2	1.6	1.7

Hostert	Equitability							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	0.8	0.6	0.8	0.6	0.7	0.8	0.7	0.8
$t.2_{pos}$	0.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0
$t.3_{har}$	0.7	0.7	0.7	0.8	0.7	0.8	0.7	0.8
$t.4_{hoe}$	0.8	0.7	0.8	0.8	0.8	0.9	0.8	0.9
$t.5_{hoe+}$	0.7	0.6	0.8	0.7	0.7	0.9	0.8	0.9
$t.6_{comb}$	0.8	0.6	0.8	0.8	0.8	0.9	0.8	0.9
$t.7_{mix}$	0.7	0.5	0.7	0.6	0.6	0.8	0.7	0.9

Appendix 33: Mean number of weed individuals (number m^{-2}) and weed species (number m^{-2}), average values of the Shannon index, the Shannon index maximum and the equitability ratio for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Manternach 2018 and Manternach 2019. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's HSD test or to Tukey's LSD test $^{+}$ and to Fisher's test with preceded Kruskal-Wallis test $^{++}$.

Manternach	**Weed individuals [number m-2]**							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018^{++}	2019^{+}	2018^{++}	2019^{++}	2018	2019^{+}
$t.1_{neg}$	25.3 n.s.	119.8 n.s.	25.3 a	119.8 a	137.0 a	68.3 a	109.2 a	53.0 a
$t.2_{pos}$	21.8	119.0	0.0 c	0.0 d	0.0 d	0.0 d	0.0 c	0.0 c
$t.3_{har}$	20.2	90.0	0.5 c	50.7 ab	46.2 c	15.3 bc	54.0 b	22.2 b
$t.4_{hoe}$	20.0	120.8	3.0 b	11.8 c	71.8 ab	16.3 bc	55.5 b	28.5 b
$t.5_{hoe+}$	18.7	80.8	2.2 b	12.5 c	66.0 bc	12.7 c	63.8 ab	39.8 ab
$t.6_{comb}$	15.7	112.5	2.3 b	17.3 c	69.8 bc	13.8 c	46.5 bc	28.2 b
$t.7_{mix}$	35.8	95.7	0.3 c	42.7 b	47.5 c	33.3 ab	82.0 ab	36.2 ab
p-value	0.33	0.72	2.36E-03	1.20E-03	4.10E-03	3.80E-03	4.31E-05 ***	1.13E-03 **

Manternach	**Weed species [number m-2]**							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019^{+}	2018	2019	2018	2019
$t.1_{neg}$	4.7 n.s.	6.7 n.s.	4.7 a	6.7 a	8.6 a	6.6 a	5.5 a	4.7 a
$t.2_{pos}$	4.2	6.8	0.0 b	0.0 d	0.0 c	0.0 d	0.0 b	0.0 b
$t.3_{har}$	3.3	6.6	0.3 b	5.5 b	5.3 b	2.7 c	4.9 a	3.5 a
$t.4_{hoe}$	3.8	8.1	1.2 b	3.1 cd	5.7 b	3.8 bc	4.1 a	4.2 a
$t.5_{hoe+}$	4.3	7.4	0.9 b	2.6 cd	5.9 b	2.1 cd	4.8 a	3.1 a
$t.6_{comb}$	3.9	8.0	0.8 b	3.8 bcd	6.1 b	3.3 bc	4.8 a	4.2 a
$t.7_{mix}$	5.1	6.5	0.2 b	5.6 bc	5.8 b	5.3 ab	5.2 a	4.7 a
p-value	0.34	0.29	1.48E-08 ***	3.59E-06 ***	1.66E-08 ***	2.64E-06 ***	2.43E-06 ***	1.44E-04 ***

Manternach	**Shannon index**							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019^{+}	2018	2019
$t.1_{neg}$	1.3 n.s.	1.2 n.s.	1.3 a	1.2 ab	1.3 a	1.5 a	1.0 a	1.1 a
$t.2_{pos}$	1.2	1.4	0.0 b	0.0 c	0.0 b	0.0 d	0.0 b	0.0 b
$t.3_{har}$	1.0	1.2	0.1 b	1.2 ab	1.3 a	0.8 c	1.1 a	0.9 a
$t.4_{hoe}$	1.0	1.5	0.2 b	0.9 ab	1.3 a	1.1 ab	1.0 a	1.1 a
$t.5_{hoe+}$	1.3	1.4	0.2 b	0.7 b	1.3 a	0.5 c	1.0 a	0.7 a
$t.6_{comb}$	1.1	1.6	0.1 b	1.1 ab	1.3 a	0.9 bc	1.2 a	1.0 a
$t.7_{mix}$	1.3	1.4	0.0 b	1.4 a	1.3 a	1.4 a	1.2 a	1.2 a
p-value	0.26	0.11	3.49E-10 ***	1.60E-05 ***	4.80E-08 ***	3.09E-06 ***	7.35E-06 ***	1.28E-04 ***

Manternach	**Shannon index maximum**							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	1.5	1.9	1.5	1.9	2.1	1.9	1.7	1.5
$t.2_{pos}$	1.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0
$t.3_{har}$	1.1	1.8	0.1	1.6	1.6	0.9	1.6	1.1
$t.4_{hoe}$	1.2	2.1	0.2	1.0	1.7	1.3	1.3	1.4
$t.5_{hoe+}$	1.4	2.0	0.2	0.8	1.8	0.7	1.5	1.0
$t.6_{comb}$	1.3	2.1	0.1	1.2	1.8	1.0	1.5	1.2
$t.7_{mix}$	1.6	1.8	0.0	1.7	1.7	1.6	1.6	1.4

Manternach	**Equitability**							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	0.8	0.6	0.8	0.6	0.5	0.8	0.5	0.8
$t.2_{pos}$	0.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0
$t.3_{har}$	0.9	0.7	1.0	0.8	0.8	0.9	0.7	0.8
$t.4_{hoe}$	0.7	0.7	1.0	0.9	0.8	0.7	0.8	0.8
$t.5_{hoe+}$	0.9	0.7	1.0	0.9	0.7	0.9	0.7	0.7
$t.6_{comb}$	0.8	0.8	1.0	0.9	0.7	0.9	0.8	0.8
$t.7_{mix}$	0.8	0.8	0.0	0.8	0.8	0.8	0.7	0.8

Appendix 34: Mean number of weed individuals (number m⁻²) and weed species (number m⁻²), average values of the Shannon index, the Shannon index maximum and the equitability ratio for each treatment $t.1_{neg}$ (1), $t.2_{pos}$ (2), $t.3_{har}$ (3), $t.4_{hoe}$ (4), $t.5_{hoe+}$ (5), $t.6_{comb}$ (6) and $t.7_{mix}$ (7), for BWC, AWC, FLO and HAR, for Sprinkange 2018 and Sprinkange 2019. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's HSD test or to Tukey's LSD test ⁺ and to Fisher's test with preceded Kruskal-Wallis test ⁺⁺.

Sprinkange	Weed individuals [number m-2]							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018⁺⁺	2019	2018⁺	2019
$t.1_{neg}$	91.5 b	409.3 n.s.	91.5 b	NA	81.8 b	NA	75.3 b	NA
$t.2_{pos}$	119.8 ab	NA	0.0 c	NA	0.0 d	NA	0.0 d	NA
$t.3_{har}$	132.2 ab	383.3	132.2 a	NA	113.8 a	NA	95.2 ab	NA
$t.4_{hoe}$	119.7 ab	373.0	29.2 c	NA	40.7 c	NA	43.7 c	NA
$t.5_{hoe+}$	107.0 ab	361.3	25.5 c	NA	33.7 c	NA	34.5 c	NA
$t.6_{comb}$	153.2 ab	473.7	28.0 c	NA	34.8 c	NA	45.2 c	NA
$t.7_{mix}$	172.3 a	488.3	108.0 ab	NA	100.5 a	NA	105.5 a	NA
p-value	0.03 *	0.58	2.97E-09 ***		5.70E-04		8.62E-06 ***	

Sprinkange	Weed species [number m-2]							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	10.0 n.s.	10.3 n.s.	10.0 a	NA	11.3 a	2.0 n.s.	10.4 a	8.3 n.s.
$t.2_{pos}$	9.8	NA	0.0 c	NA	0.0 c	NA	0.0 c	NA
$t.3_{har}$	9.9	10.2	9.9 a	NA	10.5 a	2.0	9.8 a	7.1
$t.4_{hoe}$	9.8	9.8	4.7 b	NA	6.9 b	1.8	6.6 b	8.0
$t.5_{hoe+}$	9.8	10.2	4.7 b	NA	6.3 b	1.8	6.2 b	7.3
$t.6_{comb}$	9.5	12.3	4.3 b	NA	5.9 b	1.5	6.3 b	7.3
$t.7_{mix}$	10.3	10.5	8.3 a	NA	10.7 a	1.9	10.0 a	7.3
p-value	0.92	0.79	3.19E-11 ***		5.69E-10 ***	0.64	6.95E-10 ***	0.42

Sprinkange	Shannon index							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018⁺	2019	2018⁺⁺	2019	2018	2019
$t.1_{neg}$	1.8 ab	1.6 n.s.	1.8 a	NA	2.1 a	NA	2.0 a	NA
$t.2_{pos}$	1.8 ab	NA	0.0 d	NA	0.0 d	NA	0.0 c	NA
$t.3_{har}$	1.7 b	1.5	1.7 ab	NA	1.8 ab	NA	1.9 a	NA
$t.4_{hoe}$	1.8 ab	1.5	1.3 c	NA	1.6 bc	NA	1.6 b	NA
$t.5_{hoe+}$	1.9 a	1.6	1.2 c	NA	1.5 c	NA	1.5 b	NA
$t.6_{comb}$	1.7 ab	1.7	1.2 c	NA	1.5 c	NA	1.5 b	NA
$t.7_{mix}$	1.7 ab	1.4	1.7 b	NA	2.0 a	NA	1.8 ab	NA
p-value	0.02 *	0.58	1.29E-10 ***		2.10E-03		2.09E-12 ***	

Sprinkange	Shannon index maximum							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	2.3	2.3	2.3	NA	2.4	NA	2.3	NA
$t.2_{pos}$	2.3	NA	0.0	NA	0.0	NA	0.0	NA
$t.3_{har}$	2.3	2.3	2.3	NA	2.3	NA	2.3	NA
$t.4_{hoe}$	2.3	2.2	1.5	NA	1.9	NA	1.9	NA
$t.5_{hoe+}$	2.3	2.3	1.4	NA	1.8	NA	1.8	NA
$t.6_{comb}$	2.2	2.5	1.4	NA	1.7	NA	1.8	NA
$t.7_{mix}$	2.3	2.3	2.1	NA	2.4	NA	2.2	NA

Sprinkange	Equitability							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
$t.1_{neg}$	0.8	0.7	0.8	NA	0.9	NA	0.9	NA
$t.2_{pos}$	0.8	NA	0.0	NA	0.0	NA	0.0	NA
$t.3_{har}$	0.7	0.6	0.7	NA	0.8	NA	0.8	NA
$t.4_{hoe}$	0.8	0.7	0.9	NA	0.8	NA	0.8	NA
$t.5_{hoe+}$	0.8	0.7	0.9	NA	0.9	NA	0.8	NA
$t.6_{comb}$	0.8	0.7	0.9	NA	0.9	NA	0.8	NA
$t.7_{mix}$	0.8	0.6	0.8	NA	0.8	NA	0.8	NA

Appendix 35: Mean number of weed individuals and species (number m-2), and cover (%) of Soybean, Weeds and Ground, assessed in soybean rows of treatments t.4$_{hoe}$ (4), t.5$_{hoe+}$ (5) and t.6$_{comb}$ (6), for Hostert 2018 and Hostert 2019. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's test and to Fisher's test with preceded Kruskal-Wallis test ++.

Hostert	Weed individuals in soybean rows (number m^{-2})							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
t.4$_{hoe}$	118.7 n.s.	13.0 n.s.	88.5 a	13.0 n.s.	51.7 n.s.	24.8 n.s.	7.8 n.s.	6.2 n.s.
t.5$_{hoe+}$	143.7 n.s.	21.5 n.s.	71.3 ab	11.0 n.s.	60.3 n.s.	8.5 n.s.	15.5 n.s.	4.7 n.s.
t.6$_{comb}$	103.3 n.s.	17.8 n.s.	50.3 b	10.0 n.s.	40.2 n.s.	8.5 n.s.	8.2 n.s.	2.7 n.s.
p-value	0.36	0.83	5,28e-03 **	0.70	0.20	0.11	0.516	0.57

Hostert	Weed species in soybean rows (number m^{-2})							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
t.4$_{hoe}$	8.8 n.s.	3.8 n.s.	7.3 n.s.	2.5 n.s.	5.5 n.s.	5.3 n.s.	1.6 n.s.	1.6 n.s.
t.5$_{hoe+}$	8.0 n.s.	3.5 n.s.	6.1 n.s.	2.3 n.s.	6.3 n.s.	2.6 n.s.	2.3 n.s.	1.8 n.s.
t.6$_{comb}$	8.2 n.s.	3.7 n.s.	5.8 n.s.	1.9 n.s.	5.4 n.s.	2.3 n.s.	1.8 n.s.	1.3 n.s.
p-value	0.73	0.94	0.20	0.62	0.52	0.22	0.848	0.51

Hostert	Soybean cover in soybean rows (%)							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018++	2019	2018	2019++
t.4$_{hoe}$	60.8 n.s.	47.5 n.s.	65.0 n.s.	47.5 n.s.	77.9 a	83.3 n.s.	42.1 n.s.	57.1 n.s.
t.5$_{hoe+}$	63.8 n.s.	52.5 n.s.	58.8 n.s.	53.3 n.s.	64.6 b	79.3 n.s.	45.4 n.s.	61.3 n.s.
t.6$_{comb}$	62.1 n.s.	46.7 n.s.	62.1 n.s.	46.7 n.s.	80.8 a	80.4 n.s.	43.8 n.s.	57.5 n.s.
p-value	0.95	0.67	0.29	0.56	0.03	0.77	0.962	0.86

Hostert	Weed cover in soybean rows (%)							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018++	2019	2018	2019	2018	2019
t.4$_{hoe}$	22.5 n.s.	2.6 n.s.	20.0 n.s.	1.5 n.s.	35.0 a	5.8 n.s.	47.9 n.s.	3.8 n.s.
t.5$_{hoe+}$	28.9 n.s.	2.8 n.s.	25.0 n.s.	1.3 n.s.	37.5 a	3.8 n.s.	47.5 n.s.	1.8 n.s.
t.6$_{comb}$	20.4 n.s.	2.5 n.s.	15.0 n.s.	1.1 n.s.	23.3 b	3.7 n.s.	32.2 n.s.	1.5 n.s.
p-value	0.76	0.93	0.64	0.60	0.02 *	0.64	0.455	0.22

Hostert	Ground cover in soybean rows (%)							
	BWC		AWC		FLO		HAR	
Treatment	2018	2019	2018	2019	2018	2019	2018	2019
t.4$_{hoe}$	18.3 n.s.	49.9 n.s.	17.1 n.s.	51.4 n.s.	2.3 n.s.	10.9 n.s.	10.8 b	3.8 n.s.
t.5$_{hoe+}$	7.7 n.s.	44.7 n.s.	16.7 n.s.	47.0 n.s.	6.8 n.s.	16.8 n.s.	8.8 b	1.5 n.s.
t.6$_{comb}$	21.3 n.s.	52.2 n.s.	23.8 n.s.	52.7 n.s.	5.5 n.s.	15.9 n.s.	24.2 a	1.5 n.s.
p-value	0.06	0.57	0.32	0.67	0.36	0.60	5,41e-03 **	0.15

Appendix 36: Mean number of weed individuals and species (number m-2), and cover (%) of Soybean, weeds and ground, assessed in soybean rows for treatments t.4hoe (4), t.5hoe+ (5) and t.6comb (6), for BWC, AWC, FLO and HAR, for Sprinkange 2018 and Sprinkange 2019. Means followed by a common letter within each column are not significantly different at p≤0.05 according to Tukey's HSD test and to Fisher's test with preceded Kruskal-Wallis test ++.

Sprinkange	Weed individuals in soybean rows (number m-2)			
	BWC	AWC	FLO	HAR
Treatment	2018++	2018	2018	2018
t.4hoe	17.2 n.s.	9.9 n.s.	13.3 n.s.	9.8 n.s.
t.5hoe+	15.7 n.s.	9.1 n.s.	11.8 n.s.	8.8 n.s.
t.6comb	20.5 n.s.	10.9 n.s.	11.7 n.s.	10.3 n.s.
p-value	0.87	0.87	0.76	0.91

Sprinkange	Weed species in soybean rows (number m-2)			
	BWC	AWC	FLO	HAR
Treatment	2018	2018	2018	2018
t.4hoe	6.1 n.s.	4.0 n.s.	5.8 n.s.	5.1 n.s.
t.5hoe+	6.3 n.s.	3.8 n.s.	5.0 n.s.	4.3 n.s.
t.6comb	5.8 n.s.	4.1 n.s.	4.7 n.s.	3.8 n.s.
p-value	0.86	0.95	0.61	0.27

Sprinkange	Soybean cover in soybean rows (%)			
	BWC	AWC	FLO	HAR
Treatment	2018	2018	2018	2018
t.4hoe	76.3 n.s.	75.4 n.s.	88.4 n.s.	78.8 n.s.
t.5hoe+	78.3 n.s.	74.6 n.s.	83.8 n.s.	80.8 n.s.
t.6comb	77.1 n.s.	72.1 n.s.	78.3 n.s.	75.8 n.s.
p-value	0.95	0.88	0.30	0.82

Sprinkange	Weed cover in soybean rows (%)			
	BWC	AWC	FLO	HAR
Treatment	2018	2018	2018++	2018
t.4hoe	6.2 n.s.	4.3 n.s.	9.3 n.s.	9.8 n.s.
t.5hoe+	7.0 n.s.	3.8 n.s.	7.8 n.s.	7.5 n.s.
t.6comb	8.8 n.s.	4.3 n.s.	6.3 n.s.	11.5 n.s.
p-value	0.21	0.95	0.66	0.82

Sprinkange	Ground cover in soybean rows (%)			
	BWC	AWC	FLO	HAR
Treatment	2018	2018	2018	2018
t.4hoe	19.3 n.s.	31.7 n.s.	8.7 n.s.	11.9 n.s.
t.5hoe+	20.4 n.s.	25.4 n.s.	9.6 n.s.	11.8 n.s.
t.6comb	16.4 n.s.	26.7 n.s.	17.1 n.s.	13.5 n.s.
p-value	0.85	0.79	0.06	0.94

Appendix 37: LeguTec leaflet designed in 2018.

Appendix 38: Snack soybeans LeguTec as give-away designed in 2018.

Appendix 39: Poster LeguTec in the formats A0 and A4.

MECHANISCHE BEIKRAUTREGULIERUNG IM SOJAANBAU IN LUXEMBURG

LeguTec

SOJA - DIE WUNDERBOHNE

Die Sojabohne (*Glycine max* (L.) Merr.) gehört zur Familie der Hülsenfrüchtler (*Leguminosae*) und zählt zu den ältesten Kulturpflanzen der Welt. Mit einem Proteinanteil von etwa 40 % und einer sehr hohen biologischen Wertigkeit aufgrund einer idealen Aminosäurezusammensetzung ist sie eine der wichtigsten Futtereiweißquellen in der Tierernährung. Als Eiweißpflanze bringt die Sojabohne eine Vielzahl an positiven Eigenschaften für den Einsatz in der Landwirtschaft mit sich: Der Anbau von Soja erweitert und lockert die Fruchtfolge, erhöht die Agrobiodiversität, führt durch die Fähigkeit zur Stickstoff-Fixierung zu einer Verbesserung der Bodenfruchtbarkeit und trägt somit zu einer Einsparung von Stickstoffdünger bei.

SOJA MADE IN LUXEMBOURG

Mit der Europäischen Soja-Erklärung aus dem Jahr 2017 will Luxemburg den regionalen Anbau von Sojabohnen und weiteren Eiweißpflanzen fördern. Ausschlaggebend dafür ist die derzeitige Abhängigkeit von Importen aus überwiegend Nord- und Südamerika. Weit mehr als 60 % der benötigten Menge an Soja wird importiert, womit diverse ökologische und soziale Probleme, wie beispielsweise lange Transportwege und Landverdrängung in den Herkunftsländern, einhergehen.

Dank neuen Züchtungen wächst die Sojabohne längst nicht mehr in nur wärmeoptimalen Lagen - eine Chance für die Steigerung der Eiweißautarkie in Luxemburg. Der Anbau der Sojabohne ist jedoch anspruchsvoll und neben der derzeitig noch nicht gewährleisteten Weiterverarbeitung in Luxemburg gibt es vor allem Wissenslücken im effizienten, nachhaltigen Beikrautmanagement. Wie kann nun dieses Anbauhemmnis überwunden werden und regional stabile und ausreichende Erträge im Sojaanbau gewährleistet werden?

MIT DEM DREIJÄHRIG GEFÖRDERTEN PROJEKT

„LeguTec: Nachhaltige, ressourcenschonende Eiweißproduktion durch mechanische und herbizidfreie Beikrautregulierungstechniken im Körnerleguminosenanbau, am Beispiel der Sojabohne" setzt das IBLA gemeinsam mit seinen Projektpartner, dem Lycée Technique Agricole (LTA) Ettelbrück, Wolff-Weyland S.A. sowie Geocoptix GmbH, an genau dieser noch zu lösenden Fragestellung an.

Auf drei Bio-Betrieben in Luxemburg und anhand eines Schauversuches auf dem LTA-Versuchsstandort in Bettendorf werden ab dem Frühjahr 2018 unterschiedliche mechanische Beikrautregulierungsmethoden im Sojaanbau getestet. Ergänzt werden die Untersuchungen durch drohnengestützte Luftbildaufnahmen. Ziel des Projektes ist es, die bestmögliche mechanische Beikrautregulierungsmethode für den Sojaanbau ausfindig zu machen um somit eine nachhaltige und ressourcenschonende Eiweißproduktion in Luxemburg zu fördern und die Eiweißautarkie der Luxemburger Betriebe zu erhöhen.

UNSER PROJEKT

Verschiedene mechanische Beikrautregulierungstechniken werden miteinander verglichen, u.a. Scharhacke mit und ohne Fingerhacken.

Bonituren vor und nach jeder Beikrautregulierungsmaßnahme werden durch drohnengestützte Luftbildaufnahmen ergänzt.

Kommunikation nach außer durch Feldbegehungen sowie Learning by Doing: Schüler der Ackerbauschule bewirtschaften ihre Versuchsfläche.

FINANZIERUNG

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PROJEKTPARTNER

IBLA; Geocoptix; Lycée Technique Agricole; agri-distribution Wolff-Weyland

Betrieb "An Dudel" Emering, Sprinkange; Betrieb Mehlen, Manternach; Betrieb François, Hostert

weitere Informationen: http://ibla.lu/legutec

Appendix 40: Article about LeguTec in the Letzebuerger Journal, 12.11.2018.

KLOERTEXT - SOJA MADE IN LUXEMBURG

LAURA LEIMBROCK
Forschung und Entwicklung,
„Institut fir biologesch Landwirtschaft an Agrarkultur a.s.b.l." (IBLA)

Landwirtschaft von Importen unabhängiger machen

In der Ernährung unserer Nutztiere spielen Eiweiß liefernde Futtermittel eine wichtige Rolle. Der klassische Eiweißträger ist die Sojabohne, welche als Sojaschrot Schweinen, Geflügel und Rindern gefüttert wird. Der Bedarf an Futtersoja ist jedoch in unseren Regionen weitaus höher als das Angebot. Daher ist Europa abhängig von Importen aus überwiegend Nord- und Südamerika, welche ökologische und soziale Probleme mit sich bringen: Gentechnisch verändertes Soja, Monokulturen mit hohem Pestizideinsatz, Abholzung von Regenwäldern und Landverdrängung. Eine Frage beschäftigt unsere Landwirte und Konsumenten daher seit einigen Jahren: Gibt es Möglichkeiten, sich von diesen Importen unabhängiger zu machen, um eine regionale Wertschöpfungskette zu gewährleisten?

„Soja ist eine Wunderbohne! Mit einem Proteinanteil von etwa 40 Prozent und einer sehr hohen biologischen Wertigkeit ist sie eine wertvolle Körnerleguminose. Dank neuen Züchtungen wächst sie längst nicht mehr nur in wärmeoptimalen Lagen. Ihre Vielzahl an positiven Eigenschaften machen sie nicht nur als Eiweißlieferant für den Einsatz in der Landwirtschaft interessant. Der Anbau von Soja erweitert und lockert die Fruchtfolge, führt durch die Fähigkeit zur Stickstoff-Fixierung zu einer Verbesserung der Bodenfruchtbarkeit und zudem zu einer Einsparung von Stickstoffdünger. Das Kultivieren der Sojabohne ist jedoch anspruchsvoll, und neben der noch nicht gewährleisteten Weiterverarbeitung in Luxemburg gibt es vor allem Wissenslücken im effizienten, nachhaltigen Beikrautmanagement, Wie kann dieses Anbauhemmnis überwunden werden und regional stabile und ausreichende Erträge im Sojaanabau gewährleistet werden?

Mit dem dreijährig geförderten Projekt ‚LeguTec: Nachhaltige, ressourcenschonende Eiweißproduktion durch mechanische Herbizid freie Beikrautregulierungstechniken im Körnerleguminosenanbau, am Beispiel der Sojabohne' setzt das IBLA mit seinen Projektpartnern, dem Lycée Technique Agricole (LTA) Ettelbrück, Wolff-Weyland S,A, sowie Geocoptix UG, an dieser Frage an. In drei Bio-Betrieben in Luxemburg und anhand eines Schauversuches am LTA werden ab dem Frühjahr 2018 unterschiedliche mechanische Beikrautregulierungsmethoden im Sojaanbau getestet. Ergänzt werden die Untersuchungen durch Luftbildaufnahmen. Ziel des Projekts ist es, die bestmögliche mechanische Beikrautregulierungsmethode für den Sojaanbau ausfindig zu machen, eine nachhaltige und ressourcenschonende Eiweißproduktion in Luxemburg anzukurbeln und die Eiweißautarkie der Luxemburger Betriebe zu erhöhen. Finanziert wird das vielversprechende Projekt von der ‚Oeuvre Nationale de Secours Grande-Duchesse Charlotte' und dem ‚Ministère de l'Agriculture, de la Viticulture et de la Protection des consommateurs' und unterstützt durch Sponsoring von Wolff-Weyland S.A..

Die Eiweißversorgung werden wir nie vollständig selber decken können. Wir können aber neben einem verbesserten Grünlandmanagement und Feldfutterbau einen bedeutenden Beitrag zur Reduzierung der Eiweißlücke leisten. Die steigende Verwendung von heimischer Soja in Luxemburg kann die ökologischen und sozialen Probleme in den Exportländern mindern und gleichzeitig ökologische Vorteile für unsere Landwirtschaft bringen."

Weitere Infos unter www.ibla.lu

„Ein steigender Anbau von heimischer Soja in Luxemburg bringt Vorteile für unsere Landwirtschaft"

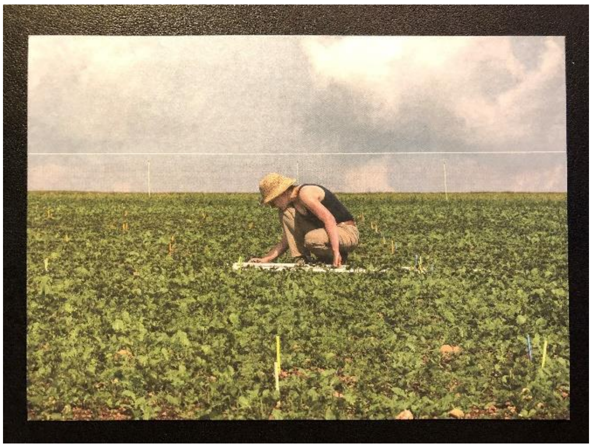
Appendix 41: List of previous media articles of the LeguTec project during the project years 2018-2020.

Institution	**Titel of report**	**Link**	**Kind of report**	**Date**
Oeuvre Nationale de Secours Grande-Duchesse Charlotte	LeguTec- Soja made in Luxembourg	https://www.oeuvre.lu/legutec-soja-made-in-luxembourg/	report	18.06.2018
100,7	Soja: eng Wonnerboun?	https://www.100komma7.lu/article/aktualiteit/soja-eng-wonnerboun	radio	12.06.2018 - 11:30
RTL	PISA- De Wëssensmagazin Am Replay: Modernen Akerbau Roboter um Feld, Soja-Comeback an zu Lëtzebuerg an e Rise-Gras aus Asien.	http://tele.rtl.lu/emissiounen/pisa-de-wessensmagazin/emissioun/1191951.html	TV-report	09.07.2018
Le Quotidien	Soja: vers une solution « Made in Luxembourg »	http://www.lequotidien.lu/a-la-une/soja-vers-une-solution-made-in-luxembourg/	article	09.06.2018
Letzebuerger Journal	„Soja made in Luxembourg"	http://www.journal.lu/article/soja-made-in-luxembourg/	article	08.06.2018
RTL	Invité vun der Redaktioun (8. Juni) Stéphanie Zimmer iwwer Soja aus Lëtzebuerg	http://radio.rtl.lu/emissiounen/den-invite-vun-der-rtl-redaktioun/1191467.html	radio	08.06.2018

Institution	Titel of report	Link	Kind of report	Date
RTL	VIDEO: Soja zu Lëtzebuerg	http://tele.rtl.lu/emissiounen/de-journal/3126987.html	TV-report	08.06.2018
Gouvernement.lu	Offiziell Feldbegehung a Virstellung vum Projet "LeguTec" zu Manternach um Betrib Mehlen	https://gouvernement.lu/lb/actualites/toutes_actualites/articles/2018/06-juin/08-legutec.htm	report	08.06.2018
Leguminosentag, Ettelbrück, LU	Mechanical weed control in soybean cultivation in Luxembourg – season 2018	https://ibla.lu/_res/uploads/2018/05/LeguTec_LeguTag_02032018.pdf	presentation	08.02.19
15. Wissenschafts-tagung Ökologischer Landbau, Kassel, Germany	LeguTec – Mechanical weed control in soybean cultivation in Luxembourg	https://orgprints.org/36241/	poster presentation	06.-08.03.19
IBLA Newsletter	Legume Day 2019	https://ibla.lu/_res/uploads/2019/04/11_18_Ibla_Newsletter_7_Digital.pdf	article	29.04.19
Alcovit	8. Leguminosentag „Soja made in Luxembourg"JA MADE IN LUXEMBOURG"	http://www.alcovit.lu/index.php/news-aktuelles/487-iblalegu.html	article	05.05.19
Webpage gouvernement.lu	Offizielle Begehung des Versuchs- und Lehrfeldes	https://gouvernement.lu/dam-assets/documents/actualites/2019/06-juin/20190614-Pressemitteilung-Centrale-Paysanne-LTA-Feldbegehung-in-Bettendorf.pdf	Press release	06.06.19
Webpage IBLA	Press release IBLA – field visit	https://ibla.lu/en/pressemeldung abendfeldbegehung-legutec/	article	31.07.19
Webpage	LeguTec	https://agriculture.public.lu/de/beihilfen/innovation-forschung/forschungsprojekte-pflanzenbau/Legutec-nachhaltige-ressourcenschonende-eiweissproduktion.html	project description and results	31.07.19
IBLA Newsletter	Abendfeldbegehung im Projekt LeguTec	https://ibla.lu/_res/uploads/2019/09/IBLA_Newsletter_8_web-1.pdf	article	26.09.19
EGU General Assembly 2020, Vienna, Austria (online)	Effects of mechanical weed control in organic soybean cultivation on weed biomass and diversity in Luxembourg	https://meetingorganizer.copernicus.org/EGU2020/EGU2020-7564.html	online presentation	04.-08.05.20

Appendix 42: First photos submitted by photographer Nikos Zompolas.

Appendix 43: Postcard from etika about LeguTec. Photo by Nikos Zompolas as result of a competition at etika.



Appendix 44: Abstract of poster presentation at the 6th International Conference on Organic Agriculture Sciences (ICOAS) from 7th to 8th of November 2018 in Eisenstadt, Austria 2018.

LeguTec – Mechanical weed control in soybean cultivation in Luxembourg

Leimbrock, L.[1]; Rock, G.[2]; Diederich, R.[3]; Krier, R.[4]; Reiland, G.[4]; Stoll, E.[1]; Zimmer, S.[1]

[1] Institut fir biologesch Landwirtschaft an Agrarkultur Luxemburg (IBLA) a.s.b.l., Luxembourg;

[2] Geocoptix GmbH, Germany;

[3] Wolff-Weyland, Luxembourg;

[4] Lycée technique agricole (LTA) Ettelbrück, Luxembourg

Soybean (Glycine max (L.) Merr.), a member of the family Leguminosae, has a protein content of about 40 % and a very high biological value due to an optimal amino acid composition, making it one of the most important feed protein sources in animal nutrition (Bernet et al. 2016). Being one of the EU-states that signed the European Soya Declaration (2017), Luxembourg aims to promote the regional cultivation of soybeans and other protein crops. The decisive factor is the current dependency on imports from mainly North and South America. Far more than 60 % of the required amount of soybean is imported (Bernet et al. 2016), which causes various environmental and social problems (Beste et al. 2011). Thanks to breeding of new varieties with very early maturity, soybean cultivation is nowadays possible under low temperature conditions – an opportunity to introduce soybean production in Luxembourg and thus increase its protein autarky. However, the organic cultivation of soybean is demanding and in addition to the currently not yet guaranteed further processing in Luxembourg (e.g. toasting as one heat treatment possibility) there are above all knowledge gaps in efficient and sustainable mechanical weed control techniques.

From spring 2018 onwards, five mechanical weed control methods in soybean cultivation (variety Merlin) are tested and compared under real conditions on three organic farms spread over Luxembourg: 1) harrow, 2) interrow cultivator with duck foot shares, 3) interrow cultivator with duck foot shares and finger weeder, 4) a flexible system, a combination of treatment 1 and 3, while the decision is made according to the actual site and weather conditions and 5) mixed cropping of soybean and camelina in combination with harrow. A negative control, where no weed control is administered, and a positive control, where all weed is taken out of the plots by hand, are considered as well. The trials are implemented each as a one-factorial-exact-trial with 4 replicates. Additionally, an on-farm trial is conducted at the experimental site of the Lycée Technique Agricole in Bettendorf. Weed and soybean biomass and cover, weed species and number of plants/species as well as number of soybean plants were taken before and after each weed treatment as well as at flowering and at harvest to assess the efficiency of the used technique and potential plant damages. Statistical analysis is performed with ANOVA and linear mixed models testing whether treatments significantly differ from each other in terms of yield and biomass. The company Geocoptix GmbH complements the assessments with the help of drone-supported aerial photographs using different true colour and multispectral images of the treatments. First results in yield, yield formation, biomass and interactions within the analysed plant and weed parameter of the first year are presented on a poster within ICOAS.

Bernet B, Recknagel J, Asam L and Messmer M (2016) Biosoja aus Europa. FIBL Dossier 5.
Beste A, Boeddinghaus R (2011) Artenvielfalt statt Sojawahn. Martin Häusling MDEP 33.
European Soya Declaration (2017) European Soya Declaration: Enhancing soya and other legumes cultivation. Available at: https://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Pflanze/SojaErklaerung.pdf?__blob =publicationFile [Accessed 10 June 2018].

Appendix 45: Poster presentation at the conference WiTA in Kassel, March 2019.

LEGUTEC: MECHANISCHE BEIKRAUTREGULIERUNG IM SOJAANBAU IN LUXEMBURG

Leimbrock L.[1], Rock G.[2], Diederich R.[3], Krier R.[4], Reiland G.[4], Stoll E.[1], Zimmer S.[1]

[1]Institut fir biologesch Landwirtschaft an Agrarkultur Luxemburg a.s.b.l. (IBLA), 13, rue Gabriel Lippmann, L-5365 Munsbach, leimbrock@ibla.lu, www.ibla.lu
[2]Geocoptix GmbH, Max-Planck-Straße 6, D-54296 Trier, Deutschland, www.geocoptix.com
[3]Wolff-Weyland S.A., 14, Niederpallenerstrooss, L-8551 Noerdange, Luxemburg, www.wowey.eu
[4]Lycée technique agricole (LTA) Ettelbrück, 72, av. Salentiny, L-9080 Ettelbrück, Luxemburg, www.lta.lu

Hintergrund

Mit einem Proteinanteil von etwa 40 % und einer sehr hohen biologischen Wertigkeit aufgrund einer idealen Aminosäurezusammensetzung ist die Sojabohne (*Glycine max* (L.) Merr.) eine der wichtigsten Futtereiweißquellen in der Tierernährung (Bernet et al. 2016). Mit der Unterzeichnung der Europäischen Sojaerklärung (2017) hat sich Luxemburg zum Ziel gesetzt, den regionalen Anbau von Sojabohnen und anderen Eiweißpflanzen zu fördern. Grund dafür ist die derzeitige Abhängigkeit von Importen aus hauptsächlich Nord- und Südamerika (>60 %). Jedoch ist der Anbau anspruchsvoll und es gibt Wissenslücken im effizienten, nachhaltigen Beikrautmanagement in Luxemburg (Zimmer et al., 2016).

Ziel des Projekts ist es, die Effizienz der ausgewählten mechanischen Systeme unter Berücksichtigung von Pflanzenverlusten, Pflanzen- und Unkrautbiomasse und Deckung zu untersuchen.

Material und Methoden

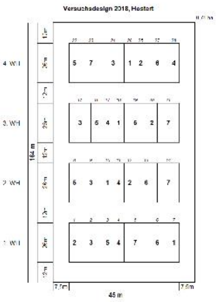


Abb. 1: Versuchsaufbau des Standortes Hostert.

Variante		Parzellenbreite
1	negative Kontrolle	3
2	positive Kontrolle	3
3	Striegeln	6
4	Hacken zwischen Reihen	3
5	Hacken zwischen und in der Reihe	3
6	Kombination 3+5	6
7	Mischkultur Soja/Leindotter	6

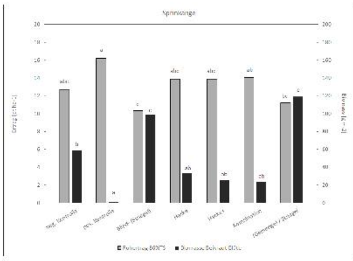
- **Design:** einfaktorieller Exaktversuch in vierfacher Wiederholung auf drei Bio-Betrieben in Luxemburg (s. Abb. 1 und Abb. 2)
- **Saat:** ab 20.04.2018, Sorte Merlin, Impfmittel BIODOZ Soja, Saatstärke 65 K/m², Saatbreite 12,5 cm (Hacke) und 37,5 cm (Striegel); Blindstriegeln in Variante 3, 6, 7
- **Kommunikation:** On-farm Versuch der Ackerbauschule (LTA)

	Mantemach	Sprinkange	Hostert
Höhe (m ü. NHN)	281	336	464
Temperatur (°C)	9.8	9.7	9.1
Niederschlag (mm)	617	681	921
Saat	23.04.2018	17.05.2018	24.04.2018
Ernte	24.08.2018	17.09.2018	04.09.2018

Abb. 2: Versuchsstandorte in Luxemburg. Auf den Bio-Betrieben in Mantemach, Sprinkange und Hostert befinden sich die Exaktversuche und in Bettendorf der On-Farm Versuch auf den Versuchsfeldern der Ackerbauschule LTA.

Ergebnisse und Diskussion

- Kornertrag und Beikrautbiomasse zur Blüte zeigen signifikante Korrelation (Pearson-Korrelation, $p<0{,}05$) mit $r = -0{,}72$ (Sprinkange) und $r = -0{,}86$ (Hostert)
- Sprinkange: signifikant höhere Erträge und geringe Beikrautbiomasse in Kombination als in Striegelvariante (s. Abb 3)
- Hostert: sehr hoher Beikrautdruck von Beginn an; am signifikant höchsten in den Striegelvarianten (7 und 3); höchste Erträge in Kombinationsvariante, niedrigste in Striegelvarianten (n.s.)
- Mantemach: keine sign. Unterschiede in Biomasse und Ertrag a.G. sehr geringem Beikrautdruck; 15% der Hülsen frühzeitig aufgeplatzt
- Keine signifikanten Unterschiede in der Zahl der aufgelaufenen Pflanzen und Pflanzenverluste (hier nicht gezeigt).



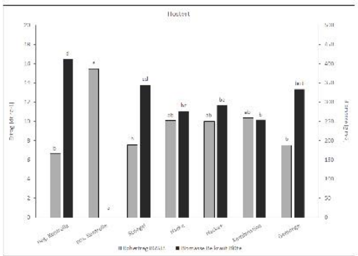


Abb. 3: Ertrag [dt ha⁻¹] und Biomasse des Beikrauts zur Blüte [g m⁻²] der Standorte Sprinkange und Hostert in Abhängigkeit der verschiedenen Beikrautregulierungsvarianten; Erträge (n=4), Biomasse (n=12); unterschiedliche Buchstaben bedeuten signifikante Unterschiede (ANOVA, TukeyHSD, $p<0{,}05$).

Abb. 4: Beikrautregulierung mit dem Striegel (links), der Scharhacke und den Fingerhacken (Mitte) und nur mit der Scharhacke (rechts).

Fazit

- Erträge generell in Hackvarianten höher als in Striegelvarianten, aber keine signifikanten Unterschiede innerhalb der einzelnen Hackvarianten
- Geringere Beikrautbiomasse zur Blüte in Hackvarianten und besonders in Kombinationsvariante -> Regulierungserfolg
- Trockenheit nach Blüte von Jun-Aug: hohe Ertragsverluste
- Hostert: geringe Erträge a.G. hohem Beikrautdruck von Anfang an -> Management des Standortes ausschlaggebend
- Erstes Versuchsjahr -> Saison 2019 wird weitere Aussagen zulassen

Literatur

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European Soya Declaration (2017) European Soya Declaration: Enhancing soya and other legumes cultivation. Available at: https://www.bmel.de. [Accessed 10 June 2018].
Zimmer S, Haase T, Piepho HP, Stoll E, Heß H, Bohn T, Heß J (2016a): Evaluation of grain legume cropping systems for animal fodder potential and impacts on subsequent wheat yield under less favourable soil condition in organic agriculture in Luxembourg. Journal für Kulturpflanzen. DOI:10.5073/JFK.2016.06.02.

Danksagung

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IBLA — GEOCOPTIX — Lycée Technique Agricole — agri-distribution WOLFF-WEYLAND L-8551 NOERDANGE - 00352 23637-200 www.wowey.eu - info@wowey.eu

Institut fir biologësch Landwirtschaft an Agrarkultur Luxemburg
IBLA Luxemburg, 13, rue Gabriel Lippmann, L-5365 Munsbach
Tel. +352 26 15 13 88, Email info@ibla.lu, www.ibla.lu

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Impact of different mechanical weed control methods on weed communities in organic soybean cultivation in Luxembourg

David Richard · Laura Leimbrock-Rosch · Sabine Keßler · Stéphanie Zimmer · Evelyne Stoll

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Abstract Knowledge gaps have been identified for legumes cultivation in Luxembourg, especially in terms of weed control, where soybean production is still at its initial stages. The study tests different mechanical weed control methods in organic soybean cultivation on-farm. The impacts of different weeding techniques are observed from an ecological point of view, in terms of species number and diversity. The cultivation trials, one-factorial exact trials with four replicates, were conducted on two organic farms in 2018 and 2019. Five different treatments were tested: harrow, interrow cultivator with duck foot shares, interrow cultivator and finger weeder, combination of harrow, interrow cultivator and finger weeder and an intercropping soybean-camelina combined with harrow. For each, the number of weed species, as well as their identification, has been assessed three times: before weed control, after weed control and at the flowering of soybean. Calculated Shannon indexes have quantified the diversity of weeds. Forty-nine weed species have been counted in total, for all sites. Calculated Shannon indexes were common values for organic fields. Weed control has a negative impact on weed diversity. Low abundant species were more likely to disappear, while few species, one to four, keep being more dominant. The use of the interrow cultivator, in combination with the harrow (as blind harrowing) and the finger weeder, tends to lower the most the number of species and the diversity of weeds. Further ecological research is necessary to better determine the interactions between weeds and soybean.

Keywords Soybean · Mechanical weed control · Weed ecology · Luxembourg · Organic agriculture

Introduction

Soybean (*Glycine max* (L.) Merr.) is one of the most important fodder crops and difficult to replace in feeding rations. Due to its high protein content (about 40%) and an ideal composition of amino acids, soybean, a species of the family Leguminosae, is a very important source of proteins for animal feeding (Bernet et al. 2016). By signing the European Soybean Declaration (2017), Luxembourg aims to promote regional and sustainable soybean and other legumes production, to reduce the dependency towards imports and to limit the known massive ecological and environmental impacts on the production sites mainly in North and South America (Stolon and Dudley 2014). To date, Luxembourg has no real soybean production and is highly dependent on

D. Richard (✉) · L. Leimbrock-Rosch · S. Keßler · S. Zimmer · E. Stoll
Institute for Organic Agriculture Luxembourg (IBLA), 27, Op der Schanz, L-6225 Altrier, Luxembourg
e-mail: richard@ibla.lu

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Editor

Institut fir Biologësch Landwirtschaft an Agrarkultur Luxembourg a.s.b.l.

25, op der Schanz

L-6225 Altrier

Tel / 26 15 13 88

E-Mail / info@ibla.lu

www.ibla.lu

Author / Laura Leimbrock-Rosch, David Richard, Dr. Stéphanie Zimmer and in cooperation with

/ Geocoptix GmbH: Dr. Gilles Rock, Vanessa Hueffer

/ LTA: Ronny Krier

IBLA project team/ Laura Leimbrock-Rosch, David Richard, Dr. Stéphanie Zimmer, Jemp Schweigen, Mathieu Wolter, Gilles Altmann, Evelyne Stoll, Dr. Sabine Keßler and the interns in 2018 and 2019

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