Sowing cover crops with drones

An overview of the currently available knowledge on sowing cover crops with UAV’s

Ardy Saarloos

1050356

ardy.saarloos@wur.nl

MSc Climate Studies

Supervisor Agrosystems Research: Thierry Stokkermans

Supervisor WUR: Lammert Bastiaans

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Summary

Cover crops are thought to be an important asset in reducing the environmental impact of agronomical systems. They play an important role in the new GLB and on sandy soils farmers are obliged to sow cover crops after cultivating maize. This study looked at the potential of undersown cover crops in maize when seeded with a drone. In order to do so, a literature study and a small experiment were performed. The results show that good weather circumstances are crucial for the development of cover crops sown with a drone. Besides, predation and competition for light can be an important limiting factor. Those factors can be alleviated by wrapping seeds in seed balls and selecting the correct cover crop species. The results of the experiment performed with seed balls in this study do not show an increased germination rate as a result of sowing seed balls. This is not in line with existing literature, and is most likely caused by a high irrigation rate. It is recommended to gain practical experience with undersowing using different cover crop species and seeding rates.

Key words: drones; cover crops; undersown; maize; carbon sequestration; nitrogen scavenging; seed balls.

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Description of research assignment

In June 2021, I took the course *Conservation Agriculture*. This course teaches students about farming systems that promote maintaining a soil cover with plant residues, reducing mechanical soil disturbance by tillage and the usage of crop rotations and cover crops. Next to the traditional lecture-exam grading system, the course included a designing assignment and a field trip. During those interactive moments, I got to know Thierry Stokkermans, who is a researcher for Wageningen Research and was seeing what the course was about to potentially be involved as a teacher the next year. Thierry is an expert in soil health, and has a strong background in farming technology. We ended up having interesting conversations about farming systems, soil health and the future of agriculture. We both enjoyed these conversations, resulting in an exchange of our contact details with the intention to look into the possibilities of me doing an internship at the Agrosystems Research department at Wageningen Research. Agrosystems Research is studies the soil-crop-environment continuum at both process and ecosystem level, and aims to improve sustainable agriculture, food security and efficient use of resources. One of the important aspects of Agrosystems Research is working on the Nationale Proeftuin Precisie Landbouw (NPPL), a Dutch organization working on precision agriculture.

Fast forward to Spring 2022. The internship will actually happen, and Thierry and I are discussing my activities during the internship. With the goals of Agrosystems Research and the expertise of Thierry in mind, this will most likely be about improving the sustainability of a farming system by implementing technological developments. Thierry suggests an idea that he has had in his mind for a while, but did not have time to look into. It is about using drones to sow cover crops, while the main crop is still on the field. The assignment is simple: create an overview of the currently available academic and grey literature, and make an indication of its potential usage. While creating this overview, we can see whether follow-up work is relevant and in what form.

Although we saw each other on a daily base in the office, each Monday Thierry and I would meet and have a more in-depth discussion on my findings so far. During those discussions, we came to the conclusion that technically, a lot is possible with the concept. Besides, companies were interested in implementing the technique. For the literature review, I had come in touch with a company who already had expertise in seeding with drones. This company was interested in expanding its application to sowing cover crops. Eventually, this led to writing a proposal for a Public Private Cooperation (PPS). This also meant that I had a second assignment: write a PPS proposal.

When submitting a PPS proposal, it is important to make an indication of the costs of a study, and where this money would come from. So far, we would work together with a company interested in executing the field work, but it had little financial capabilities. To get the finances in order, financially strong companies need to be willing to invest in our study. This resulted in my third task: approach companies that might be interested in the results of this study and do the acquisition. Because of privacy reasons, the PPS proposal and the results of the acquisition could not be included in this report. Therefore, the decision was made to solely include the literature study.

I hope this report can function as a future reference point when researchers of agrosystems research or any other organization want to know more about the possibilities of sowing with drones. The application of drones in agriculture is increasing in popularity, and it is not unlikely that future projects will also consider seeding with drones. This is concretized by the fact that we were put in contact with a couple of students from the university of applied sciences in Dronten because they were doing a similar project. To make the knowledge gathered available for everybody, the report will be submitted to the CRKLS, a digital knowledge platform. Besides, the report is part of the foundation of the PPS-proposal. If the PPS-proposal will be accepted, scientifically underpinned practical knowledge can show the added value of drones making it possible to implement it in agricultural farming systems.

Scientific context internship

As learning goal, I stated:

"I want to learn what steps are part of the creation of new scientific knowledge, and which obstacles are faced".

Introduction to the topic

Cover crops are thought to be an important asset in reducing the environmental impact of agronomical systems. Amongst others, cover crops can contribute to weed management (Osipitan et al., 2019), add organic matter to the soil (Clay et al., 2019), and minimize soil erosion (Chapagain, Lee, & Raizada, 2020). Besides, winter annual cover crops can play an important role in nutrient management practices. By scavenging N during its growth, cover crops can prevent N from leaching out of agricultural systems. This N is then released after degradation and becomes available to the subsequent main crop (Thapa, Mirsky, & Tully, 2018).

Because of those benefits, cover crops play a key role in the new GLB. The new GLB requires farmers to comply with several sustainable requirements in order to receive subsidies. One of the measures farmers can take, is interseeding a catch crop between the main crops. From now on, this practice is referred to as undersowing.

Another factor making undersown cover crops increasingly popular is the obligation for farmers in the Netherlands sow a catch crop before October after growing maize on sandy and loess soils. Ever since 2019, when the law was implemented, farmers are struggling to harvest their maize in time to make space for the cover crop. When this cover crop is being undersown, the need to harvest the maize early can be taken away. Therefore, the decision was made to focus this study on the application of undersowing in maize.

Next to storing nitrogen, cover crops can contribute to mitigation climate change by storing carbon in soils. According to the 4 per 1000 initiative, increasing the amount of carbon in the top 30-40 cm of soils by 0.4% each year could offset the anthropogenic carbon emissions and therefore be an important tool in fighting climate change (Soussana et al., 2019). The storage of carbon can especially be increased by expediting the sowing moment. Norén, van Geel & de Haan (2021) showed that sowing a cover crop in August instead of October could more than double the amount of carbon captured.

This results in the need of a method to sow cover crops efficiently while the main crop is still on the field. Although several methods already exist (such as spreading seeds with a fertilizer spreader and the high boy), this report studies an innovative method by looking in the possibilities of broadcasting cover crop seeds by making use of a seeder drone. Broadcasting is defined as the practice of spreading crop seeds, without drilling the seeds into the soil. Planting by broadcasting before harvesting the main crop has several advantages: it shifts the workload away from the busy harvest season, it is less labour-intensive as more hectares can be planted through broadcasting at the same time, and seeding through broadcasting can be cheaper (Koehler-Cole & Elmore, 2020).

To study the potential of seeding cover crops with drones, the following research question was formulated:

What knowledge is currently available on undersowing cover crops in maize through broadcasting with drones?

The question will be answered by studying various aspects of cover crop development. First, a short market analysis will be performed to assess which drones that are currently available are most suitable to sow cover crops with. Then, the biological aspect will be considered. How do cover crops compete with the main crop when undersown, and which cover crop is most suitable to be undersown? Finally, the legislation on the usage of drones will be described. To know the possible additional value of drones over currently common sowing techniques, a comparison with other methods to undersow cover crops will be made in the discussion.

This study is part of the Nationale Proeftuin Precisie Landbouw (NPPL) and contributes to its goals by investigating an innovative way to approach a closure of the nutrient cycle. In circular agriculture, agricultural additives such as nutrients are utilised as efficient as possible to minimize losses. This is not only beneficial for the environment, but might also lower the cost price of the development of the crop for the farmer. By utilizing cover crops as efficiently as possible the emission of N to the environment is minimized, with all the benefits that entails. Besides, the cover crops add organic matter to the soil. By having a longer growing period, cover crops generate more leaf biomass which might mean that more organic matter is stored in the soil. This contributes both the adaptation and mitigation to climate change.

Methodology

To perform the literature study, peer-reviewed papers and some grey literature were analysed. The papers were obtained via search engines such as *Google Scholar*, *Scopus*, etc. To narrow the results down, the decision was made to focus on maize as a main crop, rather than any crop one could think of.

The results of each study were compared by making use of a multi-criteria analysis (MCA). An MCA is an analysis which can be performed to compare several options, which are often contradicting. For the MCA, a list of variables is created based on which the different options will be analysed. Practically, this meant that for the consideration of which crop was most suitable to be undersown, crop characteristics that are required for undersowing were listed and graded based on their suitability. The grades were based on available literature and indications of experts. Eventually, the average grade for each option is calculated and the option with the highest grade is the best decision.

Figure 1: Seed balls

Next to the literature study, a small experiment was performed to study the added value of seed balls. The main goal of this experiment was not to obtain scientific knowledge on seed balls, but rather to gain practical experience with them. An explanation on seed balls is given in the results on page 15.

Seed balls were created out of compost. This compost was soaked into water and rolled into little balls. The balls were left to dry for 2 days. Eventually, this resulted in the balls presented in figure 1.

In each ball, one seed of *Lolium perenne* was added. Only one seed was added to be able to properly study its germination rate. In a practical situation, more seeds can be added to each seed ball. The balls were placed in pots of 100 cm^2, filled with 100g of potting soil. Each pot fitted 4 seed balls. The working of seed balls was compared to broadcasted seeds. Therefore, 4 grass seeds were placed on the surface of pots filled with 100g of potting soil (figure 2).

Figure 2: Seed balls in pots

As seed balls are thought to improve the water availability for the seeds, the seeds were exposed to different daily water treatments which would be equal to 0 mm/ha, 5 mm/ha, and 10 mm/ha. As the size of the pots was 100cm^2, this meant that the seeds were watered with 0ml, 50ml, and 100ml. For each treatment, three replicates were made. An overview of the different trials and treatments is given in table 1. The pots were located outside to mimic in-situ situations.

Table 1: Seed treatments

Irrigation	**Seeding technique**	
	Seed ball	Non-seed ball
0 mm		
5 mm		
10 mm		

Results

Drone technology

Drones, also referred to as Unmanned Aerial Vehicles (UAVs) or Remotely Piloted Aircraft Systems (RPAS), have been increasingly popular in the agricultural sector. Drones are defined as a remotely piloted aircraft controlled directly by a human operator, or with various levels of autonomy achieved by autopilot technology (van der Merwe et al., 2020). Currently, drones in agriculture are mainly used to win information about crops and the field they are growing on. For instance, drones are applied for crop health imaging, the production of task maps for precision agriculture tools and minimizing the need to physically go through the field (Ayamga, Tekinerdogan & Kassahun, 2021).

Lately, drones have been used more frequently for the application of agricultural chemicals. This application can be performed at an unprecedented level of precision, minimizing environmental pollution (van der Merwe et al., 2020). Likewise, drones can be used to distribute seeds in agricultural fields. Generally, drones can be classified as the three different types presented in figure 3; fixed-wing drones, single-rotor drones, and multi-rotor drones (van der Merwe et al., 2020).

Fixed-wing drones are designed as small airplanes. The lift generated by the wings reduces the energy required to fly the drone, making it the most efficient drone design. Because of this energy use efficiency, fixed wings have the longest flight time and are capable of carrying large payloads for longer distances. Besides, the drones provide a better aerodynamic performance, reducing the influence of wind and turbulation. A downside of these type of drones is its limited mobility; the drones need a relatively large area for lift off, and are not capable of making short turns (Annand, 2021).

Single-rotor drones are drones designed as a small helicopter. Although not many drones are equipped with a single rotor, its energy use efficiency is higher than for multi-rotor drones. A single-rotor drone allows for longer blades, which make it possible to spin at a slower rate and therefore requires less energy. They are especially suitable for carrying heavier cargos. A downside of single-rotor drones is the reduced stability; environmental factors will affect the functioning of the drone causing vibration. When sowing cover crops, this could lead to an uneven distribution of the seeds (KDE Direct, 2017).

Multi-rotor drones are equipped with multiple rotors; usually those are either quadcopters, hexacopters or octocopters. Increasing the amount of rotors, just as upgrading from a single-rotor, results in a pay-off. Quadcopters are fast, relatively small and compared to hexa- and octocopters high in their energy use efficiency. Besides, they are easy to manufacture, making quadcopters relatively cheap. Hexa- and octocopters have a higher mobility compared to quadcopters, but also require more energy. Because of the low energy use efficiency, hexa- and octocopters are usually used for aerial information gathering with cameras, and are less suitable for the carriage of cargo (KDE Direct, 2017)

(a) (b) (c)

Figure 3: Three types of drones; multirotor (a), fixed-wing (b), and a single rotor (c) ((UAV Types: Multi-Rotor (a), Fixed Wing (b), and Single-Rotor (c)., 2019)

It is possible to control the drone manually, but nonrecreational users usually rely on so called integrated flight systems, which are autopilots that enable safe precision flying, improved stability control and the ability to replicate flights. Besides, the battery-monitor system ensures a return to the home-base when the battery is running low and attempts to land safely in case of an emergency. To safely fly a drone, an integrated flight system is a requirement (Hogan et al., 2017).

Table 2 shows different companies currently offering drones that can be utilized as seeder drones. Of these organizations, the company Aeroseeder seems to be the best option. Aeroseeder is specified in seeding with drones, and has designed its drones specifically for this purpose. Their maximum payload fits in the European legislation, and the price is relatively lower than other providers. The drones of DJI and Alta X in combination with CFR spreaders are used by several companies spreading seeds with drones, such as Covercropinnovations. Besides, two companies located in the Netherlands work with drones to spread agricultural products. Those are Qlobel and Koppert. Qlobel has developed its own drone and says to have multiple years of experience in seeding cover crops with a drone.

Table 2: Companies offering seeder drones and their performances

Company	**Price (€)**	**Weight drone**	**Payload**	**Ha/hour**	**Battery time**	**Type**
Aeroseeder	13 000		13.6 kg	12	3.5 mins	Octocopter
Droneassamble	6 700		10 kg			Hexacopter
Dronecoria	2000	8kg	8 kg			Hexacopter
DJI Spreading wings S1000 + CFR Innovations spreader	4100	4 kg	30 L		15 mins	Octocopter
Asta SAGL-20 + CFR Innovations spreader	8500	5.5kg		10		Hexacopter
Nongyehangkong		26kg	20kg	2.5	6 mins	Quadcopter
Agrodrone	39 500		10kg		15 mins	Quadcopter
Alta X	16 750		15.8		8 mins	Quadcopter

Biology

When sowing cover crops with a drown, the seeds are broadcasted over the field. Broadcasting has several benefits such as decreasing soil compaction and making interseeding of cover crops possible, without damaging the main crop. Though, incorporating seeds in the soil is thought to result in a better germination rate. Based on peer reviewed literature, three different limitations on interseeding cover crops through broadcasting can be established. Those are weather circumstances, competition, and seed predation.

Weather circumstances

Fisher, Momen, and Kratochvil (2011) analysed the effectiveness of broadcasting for cover crop planting by comparing the germination rate of broadcasting to direct drilling. They concluded that treatments which incorporated seeds into the soil grew into better stands and took up more N. The performance of the broadcast treatments was highly dependent on rainfall and mild temperatures for success. In years during which circumstances were suitable, the N uptake was relatively good.

This is presented in figure 4, which derived from Fisher, Momen, and Kratochvil (2011). It shows that while the no-till drill (NT) seedlings emerge directly after seeding, the broadcasted (BC) seeds need precipitation in order to germinate. Wilson, Baker, & Allan (2013) confirm that rainfall is the best predictor for cover crop emergence. Rainfall is an important determent because surface soil moisture in the top few centimetres is highly variable and can change quickly compared to deeper soil layers due to evaporation.

Likewise, Haramoto (2019) found that broadcasting seeds at dry conditions resulted in a reduced cover crop development. Though, the authors state that with adequate moisture contents, the planting method did not affect ground cover or biomass. This indicates that broadcasting cover crop seeds can potentially give the wanted results, but the method is vulnerable to suboptimal circumstances.

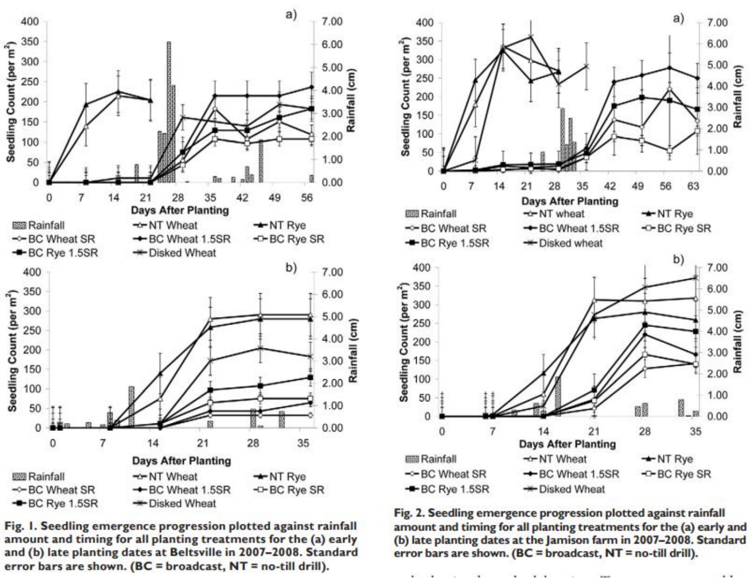

Figure 4: Seedling emergence immediately happened immediately with drilling, while rainfall was required for broadcasted seeds.

Competition

According to Noland et al. (2018) competition for solar radiation is one of the most important limiting factors for the development of undersown cover crops. From the 5- to the 12-leaf collar growth stages, the absorbed incoming photosynthetically active radiation by the maize increases from ~20% to ~90%. Likewise, Schmitt et al. (2021) state that limited light intensity under the maize canopy was the most important factor for undersown cover crop establishment. During their study, it was observed that the green cover of cover crops declined as the canopy closed due to maize development. When the canopy opened as the maize reached maturity, the green cover of the cover crop increased gradually again, indicating that light stress was the limiting factor for the development of the cover crop.

Light stress being the most limiting factor underlines the importance of precise timing of sowing for successful cover crop development. Seeding the cover crop too late could result in a hindered crop development, while early seeding could result in competition with the main crop. This is even reported by farmers as the most important concern with interseeding (Hall, Swanton, & Anderson, 1992).

Though, several studies analysed the effect of interseeding cover crops, and none of them found a significant effect on maize yields (Appendix A). Brooker, Renner, and Sprague (2019) concluded that broadcasted cover crops did not affect maize yields, even when the cover crop was seeded at the V2 stage. Nevertheless, this could be the result of the low germination rate because of the broadcasting. Curran et al. (2018) found that maize yields decreased when cover crops were drilled at or before the V3 growth stage, and therefore recommend to seed at or after V4 to prevent competition.

Practically, this means that cover crops with a low germination rate could be seeded from the end of May without damaging the main crop, while cover crops with a higher germination rate could be sown from early June. However, the timing of seeding is important for the development of the cover crop as well. Generally, early establishment allows cover crops to capture more growing degree days and precipitation. Eventually, this results in more biomass (Fisher et al., 2011). Besides, Fisher et al. (2011) conclude that early planted cover crops consistently take up more N, with an increase of up to 100%. Although soil NH_4 concentrations are similar in situations with and without undersown cover crops, NO_3 concentrations decrease up to 67% when a cover crop is undersown. This difference is thought to be caused by the charge of the molecules; as NH_4 is a cation it can bind to clay minerals making it less available to plants, while NO_3 is an anion which can easily be transported through water (Rozic et al., 2000).

Undersowing might even enlarge the benefits provided by cover crops. Because of their capacity to fixate N_2, legumes can enhance the nutrient availability in soils. Although no studies have been performed on the N uptake of undersown cover crops by broadcasting legumes, several other studies suggest that intercropping legumes in maize might increase the nitrogen fixation of the legume. For instance, Li et al. (2003) found that the N fixation of faba beans is increased when grown in an intercropping system with maize. Though, this form of direct facilitation is only provided when the cover crop has the opportunity to develop into full maturity. Because of the narrow seeding of maize resulting in light competition, it is unlikely that undersown legumes can enhance maize productivity. Further research is needed to confirm this.

Next to competing with the main crop, the cover crop is also in competition with weed populations. Abdin et al (1997) showed that high weed population hinder the development of undersown cover crops. Yet, the presence of cover crops also results in additional competition for weeds. Uchino et al. (2012) showed that because of the increased vegetation cover ratio by the cover crops, weed growth was reduced significantly as early as 150 growing degree days after sowing. This is confirmed by Youngerman et al. (2018), who observed lower weed biomass in plots with undersown cover crops.

However, all the existing literature focusses on undersowing the cover crop in early stages of the maize. Limited knowledge exists on the interaction between cover crops and maize when the cover crop is sown in August, when the maize start to ripen and lowers its leaves. Even “Grondig boeren met maïs”, one of the leading studying programmes in reducing the environmental harm of maize production, has not studied undersowing in August. This could be of particular interest for undersowing with drones.

Predation

Invertebrate predators have the potential to considerably reduce cover crops populations. According to Youngerman et al. (2020) broadcasting the seeds makes cover crops more susceptible to predation, as White et al. (2007) and Kulkarni et al. (2015) have shown that seeds on the soil surface are much more likely to be consumed. Wilson et al. (2014) reported losses up to 98% of aerially seeded cover crops 1 week after seeding and suggested that those losses were caused by seed predation.

Though, the predation rate varies per cover crop species. Therefore, Youngerman et al. (2020) recommend to use cover crop species that are avoided by predators when broadcasting seeds. Examples of such species are barley and hairy vetch. Their predation rate is thought to be lower because of the relatively large seed size, and hard/fibrous seed coat.

Besides, the establishment of cover crops might increase the predation rate of weed seeds. By providing favourable habitats, natural enemies are more likely to be present in fields undersown with cover crops (Saska, Martinkova, & Honek (2010)). For instance, growing hairy vetch lowers soil temperatures and increase relative humidity, which in relatively warm climates favours the abundance of the beetle *Harpaulus rufipes*. This results in a larger population sizes of the weed seed predator, and therefore increases the predation rate (Shearin et al., 2008). Next to that, Blubaugh et al. (2016) observed an increase in seed consumption per predator in the presence of cover crops.

Seeding rate

Several authors state that the lower germination rate of broadcasting practices can be compensated for by increasing the seed application rate, given that the price of the cover crop is relatively low. Though, Koehler-Cole & Elmore (2020) conclude that germination rate does not always increase linearly with the seeding rate, depending on crop species, environmental circumstances and especially seeding moment. The authors state that increasing seeding rates increases in fall populations, but has limited effects for spring production. Since most cover crops in the Netherlands are seeded during fall, this should not be problematic. Similarly, Fisher et al. (2011) conclude that increasing the seeding rate does not consistently increase the N uptake of cover crops. Appendix B gives an overview of the available literature on seeding rate and cover crop performance, and seems to indicate that the benefits of increasing the seeding rate are crop specific.

Seed coatings

A possible method of increasing the plant health is by coating the seed. Seed coating provides an opportunity to add materials that benefit the seed by creating an altered microenvironment (Scott, 1989). Ma (2019) has stressed the importance of seed coating for precision agriculture. The author states that seed coating can play an important role in meeting the needs of precision agriculture by alleviating biotic and abiotic stresses. This is most commonly done by applying fungicide/insecticides to the seed, but the seed coating can also attract soil moisture. Since soil moisture availability is of special importance for the germination rate of broadcasted seeds, adding hydro-absorbers as a seed coating increases the water availability which contributes to a successful development of the cover crop.

Though, several studies find that seed coatings with hydro-absorbers in fact reduce the germination rate (Gorim & Asch (2011); Willenborg et al. (2004)). This was mostly caused by the coating thickness; the thicker the coating, the lower the germination rate. Once a seed with a coating had germinated, the plant grows more vigorously and develops into better stance (Gorim & Asch, 2017). However, this might be the result of the species sown seeding method. Gorim & Ash nor Willenborg et al. mentioned the seeding method in their paper. Archie & Hay (1992) showed that coating drilled seeds hardly affected the germination rate, while broadcasted seeds greatly benefitted from the coating. Besides, cocksfoot hardly benefited from the coating, while the germination of ryegrass was significantly affected. Likewise, Turner et al. (2006) found that coated seeds did increase the germination rate when broadcasting.

Two methods exist of coating seeds to lower the water stress. The first method is coating the seed with a hydro-absorber, which increases the uptake of water by the seed or absorbs water to elongate the availability to the seed. An example of such a coating is Stockosorb (Gorim & Ash, 2017). A second method of reducing the negative effects caused by water shortages is inducing stress tolerance in plants. For instance acetylsalicylic acid can enhance the tolerance of a variety of stresses, including heat, chilling, and drought (Senaratna et al., 2003). Most providers of grass seeds use coatings (for instance CZAV) and based on the assessed literature it is recommended to use seeds with coatings when sowing cover crops with a drone.

Another coating method is production of seed balls. By covering the seed in an aggregate of clay and soil, the seed-to-soil contact is improved. Although concessive peer-reviewed literature in agricultural application is lacking, Tamilarasan, Jerlin & Raja (2020) made an analysis of the added values of seed balls in reforestation. They concluded that by creating conditions for a seed which are similar to being buried in a hole, seed balls reduce the predation rate of seeds by birds and vertebrates, offer protection against environmental conditions and provide both the moisture and nutrients required by the seed to germinate and successfully develop

According to the study of Tamilarasan et al. (2020), seed balls can be easily made from seeds weighing less than 1 g. In their study, the seed balls were made from red soil and vermicompost and cost USD 0.013 per seed ball. Though, several other methods are available on the internet, ranging from making use of agricultural clay to kitty litter. Nevertheless, it is important to use constant ratios as a seed ball with a wrong composition is prone to breakage during transportation, and more importantly can reduce seedling emergence (Tamilarasan et al., 2021). Tamilarasan et al. (2021) found that the optimal ratio of red soil and vermicompost is 2:1 or 4:1. The type of red soil was not classified.

Table 3: Germination rate of treatments with and without seed balls for different irrigation rates

Irrigation (mm)	**Germination rate (%)**	
	Seed ball	Non-seed ball
0	17	0
5	67	67
10	41	50

In the study of Tamilarasan et al. (2020), both the irrigated and non-irrigated seeds sown with seed balls had a higher germination rate (irrigated 93% vs 82%, non-irrigated 56% vs 47%), had a longer root and shoot length, a larger dry matter production and a higher vigour index. The shorter root length can be explained by the difficulties experienced by seedlings to penetrate the soil.

Besides, the seeds in seed balls germinate earlier than the control group which were broadcasted. According to the writers, this is because of the priming effect during the drying of the seed balls. To create the seed balls, they are dried in the shade for 24 to 36 hours. During this period the seeds already absorb moisture from the clay which starts the process of germination.

Figure 5: germinated seeds in seed balls

The outcome of the experiment performed with seed balls is presented in table 3, with an example of germinated seed balls in figure 5. The table shows that the germination rate for both treatments are approximately similar. A student t-test shows no significant difference between the treatments ($p>0.05$).

Though, when looking at the moment of germination, the seeds in seed balls seem to germinate faster (figure 6). This might indicate that the seed balls have a higher water holding capacity making circumstances more suitable for the germination of the seeds, but since the water application over time is high enough the naked seeds germinate as well. An interesting follow-up experiment would be to study the germination rate with a lower water application rate.

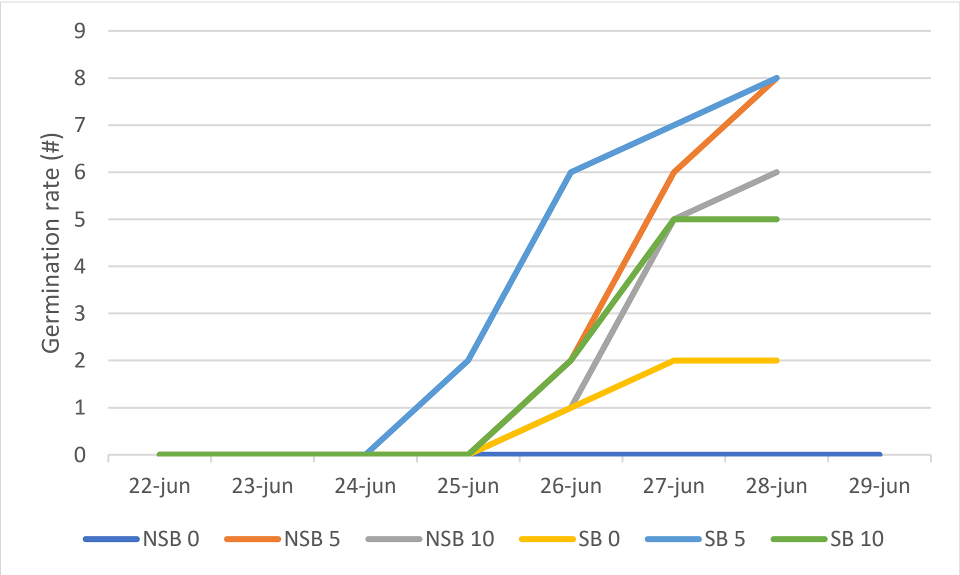

Figure 6: germination rate per treatment per day

A downside of seed balls is the reduced seeding capacity of drones. Because of the increased size, fewer seeds per hectare can be sown. A seedball weighs on average 2 grams, which equals multiple dozens of grass seeds. However, according to Arjan Jansma from Qlobel, this does not limit the application of seed balls. In his experience, making use of seed balls does increase the germination rate. Further development of drones and its regulations are required in order for seedballs to be widely applicable.

Craze B.V. has created their own method of supplying a growth medium to seeds. By compressing fertile soil into a small tablet, a lot of growth medium can be provided with a low weight and surface. When watering the medium, the tablet starts to get swollen up. Although it is not possible to include seeds in the tablet as it damages the seeds during the compressing, this technique can possibly be used by liming seeds on top of the tablets. However, Craze B.V. have tried this before but were unsuccessful. For more information, contact Martijn de Jong at martijn@letsgocraze.com.

Cover crop characteristics

The type of cover crop being seeded plays a large role in its germination rate. For instance, St Aime et al. (2021) found that hairy vetch does not respond well to drilling and could therefore well be broadcasted, while the seeding rate of other species such as crimson clover needs to be increased up to 50% to have a similar germination rate as when the seeds would be drilled.

The Dutch government has listed 11 species which are allowed to be undersown and serve as a catch crop after the cultivation of maize on sandy soils. Those are leaf cabbage, fodder radish, oat, triticale, winter rye, winter wheat, winter barley, tall fescue, and Italian/perennial/Westerwolds ryegrass. To assess each of these species, 11 characteristics have been identified which are required by a cover crop species sown by a drone. The assessment of the species is presented in appendix B.

The comparison of the cover crops shows that cereals are least suitable to be undersown with a drone. This is especially because of the heavy seed weight per hectare. This can be up to 7 times larger compared to grasses, meaning that the drone would have to be refilled multiple times per hectare.

Both grasses and fodder radish scored relatively high on the assessment, with radish scoring good because of the relatively low seeding rate (20-30kg/ha fodder radish, 8-12 kg/ha leaf cabbage), quick development, and good N scavenging. However, there is little experience with undersowing leaf cabbage and fodder radish. Limagrain does provide a seed mix that is made for the purpose of undersowing and contains 25% fodder radish. Though, when discussing the reason to include fodder radish, Limagrain admits that this is done to minimize the risk of a failure by diversifying the cover crop type. They argue that the fodder radish is underdeveloped, but that the plants that do survive provide large benefits to the soil structure and are easily incorporated in the soil. Since the assessment has shown that the species do have the right characteristics, it is therefore recommended for further research to study the usability of leaf cabbage and fodder radish as an undersown cover crop. This could also be done by mixing various cover crop species.

Grass species are most frequently used as cover crop undersown in maize. According to Herman van Schooten, researcher at the WUR and specialised in undersowing in maize, this is because grass species are the only crop that can develop with the little light availability. This is confirmed by Bernard Bles from DSV seeds, who performed multiple trials with undersowing fodder radish and leaf cabbage in maize but concluded that the crop development was insufficient.

The location of the fields can determine which cultivar is most suitable. In the south of the Netherlands, temperatures are generally higher than in the north. This means that maize develops quicker. According to John Verhoeven, undersowing expert at the WUR, undersowing at V4/V6 has a low cover crop success rate, as the maize develops too fast and leaves little light available for the cover crop. This is based on field experiments, but contradicts with peer reviewed literature of experiments that took place in North-America and Japan. Instead, it is better to sow a slow developing cultivar such as tall fescue at the same time as maize. In the north of the Netherlands, temperatures are lower and maize develops slower. Therefore, it is possible to sow the cover crop at V6. Though, it is important to choose a quick developing cultivar in this case, such as annual ryegrass. John Verhoeven that no experiments have been performed in which the germination rate of cover crops undersown in August have been studied.

Legislation

Because of its constant innovations, the legislation in the usage of drones is changing rapidly. During spring 2022, the most recent law implemented by the EU since 31 December 2020 states that there are three categories for flying with a drone; A1, A2 and A3.

- A1: Drones weighing up to 250g fall under this category. Pilots only need to register their flight when they make use of a camera attached to the drone.
- A2: Drones fall in category A2 when they weigh up to 2kg. In this category, pilots are required to own a flight license (To obtain a flight license, one needs to complete a theoretical exam); keep at least 50m horizontal distance to people; drop no goods from the drone; fly at maximum 120m height; transport no dangerous goods; have a visual line of sight with the drone.
- A3: For seeding drones, this category is the most relevant. The same rules apply as for category A2, but in this case it is only allowed to fly in areas where no humans are and the drone keeps a distance of at least 150 meters to living, industrial, or recreation zones.

Besides the general rules, there are additional rules depending on the risk of the flight. The risk is determined by the purpose of the flight. A test on the website of the government is available to determine the risk. For seeding cover crops, the risk of transportation is of special importance. Transportation is subdivided into the transportation of dangerous goods, transportation of people, and everything but dangerous goods and people. After having direct contact with the authority for the living environment and transport, they indicated that over crop seeds are perceived as non-dangerous and therefore the legislation falls under the category specific.

To get a license in the category specific, an additional test is required. Besides, it is possible to get a light UAS operator certificate (LUC). With an LUC, it is possible to do standard flights without being obligated to register each flight at the RDW. However, the company asking for this permit has to fulfil multiple requirements.

The law *Besluit luchtverkeer 2014, artikel 10* states that no objects are allowed to be dropped from a drone. Though, article 10.2.c states that goods that promote or protect the environment, agriculture, horticulture, or forestry, are allowed to be dropped. This also includes crop seeds.

When it is allowed to fly the drone there are also restrictions when it comes to sowing, specifically when the seeds are coated. Although treated seeds are often perceived as a safe pesticide application, they can still pose an environmental risk when expelled during sowing. When coated seeds are spread over the field, small particles of the chemicals get loose and form a small cloud (Foqué et al., 2017). Those particles might end up in ditches or urban areas, and are therefore considered as drift.

The amount of dust created depends on the quality of the seed coating and is assessed by the Heubach value. However, in most countries there is currently no legislation concerning the acceptable amount of dust created by treated seeds (Zwertvaegher et al., 2016).

In the Netherlands, there is a general law that states that no chemicals are allowed to be released when spreading seeds over a field. However, treated seeds are currently not considered as plant protection products. If this would be the case, this would still not limit the seeding of cover crops through drones. This is because laws exist about the location where the dust is created in sowing machines, but such laws are lacking when seeds are broadcasted.

Discussion

So far, this report has listed multiple benefits of undersowing cover crops in maize. However, undersowing cover crops is still relatively uncommon and especially in combination with seeder drones there is little experience. This report contributes to the scientific context by pioneering in the application of seeder drones for cover crops, and creating an overview of the currently available knowledge. This chapter will discuss the problems faced when undersowing and why it is currently uncommon. This will be done by discussing the reasons mentioned by farmers and experts on why undersowing is currently not applied, and will follow this up by shining extra light on the results mentioned in the previous chapter.

Farmers´ perspective

Based on discussions with farmers and undersowing experts, several reasons why undersowing is uncommon have been established.

The first reason why monocrop sowing is preferred over undersowing is the improved quality of early maize cultivars. Originally, relatively late harvested maize cultivars had higher yields than early cultivars. However, development of early cultivars have resulted in approximately similar yields, making early harvesting possible. This reduces the need for alternatives for sowing cover crops.

The second reason mentioned by farmers is the fact that it is not possible to work with the soil after harvesting the crop. Jan Roothaert from Limagrain, specialized in undersowing cover crops in maize, states that many farmers want to prepare their fields for winter by equalizing it. When the cover crop already has been undersown, this is not possible.

A third reason for farmers not to undersow maize is the belief that the cover crop will not develop optimally because of the limited light availability. This also holds for grass species. Several farmers in South-Holland state that they are not convinced by the benefits of undersowing, as the cover crop gets minimal opportunities to develop. Likewise, farmers in the Achterhoek who have experience with undersowing gras in maize think that it takes too long for the cover crop to grow between the harvested maize plants. According to the farmers, this development goes faster when the grass is sown after harvest. Based on the results of this study it indeed can be concluded that the development of the cover crop is hampered by light stress. Though, no claims can be made whether this light stress results in a reduced crop biomass compared to the situation where it is sown later. Besides, farmers think the cover crop will hamper the development of the maize due to competition for nutrients. Yet, this is not in line with the findings of this study and according to John Verhoeven who is an undersowing expert at the WUR, a failed undersown cover crop is most often the result of failing farming management, unsuitable weather methods and a lack of knowledge of the farmer rather than nutrient stress.

This shows the importance of good communication of study results and good crop management consultation. Currently, farmers that are willing to undersow their cover crop hardly do so because they are convinced by its benefits. According to Jan Roothaert, farmers would prefer a flexible deadline for seeding the cover crop, in order to assure good harvesting and seeding circumstances. However, as this is not the current situation, some farmers do not want to take any risks and therefore undersow the cover crop in the maize, to avoid a deadline before which the maize needs to be harvested.

A fourth reason farmers decide not to undersow their cover crop, is that it limits the options with chemical weed control. In conventional farming systems, chemicals are applied to minimize the damage caused by non-maize species. However, when two different plant types are wanted, herbicides are required that do not harm the grass and maize, but do eradicate the weeds. According to John

Verhoeven, these chemicals currently hardly exist. In order to solve this situation, grass species should be bred that have similar resistance as maize species. It is questionable whether this will happen, as the application of agricultural chemicals is decreasing and will keep doing so in the future.

A final reason that farmers prefer to sow their cover crop after harvesting the maize, is the possibility to choose a cover crop that contributes to the control of nematodes. As undersown cover crops are usually grasses, nematodes can multiply easily. These nematodes might eventually damage the maize crop, or another crop that is sown in a subsequent year. When sowing the cover crop after harvesting the maize, it becomes possible to choose for a cover crop that does not contribute to the multiplication of a specific type of nematode.

Technology

When looking at the technical development of seeder drones, it can be concluded that several companies that sell seeding drones already exist, with a large range in prices. However, especially in the application for the seeding of cover crops, a high price can be a large obstacle. Usually, farmers are not willing to invest large sums of money in techniques related to cover crops because those cover crops do not give a direct yield. Instead, cover crops improve crop yields indirectly by improving soil health, soil structure and the soil organic matter content. Because of the lack of short term financial return, the willingness to invest in cover crops is generally limited.

This weakness might be overcome by new agricultural policies implemented by the Dutch government. Haruna et al. (2020) already concluded that in order to achieve improved cover cropping systems, governmental support is needed not only to bridge the knowledge gaps in its application, but also achieve economic benefits of cover crops. The new GLB might be that new stimulus to convince farmers to invest in cover crops. Based on the discussions with cover crop experts, this system works better than the so called calendar-farming which is being applied on sandy and loess soils. By obliging farmers to have sown a cover crop before a certain date, there is no space for natural variation while this will always be a crucial component of agricultural systems. With the new GLB, farmers can themselves decide on which measurements to implement, and how they achieve this. If they decide to invest in cover crops, they will get a financial return for this. This makes the willingness to invest in cover crops larger. If due to technological developments the price of seeder drones drops even further, seeding cover crops might financially become an interesting option.

When looking at alternatives for sowing cover crops with a drone, two options can established; a high boy and a fertilizer spreader.

A high boy has a similar design as a spraying machine. The arms of a high boy can go through fully grown corn to seed the cover crop. The largest benefit of a high boy is the usage of tubes. By placing the seeds underneath the canopy, seed losses by leaf interception are minimized (Seed, 2020). Another benefit of a high boy is the possibility of placing the seeds to a certain extent into the soil. By shooting the seeds out of the tube it can be penetrated deeper into the soil compared to broadcasting with a drone or fertilizer spreader. Finally, the high boy allows more exact placement of the seeds. This does not only result in an equal distribution of the cover crop over the field, but also allows drift into neighbouring fields (Robison, 2020). However, a downside of a high boy is the damage it might cause to the maize plant. The tubes are dragged through the plants. This requires a good functioning GPS system, especially in irregularly shaped fields. Another downside of a high boy is the slow application rate. Compared to a drone, a high boy can seed les hectares per day. Finally, the soil circumstances need to be good in order to drive through the fields with a tractor to prevent compaction. This is not a limiting factor for drones.

Fertilizer spreaders are most frequently used to broadcast cover crops into main crops. The largest benefit of the fertilizer spreader is that almost all farmers already possess one. Since a lot of farmers prefer not to do big investments into cover crops as it gives no direct return, the importance of this argument should not be underestimated. Another benefit is its quick application rate. Fertilizer spreaders can hold much more weight than drones, and can therefore seed more hectares per day. A downside of spreading cover crop seeds with a fertilizer spreader is the limited time frame it can be used in. When the maize plants grow too tall, the canopy leaves will block the seeds and prevent a good spread over the field. Next to that, the spreading of the seeds might damage the maize plant and the tractor can cause soil compaction. So, as the benefits of sowing in August are not applicable for sowing with a fertilizer spreader.

Biology

When seeding cover crops with drones, seeds are broadcasted over a field rather than drilled into a soil. However, this has several downsides. According to the FAO, broadcasting is only recommended in low-energy situations and with predictable climatic circumstances, including predictable rainfall and air humidity (Baker et al., 2007). Because of the transition to a sustainable farming system, a low-energy situation is preferred at any time. Since drones can fly on electrical energy, this is low energy input is a benefit of seeding with drones. However, the predictable rainfall and air humidity might be problematic when seeding cover crops with drones.

The results of this study have shown that the sensitivity to drought stress significantly increases when seeds are broadcasted on the top of the soil. Besides, the results have shown that competition for light might be the largest limiting factor for the development of the cover crop, while competition for nutrients does not seem to affect the main crop yield. Both weakness might be alleviated by sowing in August/September instead of April/May, when the currently undersown cover crops are seeded. First of all, the maize crop drops its leaves while ripening. This increases the amount of photosynthetically active radiation that reaches the soil surface, thus increasing the survival rate of cover crop plants. Secondly, in the Netherlands the precipitation is larger in late summer than in spring. Figure 7 shows the average precipitation for each month since 1974 in Rotterdam based on the measurements by the KNMI. It shows that April and May are the months with the least precipitation. In August and September, the amount of precipitation has almost doubled compared to April. However, this benefit might be compensated for by the higher air temperature and therefore faster evaporation rate. More research is needed to study this potential trade-off. The faced weaknesses of the concept remain as the options suggested do not give certain solutions, but this report shows that there are potential methods to avoid the issues faced.

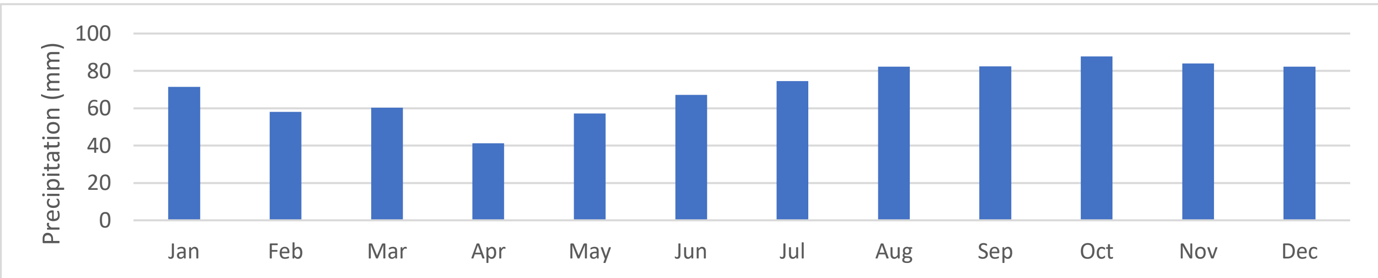

Figure 7: Average precipitation per month in Rotterdam between 1974 and 2021

Seeding with drones also improves two agricultural components which are poorly supported by the currently mainstream applied methods. First of all, because of the obligation to grow cover crops on sandy soils and the stimulation by the new GLB, more cover crops will be grown and with the traditional methods this would mean extra perturbation of the soil. Disturbance of the soil structure exposes the organic matter that used to be protected by microaggregates and therefore increases the decomposition rate of the organic matter. As one of the reasons to grow cover crops is to improve the soil organic matter content, the extra round of tillage is counter-effective. The second improvement compared to the currently applied cover crops seeding method, is the avoidance of soil compaction. With the currently applied methods, cover crops would be drilled into the soil in September/October. As figure 7 shows, those are some of the months with the highest precipitation amounts of the year. Using heavy machinery on wet soils deteriorates the soil structure and results in soil compaction which will not only affect the development of the cover crop, but also the development of the main crop in the subsequent year. By hovering over the field and sowing the cover crop from the air, both issues are avoided.

Seed coatings

The results of this study show that a possible adaptation method to the drought stress experienced by broadcasted cover crops is the usage of seed balls. Seed balls increase the water availability of the seeds and are therefore thought to increase the germination rate. The results of the experiment performed in this study do not confirm this. Nevertheless, the results did show an early germination of the seeds. The fact that no difference in germination rate was observed might be caused by the high irrigation rate. Because of the high water availability, a method to adapt to water stress was not required. For a follow-up experiment, it is recommended to reduce the irrigation application rate, or change the interval from daily to for instance every third day.

Overall, the application of seed balls is unlikely to mimic the stance of cover crops of which the seeds were drilled. However, the development of the cover crop is not the end goal. If the net increase in soil organic matter content and the improvement of the soil structure is larger in the cover crops which were sowed with seed balls than the ones drilled, the growth of cover crops with seed balls has been a success. The net increase of soil organic matter content is not unlikely, as the carbon sequestration by early sown cover crops largely increases. Norén, van Geel & de Haan (2021) showed that grasses sown on October 1 sequester 1800kg of organic matter per hectare, while grasses sown on August 1 sequester 4650 kg/ha. Besides, the low germination rate might be compensated for by a higher seeding rate. Next to that, the results of the literature study show that depending on the species, a higher seeding rate can compensate for a lower germination rate.

Cover crop characteristics

Based on the assessment made in this study, it can be concluded that grass species are the most suitable to be undersown. The species considered are the cover crops allowed to be grown after maize on sandy soils. Therefore, this assessment is mostly valid for cover crops on sandy soils. Grasses are the best option because of its shade tolerance and low seed weight. Though, this does not mean that other species should not be considered.

Fodder radish scores very well on each aspect, except for the shade tolerance. Fodder radish are of special interest as cover crop because of its interaction with nematodes. The low assessment for shade tollerance is based on the words of cover crop expert Herman van Schooten from WUR and Bernard Bles, sales manager at DSV seeds. However, Brooker, Renner & Basso (2020) studied the undersowing of several cover crops in corn, and concluded oil seed radish (which is just like fodder radish part of the *Raphanus* genes) develops well when being undersown. Because of this contradiction, it is recommended to gain practical experience of undersowing fodder radish.

Legislation

With the current formation of new legislation for flying with drones, it is uncertain which requirements need to be met for the application of a seeding drone. For now, the general rules of December 31 2020 apply. However, new rules are to be formed for the category specific, which will apply to sowing cover crops with drones.

What is already clear, is that with a drone of the category specific it is also possible to fly in no-fly zones. Those no-fly zones are located around airports and other places where flying is perceived as dangerous. Especially in eastern Brabant there are many restrictions to the usage of drones (figure 8). A complete overview of the no-fly zones can be found on noflyzone.nl. This is by many perceived as a limiting factor for the application of drones in agriculture in the Netherlands, but few people know it is possible to fly in those areas as long as you have the right permits.

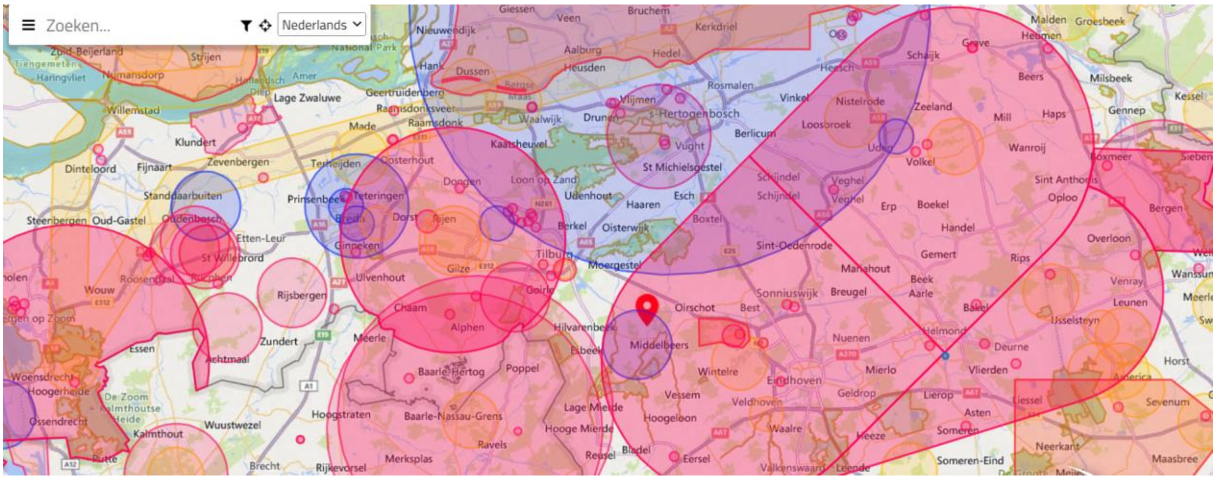

Figure 8: no-fly zones in eastern Brabant

Conclusion & recommendations

This report has studied the currently available knowledge on undersowing cover crops through broadcasting with drones. Based on the assessed sources, it can be concluded that:

- Early sowing has the potential to double the carbon sequestration of cover crops and substantially increase the nitrogen scavenging;
- Technically much is possible when it comes to sowing with drones with several companies already selling seeding drones;
- Three biological limitations have been established: water availability, competition for light and predation;
- There seems to be no yield reduction of the main crop;
- In order to sow with a drone, subcategory A3 with a license in the category specific is required.

Based on the findings of this report, it is recommended that:

- The sowing drone is a multi-rotor drone (preferably a quadcopter);
- Seed balls are used to alleviate the drought stress and predation rate;
- To study per species whether increasing the seeding rate is of benefit;
- Grasses are used as cover crop; but additional research is done for the undersowing of fodder radish.

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Appendix A: Competition between main and cover crop

Does seeding cover crop harm main crop?									
Reference	**Conclusion**	**Where?**	**Seeding method**	**Stage of seeding**	**Fertilization?**	**Irrigation?**	**Crop type**	**Type of CC**	**Sowing moment**
Wallace et al. (2021)	No effect grain yield, interseeding increases N uptake	Pennsylvania, US	Broadcast & Drilling	V5-V7	Mushroom, hog-chicken, or solid dairy. Artificial fert. N.a.v.	n.a.v.	Grain maize	Ryegrass, Orchardgrass, Forage radish	June
Brooker et al. (2020)	No effect grain yield, rainfall during interseeding improved CC emergence	Michigan, US	Broadcast	V3/V6	n.a.v.	n.a.v.	Grain maize	Annual ryegrass, crimson clover, oilseed radish	June-September
Youngerman et al. (2018)	No effect grain yield, improved weed surpression	Pennsylvania/Maryland, US	Drilling	V3-V5	Poultry/dairy manure	Yes	Grain maize	Cereal rye, annual ryegrass, hairy vetch, red clover	June
Curran et al. (2018)	Grain yield decreased at V2-V3, no effect at or after V4	Pennsylvania	Drilling	V2-V6	NPK based on soil test recommendation	n.a.v.	Grain maize	Annual ryegrass, common red clover, crimson clover, hairy vetch	June
Abdin et al. (1997)	No effect grain yield, except one site due to good establishment and early germination	Quebec, Canada	Broadcast	V2-V5	Yes	n.a.v.	Grain maize	Fall rye, hairy vetch, clover, alfalfa, black medic	June
Baributsa et al. (2008)	No effect grain yield	Michigan, US	Broadcast	V5-V7	Yes	n.a.v.	Grain maize	Red clover	July-August
Rushch et al. (2020)	No effect grain yield	Minnesota, US	Broadcast	V4-6	Yes	n.a.v.	Grain maize	Annual ryegrass, forage radish, crimson clover	August-September
Wallace et al. (2019)	No effect grain yield	Maryland, Pennsylvania	Drilling	V5-V8	Yes	n.a.v.	Maize, n.s.	Annual ryegras, legume cover crops	September
Blanco-Canqui et al. (2017)	No effect grain yield, but no other benefits either (besides prevented erosion)	Nebraska, US	Broadcast	Late August	Yes	Yes	Grain maize	Winter rye	September
Uchino et al. (2009)	Pre- and same seeding moment decreased grain yield, post no effect	Sapporo, Japan	n.a.v.	Pre: 14 days before main crop, same: same day, post: 21 after main crop	No	Yes	Sillage maize	Winter rye	May

Appendix B: Effect of increasing seeding rate

Reference	Conclusion	Where?	Seeding method	Stage of seeding	Fertilization?	Irrigation?	Crop type	Type of CC	Moment of seeding
Brooker et al. (2020)	No increase	Michigan, US	Broadcast	V3/V6	n.a.v.	n.a.v.	Grain maize	Annual ryegrass, crimson clover, oilseed radish	June-September
Koehler-Cole & Elmore (2020)	Increase plant population, limited effect biomass	Nebraska, US	Broadcast	R5	n.a.v.	Weekly	Maize, n.s.	Cereal rye, hairy vetch	September
Boyd et al. (2009)	Increases biomass production and weed suppression	California, US	Drilling	NOT INTERSEEDED	n.a.v.	Yes	CC	Winter rye	October
Haramoto (2019)	Lower seeding rate does not reduce cereal rye biomass as cc. Higher seeding rate increases percent ground cover, but didn't affect weed biomass. Dry years: drilling > broadcasting.	Tokyo, Japan	Broadcast & Drilling	NOT INTERSEEDED	Yes	n.a.v.	CC	Winter wheat, cereal winter rye	October
Brennan & Leap (2014)	Broadcasting requires 50% to 100% more seeds than drilling, implying that it increases crop performance	California, US	Broadcast & Drilling	NOT INTERSEEDED	n.a.v.	Yes	CC	Rye, purple/common vetch	December
Fisher et al. (2011)	No increase in crop performance	Maryland, US	Broadcast & Drilling	NOT INTERSEEDED	Yes	N.a.v.	CC	Winter wheat, cereal rye	October
Ruis et al. (2019)	Increases biomass production	Meta-analysis	Broadcast & Drilling	NOT INTERSEEDED	n.a.v.	n.a.v.	CC	No specific CC	September-October

Appendix C: Comparison of different cover crops

Suitability of cover crops for seeder drones													
English name	Dutch name	Quick developme	Germination r	Organic matte	N scaveng	Shade toleranc	Unsensitive to c	Seeding momei	Low seed weigl	Weed suppres	Low predation r	Nematodes	Score
Leaf cabbage	Bladkool	8	7	7	8	n.a.v.	8	5?	10	8	n.a.v.	n.a.v.	7.0
Fodder radish	Bladrammenas	8	7	6	8	3	5	8	8	8	n.a.v.	10	7.1
Oat	Japanse haver	10	6	8	8	n.a.v.	6	10	1	8	n.a.v.	6	7.0
Triticale	Triticale	6	4	8	8	n.a.v.	8	4?	1	8	4	7	5.4
Winter rye	Winterroge	8	3	6	8	n.a.v.	10	1	1	8	4	5	5.4
Winter wheat	Wintertarwe	4	4	7	7	5	10	1	1	8	n.a.v.	6	5.3
Winter barley	Wintergerst	8	6	8	8	5	10	1	1	8	8	6	6.3
Italian rye-grass/annual	Italiaans raaigras	10	7	8	8	5	6	10	8	8	4	6	7.3
perennial ryegrass/engli	Engels raaigras	8	6	8	8	4	6	10	8	8	4	6	6.9
Westerwolds ryegrass	Westerwolds raaigras	10	7	8	8	5	6	10	8	8	4	6	7.3
Tall fescue	Rietzwenkgras	6	6	8	8	5	6	10	10	8	4	6	7.0
Triticale	Triticale	5	6	8	8	n.a.v.	8	3	1	8	8	8	6.3
Spelt/dinkle wheat	Spelt	5	6	8	8	n.a.v.	8	1	1	8	4	n.a.v.	5.4