Identifying plants suitable for aerial seeding by drones in Dutch maize fields during late summer

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Photo cover: a mixture of ryegrass and clover seeded by drone prior to the maize harvest (Jansink et al., 2025)

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Abstract

As understanding of soil health and nutrient cycling has advanced, farmers have shown increased interest in adopting catch crops. In addition, the Dutch government implemented a law stating that after cultivating maize, catch crops must be planted before the first of October. However, maize often cannot be harvested before this date. This leads to difficulties with sowing a catch crop on an empty field. To tackle this problem, aerial seeding with drones is proposed as an alternative sowing method. The primary objective of this study was to discover which plants can be used for aerial seeding by drones. To investigate this, four main characteristics were identified: germination, rooting, shade tolerance, and resistance to machinery traffic. Plants were scored based on their performance for each characteristic. A literature search was conducted in scientific databases and grey literature. In addition, interviews were held to gain more information and practical knowledge. The conclusion is that perennial ryegrass, timothy and orchardgrass are the most suitable grasses. Red clover is a good option within the leguminous species. Within the Brassicaceae family, fodder radish seems to be the best option. Chicory is a viable option to undersow from the other families. These species should be included in future field trials, as they are expected to perform well when seeded by drones. Given the variability in trial conditions reported in the literature, it is essential to conduct new trials in Dutch fields. This is to ensure that results are applicable and relevant to Dutch environmental conditions.

Samenvatting

Door de groeiende inzichten in bodemgezondheid en nutriëntenbeheer neemt de belangstelling van boeren voor vanggewassen aanzienlijk toe. Bovendien is recent nieuwe wetgeving van kracht geworden die een groot deel van de boeren verplicht om na de teelt van maïs vóór 1 oktober een vanggewas in te zaaien. In de praktijk blijkt echter dat het oogsten van maïs vóór deze datum niet altijd haalbaar is, waardoor het tijdig inzaaien van een vanggewas onder druk komt te staan. Om dit knelpunt te ondervangen, wordt het inzetten van drones voor het zaaien van vanggewassen voorgesteld. Over deze techniek en de effectiviteit ervan is echter nog beperkte kennis beschikbaar. Het doel van deze studie is dan ook om te bepalen welke vanggewassen het meest geschikt zijn voor dronezaaiing. De geschiktheid van gewassen is beoordeeld op basis van vier eigenschappen: kieming aan het oppervlak, bodempenetratie van de kiemwortel, schaduwtolerantie en bestendigheid tegen verkeer van landbouwmachines. Voor deze analyse zijn verschillende bronnen geraadpleegd, waaronder wetenschappelijke literatuur, grijze literatuur en praktijkinformatie verkregen via interviews. Engels raaigras, timoteegras en kropaar komen naar voren als de best presterende grassoorten. Binnen de vlinderbloemigen blijkt rode klaver een geschikte optie. Voor de kruisbloemigen wordt bladrammenas als meest effectief beschouwd. Onder de overige gewassen wordt

cichorei aanbevolen als het beste alternatief. Vervolgonderzoek in veldomstandigheden wordt aanbevolen om deze gewassen verder te evalueren, aangezien zij naar verwachting goed kunnen omgaan met de specifieke eisen van dronezaaiing. Gezien de grote variatie in omgevingen en omstandigheden in de geraadpleegde literatuur, is aanvullend veldonderzoek onder Nederlandse omstandigheden essentieel om de toepasbaarheid en betrouwbaarheid van de resultaten te verifiëren.

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1 Introduction

In recent years, growing concerns over agricultural water pollution in the Netherlands have prompted increased attention to sustainable farming practices. Past and current fertilizers and manure management has led to significant contamination of groundwater, with nitrate identified as the primary pollutant. To address this issue, the government has set ambitious targets to improve water quality, including the reduction of nitrate concentrations. One key strategy to achieve these goals is the use of catch crops, particularly following maize cultivation. However, conventional sowing methods have a number of downsides. As a result, alternative approaches such as aerial seeding with drones are being explored. This report investigates which catch crop species are best suited for aerial seeding in late summer, focusing on four critical plant traits: surface germination, root penetration, shade tolerance, and resilience to machinery traffic.

1.1 Background

Over the past years, the agricultural practices in the Netherlands have been leading to increased water pollution (Kros et al., 2023). Groundwater pollution is mainly caused by the use of fertilizer and manure in high concentrations (Rozemeijer & Broers, 2007). The use of pesticides also results in contaminated groundwater bodies within the agricultural sector (Rad et al., 2022). This has adverse effects on the environment, such as eutrophication, loss of biodiversity, and scarcity of fresh water (Ravindiran et al., 2023).

Nitrate is considered to be the main water pollutant that leaches into the ground and surface water. The leaching of nitrogen occurs mostly in agricultural areas with sandy soils, where the nitrate limit of 50 mg/L is often exceeded. Therefore, the Kaderrichtlijn Water (KRW), which is a European directive focused on improving the quality of surface water, set goals to improve water quality, such as reducing the amount of nitrate in the groundwater. These goals have to be achieved before 2027. To reach these goals, actions such as changing the moment of fertilizer application and using catch crops need to be taken.

To reduce nitrate leaching, many maize farmers in the Netherlands must sow a catch crop before the first of October (RVO, 2025). The absorption of nitrogen by maize during its growing cycle does not match the dynamic of mineralisation in dutch soils. This often results in high level of nitrate early in the fall and, if nothing is done to catch them, nitrate leaching will happen. A catch crop will reduce this leaching by taking up the residual nitrogen.

To be able to sow a catch crop with a conventional seeder before October first, maize must be harvested before this date (RVO, 2025). However, weather variations can lead to a delay in maize maturity. This means that maize might be harvested before maturity, to ensure that the catch crops can be seeded on an empty field before the first of October.

Nonetheless, early harvesting is not advisable, given its potential to negatively impact crop yield (Gaile, 2008). Alternative sowing methods for the catch crops can be a solution to this.

1.2 Problem statement

There are different options for seeding catch crops. One of the options is post-harvest seeding, which happens on an empty field after the main crop is harvested (ForFarmers, 2024). Another option is interseeding, which means sowing a catch crop before, during or after maize seeding in April/May (ForFarmers, 2024). Its disadvantages are the significant competition with the maize, and limitations on herbicide use (ForFarmers, 2024). Finally, undersowing is the practice of seeding a catch crop during the growing phase of maize. Undersowing can take place when the plant is at knee height, around mid-June. The disadvantages of undersowing in mid-June include a short window of seeding, limitations on herbicide effectiveness, and the risk of excessive moisture in the maize fields (ForFarmers, 2024). Besides, it requires tractor traffic on the fields, which can result in soil compaction (when there is excessive moisture in the field) and damage to the maize plants.

Figure 1. DJI Agras T50 drone used for aerial seeding of a clover mixture in Lelystad.

An alternative is to undersow catch crops in late summer, specifically in August and September. But a problem with undersowing in late summer is that maize plants often grow tall (about 3 meters), meaning common tractors cannot enter the field to sow the catch crops. A solution to this is to sow a catch crop using aerial seeding with drones

(Figure 1). However, this method comes with new challenges, particularly in selecting plants with the right characteristics to thrive under the maize canopy. Within the Netherlands, only 11 catch crops are registered to function as a catch crop after maize cultivation (RVO, 2025). Therefore, farmers currently face difficulties in selecting suitable crops for undersowing during late summer (Appendix 7.2).

1.3 Scope

The four main characteristics that should be investigated when selecting a plant that is suitable as a drone seeded catch crop in maize are: germination, rooting, shade tolerance, and resistance to machinery traffic. When the seeds are broadcasted on the field instead of drilled into the soil, the seeds are lying on the soil. This impacts the way plants germinate as the conditions above the soil are different to the conditions in the soil. It also changes the roots development, especially the radicle which emerge of the seeds above ground and needs to drill itself into the ground. Additionally, the plant should be able to survive limited light conditions and therefore be somewhat shade tolerant, to thrive under the shadow that is created by the maize plants. Finally, the plant sown as a catch crop should be resistant to heavy machinery traffic, because it is seeded before the maize harvest which generate some traffic such as the silage harvester.

1.4 Research questions

This report and table 1 will provide some suggestions to the following research question: **Which plants have favourable characteristics for aerial seeding by drones on Dutch maize fields in late summer, regarding germination, rooting, shade tolerance, and resistance to machinery traffic?**

The following sub-questions will be answered:

Sub-question 1: Which plants germinate when broadcasted on Dutch maize fields in late summer?

Sub-question 2: Which plants easily root into the soil when broadcasted on Dutch maize fields?

Sub-question 3: Which plants will grow in shaded conditions when sown in Dutch maize fields in late summer?

Sub-question 4: Which plants resist machinery traffic in Dutch maize fields?

2 Methodology

To evaluate the suitability of catch crops for aerial seeding with drones in maize fields, a structured data collection and scoring approach was applied. Academic literature was used, supplemented by grey literature. Additionally, interviews with farmers and agronomists provided field-based knowledge. The collected data informed a scoring system that assessed plant species on four key characteristics—germination, rooting ability, shade tolerance, and resistance to machinery traffic—using a standardized scale to compare performance across species.

2.1 Data collection

To conduct the literature study, both academic and practical information on the use of aerial seeding with drones in maize fields were gathered.

Searches within the scientific databases Scopus and Web of Science were performed. To obtain earlier studies that were relevant to the project, backwards snowballing was used by reviewing the reference lists of the selected articles.

Because a lot of knowledge about the growth of plants is practical, a second research method was used. Grey literature was used to obtain non-academic papers, using resources such as Google Scholar and Google. Papers from consultancy companies were included, which gave insights into practical research projects. These findings added to the academic papers with practical information of this technique and showing results from the field.

A third method of data collection was used, which involved conducting interviews with various stakeholders, including farmers working with drones in maize fields and crop consultants (Appendices 7.1 – 7.4). The stakeholders were selected (via recommendations and online searches) based on their knowledge about already existing catch crops. Before each interview, guiding questions were prepared to ensure a structure within the interviews, based on the expertise of each interviewed (Appendices 7.1 – 7.4). The interviews verified or elaborated on findings from online sources and provided practical knowledge about seeding with drones.

2.2 Scoring of the characteristics

The data gathered was used to create a table (Table 1) where different plant species, which could function as a catch crop, were scored on the four characteristics. The scoring was given ranging from two minuses (--) to two plusses (++), with plus/minus (+/-) as an intermediate score. When a plant species scored very good on a certain characteristic, it received a ++ score. A plus (+) score was given when the plant species did well, a score of +/- when it performed intermediate, a minus (-) score when it did not perform well, and a score of - - when the plant species performed very poorly on a specific characteristic. A plant species was scored with a question mark (?) when no information was available regarding a specific characteristic for that plant species. In addition, a plant received a "?" when the team did not have enough time to look into that characteristic.

The method of scoring was different for each of the four characteristics. For germination, the germination rate for seeds placed above ground was used to score the plant species, which is expressed in percentages. The percentages belonging to the germination rate were scored as follows: 0-20% received --, 20-40% received -, 40-60% received +/-, 60-80% received +, and 80-100% got the highest score, which is ++ (Appendix 7.5).

For scoring the rooting ability, the radicle-entry ability was investigated. In other words, the capability of a radicle that is located above the soil to enter it and root in it. The percentages of radicles entering the soil surface were searched and compared. Plants with higher percentages were given ++ or +. Plants with average entry ability or that relied on soil conditions were given +/-. For the plants showing lower entry ability or that could not root under broadcasting conditions, the score was - or --. Also, several articles that mentioned the same species were found, but their performance varied due to different soil conditions and/or cultivar, so a comprehensive score based on their overall performance was given (Appendix 7.6).

Regarding the characteristic shade tolerance, most articles that were found already based their rating on a score. For instance, in research from Bloksma & Jansonius (2001), a scoring from + to ++++ was given to the shade tolerance of a plant. Besides, within the table of the Government of British Columbia (2024), a scoring system of 1 (lowest score) to 5 (highest score) was applied. All results were translated to the scoring system used in this report, where their lowest score is converted to "- -" and their highest score to "+ +" (Appendix 7.7).

For machinery, plants with resistance to heavy machinery and the ability to regrow after damage were investigated. In an article studying the resistance to heavy machinery, the authors had already tested and graded the tolerance levels of different catch crops to machinery traffic. Their gradings were directly used and converted into the scoring system used in this report. For the catch crops' regrowth ability, studies on the regrowth ability of catch crops after grazing were used. Plants with higher levels of machinery tolerance or regrowth ability were given ++ or +, plants with average levels were given +/-, and plants with lower levels were given - or -- (Appendix 7.8).

3 Results

This section consists of the main findings from the literature search and interviews with various stakeholders, which are all summarized in Table 1. As mentioned in the methods, plants were scored from -- to ++ and received a “?” when no information was available for that specific characteristic. Besides, for each characteristic, an explanation was added to support the results.

Table 1: Overview of the scores given to plants regarding germination, rooting, shade tolerance, and machinery traffic. Plants were scored “++” (dark green), “+” (light green), “+/-” (yellow), “-” (light red), and “- -” (dark red). When no information was found, plants were given a “?”.

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Fodder radish	Raphanus sativus var. oleiformis	+	?	+/-	+/-
Forage radish	Raphanus sativus	?	?	+/-	?
Leaf cabbage	Brassica oleracea	++	?	-	+/-
Radish	Raphanus sativus	?	?	+/-	?
Rapeseed	Brassica napus	?	?	-	--
Turnip	Brassica rapa var. rapa	++	?	-	+
White mustard	Sinapis alba	++	?	-	+/-

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Woad	Isatis tinctoria	?	?	+/-	-
Akaroa var. cocksfoot	Dactylis glomerata	?	-	?	?
Bahiagrass	Paspalum notatum	?	?	-	++
Barley	Hordeum vulgare	++	?	+/-	?
Bermuda grass	Cynodon dactylon	?	?	-	++
Bristle oat	Avena strigosa	++	?	-	+
Chewing's fescue	Festuca rubra ssp. commutata	?	?	+	?
Crabgrass	Digitaria	?	?	?	+
Dallisgrass	Paspalum dilatatum	?	?	?	++
Gamagrass	Tripsacum dactyloides	?	?	?	+/-
Harding grass	Phalaris aquatica	?	+/-	?	?

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Italian ryegrass	Lolium multiflorum	--	?	++	++
Kentucky bluegrass	Poa pratensis	?	?	-	+
Durum wheat	Triticum durum	?	+	?	?
Orchardgrass	Dactylis glomerata	+	++	?	+/-
Pearl millet	Pennisetum glaucum or Cenchrus americanus	?	?	?	-
Perennial ryegrass	Lolium perenne	++	++	+/-	+/-
Phalaris	Phalaris tuberosa	?	+/-	?	?
Rescuegrass	Bromus catharticus	?	?	?	-
Rye	Secale cereale	--	?	+	?
Sudan grass	Sorghum drummondii	?	?	+/-	-
Supina bluegrass	Poa supina	?	?	+	?

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Switchgrass	Panicum virgatum	?	?	?	+/-
Tall fescue	Festuca arundinacea	?	?	+	+/-
Timothy	Phleum pratense	?	+	+/-	++
Triticale	Triticum x Secale	?	?	+	?
Sorghum vidan	Sorghum bicolor x Sorghum sudanense	?	+/-	?	?
Common wheat	Triticum aestivum	+	?	+/-	?
Alfalfa	Medicago sativa	++	--	-	+/-
Alsike clover	Trifolium hybridum	?	+	+/-	?
Berseem clover	Trifolium alexandrinum	?	?	+/-	?
Common kidney vetch	Anthyllis vulneraria	?	?	?	+
Bitter vetch	Vicia ervilia	?	--	?	?

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Birdsfoot trefoil	Lotus corniculatus	-	?	-	?
Black medic	Medicago lupulina	?	?	+	?
Blue lupin	Lupinus angustifolius	?	?	?	--
Crimson clover	Trifolium incarnatum	--	?	+	+/-
Egyptian clover	Trifolium alexandrinum	?	?	+/-	?
Hairy vetch	Vicia villosa	+/-	?	+/-	-
Hop clover	Trifolium campestre	?	?	?	-
Lentil	Lens culinaris ssp. microsperma	?	--	?	?
Lotus	Lotus pedunculatus	?	--	?	?
Mengnong Sainfoin	Onobrychis viciifolia var.Mengnong	-	+	?	?
Pea	P.sativum subsp. arvense	+/-	?	+/-	--

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Persian clover	Trifolium resupinatum	-	?	+	+/-
Prairy milkvetch	Astragalus Adsurgens	-	+/-	?	?
Red clover	Trifolium pratense	-	+	+	+
Subterranean clover	Trifolium subterraneum	?	+	+	?
Vetch	Vicia sativa	-	?	+	+/-
White clover	Trifolium repens	-	+/-	+	++
Buckwheat	Fagopyrum esculentum	?	?	-	-
Chicory	Cichorium intybus	+	?	+	+
Field gentian	Gentianella campestris	-	?	+/-	++
Lacy phacelia	Phacelia tanacetifolia	+	?	+/-	-
Plantago	Plantago major	?	?	?	+

Plant	Latin name	Germination	Rooting	Shade tolerance	Machinery traffic
Winterfat	Krascheninnikovia lanata	++	+/-	?	?

3.1 Germination

For the germination of a seed, several environmental conditions are of great importance. The most important conditions are: moisture, temperature, light availability, and nutrients (Han & Yang, 2015). Both light and nutrients are important environmental signals needed to break seed dormancy and stimulate germination. This dormancy is a state in which a seed is not able to germinate under suitable growing conditions. When broadcasting seeds, the seeds are distributed on top of the soil. This means that seeds are affected more by external environmental factors compared to drilled seeding. Especially dry conditions might impact the germination rate(Koehler-Cole & Elmore, 2020).

Plants were scored for germination, based on their germination rate when lying on the soil (Table 1). The score for the grasses varied a lot, with barley (89%) and perennial ryegrass (95%) having a high germination rate, while rye (5-24%) and Italian ryegrass (4-20%) had quite poor germination rates (Appendix 7.5). The germination rate within these low germination scores tended to vary. Another grass that performed well, according to Peter Jan Jongenelen, was bristle oat (Appendix 7.3). Most of the legumes had a low germination rate, crimson clover (2-23%), white clover (20%), bird foot's trefoil (31%), and red clover (37%). An exception to this was found for alfalfa, which had a germination rate of 94%. For the Brassicaceae the germination rate was, according to Peter Jan Jongenelen, mostly high, with Fodder radish, white mustard, leaf cabbage and turnip all scoring ++ (Appendix 7.3).

3.2 Rooting

Germination on the soil surface is important for seedling establishment when seeds are broadcasted with a drone. However, the soil surface can be a barrier for radicles of germinated seedlings to penetrate the soil (Figure 2). This stage of radicle-entry is susceptible to environmental influences, such as an extremely dry soil (Campbell & Swain, 1973), as roots do not have access to nutrients and moisture before entering the sub-surface soil layer (Awan et al., 1996). The ability to penetrate the soil mainly depends on the biological characteristics of the seedling, including the timing of root hair development, seed anchorage, and the pushing force of the radicle (Kislev et al., 1979).

The ability of the radicle to penetrate the soil was scored based on the percentage of seedlings that successfully entered the soil matrix, which can also be defined as radicle-entry. In this study, the radicle-entry ability of several plant species was investigated.

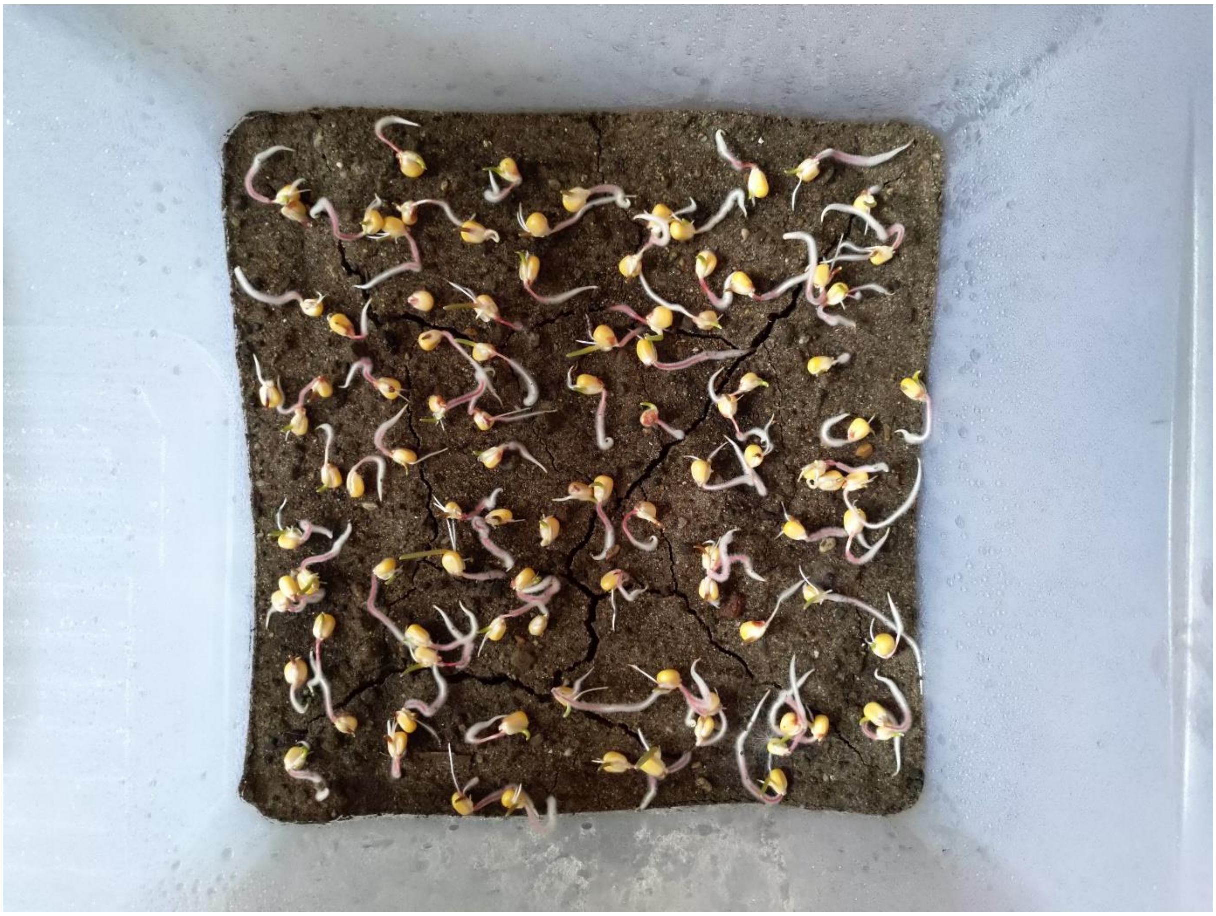

Figure 2. Germinated seeds trying to find their way into the soil (Stokkermans, 2021).

Species such as orchardgrass and perennial ryegrass exhibited strong radicle-entry ability (Table 1 and Appendix 7.6). Other species, including Durum wheat, alsike clover, red clover, mengnong sainfoin, and subterranean clover, also showed good performance. Species like harding grass, phalaris, sorghum vidan, and prairy milkvetch demonstrated moderate radicle-entry ability, and some of them were more dependent on specific soil conditions. For example, sorghum vidan had difficulty penetrating sandy soils well, but entry ability was better in sandy loam.

On the other hand, species such as akaroa cv. cocksfoot, alfalfa, bitter vetch, lentil and lotus exhibited very low radicle-entry ability. In particular, bitter vetch and lentil often failed to develop roots when broadcasted.

Winterfat had interesting results as seed preparation and/or seedling environment had a substantial effect on rooting. Broadcasting the fruits provided 5 folds more rooted radicle than broadcasting bare seeds, respectively 79 and 16% (Booth & Schuman, 1983).

3.3 Shade tolerance

One of the four characteristics that were used in this report to find suitable plants to undersow in maize fields is the shade tolerance of a plant species. Since the plants used as catch crops will grow under the canopy of maize for the first days/weeks (Figure 3), the species should be able to tolerate lower light availability (Gravel et al., 2010). Shade tolerance was also defined as the "species-specific minimum light required for survival" by Valladares et al. (2016). However, this shade tolerance does not directly indicate a preference for low light conditions. Shade-tolerant species, compared to shade-intolerant species, are better adapted to function optimally in low light conditions by balancing photosynthesis and respiration (Snyder, 2010; Ruberti et al., 2011).

Figure 3. A maize field in the V7 stage, showing that the canopy of the maize causes the soil to be in the shade (Stokkermans, 2019).

Table 1 shows that especially clovers have a good shade tolerance. Crimson clover, red clover, subterranean clover, and white clover outperformed other plants that were used as catch crops in British Columbia, Canada (Appendix 7.7). The results from Table 1 show that an interesting leguminous shade-tolerant plant to consider as a catch crop in maize fields is black medic, based on research conducted in an orchard in the Netherlands (Bloksma & Jansonius, 2001).

Besides, grasses such as Italian ryegrass, rye, tall fescue, chewing's fescue, and supina bluegrass grew well in shaded conditions. Shade-intolerant plants, as shown in Table 1 above, are most often part of the Brassicaceae family and include: leaf cabbage, rapeseed, turnip, and white mustard. Rapeseed, turnip, and white mustard are based on the field research from Bloksma & Jansonius (2001). These plants prefer full sun conditions and tend to grow less biomass in shaded conditions (figure 4 and Appendix 7.7). Besides, other plants that were considered shade intolerant compared to others were bahiagrass, Bermuda grass, birdsfoot trefoil, bristle oat, kentucky bluegrass, buckwheat, and alfalfa (Appendix 7.7).

Figure 4. Radishes growing in a shaded environment. The picture on the right shows a lot of stem elongation probably due to the low light conditions (Stokkermans, 2023).

3.4 Machinery traffic

A suitable catch crops for aerial seeding before the maize harvest should resist to heavy machinery traffic, especially the maize harvester and the transport of the harvested maize (Figure 5). To assess their resistance or tolerance to traffic, an important factor to consider is the intensity of the damage on the plant. Additionally, its ability to regrow buds or tillers and restore its biomass after being damaged (de Jong & van der Meijden, 2000). However, this has not been tested a lot in the field, which is why current literature is lacking. From interviews held with researchers and farmers, it is possible to conclude that in general, grasses, rye, common wheat, and barley are somewhat tolerant to machinery traffic (Appendices 7.1 – 7.4). According to John Verhoeven, cabbage and radish are less tolerant to machinery traffic, but leaf cabbage might be able to grow back

(Appendix 7.1). The potential regrowth ability of leaf cabbage was confirmed by Els Uijterlinde (Appendix 7.2).

Figure 5. On the left, the damage by heavy machinery traffic to fodder radish and collard greens is visible compared to the right, where reduced heavy machinery traffic resulted in less damage to the plants (Buitenhuis, 2023).

Because of a lack of abundant information on the resistance of plants to machinery traffic, the regrowth ability of plant species after being damaged was added as parameter. Previous research on grazing and trampling by animals provides quite a lot of information on regrowth ability. These findings are incorporated to estimate the regrowth ability after heavy machine traffic (Appendix 7.8). However, as machinery traffic is significantly heavier than the weight of grazing animals, further research is needed to test the plant species' actual resistance to heavy machinery traffic.

Species such as bahiagrass, Bermuda grass, crabgrass, dallisgrass, kentucky bluegrass, red clover, white clover, and field gentian showed good regrowth ability (Appendix 7.8). This means that even after being damaged by heavy machinery, they can recover and regrow. However, species like pearl millet, rescuegrass, and sudan grass have poor regrowth ability, or they rely on specific conditions, such as remaining above-ground biomass or having enough stored energy reserves, to support regrowth after damage.

Although there is little information available on plants' resistance to machinery traffic, a practical report was published by Petersen (2018), who tested the performance of some species under heavy machine traffic in the field. Among the tested species, persian clover, italian ryegrass, birdsfoot trefoil, timothy, chicory, plantago, and orchard grass showed high tolerance to machinery traffic. In contrast, species like woad, hairy vetch, hop clover, rapeseed, and perennial ryegrass are not as tolerant to heavy machinery traffic (Petersen, 2018).

3.5 Best candidates for an aerial seeded catch crop

Firstly, when considering the researched plant species, it seems grasses are suitable catch crops for aerial seeding by drones in maize fields. Perennial ryegrass outperformed all the other species. It germinates well (95%) under broadcasted conditions, the radicle can penetrate the soil, and the plant species can tolerate moderate shaded conditions. A disadvantage of this grass species could be that it is not as resistant to heavy machinery compared to other plant species. Two good alternatives for perennial ryegrass are timothy and orchard grass. Timothy scored well for rooting and resistance against machinery traffic, but lacked shade tolerance. Orchard grass scored high for rooting and germination, but was a bit less resistant to heavy machinery.

Secondly, the scores within the Brassicaceae varies a lot. However, all plants did tend to have a low score for shade tolerance. On germination and machinery resistance there were some plants that scored well. Specifically, turnip scored very well on germination (++) and machinery resistance (+). Leaf cabbage and white mustard had a similar score, but scored a bit lower on resistance against heavy machinery traffic. For rooting, no information was found for the Brassicaceae.

Thirdly, within the leguminous species, red clover, subterranean clover, and white clover showed favourable characteristics for aerial seeding by drones. These outperformed other legumes, particularly regarding shade tolerance. The downside of undersowing red clover and white clover is the fact that these species will not germinate well. The study of Goodell (2005) showed that red clover had a germination rate of only 37% under broadcasting conditions. Germination rates of white clover were only 20%, and these low rates were confirmed by Peter-Jan Jongenelen (Appendix 7.3). No information on the germination of subterranean clover was found. This should be further investigated to draw any further conclusions.

Finally, considering the other species, chicory scored very positively on germination, shade tolerance, and resistance to heavy machinery traffic (see Table 1 and Appendices 7.5, 7.7 and 7.8). Therefore, chicory has potential for undersowing in maize fields. Information on rooting potential is lacking and should be further investigated in the field. Besides chicory, field gentian could be considered a viable catch crop option. Table 1 and Supplementary Table 5 (Appendix 7.8) describe the strong regrowth ability of this plant species, and therefore its potential to resist heavy machinery traffic. Field gentian is capable to grow in partial shade, but whether it will thrive under the canopy of maize should be tested in the field. Besides, information regarding the other two characteristics is lacking. Further research is needed to investigate the potential of this plant species to function as a catch crop under maize plants.

4 Discussion

Throughout this project, the team has been working on identifying suitable plants to sow as catch crops in Dutch maize fields during late summer. Four important characteristics were considered: surface germination, radicle rooting, shade tolerance, and resistance to machinery traffic. This study aimed to answer the main research question: Which plants have favourable characteristics for aerial seeding by drones on Dutch maize fields in late summer, regarding these four characteristics?

4.1 Farmers' perspective

There are multiple reasons for a farmer to undersow a catch crop in maize fields. For many farmers, it is mandatory to sow a catch crop before the first of October, while the maize is not yet at maturity (ForFarmers, 2024). For some farmers, soil health and biodiversity are important reasons to undersow their fields. Having an established catch crop when harvest starts helps catching the nitrate, but also improves the soil quality and soil organic matter.

However, undersowing also comes with challenges, which can be reasons for farmers not to use aerial seeding by drones. Firstly, environmental conditions can result in a poor establishment of catch crops. Especially, the moisture content in the soil is an important factor. When the soil is too dry, the seeds will not germinate, and the catch crop will not survive. This means that the success of undersowing is weather dependent.

Secondly, killing the catch crop in the later winter can be a challenge. When catch crops are selected for having a good regrowth ability, the chances are higher that their killing will require more attention. In these cases, herbicides or machinery are used to destroy the catch crop. The use of herbicides is shown to be harmful to the environment by contaminating the groundwater, negatively affecting soil life, and resulting in the selection of herbicide-resistant plants (Basu & Rao, 2020). Mechanical alternatives include mowing, rolling, or undercutting. However, these individual methods are not able to kill all types of catch crop species (Creamer & Dabney, 2002).

Lastly, weeds can compete with the catch crop for water and nutrients, resulting in a suppression of the growth and biomass of the catch crop. This might lead to a lower ability of the catch crop to take up nitrogen and prevent leaching. On the other hand, weeds are also able to catch nutrients from the soil, thereby they could function as a catch crop (Kaur et al., 2018). However, these weeds are still able to disperse their seeds, which could lead to more weeds that can complete with the maize seedlings (Kwiatkowski et al., 2016). It is also shown that catch crops can prevent the germination of weeds by the excretion of certain substances (Brust et al., 2011).

4.2 Difficulties

During this project, selecting suitable plants to sow as catch crops was difficult. First, not all four characteristics were described for a certain crop. For example, when a plant showed good germination properties and rooted easily, information was lacking about its shade tolerance. This resulted in question marks in Table 1, these plant properties need further investigation.

Additionally, plant-plant interactions, plant-soil and plant-insect interactions were not taken into account. These interactions could have either a positive or negative impact on the findings shared in this report (van Dam, 2009). For example, nematodes were also excluded from this study. Such nematodes can influence plant growth, altering the main outcomes of this publication.

For germination, all of the germination scores are based upon experiments done in varying environmental conditions. Especially, the availability of sufficient moisture is very important in achieving germination (Hou et al, 2022). Therefore, to achieve sufficient insights into the germination rate, these environmental conditions should be similar. Additionally, germination can also be dependent on the age of the seeds that were used. For example, the germination rate of red clover (37%) was based on seeds that were stored for a prolonged period, making them less likely to germinate (Goodell, 2005). Also, the size of the seeds can influence the germination, small seeds tend to germinate better since they have a high surface volume ratio (Appendix 7.5).

For rooting, different indicators from literature were used, such as radicle-entry, radicle penetration, and seedling establishment. Seedling establishment is defined as the moment right after the seed is no longer dependent on internal nutrition. This means that the seedling can take up nutrients and moisture from the soil (Fenner, 1985). Although seedling establishment is a different stage from the radicle-entry stage, they are closely related and therefore both are used. Also, the environmental conditions as soil conditions and soil type, were different in the literature studies. This makes it harder to compare the scores of different plant species. However, for most plant species, multiple literature studies were compared, making this uncertainty smaller. Moreover, most of the literature studies used were relatively old.

For shade tolerance, when searching for plant survival in low light conditions or shade tolerance, different terms were used in different papers. Therefore, some information might be missing. Besides, as the time for extensive literature research was lacking, only one parameter (shade tolerance) was used to look for shade-tolerant plants. Other parameters should be considered to gain more possible plants as catch crops, such as the reflectance of green light of a plant (more reflectance means more suitable in full sun areas). Considering more parameters will result in more suitable plants as catch crops.

For machinery traffic, information was lacking. The assumption was made that if a plant was not able to regrow after being trampled by animals, it would not survive machinery traffic either, as machines are heavier than grazing animals. The assumption vice versa, when a plant survives animal trampling, it could possibly survive heavy machines as well. This should be tested in the field.

4.3 Limitations

There were some limitations within this study. The most important are: available time, limited publications, novelty of the seeding technique, impact of local conditions and impact of the cultivar on the final results.

Because of time constraints, a limited number of interviews with seed companies were possible. These interviews could have provided useful information about the germination, rooting, shade tolerance, and resistance to machinery traffic of certain plant species. Besides, a large number of plant species could possibly function as a catch crop. A longer study would result in a longer, more extensive literature-supported list of catch crops. Moreover, there is a lack of experience with seeder drones in the field. This technique is still very new and not widely used. Meaning that there is a lack of practical knowledge. This knowledge would be useful to gain information about the performance of catch crop species within the environmental conditions that come with aerial seeding.

The scientific literature consulted in this study often reflects environmental conditions that differ from those commonly found in Dutch maize fields. For instance, Petersen (2018) presents findings based on trials conducted in Danish spring barley fields, which may not be directly comparable. As a result, variations in plant performance are likely when these species are tested under Dutch maize cultivation conditions.

Although hundreds of domesticated plant species can potentially be sown in late summer in the Netherlands, this study identified usable information for only 63 of them. This limited coverage reflects both the scarcity of published research on drone-based catch crop seeding and the restricted time available for stakeholder interviews. Nonetheless, the genetic potential remains vast, and future research is expected to expand the knowledge base—making Table 1 likely to grow over time. For instance, van der Vegte (2023) suggests that spurrey (*Spergula arvensis*), a species familiar to Dutch agronomists (van Leeuwen-Haagsma et al., 2019), may be capable of germinating, rooting, and growing under maize when broadcasted by drone. However, published data on this species remains limited, particularly in relation to the four research criteria. Spurrey therefore represents a promising candidate for further investigation.

For several of the studied species, it became evident that cultivar selection significantly influences performance outcomes. For instance, Petersen (2018) tested two different cultivars of Persian clover and observed notable differences in their resistance to machinery traffic. This finding underscores the importance of evaluating cultivar-level variation when developing drone-based seeding techniques. To identify the most suitable candidates, agronomists will eventually need to assess and compare cultivars within promising species. This step will be essential for delivering effective, scalable solutions and maximizing the success of aerial catch crop establishment.

5 Conclusion and Recommendations

The goal of this research was to find suitable catch crops for aerial seeding by drones in Dutch maize fields during late summer. This investigation is based on the four characteristics: surface germination, radicle penetration & rooting, shade tolerance, and resistance to heavy machinery traffic. A table is provided in which plants were scored based on their capabilities and performance (Table 1).

Based on Table 1 and this report, it is possible to conclude that from the Brassicaceae family, fodder radish seems to be the best option for undersowing. However, information is lacking regarding rooting capabilities. From the grasses, perennial ryegrass, orchardgrass, and timothy are the most suitable. For the leguminous species, especially red clover, but also subterranean clover, and white clover can be considered good options. Within the other species, chicory is a viable option to try and field gentian also scored quite well.

Besides the investigation on different plant species, this study has also highlighted the impact of various environmental factors, such as moisture and light availability, as well as weather conditions, that could influence the drone seeding method. As some information was lacking on different characteristics, more field trails are required to get a complete overview of the plants, for instance on a species' resistance to machinery traffic, potential suitable plants should be tested in the field. Future research should therefore focus on the practical aspects of aerial seeding with drones. Besides, future research in Dutch fields is needed to ensure that the results apply to the Dutch environment.

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7 Appendices

7.1 Interview John Verhoeven

- What kind of study did you do related to maize seeding?

John: I worked on Boeren met Mais. I started the project 15 years ago, it was obliged to have a catch crop after maize. But this was not well executed. The idea rose to give the catch crop a head start by sowing it earlier in the field. A demonstration with Italian ryegrass showed the effect if you sow really early. The Italian ryegrass will take up all the water and nutrients, leaving not enough for the maize. But if you sow too late, it will be too dark and dry for the plant to develop well in the canopy. When sowing tall fescue at the same time as maize, it works quite well. Tall fescue grows more slowly compared to maize, so maize has a head start. But tall fescue will start developing later on.

John: Other crops were also investigated to get the same effect as interseeding. The object was to have a green field as soon as possible after maize harvest, to prevent nutrient leaching. To achieve this, a farmer needs plants that are somewhat winter hardy. Otherwise, it will not have an effect. On top of that, as soon as it goes to the generative stage it will not develop anymore. If you have a crop undersown and it reaches this phase too early, it stops growing. Grasses have an advantage in that they will not get generative in the first year.

- How important is it to take into account the catch crops endurance to machinery traffic at harvest of the cash crop?

John: Machinery traffic is very important. You need a certain biomass of the crop when the maize is harvested. As soon as the maize is harvested, the grass gets moisture and light, it will be able to start developing further. Wheat and rye will grow longer, others will stop in October and November.

- When does a plant germinate well?

John: You need to incorporate it into the soil, because nothing will happen if the circumstances are too dry. The plant will immediately die. Moisture is the most important factor for germination.

- We would like to discuss our four characteristics to see if you have any suggestions on how to research them with or what good indicators are for it.

John: Okay

Our first research question is**:** Which plants germinate when dispersed on Dutch maize fields in late summer?

John: Moisture is really important. Trials with catch crops I did were a nightmare because it was too dry. When undersowing in maize fields in late summer, it will be the same. The catch crops had a variation of establishment when sown at the 6-leafs stage.

- Our next sub question is: Which plants develop strong roots when dispersed on Dutch maize fields? We have as indicators: Higher root: shoot ratio, longer root length, larger root width, faster rooting speed. Which one do you think is the most important? At what standard should we consider the rooting of this plant is +? Should we focus on one of these characteristics or take all of them into consideration?

John: Root shoot ratio is an interesting parameter, but how much rooting does a crop need to catch the leaching nitrate? Tall fescue has a lot of roots, which might even be too much because you cannot remove them. Some clovers can also root deeply, but will develop more slowly. Clovers do not grow in low temperatures. Leaf cabbage and yellow mustard will not survive a frost. The speed of establishment could be interesting. I have a negative experience with broadcast sowing, because you need to incorporate it in the soil, otherwise the risk that it will not establish is too high.

- Our next sub question was: Which plants resist machinery traffic in Dutch maize fields? Do you have an idea for searching for plants that are resistant to machinery traffic? Or do you have a list of plants that are more or less resistant to machinery traffic?

John: In general, grasses, wheat, rye. The whole Poaceae family of grasses can resist traffic quite well. If you look at young clovers and leaf cabbage, yellow mustard I doubt how tolerant they are. For leaf cabbage, if it is well established, it might regrow. Keep into mind that the heavy machinery used on old crops is not the same as on young crops. Perennial rye grass is more traffic-tolerant than Italian rye grass. Westerwold ryegrass is less tolerant and is hardly used. Wet and drought conditions will also change a lot. The wetter the better. But overall, it will be very hard to find, because it is not really tested in trials. To get a better overview, it might be interesting to ask contractors and farmers about their experience.

- Our last sub question is: Which plants will grow in shaded conditions when sown in Dutch maize fields in late summer? We found this link, do you think this is relevant and useful to the project?

John: Shade tolerance is when it is established. You need to take into account where this data is based on, geographically. The conditions are really important, which makes this research also really difficult. Make sure to think about moisture, it is one of the most important indicators.

7.2 Interview with Richard Jansink and Els Uijterlinde

- What is your background?

Els: I am a farmer and researcher at the same time. I graduated in 2011 in Animal Sciences. I focused on animal nutrition and adaptation physiology. I took over the family farm, where I perform research projects. De Landbouwers wanted help to lead the project on drone sowing, which I am interested in.

Richard: I work at Aveco the bond, and De Landbouwers. I lead the projects in aerial seeding with drones. I started last year. I also lead Kaderrichtlijn Water projects. I coordinate the connection with the provinces, Waterschappen, and farmers. I focus on budget, time-planning, and the quality of investigation.

- What are your experiences with aerial seeding?

Els: Aerial seeding with drones is mostly practiced by livestock farmers. The main farmers are livestock farmers in Twente, this is because of history and soil characteristics. I prefer to use clovers and beans as catch crops. But this is difficult since these are not registered in the Netherlands.

- Why do mostly dairy farmers grow maize?

Els: As a dairy farmer, you grow maize and grass for the cows. 80% of your land is grass (grazing) and 20% is arable land. This differs per farmer, but farmers often grow the maize on a field that is not close to the farm. This is since maize is harvested only once a year, and grass needs to be harvested way more often. Farmers grow the maize at fields which was grass before. Every 5 to 7 years, you change to maize (crop rotation system), to make sure that the soil is not depleted by the grass.

- Which plants have you tested with drone seeding?

Els: I have experience with drone seeding. I planted collard with clover on 11 July en 16 July. Tractors open up the ground, which makes it easier to sow. This was one of the main problems that we saw with drone seeding.

Els: 2 years ago, I did a rotation with faba beans and wheat, but all the wheat seeds were eaten. We used no coating around the seeds, and I later heard that I could have better used barley. I have also used leaf cabbage, because of weak winters. It is in the soil now. De Landbouwers have experimented with Italian ryegrass, rye, and leaf cabbage.

Els: The challenges I noticed for a catch crop; it should be able to grow in shaded conditions, and it should not be blown away by wind.

- Were the farmers happy with the results?

Richard: Most farmers were surprised it worked and responded with enthusiasm. Happy that it was wet enough, so a tractor was not needed. And that the plants germinated.

Els: Evaporation can be 7mm of water per day, so opening the ground with a tractor might cause more evaporation than broadcasting on the soil does. This could be beneficial for the maize since it does not lose that water.

- Do you know crops that are less mechanically resistant?

Els: Alfalfa does not like to be driven over.

- What is the main goal of catch crops for most farmers?

Els: 95% of farmers just do it for regulation, so the main catch crop sown is ryegrass because it is cheap and it will develop (has good properties). Farmers just want their fields to look green after they cultivate maize. The downside of ryegrass is that it will always come back up, so you need glyphosate to destroy it.

Els: I like the diversity in the cover crops and think it is important to improve the soil quality. I see the importance of biodiversity. After growing the catch crop, it should always be destroyed and tilled into the soil.

- Are there any other characteristics we should keep in mind?

Els: Related to heavy machinery, the parts that die when driven over will regrow because of the competition between the catch crops. I think that clovers might be weak. It might be interesting to look at lignin content, I think lower lignin content is better. Root shoot ratio also sounds interesting.

7.3 Interview with Peter-Jan Jongenelen

- What is your function in Joordens zaden?

Peter-Jan: Joordens zaden has a background in catch crops. I am an international manager. I focus on the effect that catch crops can have on the soil condition. Each sector uses different catch crops, this is mostly caused by the objective of the catch crop.

- What is the reason that you breed catch crops? Which sorts did you choose and why?

Peter-Jan: We mainly focused on Brassicaceae, since these fit well in a cooler climate. It is also used since there were problems with nematodes in beet cultivation back in the day. Brassica's were good at helping against these nematodes.

- Did you ever consider breeding legumes as a catch crop?

Peter-Jan: We had a small program for clovers, vetch, and hairy vetch. These are mostly sold in mixtures.

- Which catch crops are suitable under what conditions?

Peter-Jan: This is rotation-controlled. Where is the space for the sowing of catch crops? Mostly focus on soil pathogens. Breeds are suitable for the different climate zones that can be met in the field.

- We research the drone seeding of catch crops in maize fields. And are interested in which plants could be suitable for this. Do you have any suggestions for catch crops that could perform well?

Peter-Jan: Drone seeding is difficult because of the legislation. Formerly, undersowing was done. This did not work well because of the competition between the catch crop and the main crop. Sowing kale after maize worked well, but this declined, and the farmers returned to grasses.

Peter-Jan: Farmers are used to cultivating grass, as it always grows. But kale and turnip are also good options. Turnip develops faster than kale, but there are complications if it is wet.

- Did you ever work with seed coatings?

Peter-Jan: I always used seeds that were tilled. But we are going to experiment with 3 seeds in a coating. After wheat is harvested, the coated seeds will germinate because of the microclimate in the residues. Oil-containing seeds, like crucifers, can be broadcast on the ground and germinate. It didn't work for all, but radish worked well for sure.

- We are looking at seeds that germinate well when they are not incorporated into the soil, can root well, have a good shade tolerance, and can handle machinery traffic. Do you know how your catch crops would score for these characteristics?

Peter-Jan: I did not have a look at it, but grasses are often better against machinery, all others are sensitive to it. Especially clover and vetch.

Peter-Jan: When looking at rooting, you could have a look at the root atlas. This is a German book with plants that are researched for their root architecture. From what I know, grasses have strong roots in the 0-40cm layer, crucifers and taproots can go up to 2 meters deep, phacelia has mostly roots in the upper layers, vetch goes into the deeper layers but has fewer lateral roots, and turnip, hemp, and alfalfa can grow really deep roots but this takes more than a year.

Peter-Jan: But root systems are also really dependent on sowing density. If you have a plant that roots deeply, you can catch more nitrate but just sowing more. As deep rooting is more important than the above-ground space.

- Do you think it is possible to breed for these characteristics, and did you consider this?

Peter-Jan: We test grasses on machinery resistance at Barenbrug. What we consider important for catch crops is their ability to grow after sowing, frost sensitivity, and soil-borne pathogen interactions. For maize farmers, the most important thing is complying with the law. When this is fulfilled, the cheaper the better.

- We also made a table from the catch crops we could find on your website, and how they score on our characteristics. Do you think this fits?

Peter-Jan: I will look at it after the interview.

Supplementary Table 1: Table that was sent to Peter-Jan

Plant	**Type**	**Kieming**	**Beworteling**	**Shaduwtolerantie**	**Machineverkeer**
Bladrammenas	Brassicaceae	++	++	+/-	+/-
Gele mosterd	Brassicaceae	++	+	-	+/-
Japanse haver	Grassen	++	+/-	-	+
Phacelia/bijenvoer	Overig	+	-/+	+/-	-
Boekweit	Overig	++	+	-	-
Inkarnaatklaver	Peulvruchten	--	+	+	-/+
Rode klaver	Peulvruchten	-	+/-	+	+
Witte klaver	Peulvruchten	-	+/-	+	++

Perzische klaver	Peulvruchten	-	+/-	?	+/-
Rolklaver	Peulvruchten	-	+(+)	?	+
Hopklaver	Peulvruchten	-	+/-	+	?
Alfalfa/luzerne	Peulvruchten	++	++	?	+/-
Bonte wikke (winter wikke)	Peulvruchten	+/-	-/+	+/-	-
Wikke (zomer)	Peulvruchten	-	-/+	?	+/-
Blauwe lupine	Peulvruchten	?	--	?	--
(voeder)erwt	Peulvruchten	+/-	-/+	+/-	--
Bladkool	Brassicaceae	++	+	+/-	+
(blad) Raap	Brassicaceae	++	+	-	+

7.4 Interview with Anna Morrow

- What is your role within Midwest cover crops?

Anna: I am a program manager of the Midwest cover crop. I was an educator at a university before, but right now, I coordinate at a council. I mostly do education about seeding dates, rates, and more. By educating on cover crops, I try to get farmers to start using them more.

- How popular is cover crop usage among American farmers?

Anna: It is uncommon in America to use cover crops. On less than 5% of the acreage in America, cover crops are used. As a company, we can assist farmers on how to use them.

- Are there any trends in cover crop usage in America?

Anna: Cover crop usage is increasing slowly, and the government is a bit more interested in it, which helps with the increase. But it is hard to measure.

- Idaho is known for maize, are cover crops used a lot with maize?

Anna: We recommend cover crops after maize and before soybeans. We see problems with interference if we do it before maize. This is a problem with seedlings, in the winter ahead of maize. Most of the cover crops we use are grass species, most popular is cereal rye.

- The problem in the Netherlands is that you cannot sow catch crops afterwards, because of the law. What does the timing of sowing look like in America?

Anna: They are researching seeding during the growing season. In some regions in the North, it is more common to do early interseeding. In the Southern Midwest, this is less useful because it stays in the canopy. But usually it is after harvest, because drilling is possible, which can be in October and November.

- Have there been tests done on undersowing?

Anna: For soybeans, this is done when about 25% of the leaves are yellow. Further north, it works better to seed red clover because it is established when wheat is harvested. The red clover does not get damaged. Because it is small and competing with the wheat.

- On what type of crops has undersowing been done?

Anna: The most common are maize and soybeans. On our website, we have recipes. Some of these recipes are: cereal rye before soybean, and oats or radish before maize. Cover crops after wheat can be done in summer and fail. Lastly, maize silage is an opportunity as well.

- What are good cover crops in America and why?

Anna: Cereal rye is the most popular. It is mostly sown late in the season. Earlier in the season, annual ryegrass is used because it is shade-tolerant. Rape seed does well with late planting. Several brassicas do okay in underseeding situations.

- Are there tests that you know of on machinery traffic?

Anna: In the decision tool we created, withstanding traffic is one of the characteristics you can select.

- Are there tests that you know of on germination rate?

Anna: Small seeds work better because they have more soil contact for their volume. We do not have data on germination rate. But we recommend broadcasting in wet weather conditions. And if it is possible, we recommend drill seeding.

- Do you have connections with cover crop experts?

Anna: I know some people who do drone seeding work. They did a webinar, a couple of weeks ago, about interseeding, in Michigan and Ontario.

https://www.youtube.com/watch?v=XF6qyi8aqw0&t=2783s

- Which companies/research/universities know most about cover crops?

Anna: I know some universities are looking into it. But I do not have a lot of data on it.

- Have you ever had contact with universities in Europe?

Anna: No, not a lot. A bit with the WUR on the decision tool. But something I do notice compared to Europe is that we have more cover crops.

7.5 Germination

Supplementary Table 2: Explanation on scoring given for germination.

Plant	Latin name	Type	Score	Explanation	Source
Fodder radish	Raphanus sativus var. oleiformis	Brassicaceae	+	In the USA, emergence rate of 12-62%, in broadcasted overseeded conditions between maize rows at the V3 (plants with three leaves visible) and V6 (All leaves visible) stages of maize. Experiments were conducted on nine locations in Michigan. Weeds were removed by tillage or herbicides. In the Netherlands, the interviewed agronomist scored its germination with++.	(Brooker et al., 2020) (Appendix 7.3)
Leaf cabbage	Brassica oleracea	Brassicaceae	++	Based on the experience of one agronomist.	(Appendix 7.3)
Turnip	Brassica rapa subsp. rapa	Brassicaceae	++	Based on the experience of one agronomist.	(Appendix 7.3)
White mustard	Sinapis alba	Brassicaceae	++	Based on the experience of one agronomist.	(Appendix 7.3)
Barley	Hordeum vulgare L.	Grass	++	Emergence rate of 89% when seeds were broadcasted by sowing the seeds by hand in split plots on wet soils.	(Baker et al., 1988)
Bristle oat	Avena strigosa	Grass	++	Based on the experience of one agronomist.	(Appendix 7.3)
Italian ryegrass	Lolium multiflorum	Grass	--	Emergence rate of 4-20%, in broadcasted overseeded conditions between maize rows at the V3 (plants with three leaves visible) and V6 (All leaves visible) stages of maize. Experiments were conducted on nine locations in Michigan. Weeds were removed by tillage or herbicides.	(Brooker et al., 2020)

Orchardgrass	Dactylis glomerata	Grass	+	Germination rate of 70-76% when broadcast seeded by hand into pastures within rows. Germination rate was determined by counting the number of germinated seeds out of hundred seeds originally sown.	(Goodell, 2005)
Perennial ryegrass	Lolium perenne	Grass	++	Germination rate of 78-92%, in broadcasted overseeded conditions between maize rows at the V3 (plants with three leaves visible) and V6 (All leaves visible) stages of maize. Experiments were conducted on nine locations in Michigan. Weeds were removed by tillage or herbicides. Germination rate of 95%, seeds were broadcasted in two locations. In Lafayette, the seeds were sown on silt loam soil in dry conditions. Two weeks after seeding the first rain appeared. In Brook, irrigation was applied every week. Emergence was defined as plants having one to three leaves initiated.	(Brooker et al., 2020) (Mellbye et al., 2018)
Rye	Secale cereale	Grass	--	Emergence rate of 5-24%, seeds were broadcasted by interseeding into soybean and maize at two locations in Nebraska. In Clay Center irrigation was applied every week and in Mead the field was rainfed. Emergence rate of 13% when seeds were broadcasted in soybean and maize fields at two locations in Nebraska. Both sites received rainfall within one week.	(Koehler-Cole & Elmore, 2020) (Koehler-Cole et al., 2020)
Common wheat	Triticum aestivum L.	Grass	+	Emergence rate of 64-69%, when seeds were broadcasted while residues were left on the	(Zhai et al., 2018)

				soil. The experiment was conducted during two growing seasons. In the second growing season, the soil water content was relatively low. Emergence was measured by selecting four areas of one squared meter and counting the emerged seedlings in those areas.	
Alfalfa	Medicago sativa	Legume	++	Germination rate of 94% when broadcast seeded by hand into pastures within rows. Germination rate was determined by counting the number of germinated seeds out of hundred seeds originally sown.	(Goodell, 2005)
Birdsfoot Trefoil	Lotus corniculatus	Legume	-	Germination rate of 31% when broadcast seeded by hand into pastures within rows. Germination rate was determined by counting the number of germinated seeds out of hundred seeds originally sown.	(Goodell, 2005)
Crimson clover	Trifolium incarnatum	Legume	--	Emergence rate of 2-23%, in broadcasted overseeded conditions between maize rows at the V3 (plants with three leaves visible) and V6 (All leaves visible) stages of maize. Experiments were conducted on nine locations in Michigan. Weeds were removed by tillage or herbicides.	(Brooker et al., 2020)
Hairy vetch	Vicia villosa	Legume	+/-	Based on the experience of one agronomist.	(Appendix 7.3)
Mengnong Sainfoin	Onobrychis viciifolia var. Mengnong	Legume	-	Germination rate ranged from 8 to 46 percent. The seeds were aerial seeded on a loamy soil with a moisture content of 15 percent.	(Mi et al., 2008)
Pea	Pisum sativum	Legume	+/-	Based on the experience of one agronomist.	(Appendix 7.3)

Persian clover	Trifolium resupinatum	Legume	-	Based on the experience of one agronomist.	(Appendix 7.3)
Prairy milkvetch	Astragalus Adsurgens	Legume	-	Germination rate ranged from 9 to 38 percent. The seeds were aerial seeded on a loamy soil with a moisture content of 15 percent.	(Mi et al., 2008)
Red clover	Trifolium pratense	Legume	-	Germination rate of 37% when broadcast seeded by hand into pastures within rows. Germination rate was determined by counting the number of germinated seeds out of hundred seeds originally sown.	(Goodell, 2005)
Vetch	Vicia sativa	Legume	-	Emergence rate of 15–54%, seeds with aerial interseeding into soybean and maize at two locations in Nebraska. In Clay Center irrigation was applied every week and in Mead the field was rainfed. Emergence rate of 5-40% when seeds were broadcasted with different methods (broadcast with rototiller, broadcast with cultivator and broadcast with disc). The seeds were sown on a loamy sand soil which was rainfed. The total rainfall during the experiment was 121 mm. Emergence rate of 30%, when seeds were broadcasted in soybean and maize fields at two locations in Nebraska. Both sites received rainfall within one week.	(Koehler-Cole & Elmore, 2020) (Koehler-Cole et al., 2020) (Brennan & Leap, 2014)
White clover	Trifolium repens	Legume	-	Emergence rate of 20%, when seeds were distributed on top of the soil in a growth chamber.	(Chu et al., 2022)

				In the Netherlands, the interviewed agronomist scored its germination with --.	(Appendix 7.3)
Chicory	Cichorium intybus	Other	+	Germination rate of 68% when broadcast seeded by hand into pastures within rows. Germination rate was determined by counting the number of germinated seeds out of hundred seeds originally sown.	(Goodell, 2005)
Field Gentian	Gentianella campestris	Other	-	27% emergence when seeded at 2mm deep (almost surface seeding). The seeds used in this experiment were collected in the wild. Seeds from domesticated cultivars are likely to have higher germination rate.	(Milberg, 1994)
Lacy phacelia	Phacelia tanacetifolia	Other	+	Based on the experience of one agronomist.	(Appendix 7.3)
Winterfat	Krascheninnikovia lanata	Other	++	The study has tested the surface germination capability of both bare seeds and seeds left in the fruit. 97% of the bare seeds have germinated and about 89% of the fruits containing one or several seeds have generated a seedling.	(Booth & Schuman, 1983)

7.6 Rooting

Supplementary Table 3: Explanation on scoring given for rooting.

Plant	**Latin name**	**Type**	**Score**	**Explanation**	**Source**
Akaroa cv. cocksfoot	Dactylis glomerata	Grass	-	The literature highlights limited rooting capabilities compared to the other plants.	(Campbell, 1968)
Harding grass	Phalaris aquatica	Grass	+/-	It scored average in the article. It was in between Perennial ryegrass and Lucerne.	(Campbell, 1992)
Orchardgrass	Dactylis glomerata	Grass	++	It has the highest score in the paper and does a lot better than white and red clover	(Brooke & Holl, 1988)
Perennial ryegrass	Lolium perenne	Grass	++	Best in (Campbell & Swain, 1973) and (Campbell, 1992) and second best in (Campbell, 1968)	(Campbell, 1968) (Campbell, 1992) (Campbell & Swain, 1973)
Phalaris	Phalaris tuberosa	Grass	+/-	It scores average in both sources.	(Campbell & Swain, 1973) (Campbell, 1968)
Timothy	Phleum pratense	Grass	+	It established well compared to the other plants, had a high score	(Brooke & Holl, 1988)
Sorghum vidan	Sorghum bicolor x Sorghum sudanense	Grass	+/-	The plant is able to root well, but is really dependent on the condition. In Sandy loam it is able to root well. In Sandy conditions, it can't root that well.	(Kislev et al., 1979)
Durum Wheat	Triticum durum	Grass	+	This plant roots well in both sandy and sandy loam conditions.	(Kislev et al., 1979)
Alsike clover	Trifolium hybridium	Legume	+	This plant has the second highest rooting capability according to the source and roots better than white clover.	(Brooke & Holl, 1988)
Alfalfa	Medicago sativa	Legume	--	In both articles it has the lowest rooting. It doesn't look good at all.	(Campbell, 1992) (Campbell & Swain, 1973)

Bitter vetch	Vicia ervilia	Legume	--	Wasn't able to penetrate root according to the article.	(Kislev et al., 1979)
Lentil	Lens culinaris, ssp. Microsperma	Legume	--	Wasn't able to penetrate the root into the soil.	(Kislev et al., 1979)
Lotus	Lotus pedunculatus Var. 'Grasslands Turoa'	Legume	--	It has the lowest penetrating root into the soil in the published source.	(Charlton, 1977)
Prairy milkvetch	Astragalus Adsurgens	Legume	+/-	It is not that good in attaching to the soil as Mengnong Sainfoin.	(Mi et al., 2008)
Red clover	Trifolium pratense (var. Grasslands Turoa' (Charlton, 1977)) (var. Cowgrass (Campbell, 1968))	Legume	+	The 2 sources used different cultivars and obtained different results. The cultivar will play a role in obtaining a successful catch crop.	(Charlton, 1977) (Campbell, 1968)
Mengnong Sainfoin	Onobrychis viciifolia var. Mengnong	Legume	+	It can attach strongly to the soil surface and really fast with radicle	(Mi et al., 2008)
Subterranean clover	Trifolium subterraneum (var. Woogenellup (Campbell & Swain, 1973) & (Charlton, 1977)) (Var. Mt Barker for (Campbell & Swain, 1973))	Legume	+	In (Campbell, 1968), it scored the highest. In (Charlton, 1977) and (Campbell & Swain, 1973) it scored medium to high. The sources used different cultivars and obtained different results. The cultivar will play a role in obtaining a successful catch crop.	(Campbell, 1968) (Charlton, 1977) (Campbell & Swain, 1973)
White clover	Trifolium repens (var. Grasslands Huia (Charlton, 1977)) (var. 'New Zealand' (Campbell, 1968))	Legume	+/-	In (Campbell, 1968) and (Brooke & Holl,1988) it scored one of the lowest. In (Charlton, 1977) it scored one of the highest. The sources used different cultivars and obtained different results. The cultivar will play a role in obtaining a successful catch crop.	(Campbell, 1968) (Brooke & Holl, 1988) (Charlton, 1977)

Winterfat	Krascheninnikovia lanata	Other	+/-	The study has tested the rooting capability of both bare seeds and seeds left in the fruit. Only 16% of the bare seeds have entered their radicle in the soils while 79% of the fruits containing one or several seeds have generated a seedling that rooted into the soil. It is clear that seed-preparation and/or seedling-environment matters for a successful rooting of Winterfat.	(Booth & Schuman, 1983)

7.7 Shade tolerance

Supplementary Table 4: Explanation on scoring given for shade tolerance

Plant	Latin name	Type	Score	Explanation	Source
Fodder radish	Raphanus sativus var. oleiformis	Brassicaceae	+/-	Scores "good" regarding shade tolerance when grown in Iowa, US, but grow better with at least 6 hours of sun.	(*USDA et al.*, 2024a)
Forage radish	Raphanus sativus L.	Brassicaceae	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Leaf cabbage	Brassica oleracea	Brassicaceae	-	According to the source: leaf cabbage starts growing when there is sunlight. It requires 6-8 hours of daily sunlight.	(Appendix 7.2)
Radish	Raphanus sativus	Brassicaceae	+/-	Scores "good" regarding shade tolerance when grown in Iowa, US, but grow better with at least 6 hours of sun.	(*USDA et al.*, 2024a)
Rapeseed	Brassica napus	Brassicaceae	-	The results rated the shade tolerance of Rapeseed + on scale from + to ++++.	(Bloksma & Jansonius, 2001)
Turnip	Brassica rapa var. rapa	Brassicaceae	-	The results rated the shade tolerance of turnip + on scale from + to ++++.	(Bloksma & Jansonius, 2001)
White mustard	Sinapis alba	Brassicaceae	-	The results rated the shade tolerance of White Mustard + on scale from + to ++++.	(Bloksma & Jansonius, 2001)
Woad	Isatis tinctoria	Brassicaceae	+/-	Woad can grow in semi-shade (woodland) or in full sun areas.	(*Zouhar, 2009*)
Bahiagrass	Paspalum notatum	Grass	-	The article said: "In the first year, percent of ground cover for Tifway, bahiagrass, and Q-2 generally decreased with decreased light intensity" and "In general, bahiagrass was entirely unsatisfactory under the conditions of	(McBee & Holt, 1966)

				this shade experiment." Conditions were 100%, 60% and 33% light.	
Barley	Hordeum vulgare L.	Grass	+/-	The results showed that current commercialized barley cultivars had sufficient plasticity for adaptation to shade conditions. Cover cropping in British Columbia. 2 on a scale from 1 to 5.	(Arenas-Corraliza et al., 2019) (Government of British Columbia, 2024)
Bermuda grass	Cynodon dactylon	Grass	-	The results rated the shade tolerance of Bermuda grass 3.8 on a scale from 1 to 9.	(Tegg & Lane, 2004)
Bristle oat	Avena strigosa	Grass	-	Handles drought conditions, but is not highly shade tolerant.	(Dial, 2014)
Chewing's fescue	Festuca rubra subsp. commutata	Grass	+	"Highly shade tolerant".	(Silver Falls Seed, 2024)
Italian ryegrass	Lolium multiflorum	Grass	++	The results show no effect on the biomass when grown in a 50% shaded condition. Cover cropping in British Columbia. 4 on a scale from 1 to 5. A USA-based agronomist shared the same knowledge.	(Tramacere et al., 2022) (Government of British Columbia, 2024) (Appendix 7.4)
Kentucky bluegrass	Poa pratensis	Grass	-	Kentucky bluegrass was found to be shade intolerant, in 30, 50 or 70% artificially shaded conditions. Shadecloth was used to simulate stadium 'shade stress'.	(Tegg & Lane, 2004)

Perennial ryegrass	Lolium perenne	Grass	+/-	80% shade condition reduced herbage productivity on average by 50%, but results showed feasibility to manage white clover/ryegrass mixture under low to moderate shade in Western Europe.	(Ehret et al., 2015)
Rye	Secale cereale	Grass	+	Cover cropping in British Columbia. 4 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Sudan grass	Sorghum drummondii	Grass	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Supina bluegrass	Poa supina	Grass	+	Supina bluegrass was shown to grow well (quality rating) in 65% shaded condition, score 6.8 on scale from 1 to 9.	(Tegg & Lane, 2004)
Tall fescue	Festuca arundinacea	Grass	+	Tall fescue was shown to grow well (quality rating) in 65% shaded condition, score 6.5 on scale from 1 to 9.	(Tegg & Lane, 2004)
Timothy	Phleum pratense	Grass	+/-	Harvey's Seed Company. 2.5 on a scale from 1 to 5. Based on North America.	(Harvey's seed, z.d.)
Triticale	Blend of Triticum (wheat) and Secale (rye)	Grass	+	Scores "good" regarding shade tolerance when grown in Iowa, US. Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(USDA et al., 2024b) (Government of British Columbia, 2024)
Common wheat	Triticum aestivum	Grass	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Alfalfa	Medicago sativa	Legume	-	Considered a species with high light demand. This research showed a delayed and shortened flowering time, lower quality of flowers and fruits. Reproduction was lowered to cope with shade (56.4% and 78.7%). Potential to	(Qin et al., 2022)

				breed a shade-tolerant cultivar (because of maintenance aboveground biomass).	
Alsike clover	Trifolium hybridum	Legume	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Berseem clover	Trifolium alexandrinum	Legume	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Birdsfoot trefoil	Lotus corniculatus	Legume	-	Factsheets state Birdsfoot trefoil is shade intolerant.	(Döring & Howlett, 2013) (Rhykerd et al, z.d.)
Black medic	Medicago lupulina	Legume	+	The results rated the shade tolerance of black medic +++ on scale from + to ++++.	(Bloksma & Jansonius, 2001)
Crimson clover	Trifolium incarnatum	Legume	+	Cover cropping in British Columbia. 4 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Egyptian clover	Trifolium alexandrinum	Legume	+/-	The results rated the shade tolerance of Egyptian clover ++ on scale from + to ++++.	(Bloksma & Jansonius, 2001)
Hairy vetch	Vicia villosa	Legume	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Pea	P. sativum subsp. arvense	Legume	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Red clover	Trifolium pratense	Legume	+	Cover cropping in British Columbia. 4 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Subterranean clover	Trifolium subterraneum	Legume	+	Cover cropping in British Columbia. 4 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Sweet clover	Melilotus officinalis	Legume	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)
White clover	Trifolium repens	Legume	+	80% shade condition reduced herbage productivity on average by 50%, but results showed feasibility to manage	(Ehret et al., 2015)

				white clover/ryegrass mixture under low to moderate shade in Western Europe. Cover cropping in British Columbia. 4 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Buckwheat	Fagopyrum esculentum	Other	-	Cover cropping in British Columbia. 2 on a scale from 1 to 5.	(Government of British Columbia, 2024)
Chicory	Cichorium intybus	Other	+	Reported to be shade tolerant and grows well under tree cover in intercropping systems.	(Sytar et al., 2019)
Field gentian	Gentianella campestris	Other	+/-	Reported to grow in full sun or partial shade (i.e. wild grassland).	(*Walker, 2015*)
Lacy phacelia	Phacelia tanacetifolia	Other	+/-	Cover cropping in British Columbia. 3 on a scale from 1 to 5.	(Government of British Columbia, 2024)

7.8 Machinery traffic

Supplementary Table 5: Explanation on scoring given for machinery traffic.

Plant	**Latin name**	**Type**	**Score**	**Explanation**	**Source**
Fodder radish	Raphanus sativus var. oleiformis	Brassicaceae	+/-	Based on the experience of one agronomist.	(Appendix 7.3)
Leaf cabbage	Brassica oleracea	Brassicaceae	+/-	After harvest the leaf cabbage was destroyed in the places where the tractors and combines drove, but it was able to fully cover the field again after harvest. So, it is possible to conclude that it is not resilient to machinery traffic (--), but it is able to cover the field again. (+)	(Appendix 7.2)
Rapeseed	Brassica napus	Brassicaceae	--	From Supplementary Table 6.	(Petersen, 2018)
Turnip	Brassica rapa subsp. rapa	Brassicaceae	+	Based on the experience of one agronomist.	(Appendix 7.3)
White mustard	Sinapis alba	Brassicaceae	+/-	Based on the experience of one agronomist.	(Appendix 7.3)
Woad	Isatis tinctoria	Brassicaceae	-	From Supplementary Table 6.	(Petersen, 2018)
Bahiagrass	Paspalum notatum	Grass	++	The paper states that "Retain leaves near the soil under most conditions. Bahiagrass has short rhizomes and thick stolons, making it well suited for close grazing. Dallisgrass sometimes has short rhizomes, so most energy is in the stem base". Bahiagrass handles grazing quite well and some energy is stored in the roots. Thus, it is possible that it resists machinery traffic quite well.	(Green, 2000)
Bermuda grass	Cynodon dactylon	Grass	++	From the article the following was said: "Well adapted to close grazing as it can produce leaves within ½ inch of the soil surface. Stores large energy reserves in stolons and rhizomes".	(Green, 2000)

				Bermuda grass handles grazing quite well and some energy is stored in the roots. Thus, it is possible that it resists machinery traffic quite well.	
Bristle oat	Avena strigosa	Grass	+	Based on the experience of one agronomist.	(Appendix 7.3)
Crabgrass	Digitaria	Grass	+	From the article the following was said: "Highly variable species. Some types are very prostrate, with stems that lodge onto the soil and root at the nodes. Generally, retains significant leaf area after grazing". Thus, it was concluded that it was tolerant to grazing and maybe also to machinery traffic.	(Green, 2000)
Dallisgrass	Paspalum dilatatum	Grass	++	From the article the following was said: "Retain leaves near the soil under most conditions. Bahiagrass has short rhizomes and thick stolons, making it well suited for close grazing. Dallisgrass sometimes has short rhizomes, so most energy is in the stem base". Dallisgrass handles grazing quite well and some energy is stored in the roots. Thus, it is possible that it resists machinery traffic quite well.	(Green, 2000)
Gamagrass	Tripsacum dactyloides	Grass	+/-	From the article following was said that switchgrass and gamagrass: These grasses store energy in stem base, but also in the upper root (short rhizomes) system----when grazed in the vegetative to preboot stage they remain leafy and tiller more profusely". It is likely that these grasses aren't able to regrow that well.	(Green, 2000)
Italian ryegrass	Lolium multiflorum	Grass	++	From Supplementary Table 6.	(Petersen, 2018)
Kentucky bluegrass	Poa pratensis	Grass	+	From the article the following was said: "Extremely leafy near the soil surface under grazing. Has short rhizomes that store energy, in addition to energy stored in the lower stem base". From this it was concluded that it can handle grazing well. It was also concluded that it stores some energy in the roots.	(Green, 2000)

Orchardgrass	Dactylis glomerata	Grass	+/-	The article mentioned that orchardgrass is "largely dependent upon reserves stored in stem bases, most varieties cannot tolerate frequent grazings.". Orchardgrass is unlikely to recover well after machinery damage, which likely removes all above-ground parts.	(Green, 2000)
Pearl millet	Pennisetum glaucum or Cenchrus americanus	Grass	-	The article mentioned that Pearl millet is "largely dependent upon reserves stored in stem bases, most varieties cannot tolerate frequent grazings.". Pearl millet is unlikely to recover well after machinery damage, which likely removes all above-ground parts.	(Green, 2000)
Perennial ryegrass	Lolium perenne	Grass	+/-	From Supplementary Table 6. The cultivar seems to have an impact on the results. Perennial ryegrass T1 was slightly affected by the machinery traffic but T8 suffered substantially.	(Petersen, 2018)
Rescuegrass	Bromus catharticus	Grass	-	The paper stated that: "stores energy in stem base, and its regrowth is rapid when 3-4 inches of stubble remain after grazing or harvesting. It is a leafy grass, but fairly “upright” with not many prostrate leaves near the soil surface". Because there are not many prostrate leaves, severe damages are likely to happen faster. Due to a lack of reserve energy in the roots it is less likely to regrow again after machinery traffic.	(Green, 2000)
Sudan grass	Sorghum drummondii	Grass	-	The article mentioned that Sudan grass is "largely dependent upon reserves stored in stem bases—most varieties cannot tolerate close (<3'') frequent grazings." Sudan grass is unlikely to recover well after machinery damage, which likely removes all above-ground parts.	(Green, 2000)
Switchgrass	Panicum virgatum	Grass	+/-	From the article following was said that switchgrass and gamagrass: These grasses store energy in stem base, but also in the upper root (short rhizomes) system----when grazed in the vegetative to preboot stage they remain leafy and tiller more	(Green, 2000)

				profusely". It is likely that these grasses aren't able to regrow that well, thus +/-.	
Tall fescue	Festuca arundinacea	Grass	+/-	From the article the following was said: "Under grazing, it can produce leaves within 1–2 inches of the soil surface. Endophyte-infected varieties tolerate close, frequent grazing; endophyte-free varieties are less tolerant and should be managed like orchardgrass". Because it is not exactly clear if every type of tall fescue can tolerate grazing, the score is +/-.	(Green, 2000)
Timothy	Phleum pratense	Grass	++	From Supplementary Table 6.	(Petersen, 2018)
Alfalfa	Medicago sativa	Legume	+/-	According to the first source: "new growth following harvest primary comes from crown buds and axillary buds, but depends on the energy from tap root. Does not tolerate frequent grazing except many green leaves left after grazing". From this it is likely that alfalfa is not able to regrow that well. According to the second source, its resistance to machinery traffic is moderate (see Supplementary Table 6 for details).	(Green, 2000) (Peterson, 2018)
Common kidney vetch	Anthyllis vulneraria	Legume	+	From Supplementary Table 6.	(Petersen, 2018)
Blue lupin	Lupinus angustifolius	Legume	--	Based on the experience of one agronomist.	(Appendix 7.3)
Crimson clover	Trifolium incarnatum	Legume	+/-	Based on the experience of one agronomist.	(Appendix 7.3)
Hairy vetch	Vicia villosa	Legume	-	From Supplementary Table 6.	(Petersen, 2018)
Pea	Pisum sativum	Legume	--	Based on the experience of one agronomist.	(Appendix 7.3)
Persian clover	Trifolium resupinatum	Legume	+/-	According to the source: The cultivar seems to have an impact on the results. Persian clover T3 wasn't much affected by the machinery traffic but T2 suffered substantially (see Supplementary Table 6 for details).	(Petersen, 2018)

Red clover	Trifolium pratense	Legume	+	According to the first source: "relative to alfalfa, but leaf area close to soil surface. So, more tolerance than alfalfa". According to the second source: red clover had moderate tolerance to the machinery traffic (see Supplementary Table 6 for details).	(Green, 2000) (Petersen, 2018)
Hop clover	Trifolium campestre	Legume	-	From Supplementary Table 6.	(Petersen, 2018)
Vetch	Vicia sativa	Legume	+/-	From Supplementary Table 6.	(Petersen, 2018)
White clover	Trifolium repens	Legume	++	According to the first source: "Stolon tap root provide larger reserve energy. It often thrives under frequent and close grazing, because light penetration to the stolons is so important to survival of developing buds". According to the second source: white clover is moderately tolerant to machinery traffic, the fast regrowth ability can compensate this (see Supplementary Table 6 for details).	(Green, 2000) (Petersen, 2018)
Buckwheat	Fagopyrum esculentum	Other	-	Based on the experience of one agronomist.	(Appendix 7.3)
Chicory	Cichorium intybus	Other	+	From Supplementary Table 6.	(Petersen, 2018)
Lacy phacelia	Phacelia tanacetifolia	Other	-	Based on the experience of one agronomist.	(Appendix 7.3)
Field gentian	Gentianella campestris	Other	++	From the article the following was said over Field gentian: "The strongest response was obtained after clipping on 1 July and the weakest after clipping on 2 August, thus showing a modal variation. Branch production was over compensatory for all clipping occasions". Thus it is concluded that it can tolerate machinery traffic quite well and might grow even more (++).	(Lennartsson et al., 1998)
Plantago	Plantago major	Other	+	From Supplementary Table 6.	(Petersen, 2018)

Supplementary Table 6: The ability of undersown catch crops to tolerate mechanical damage during the harvesting process of the cash crop. Tolerance is measured in November as the ratio of survived plants in plots overrun with heavy harvester to the number of plants in plots without this overrun (Petersen, 2018).

Low tolerance	Medium tolerance	High tolerance	Improved growth
Woad	Perennial ryegrass T1	Persian clover T3	Italian ryegrass
Hairy vetch	Alfalfa	Common kidney vetch	Timothy
Hop clover	Red clover	Chicory	
Rapeseed	White clover	Plantago	
Perennial ryegrass T8		Orchard grass	
Persian Clover T2			