An investigation of pea and cereal varieties for organic intercropping in Sweden

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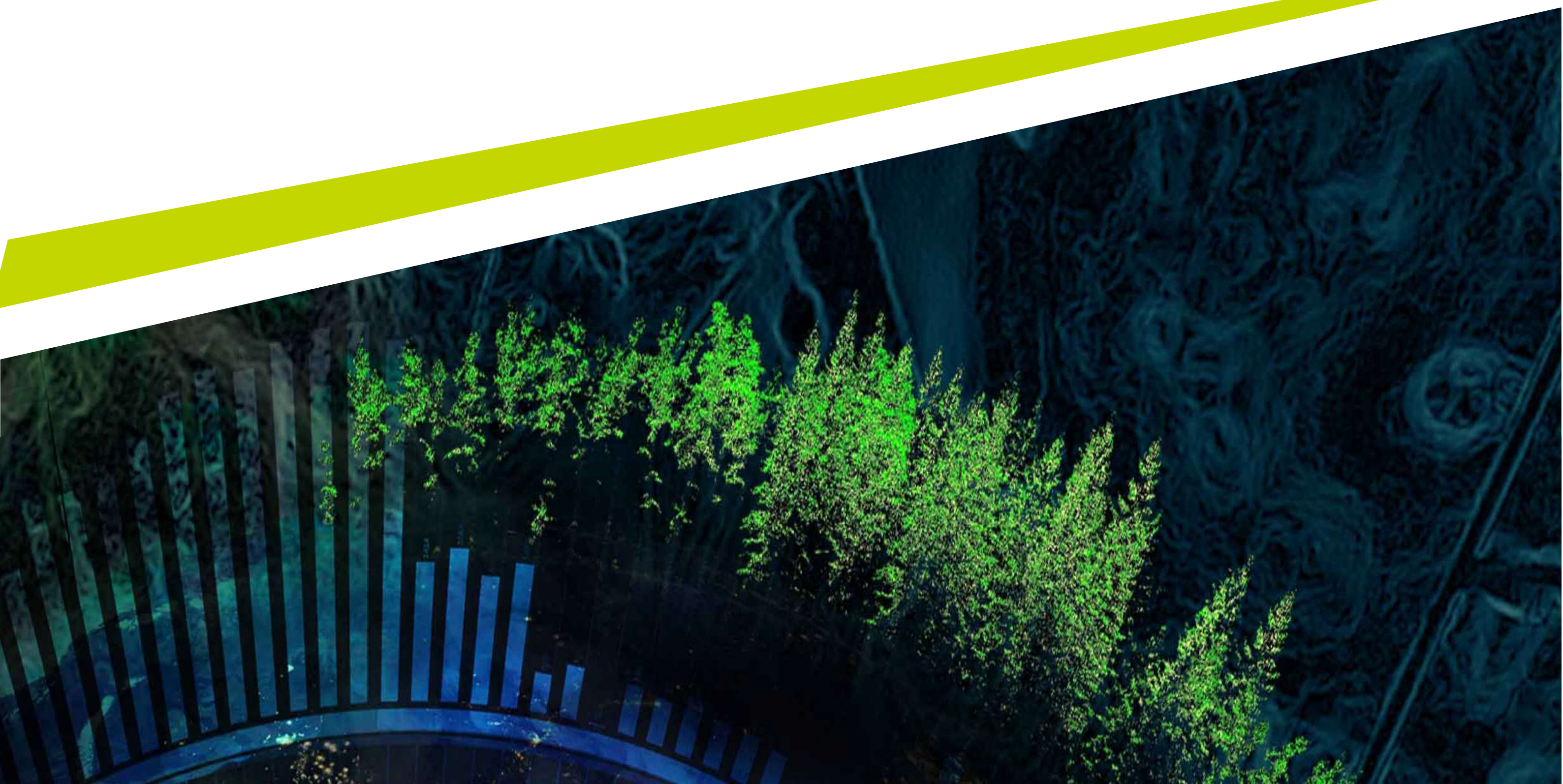

An investigation of pea and cereal varieties for organic intercropping in Sweden

Undersökning av ärt- och spannmålssorter för ekologisk samodling i Sverige

Matilda Wilson

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Abstract

Organic farming, intercropping and the conservation of landraces are agroecological methods of transitioning to a more sustainable and resilient agricultural system, however there is a lack of data on varieties suitable for organic intercropping. Therefore, two spatially parallel field trials were conducted with 11 pea varieties intercropped with oat, and 38 varieties of cereals (wheat, oat, and barley), in sole crops. The trials were conducted at the Swedish University of Agricultural Sciences (SLU), Alnarp, in the south of Sweden. Length and maturity times of the intercropping trials were measured and analysed at regular time intervals for around 15 weeks, for the cereals the same was done with height and maturity times. Grain yield was also recorded for the cereal trial. This was done to assist variety selections for an upcoming intercropping trial that will be conducted at a similar location in the years 2025-2026. The results showed a variation in height, length, and maturity times across the varieties, which in many cases overlapped or were similar to each other, offering a possibility to select combinations for further trials. The cereal yield differed between varieties, with Gutekorn (an old variety that had completely lodged by harvest) yielding the lowest at 1250kg per hectare and Esperanza and Saludo (modern organic varieties) yielding the highest at 4000kg per hectare. The results are discussed with reference to agroecological knowledge and development, with emphasis on the importance of farmer participation when selecting and developing varieties for organic intercropping systems. In conclusion, the varieties collection of both peas and cereals included a range of diversity for the assessed traits, offering opportunities for selecting good material for further organic intercropping trials.

Keywords: Intercropping, agroecology, organic, peas, cereals, heritage grains

Foreword

Although I go by the name 'Matti' to friends and colleagues, my full name is Agnes Elise Matilda Wilson. When the dentist calls for 'Agnes' in the waiting room I continue to read my book without looking up for a few minutes, until he repeats the name a few times and I realise, oh yes, he is talking to me. My full name is not something I identify with. I identify as Matti. I also identify as someone who spent her summers deep in the forests of Värmland, enchanted by the endless pine trees and the feeling of never knowing what was around the corner. This is why when I moved to Skåne to do a masters in Agroecology, I found it quite difficult to adjust to the open views and endless farm fields. To escape, I drove with my partner and son to Höör, to the nature reserve there. We stopped at a farmers shop to buy some honey. The farm was called 'Fulltofta gård'. I recognised that name. I remembered that my grandmother had spoken about her grandmother, who I was named after - in my long and unused name that I don't identify with - whose nickname was 'the party cook at Fulltofta'. Could it be the same one? Curious, we decided to continue walking around the area instead of carrying on to the nature reserve. There was a church with a graveyard, and when we walked around the graveyard, we found the grave of Elise Månsson, 1875-1962, born in Eslöv and died in Hörby. My great, great grandmother. After all this time I thought I came from the forest, but really, I came from the fields. After all this time, I thought Agnes Elise Matilda had nothing to do with Matti, but really, coming here to study Agroecology, has been coming back to a part of my identity that I didn't realize I had. Enthralled by this realisation I spoke to my grandparents more about their history. Not only this peculiar coincidence, but my grandfather had also studied agriculture in Skåne, and worked at Svalöf, before they moved to their farm in Värmland. Just like how agroecology promotes the discovery and preservation of lost traditional knowledge, studying agroecology for me has been like discovering and preserving lost and special parts of myself, my past, and my future.

Acknowledgements

I would like to thank my supervisor Dylan for painstakingly teaching me to think like a researcher and allowing me to enter his world of imagination and fascination when it comes to faba beans and peas. Before meeting him, I had no idea how interesting they could be. I would also like to thank the seed companies Agrologica, Cultivari, Dottenfelder Hof, SW seed and Lantmännen, along with some farmers, for donating seeds to the project, and of course the generations of farmers who have meticulously saved their seeds and left us with a bounty of varieties to choose from. Thankyou also to the summer interns and my friends Rebecca and Samuel for their hard work in the field, and to Johannes Albertsson for his generous proof reading.

I would like to thank my friends Sitha, Erica and Silke for supporting me on my journey as a student, a mother, and a newcomer. I hope to always know you.

I would like to thank my incredible partner Victor, for joining me on this journey, supporting me in every way and being the best father to our son anyone could ask for. I love you.

Finally, I would like to thank my son Frej, for showing me how joyful, precious and meaningful every day of life can be.

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Abbreviations

SLU	Swedish University of Agricultural Sciences
DAS	Days After Sowing
FAO	Food and Agriculture Organisation
LER	Land Equivalent Ratio
MSc	Master of Sciences
EPB	Evolutionary Plant Breeding
PVS	Participatory Variety Selection
N	Nitrogen
Nr	Reactive Nitrogen

1. Introduction

1.1 Problem statement

Conventional agriculture is a significant driver of a plethora of environmental problems such as climate change, biodiversity loss, soil erosion, and pollution of waterways (Gliessman, 2015). As Gliessman (2015) explains, the use of external inputs such as synthetic fertilizers and pesticides make conventional farming unsustainable in the long run and (p3), "sacrifices the very foundation of agriculture". This is because these inputs result in soil degradation through causing nutrient imbalances and microbial disturbances, rely on fossil fuel usage which drives climate change and so threatens agriculture, and harm biodiversity which is crucial for ecosystem services that are important for agricultural systems, amongst other things. As has been recognised through the UN's sustainable development goals (UN General Assembly, 2015), there is an acute need for a transition to more sustainable agricultural practices. The Swedish government also recognises this need, in 2021 their target was for 30% of farming to be organic in Sweden by 2030 Pia and Röös (2021). On the other hand, in Sweden there are calls for more food to be produced closer to home to achieve a greater level of self-sufficiency (Berg, 2022), suggesting a need for Swedish agriculture to further intensify and expand. There are numerous barriers to expanding organic agriculture and one of them is a lack of varieties adapted to organic conditions (Wolfe et al., 2008). Breeding specifically for organic agriculture has received little attention and Wolfe et al (2008) argue a need for different approaches to plant breeding to improve organic farming systems, including farmer participation and the use of crops buffered by variety mixtures or populations, as is often the case for landraces (Camacho Villa et al, 2005).

According to FAO (2001), it is estimated that 75% of the genetic diversity of crop plants was lost in the last century. This degradation of agrobiodiversity is because our food, fibre and feed come from a small selection of crops, through the tendency to farm a smaller and smaller range of varieties as time goes on (Gliessman, 2015). This is a problem because diverse plant genetic material is important for adapting agriculture to conditions such as climate change (Andersen, 2012), because plant breeders can use diverse genetic material as a resource for developing new crop varieties which are better equipped to withstand challenges posed by a changing climate. Gliessman (2015) believes much of our current crop's genetic basis for pest and disease resilience has been lost. In Turkey, some crop failures are perceived as a direct result of the extensive cultivation of a few modern varieties across a broad area (Bardsley and Thomas, 2005) this observation could perhaps be relevant in a Swedish context as well.

In countries which have shifted to modern agriculture such as Sweden, some farmers, particularly organic, choose to conserve and develop plant genetic diversity, often due to a need to adapt production to local environmental conditions and spread risks (Andersen, 2012). Modern varieties are bred for high input farming with increased yield levels (Newton et al, 2011) and the dominance of modern varieties deepens societies dependency on agriculture with high inputs, and these varieties are not always suitable for low-input or organic farming (Löschenberger et al, 2008, cited in Konvalina et al, 2013). Another problem with this dominance is that the loss of agrobiodiversity most likely has a knock-on effect on wild biodiversity (Jackson et al, 2005) in that it can disrupt ecological functions (such as pollination and pest control) in wild ecosystems (Duflot et al, 2022). As well as being important for biodiversity, Newton et al (2011) highlight that a diverse range of crops is nutritionally and culturally important, in the sense that crops can foster a more intimate connection between people, their history, and the food they eat. According to Newton et al (2011) the erosion of genetic diversity of crop plants results in a severe threat to the world's long term food security.

1.2 Previous research on this topic

As will be discussed in the background section of this thesis, there has been a myriad of studies investigating cereal landraces, different pea varieties, intercropping and legume-cereal intercropping in European contexts. Zeven (1998), Newton et al (2011) and Gerhardt et al (2018) found that cereal landraces display increased yield stability, Frankel et al (1995) found an increased ability to buffer against diseases and other stresses, and Newton et al (2011) also found that cereal landraces may have more developed root systems than modern cultivars. Relevant studies of peas found that they are beneficial for soil health, (Jensen et al, 2020), and that leafy peas are more competitive against weeds (Spies et al, 2011). Intercropping has also been extensively studied in Europe. It has been found that intercropping can supress weeds (Avola et al, 2008; Hauggaard – Nielsen et al, 2008; Gu et al, 2021), reduce disease instances (Hauggaard-Nielsen et al, 2008) and display higher yield stability (Stelling, 1997; Cupina et al, 2011). Jensen (1996) has emphasized that when intercropping cereals with legumes, the yield is higher than when they are grown organically in sole crops, and this has been confirmed by Zivanov et al (2018).

There have been several particularly relevant studies in the Scandinavian context. Multiple studies have delved into the performance of oat-pea and cereal-legume intercrops (James Ajal, 2021; Munz et al, 2023). Vanhala et al (2016) explored the adaptation of Swedish pea landraces to local conditions, including varieties that are used in this master's thesis study, and Jensen et al (2015) demonstrated the benefits of intercropping grain legumes and cereals for total grain yields under organic conditions. However, there is a noticeable gap in the literature regarding the potential benefits and challenges associated with incorporating old varieties and landraces into organic intercropping systems. In addition, Wolfe et al (2008) highlights that there has been little research done on developing varieties better adapted to organic farming systems. Munz et al's (2023) study primarily employed modern varieties, overlooking the potential advantages that older varieties may offer in terms of resilience and adaptability. While James Ajal (2021) shed light on the phenotypic plasticity influenced by intercropping, cultivar identity and environmental conditions, it did not specifically address the characteristics of landraces.

Rebecca Öhnfeldt's master's thesis (2021) provided valuable insights into perspectives of Swedish farmers using heritage plant varieties. Ortman et al (2023) investigated Swedish farmers motivations for landrace cereal cultivation in Sweden and found that the main motivations were that cultivating landraces fitted with farmers ideals on sustainable farming, and such farmers felt that there is a lack of modern varieties suited for sustainable and multifunctional farming systems. Öhnfeldt's and Ortman et al's studies revealed motivations of farmers but the direct implications of integrating heritage varieties into organic intercropping systems remain unexplored. Vanhala et al (2016) did not explicitly investigate the potential advantages of utilizing landraces in organic intercropping systems, and Jensen et al (2015) did not consider the utilization of old varieties and landraces within intercropping systems. In summary, while existing literature provides insight into intercropping and heritage plant varieties separately, there is a notable knowledge gap regarding the integration of heritage pea and cereal varieties into organic intercropping systems.

1.3 Aim and research questions

This project will investigate different pea and cereal (wheat oat and barley) varieties and explore if they display a variation of key traits of relevance for organic intercropping, as well as investigating their relevance for farmers. If successful, the project will reveal data and information that contributes to the possible wider adoption and development of varieties better suited to organic farming and organic intercropping. This study was conducted to contribute to developing possible solutions to the problems mentioned in section 1.1 and to address the knowledge gap mentioned in section 1.2. Furthermore, it aims to work with methods and varieties that fulfil the agroecological aims of developing ecologically and socially sustainable farming practices which require fewer external inputs, and rediscovering traditional varieties that reflect locally specific stories of food and farming. More specifically, the aim of this project is to assess traits relevant for cereal and pea intercropping, grown under organic conditions. To investigate if there are variations of traits of relevance for organic intercropping within the varieties in this study, one must consider what traits are of relevance for organic intercropping. There are many traits that may be useful, such as high straw/biomass yield and efficient nitrogen uptake (Konvalina et al, 2013). Maturity time may be an important factor in that for intercropping, it is possible that the maturity time of two crops should not differ too much for ease and success of harvesting. Height and length of the crops may be significant as these could also be relevant factors in intercrop design but may also reveal insights into competitiveness or drought tolerance. Based on this, the following research questions were identified:

1. What are the maturity times for biomass and grain harvest among the cereal and pea varieties?
2. What is the variation in lodging resistance between the cereal varieties?
3. What are the differences in height (cereal) and length (pea) development between the different varieties?
4. How do the cereal varieties differentiate in yield under organic growing conditions?

It was chosen to measure length for peas, as the pea varieties in this study are prone to lodging, and therefore measuring height would provide an inaccurate representation of their development. Measuring length gives a better representation of potential biomass yield and competitiveness, despite them lodging without proper support. Height was chosen for the cereals as they are less prone to lodging and so height is a good representation of how they would behave in different cropping systems. This study was done to assist variety selections for an upcoming research project about intercropping that will be conducted at the Swedish University of Agricultural Science (SLU), campus Alnarp in the years 2025-2026.

2. Background

2.1 Agroecology

Agroecology provides the theoretical framework for this research project, as such the results will be analysed and discussed in terms of how they relate to agroecological knowledge and development. Agroecology is a science, a movement, and a practice (Wezel et al, 2009) that responds to the current agricultural crisis by providing a model of agriculture that is sustainable - environmentally, socially, and economically. In a world where the dominant narrative is emphasis on the yield-increasing practices and approaches of industrial agriculture (Conway, 2012), agroecology provides an alternative route, focused on redesigning agroecosystems on a new set of ecological principles (Gliessman, 2015), celebrating traditional knowledge, systems thinking and low input diverse agroecosystems. Core agroecological practices include social aspects such as protecting the rights of farmers to land and food sovereignty, and biological aspects such as intercropping, nutrient cycling and pest control through encouraging natural enemies. Around the world it has become a tool in the contestation, defence, and transformation of contested rural spaces that have been lost to land grabs (Rosset and Martinez-Torres, 2011).

Agroecology deals with the loss of agrobiodiversity, in that increasing diversity in agroecosystems, both through increasing the number of different crops and through consciously selecting the varieties of crops, is a core agroecological principle. Ecological interactions in an agroecosystem are largely a function of its diversity, and these interactions are the foundation of a sustainable agroecosystem (Gliessman, 2015). There are multiple advantages of diversity in all aspects of agricultural production (Wolfe et al, 2008). Increased diversity in an agroecosystem can provide increased stability and resilience in the face of natural perturbations, less diseases, reduced need for pest control and better soil fertility (Hauggaard-Nielsen et al, 2008, Gliessman, 2015). Agroecology also promotes organic farming, in that synthetic agro chemicals such as insecticides, herbicides and artificial fertiliser are almost always rejected in agroecological farming systems. Altieri

(2015) argues that diversifying agroecosystems and organic soil management are key factors determining the severity of climate change impacts on food production.

2.2 Agriculture in Sweden

Sweden has a rich agricultural history and about 7% of Swedish land is used for farming (The World Bank, 2023). Given that the average farm size in 2022 was almost 50 hectares (European commission, 2022) and that in the year 2021 only 20% of the land was certified organic (Svensson, 2022) we know that most of the agriculture in Sweden is conventional and industrial. Farms in Sweden have not always been so large, but there has recently been a tendency for small farms to be combined into larger land plots (Jordbruksverket, date unknown) which is unsurprising considering in Sweden a farm must be 4 hectares minimum to be eligible for subsidies from the European Union Common Agricultural Policy (Jordbruksverket, 2023). However, the awareness of a need for agricultural change has grown in Sweden. The importance of ecological and social services provided by agroecological agriculture are becoming widely recognised (Holt-Giménez and Altieri, 2013) and large increases in organic farm area are expected in Sweden (Pekala, 2020). The Federation of Swedish Farmers (Lantbrukarnas Riksförbund, 2023) see that it would be beneficial to increase the amount of food grown in Sweden, something that the Swedish government of 2017 agreed with, given that they presented a strategy which puts forward that Swedish agricultural production should increase (Government Offices of Sweden, 2017).

2.3 Varieties for organic farming

Organic farming refers to farming where no synthetic chemicals are used. Conventional farming is characterised by the use of external inputs, such as synthetic fertilizers, herbicides, pesticides and fungicides. In general, commonly grown crops have been selected for traits over thousands of years, such as high yield, good taste, ease of harvest etc, but more recently, in conventional farming, crops have been selected for fast response to synthetic fertilizer, water application and genetic uniformity (Gliessman, 2015). These varieties require external inputs of inorganic agrochemicals to perform as required (Gliessman, 2015). In the EU, all varieties must pass the Distinctiveness, Uniformity and Stability (DUS) system of evaluation trials before they are accepted for commercial cultivation (Newton et al, 2011), which can be advantageous in conventional farming where predictability is more important than resistance to pests and diseases, however, these varieties may not always be suited to organic farming.

In organic farming, crops have fewer options for immediate alleviation of abiotic and biotic stress, and so it is important for varieties to be adapted to varied environmental conditions (Wolfe et al., 2008). Genetically diverse populations may be beneficial, as this allows for compensation and complementation (Wolfe et al., 2008) for example, different genotypes within a population may respond differently to changing conditions (such as soil moisture), meaning if some are adversely affected, others may not be, and so productivity can be maintained. Crop varieties in organic farms should be vigorous and competitive as to out-compete weeds and should be more able to withstand pest and diseases than crops in a conventional system. Wolfe et al (2008) argue that the performance of organic farming is limited by a lack of varieties adapted to organic conditions. Wolfe et al (2008) also found that there has been little research done on developing varieties better adapted to organic farming systems and highlighted that breeding for organic agriculture is usually centralised and non-participatory, undermining food sovereignty. They argue that it would be helpful to decentralise breeding, include farmer participation, and consider plant breeding in the context of farm system management. Therefore, to increase the success of organic farming, it is necessary to research the relevant varieties for organic production systems. Indeed, Hauggaard-Nielsen et al., (2008) highlight that when working in an organic cropping system, it is not appropriate to continue with the general knowledge gathered under conventional growing conditions.

2.3.1 Old varieties and landraces

Most varieties used in this study are old varieties or landraces. Landraces were included because landraces originating from a low-input agricultural period, may be a good alternative to organic (modern) varieties, in organic farming (Serpolay et al., 2011 cited in Konvalina., 2013). This is because varieties that originate from a low-input agricultural period are likely to be adapted to low-input agricultural conditions (organic farming is considered low-input). As such, it is possible that crops existing prior to formal plant breeding such as landraces may contain traits that make them suitable for organic farming (in particular, organic intercropping). Camacho Villa et al (2005) proposed the following definition of a landrace: a dynamic population of a cultivated plant that has historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems (in Newton et al, 2011). Landraces are usually heterogenous populations, which means they are genetically diverse; opposed to in a pure line variety where all the plants are almost identical (The Organic Research Centre, date unknown).

Advantages of landraces include increased stability, accomplished through generations of natural and deliberate selection for valuable genes for resistance to biotic and abiotic stresses and inter-genotypic competition and compensation (Newton et al, 2011). A genetically diverse population such as a landrace, has a disease buffering effect in reducing pathogen spread (Frankel et al., 1995), due to that whatever the varying biotic and abiotic stress for each plant, one or more genotypes within the population will yield satisfactorily (Zeven, 1998) in contrast to homogenous modern varieties. Because landraces and older varieties are often more resilient to pests, diseases and abiotic stresses, valuable sources for meeting the future needs of agriculture are lost as each landrace is replaced (Newton et al, 2011). Growing varieties that are less sensitive to abiotic and biotic stresses allows these crops to be grown with less external inputs, which in turn increases the environmental, social, and economic sustainability of the farm.

Since modern plant breeding started around the 1930's, many landraces have disappeared (Persson and Bothmer, 2002) however, farmers may retain landraces because they fill local socio-economic, cultural, and ecological niches that are not occupied by modern varieties (Tripp, 1996; Shand, 1997; Brush and Meng, 1998; Thrupp, 2000; cited in Bardsley and Thomas, 2005). Cultivating old varieties and landraces combats the degradation of genetic diversity. The 'European Plant Conservation Strategy' (Council of Europe, Planta Europe, 2002), 'Convention on Biological Diversity' (Convention on Biological Diversity, 1993) and the 'International Treaty on Plant Genetic Resources for Food and Agriculture' (FAO, 2001) all stress the need to improve the efficiency of techniques to conserve agricultural genetic resources, particularly those related to in situ conservation of endangered crops and crop wild relatives (Newton et al, 2011). Facilitating the use of landraces and old varieties allows farmers and consumers a greater amount of food sovereignty, in contrast to modern cultivars which are owned by agro-chemical seed companies that promote a system where farmers are dependent on buying seeds (and chemicals) regularly, dissolving the rights of farmers to save seeds and to farm independently, another paramount aspect of agroecology. Öhnfeldt (2019) found that Swedish farmers who choose to grow old varieties do so because of factors tied to their identities, memories, and sense of place. Her research shows that conserving old varieties is important for farmers themselves, not just for food production and the environment.

2.3.2 Cereal Landraces

Cereal landraces differ from modern cereal varieties in ways that may be valuable for organic farming and intercropping, which is why they have been included in this study. Gerhardt et al (2018) argue there is evidence that older cereal varieties can give more stable yields and are less sensitive to drought than modern varieties in an organic system. Wheat landraces have been shown to have more developed root systems than modern cultivars, which could explain drought tolerance, but also means landraces may be better at nutrient uptake than modern cultivars (Newton et al, 2011). Bardsley and Thomas (2005) found that Turkish wheat landraces offer protection against extreme agronomic conditions, due to the diversity they display. The Turkish wheat landrace Kirik was often favoured by farmers over modern varieties because it could be sown at more or less any time of the year and still yield satisfactorily. There are studies that suggest landraces and old varieties of wheat are more responsive to arbuscular mycorrhiza than modern wheat varieties, another trait valuable for organic farming. (Hetrick et al, 1992; Zhu et al, 2001 in Yngve 2020). Gerhardt et al (2018) recommend that more research be done on heritage cereal varieties. Several of the cereal accessions included in this study are landraces or mass selections from landraces and will be further presented in the material and methods section.

2.3.3 Legumes

Grain legumes are a major source of protein in human and animal nutrition and play a key role in crop rotations in most parts of the world. When grown in rotation with other crops, under certain environmental conditions, they can improve soil fertility and reduce the incidence of weeds, diseases, and pests (Mwanamwenge et al., 1998, cited in López-Bellido et al, 2005). Legumes are a particularly helpful crop in that they can biologically fix nitrogen from the atmosphere to the soil by symbiosis with Rhizobium bacteria and thereby reduce the reliance on synthetic fertilizers (Jensen et al, 2020). The dependence on synthetic fertilizers is a problem not just because of the use of fossil fuels to produce nitrogen (N) fertilizer, but also because the planetary boundary for terrestrial inputs of reactive nitrogen (Nr) have been transgressed, damaging terrestrial and aquatic ecosystems (Rockström et al., 2009). Increasing the production and consumption of grain legumes in Sweden can be an important aspect of transitioning to a more sustainable food system, however a lack of varieties adapted to varying conditions is a barrier to this (Röös et al., 2020). Röös et al (2020) found that it would be technically feasible to increase legume production in Sweden by about 40% if not more.

2.3.4 Peas (*Pisum satvium*)

There are two main categories of pea, field pea, grown for human consumption (either harvested immature and eaten fresh or harvested dry and rehydrated before consumption, most commonly as soup), and forage pea, peas grown for animal feed (Allen, 2013). Pea landraces have been cultivated on a large scale in Sweden until the 1950's (Osvald, 1959; Bingefors, 1986 cited in Vanhala et al., 2016) however today are only cultivated on a small scale as heirloom crops. Grey peas are often grown for animal feed but can also be used for human consumption. Peas, like other legumes, can be beneficial for soil fertility health and quality since they can biologically fix nitrogen from the atmosphere (Jensen et al, 2020). Older pea varieties are leafy and often have long vines, whereas modern pea varieties are often shorter and sometimes semi- leafless. For the latter, the leaves are replaced with tendrils, and this allows the pea to stand better on its own without lodging. This has been a critical development for the cultivation of peas, as poor lodging resistance has been a major hindrance of peas in conventional farming (Hovinen, 1988), however, desired traits for varieties in organic farming may differ from conventional.

Spies et al (2011) found that forage pea cultivars which were leafy and had long vines were more competitive than the semi-leafless varieties and were better able to maintain yield under weed presence, and better able to supress weeds. Harker et al (2008) found similar results for dry peas – that leafy peas were less susceptible to yield reduction as weed competition increased and that leafy peas often led to lower weed biomass than in semi-leafless peas. Although Harker et al (2008) found that semi-leafless peas yield at least as well as leafy pea regardless of weeds, they purport that improving leafy cultivar yield potential may lead to greater opportunities for integrated weed management. Spies et al (2011) recommend that leafy peas be grown as a green manure or cover crop, as they were difficult to harvest due to lodging. Both these studies indicate that developing techniques to reduce lodging in leafy peas is valuable.

2.4 Intercropping as an agroecological practice

Intercropping is the simultaneous growing of two or more crop species in the same field (Willey, 1979). Wolfe et al (2008) argue intercropping is important for organic agriculture and Maitra et al (2021) agree that it is a sustainable way to intensify crops with low inputs. It has many benefits, such as increasing diversity in the agroecosystem and allowing farmers to spread risk across crops in case one crop should fail (Jodha, 1980). Stelling (1997) found that peas intercropped with faba beans, generally had a higher yield stability than sole crops, a result that Cupina et al (2011) also found. A well-designed intercropping system can suppress weeds (Avola et al, 2008; Hauggaard-Nielsen et al, 2008; Gu et al, 2021;) and can result in reduced disease instances (Hauggaard-Nielsen et al, 2008). Hauggaard-Nielsen et al (2008) also found that cereals obtained more soil nitrogen when intercropped due to it being more competitive in an intercrop.

In the case of an intercrop design where there are multiple crops flowering at different times, intercropping could be beneficial for insects and pollinators. Research has also shown that intercropping can improve outcomes in drought, possibly because when combining crops with diverse root structures and water requirements, overall water use efficiency and soil moisture conservation is improved (Gliessman, 2015). Intercropping is an agroecological practice, both in terms of it being a way to increase diversity and sustainability of a farm, but also in that it is a traditional practice using often lost knowledge. Before the "fossilization" of agriculture with synthetic fertilizers and pesticides, intercropping of legumes and cereals was a common practice (Jensen et al, p. 203, 2010), necessary due to traditional varieties of peas needing to cling to the companion crop to stand upright.

2.4.1 Intercropping legumes with cereals

Jensen (1996) has emphasized that when intercropping cereals with legumes, the yield is higher than when they are grown organically in sole crops, and this has been confirmed by Zivanov et al (2018), Steen Jensen et al (2015) and Bedoussac et al (2014). Hauggaard-Nielsen et al (2008) found complementarities between grain legume with barley intercrops, and that yields for intercropped faba bean with barley were also higher than in their sole crops. There could be many possible factors behind the commonly observed advantage of legume-cereal intercrops. Because legumes biologically fix nitrogen, nitrogen transfer from legumes to non-legumes may occur directly in small amounts between crops growing together (Searle et al., 1981), which would be especially helpful in systems not using synthetic fertilizers. In addition, rooting patterns differ greatly between cereals and legumes, therefore intercrops may be more efficient in exploring a larger total soil volume if component crops have different rooting habits, in particular depth of rooting (Willey, 1979). This could be a more significant factor when old varieties are used as opposed to modern, since old cereal varieties and landraces have been shown to have more developed root systems than modern varieties (Newton et al, 2011). This could also be a factor in drought tolerance of cereal-legume intercrops.

Munz et al (2023), in oat-pea intercropping trials in Sweden and Germany, using conventional modern varieties, found that weed dry matter was significantly lower in the intercrops than in sole crops. They found that yield stability was higher in pea-oat intercrops compared to pea sole crops and contend there was an indication of complementarity in the intercrops for nutrient uptake and competition for water. Bedoussac et al (2014) emphasize that species and varietal traits suited to organic intercropping make it necessary to reconsider the varietal selection criteria.

2.5 Animal feed

Most animal feed in Sweden is either grass/legume mixtures, silage, or concentrate fodder, made up of either soybean meal, crushed cereals or/and occasionally legume seeds such as peas or faba beans (Gård och Djur Hälsan, 2016). Ruminant nutritionists have emphasized the value of legumes as a ruminant feed (Beever and Thorp, 1996). Soy is a popular product amongst farmers to increase the protein content of animal feed, however importing soybean animal feed is problematic because it drives deforestation primarily in Brazil, contributing to climate change, loss of biodiversity and socio-economic problems local to the farms (Isaksson, 2014; Song et al, 2021) Increasing the amount of protein rich animal feed grown in Sweden would contribute to a more sustainable Swedish food system. It was therefore decided to assess the potential for the varieties in this study to contribute to the production of animal food as well as human food.

For silage (biomass harvest), peas can be harvested at the flat pod stage (just after flowering has finished), or at the full pod stage. Rondahl (2007) found that in pea-oat mix silage intake was higher when the peas were harvested at the ‘full pod’ stage, however, he also explains that the quality of peas remains stable with maturity and so it is possible to use the stage of maturity of the cereal in an intercrop as the only index for the ideal time of harvest. In this study, for the purposes of identifying possible combinations of crops to intercrop for silage or whole crop forage, it was decided to analyse data from the peas based on harvesting at the ‘pod fill’ stage. Cereals for silage (biomass harvest) can be harvested around the heading stage, or at the soft dough stage (Agriculture Victoria, 2023). However, Sahlin (2008) found that the dry matter intake of silage harvested at heading stage was higher than for silage harvested at soft dough stage. In later maturity stages of cereal crops, there is a decrease in fibre digestibility and consequently a decreased feed intake, although this is not the case for barley (Sahlin, 2008).

In contrast to Sahlin (2008), Rondahl (2007) found that in terms of feed intake and milk production, the optimal time of harvest for a pea-oat mixture was when the oats where in the late milk to early dough stage. Kaiser (2007) found that the digestibility of oats decreases with advancing maturity, and they should be harvested at heading stage, however, a later harvest at anthesis when yield is higher would produce a silage of sufficient quality for production feeding from an oat-legume mixture with a legume content of 50%. After some deliberation, in this MSc thesis study, it was decided to analyse the data on the cereals for biomass/silage harvest based on harvesting at soft dough stage, number 85 on the zadoks scale (Zadok's, 1974).

3. Materials and methods

3.1 Research approach

This study uses a mixed research approach. The results are based on quantitative numerical data collected from field trials; however, some qualitative information was obtained from two farmer gatherings where it was possible to gauge farmers' interest of the crop varieties assessed in this thesis. Most of the data was collected during a 10-week period in the summer (beginning of June to late August) of 2023, with additional post-harvest data collected during the autumn.

3.2 Literature review

A literature review was performed of peer reviewed published articles in all subjects relevant to the project. These references are woven into the introduction, materials and methods, discussion, and conclusion chapters of this thesis. In order to build a picture of the relevance of this particular thesis study, the literature that specifically refers to similar studies in Scandinavia and northern Europe is presented in section 1.4.

3.3 Farmer perspective

Information on farmers' perspectives was collected on two occasions; a field visit for farmers and other interested parties held at the field trials during the summer, and a meeting for stakeholders interested in grey pea farming during the autumn. The purpose of the field visit was firstly, to allow those who were interested to visit the trials, see the varieties growing and learn about the project 'Intercropping of faba bean and pea in organic farming systems'. Secondly, the purpose of this field visit was to find and approach farmers who may be interested in conducting these field trials in slightly larger scales on their farms. The field trial was advertised through several digital channels and was open for anyone to attend, though they were required to register to the event. The purpose of the meeting for farmers interested in grey peas (no specific variety) was to discuss not only grey peas and the opportunities to grow them, advantages, and disadvantages etc., but also to discuss grey pea trials that had been conducted with farmers during the 2023 season. This was part of an ongoing grey pea project conducted by Jordbruksverket. The main points that farmers articulated are included in the results section and are drawn from the views of 13 farmers in total. The purpose of attending these events and taking stock of the views shared there, was to gain a general understanding of farmers interest in the varieties investigated in this thesis, as well as intercropping, in order to provide insights into how relevant this study is for Swedish farmers. There was no formal data collection, but the main impressions of the farmers views is summarised briefly in the results.

3.4 Description of field trials

The quantitative data used for this thesis project was collected from two spatially parallel field trials, conducted at the Swedish University of Agricultural Sciences (SLU), Alnarp, in the south of Sweden. The field trials consisted of intercrops of 10 older pea varieties with oat, and 38 varieties of cereals, in sole crops. The trials were located close to each other in the same field. Both the trials (intercropping of pea and oats and sole cropping of cereals, see below) were non-replicated pilot studies that also served as seed multiplication plots for an upcoming research project. The soil type at the studied field was a sandy light clay soil with 15-25% of clay particles. It is a soil rich in organic matter with a rate of 6- 12%. The field used for the trials is certified organic and no fertilisers were added. The preceding crops were oats (2019), lay (2021 and 2022), and spring barley (2022). The field was ploughed and harrowed once in spring before sowing. It is not close to any busy roads and has poplar windbreaks on both long sides. The trial area was protected from larger animals with an electric fence. The crops were protected from birds in the early growing stages and in the late stages when the crops began to reach maturity. The field trials for this project were conducted in Alnarp, which is located near Malmö, in Scania, in the South of Sweden. In this region, among the Köppen-Geiger classification, the climate is oceanic: a humid temperature climate. The winters are short and mild, and the summers are cool with temperatures ranging from 15 to 25°C. In Malmö, the rainfall is around 652 mm per year. The greatest amount of precipitation occurs in August with an average of 71mm and the driest month is April, with 40 mm (Climate-data.org 2023). This assessment of the climate was accurate for the year of these field trials, in which the spring was very dry, and the summer was very wet.

3.4.1 Pea - oat intercrops

The pea - oat intercrops were sown on 10 intercropping plots of 2x12.5 m each; modern oat cultivar 'Galant' with the pea varieties; Solberga, Maglaby, Brattebräcka, Bjurholmsmåärt, Concordia, Pelusk från Dalarna, Ringeriksert, Timo, Jearert and Östgötagulärt. The pea varieties used were mainly old varieties and landraces (see table 1). Figure 2 shows a map of the pea with oat intercrops. Seed density for the peas was 50 seeds per meter squared (50% of recommended seed density), and for the oats was 100g of seeds per meter squared (also 50% of recommended seed density). The plots were sown on the 20^{th} of April with a sowing machine (Wintersteiger/Öyjord) that gives 16 rows with a row distance of 12.5 cm. The seeding depth was 5-6cm. The seeds were collected from gene banks and seed saving organisations and have been multiplied within associate research projects at SLU, Alnarp.

3.4.2 Cereal plots

The cereal plot consisted of 38 strip plots (each plot approx. 12.5x2 m). There were 18 wheat plots, one of which was a durum wheat, 10 oat plots and 10 barley plots. Each plot was sown with 0,5 kg / 25m2 (based on 200 kg/ha). Figure 3 shows the cereal plot in more detail. A detailed description of the cereal varieties can be found in table 2. These plots were also sown on the 20^{th} of April with a sowing machine (Wintersteiger/Öyjord) that gives 16 rows with a row distance of 12.5 cm. Again, the seeding depth was 5-6cm. The seeds come from organic farmers in Sweden, organic breeders in Denmark and Germany, NordGen, and a conventional breeding company in Sweden.

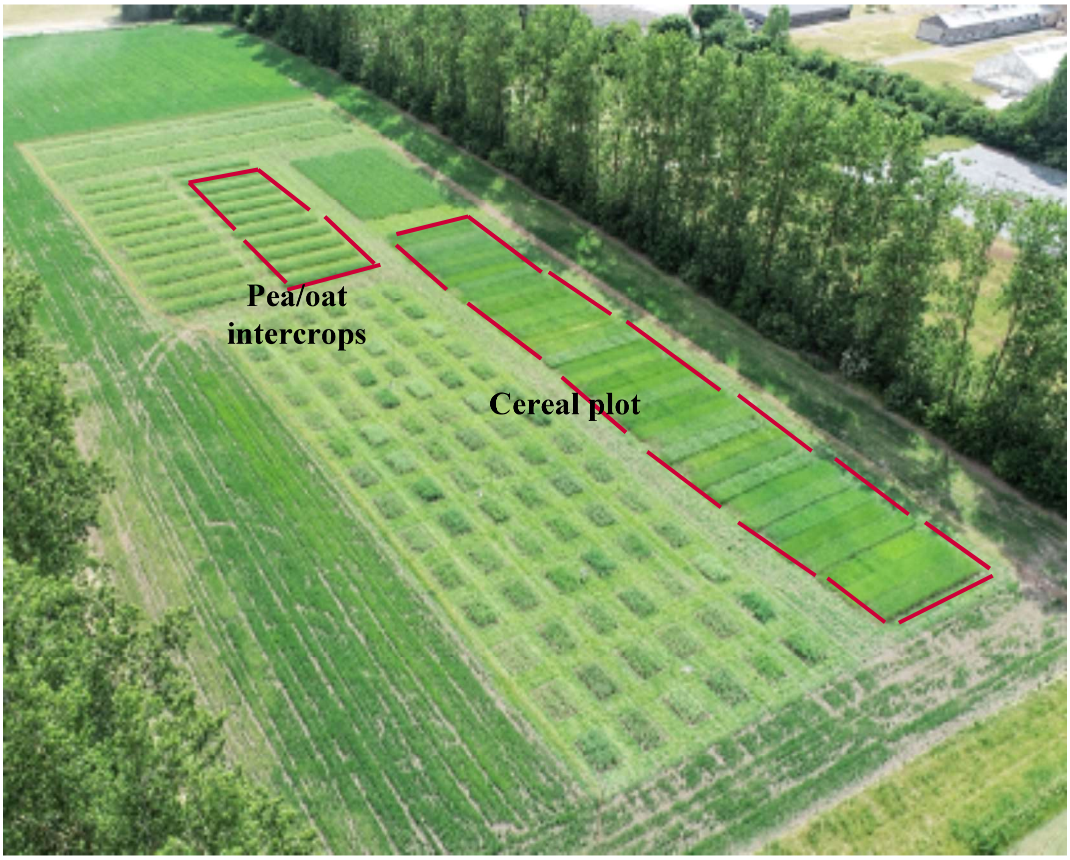

Figure 1. An aerial photograph of the field trial.

Figure 2. Diagram illustrating the pea with oat intercrop section of the field trial. The oat variety is a modern variety named 'Galant'. The crop strips are 2x12.5 meters in size.

Figure 3. Diagram illustrating the cereal trial. The crop strips are approximately 12.5 x 2 meters in size with 20 cm between them.

3.5 Varieties

Table 1. Table with a list of abbreviations, names, species, and brief description of each variety used in the split plots.

Full name	**Crop**	**Description**
Solberga	Pea	From Bohuslän county (Southwest Sweden). Grey pea. Landrace.
Maglaby	Pea	From Scania. Grey pea. Landrace.
Brattebräcka	Pea	From Bohuslän. Grey pea. Landrace.
Bjurholm småärt	Pea	From Bjurholm (north Sweden). Green pea. Landrace.
Concordia	Pea	Old variety. Green pea.
Pelusk från Dalarna	Pea	From Dalarna (north Sweden). Grey pea. Landrace.
Ringeriksert	Pea	From Norway. Landrace.
Timo	Pea	Old variety from Sweden. Fodder pea.
Jaerert	Pea	From Norway. Landrace.
Östgötagulärt	Pea	From Östergötland (South-east Sweden). Yellow pea. Landrace.
Galant	Oat	Modern variety from Sweden.

Table 2. Table with a list of abbreviations, names, species, and brief description of each variety used in the cereal plots.

Name	**Crop**	**Description**
Lantvete från Dalarna	Wheat	From Dalarna. Landrace.
Gutekorn	Barley	Old variety.
Roslags svarthavre	Oat	Black oat. Landrace.
Hallands vårvete	Wheat	From Halland (Southwest Sweden). Landrace or mass selection from a landrace.
Gull	Barley	Old variety from Gotland (island off the east coast of Sweden).
Klock II	Oat	Black oat. Old Swedish variety.
Ölandsvete	Wheat	From Öland (island off the east coast of Sweden). Landrace or mass selection from a landrace.

Balder	Barley	Old Swedish variety.
Same	Oat	Black oat. Old variety.
Fyglia I	Wheat	Old Swedish variety.
Edda II	Barley	Old Swedish variety.
Orion III	Oat	Black oat. Old Swedish variety.
Algot	Wheat	Old Swedish variety.
Holma nakenkorn	Barley	A naked/hulless population containing both six and two-row barley.
Örn	Oat	Old Swedish variety.
Diamant II	Wheat	Old Swedish variety.
Pirona	Barley	Organic naked/hulless variety from Cultivari (organic plant breeding company) in Germany.
Sol II	Oat	Old Swedish variety.
Kärn II	Wheat	Old Swedish variety.
Tolstefix	Barley	Organic variety from Cultivari (organic plant breeding company) in Germany.
Kaspero	Oat	Organic variety from Dottenfelder Hof in Germany.
Möystad	Wheat	Old Norwegian variety.
Åsa	Barley	Old Swedish variety.
Talkunar	Oat	Organic naked/hulless variety from Cultivari (organic plant breeding company) in Germany.
Svenno	Wheat	Old Swedish variety.
Widre	Barley	Modern (2001) variety from Denmark.
Talkito	Oat	Organic naked/hulless variety from Cultivari (organic plant breeding company) in Germany.
Ås II	Wheat	Old variety from Norway.
Galant	Oat	Modern Swedish variety.
Vinjett	Wheat	Modern Swedish variety.
RGT Planet	Barley	Modern malting variety.
Saludo	Wheat	Organic variety from Dottenfelder Hof (organic plant breeding company) in Germany.
Blå vårvhede	Wheat	Organic heterogeneous population (OHM) from Agrologica (organic plant breeding company) in Denmark. Has blue seeds.
Esperanza	Wheat	Organic variety from Dottenfelder Hof (organic plant breeding company) in Germany.
Peter og Pouls KH	Wheat	A variety of a Chinese wheat species from Agrologica (organic plant breeding company) in Denmark.

Durum nr. 6A	Durum	Organic variety from Agrologica (organic plant breeding company) in Denmark
Mariagertoba	Wheat	Organic heterogeneous variety (OHM) from Agrologica (organic plant breeding company) in Denmark.
Diskett	Wheat	Modern variety from SW Seed (conventional plant breeding company) in Sweden.

3.6 Data collection

3.5.1 Measuring length of the peas

To measure the length of the peas, the plant was stretched out and held up before holding the fold out ruler alongside the plant, starting at the base of the plant at the ground, to the very end of the plant. Five plants were randomly selected and measured by the person undertaking the measuring, avoiding the edge of the plot. The data was collected on 50, 60, 75, 90 and 100 days after sowing (DAS). On some occasions, data was collected one day after or before said number of DAS, due to practical considerations.

3.5.2 Measuring maturation times of peas and cereals

To measure the maturation times of the peas, data was collected every other or every third day, during which it was recorded if the peas had reached certain stages. The stages were: pod fill, pod mature and stems dry. It was recorded that they had reached this stage if 80% or more of the plants had reached this stage. To measure cereal development, the Zadok's scale (Zadok's, 1974) was used. The development of the cereal was measured every ten days, at the same time as the height and length of the cereal was measured. The whole plot was assessed when measuring the development; the stage number was chosen if approximately 80% of the plants had reached said stage. The cereal development was measured at 50, 60, 70, 80, 90 and 100 DAS. On some occasions, data was collected one day after or before said number of DAS, due to practical considerations.

3.5.3 Measuring cereal height

In the cereal plots, the height was measured also by holding a fold out ruler alongside the plant and observing the measurement in centimetres. Again, the measurement was from the base of the plant at the ground to the tallest point of the plant. Again, five plants were measured per plot. For height of cereals, data was collected on 50, 60, 70 and 90 DAS. On some occasions, data was collected one day after or before said number of DAS, due to practical considerations.

3.5.4 Measuring cereal yield

The actual plot size of the cereals varied with up to +/- 1.8 m2. The yield/land area unit was calculated based on the actual plot size.

3.7 Choice of maturation times

3.5.5 Silage and whole crop forage

To identify crops maturation times for silage purposes, data on peas was analysed based on harvesting at the ‘pod fill’ stage, and for cereals at soft dough stage.

3.5.6 Seed harvest

To identify crops maturation time for seed harvest, data on peas was analysed based on harvesting when their stems had become dry and for cereals when they had reached ‘ripe’ – number 90 on Zadok’s scale (Zadok’s, 1974).

3.6 Data analysis

This study is based on a quantitative data analysis. At first, all data was compiled and put into tables using mean values and standard deviation. For the length of the pea with oat intercrops, the mean average was calculated for the five individual plant measurements from each plot. The standard deviation was calculated from these five measurements. This resulted in two values, the mean length, and the standard deviation. For the height of the cereals the process was the same. For the maturation times of pea with oat intercrops and the cereal plots, the number of days after sowing was calculated from the date recorded in a spreadsheet. For maturation time, only one value was recorded per plot/variety, so no standard deviation was calculated.

4. Results

4.1 Maturity times

The number of days it took for the crops from both trials to reach maturity for biomass harvest are visualised in figure 4. The time to reach the stage for biomass harvest ranged from 78 to 98 days for peas, and from 75 to 102 days for cereals, with a clear overlap of different varieties of the crops. To answer research question 2, the number of days it took for the crops from both trials to reach maturity for seed harvest are visualised in figure 5. The time to reach the stage for seed harvest ranged from 84 to 121 days for peas and 85 to 110 days for cereals, again with an overlap of different varieties of the crops. The cereals that are marked with an Asterix (*) are the those that were observed to have a variation of maturation times, e.g. some kernels were number 84 and some kernels were number 91. The number of days recorded for these cereals was for the most mature plants in the variety. This will be elaborated on in the discussion.

The oat Galant was the oat variety used in the pea and oat intercrops. As a sole crop, as we can see in figure 4 below, Galant had the most similar maturity times for biomass harvest to the pea varieties Pelusk från Dalarna, Jaerert, Maglaby, Bjurholm smååärt, Östgötagulärt and Ringeriksert. The maturity time of Galant oat for biomass was not dramatically different from any of the pea varieties studied. For seed harvest, as seen in figure 5, Galant had the most similar maturity times to Jaerert, Ringeriksert, Pelusk från Dalarna, Östgötagulärt, Bjurholmsmåärt, Maglaby, and Concordia. The maturity time for Galant to reach seed harvest did not differ dramatically from Timo, but it did differ quite significantly from Brattebräcka and Solberga for seed harvest.

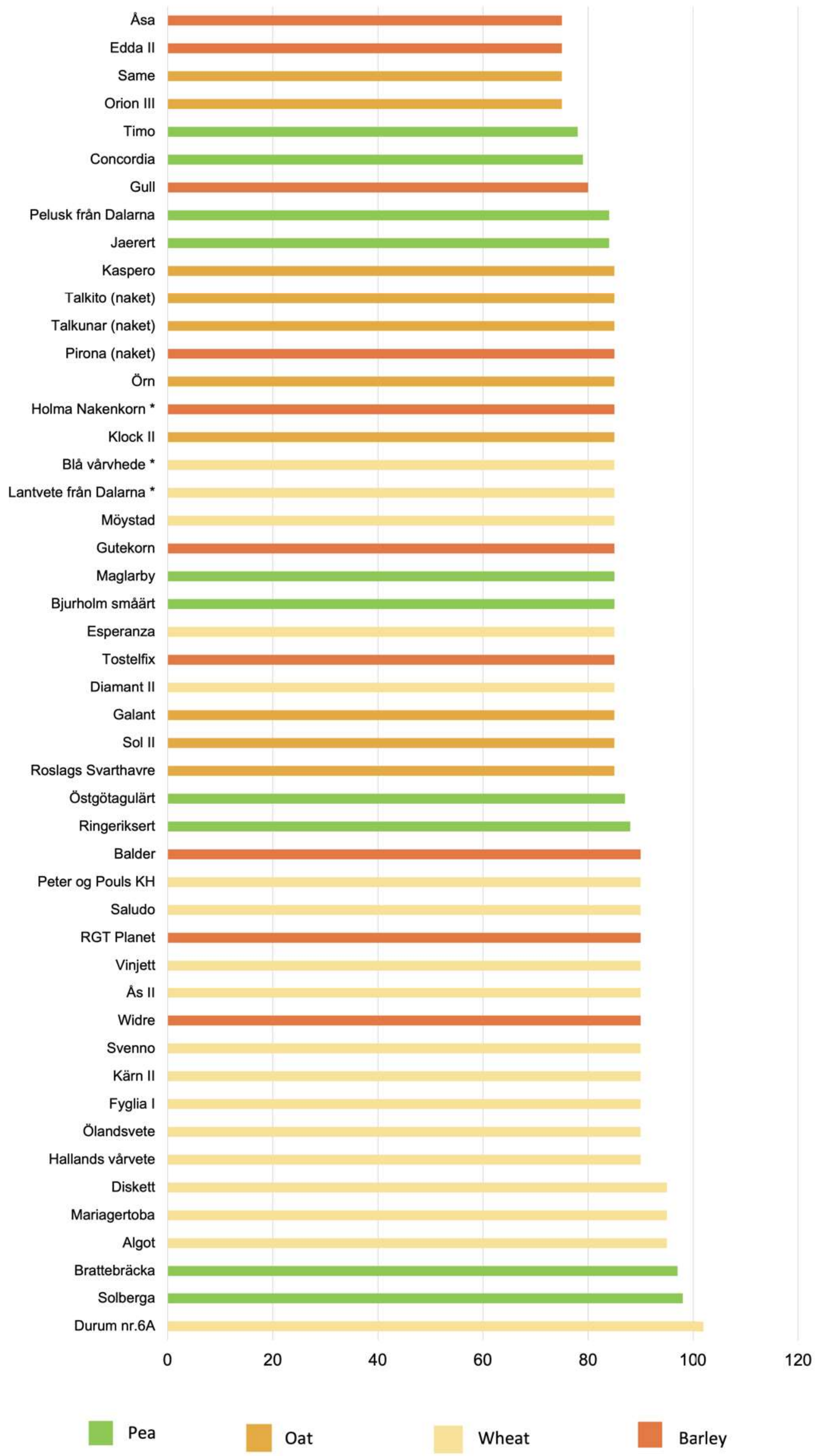

Figure 4. Diagram showing the number of days for the pea varieties (intercropped with oat) to reach maturation stage for biomass harvest. This means peas were at pod fil and the cereals were at the

*dough stage on the Zadok's scale (number 85). Varieties marked with * had a variation in maturation time due to heterogeneity. Latest maturity stage was recorded for these.*

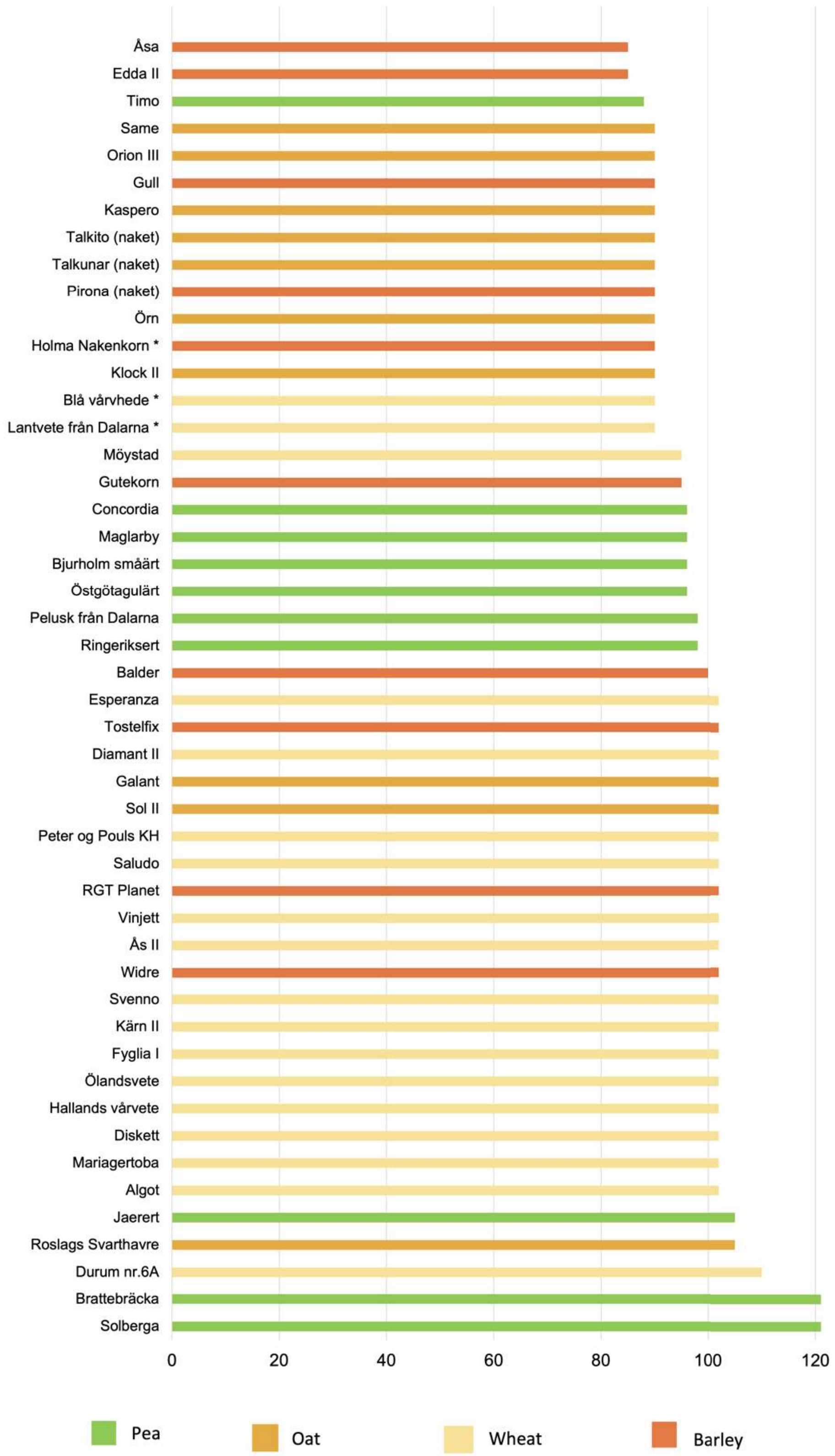

*Figure 5. Diagram showing the number of days for the pea varieties (intercropped with oat) to reach maturation for seed harvest, This meant the peas were at dry stems, and all the cereals had a hard grain (number 90, ready for harvest). Varieties marked with * had a variation in maturation time due to heterogeneity. Latest maturity stage was recorded for these.*

4.2 Cereal height

The height development of the different cereal species is visualised in figure 6, 7 and 8. Even though it is the height and not length that is measured, the highest point in the graphs corresponds approximately with the length of each variety. As the values are decreasing, the level of lodging is indicated. At 50 DAS the shortest cereal was Widre, a modern variety of barley, which measured at 41cm. The tallest cereal at 50 DAS Edda II, an old variety of barley, at 80cm. Edda II had therefore reached double the height of Widre in the same number of days. On the last measurement at 90 DAS, the shortest cereal (aside from those that had lodged) was still Widre, measuring 46cm, and the tallest was Roslags svarthavre, an oat landrace was the tallest, measuring 116cm, with a standard deviation of 9. Klock II (oat) had completely lodged by harvest (90 DAS) and measured 65cm, however had a standard deviation of 12. Gutekorn, an old variety of barley, had completely lodged by harvest, measuring 40cm with a standard deviation of 11. Fyglia (wheat) had mostly lodged by harvest, with a final measurement of 64cm and a standard deviation of six.

Edda II (barley), Orion III (oat), Algot (wheat), Åsa (barley) and Durum nr. 6A (Durum wheat) grew particularly quickly in the beginning of the growing period. Edda II had grown 80cm 50 DAS, Orion III had grown 71cm 50 DAS, Algot had grown 71cm 50 DAS, Åsa had grown 79cm 50 DAS and Durum nr. 6A had grown 78cm 50 DAS. Edda and Åsa were the fastest maturing cereals for both biomass and grain harvest. Despite being one of the fastest growing and tallest cereals (average height of 101cm), Durum nr.6A was the slowest maturing cereal for both biomass and seed harvest. Not all of the other very tall cereal varieties matured slowly.

Lantvete från Dalarna, a wheat landrace, had a consistently high standard deviation of height which averaged at 9 across the data collection period. It is a tall cereal with its height across the data collection period averaging at 96cm, and it was medium yielding (see figure 10). Åsa, an old Swedish variety, had an average standard deviation of 10 across the data collection period but less consistently spread across measurements (12, 5, 7, 11 and 16). The same was true for Durum nr. 6A (organic variety), with average standard deviation of 9 (9, 16, 7, 7, 8), and Same, (old variety), with average standard deviation of 8 (11, 13, 2, 6, 7). Some cereals had consistently low standard deviations throughout the growing period, Pirona – 4, Tolstefix – 3 and Widre – 2. Pirona and Tolstefix are organic varieties from the organic plant breeder Cultivari, and Widre is a modern variety. Pirona and Tolstefix are medium tall cereals, with average heights of 64, and 61. Widre had an average height across the data collection period of 46. All three were medium yielding.

The oat variety Galant (used in the pea intercrop) reached a height of 80cm at harvest (around 90 DAS) planted as a sole crop. At the same number of DAS, when intercropped with Solberga pea, Galant reached 69cm. When intercropped with Maglaby, 73cm. When intercropped with Brattebräcka, 70cm. When intercropped with Bjurholmsmåärt, 68cm. When intercropped with Concordia, 69cm. When intercropped with Pelusk från Dalarna, 67cm. When intercropped with Ringeriksert, 66cm. When intercropped with Timo, 71cm. When intercropped with Jearert, 75cm. When intercropped with Östgötagulärt, 59cm. The oat Galant grew taller in a sole crop then when intercropped with peas.

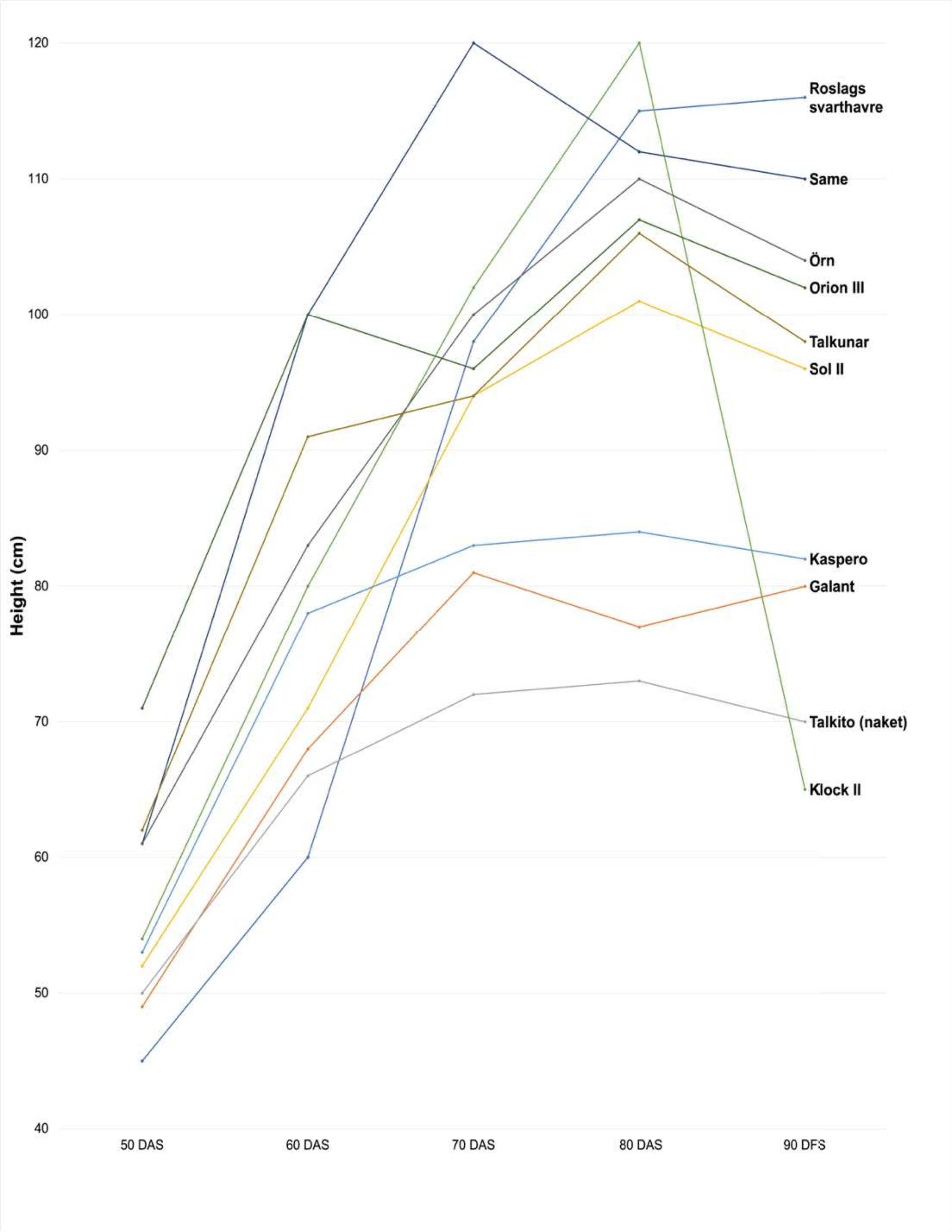

Figure 6. A diagram showing the height (cm) curve of all the oat varieties across the growing period from 50 DAS to 90 DAS.

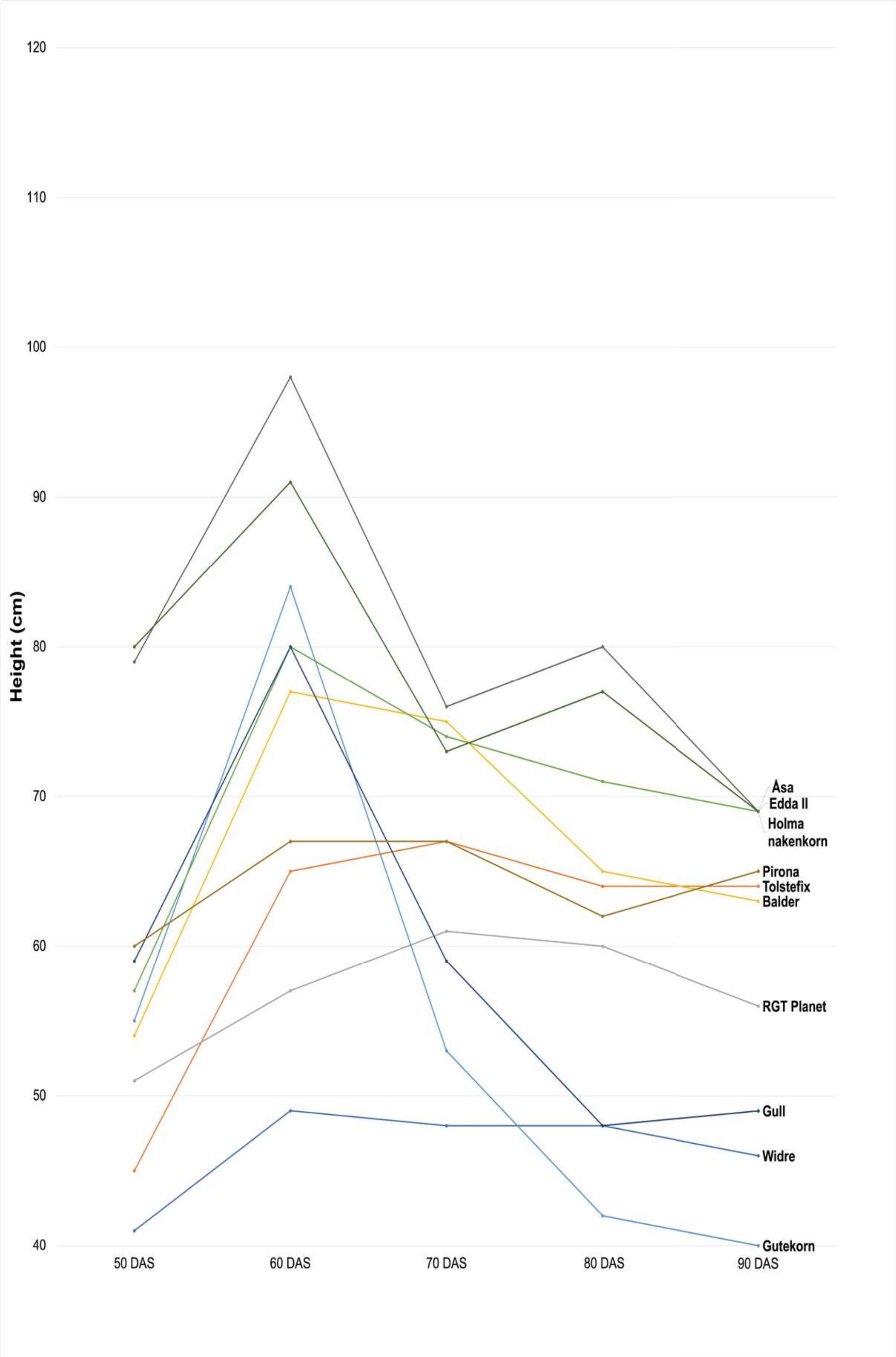

Figure 7. A diagram showing the height (cm) of all the barley varieties across the growing period from 50 DAS to 90 DAS.

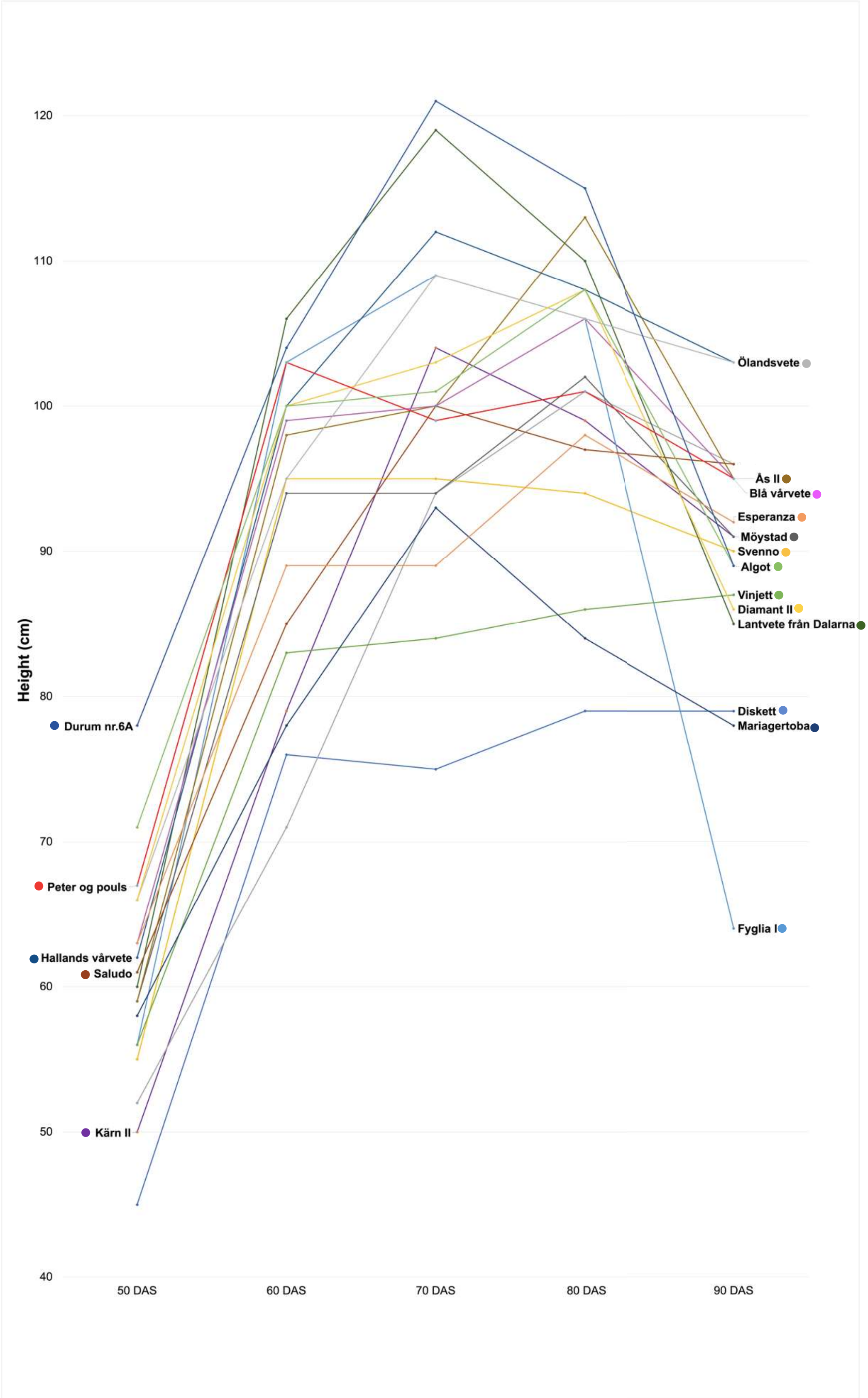

Figure 8. A diagram showing Figure 8. A diagram showing the height of the wheat varieties across the growing period from 50 DAS to 90 DAS.

4.3 Length of pea (intercropped with oats)

The length of the peas (intercropped with oats) is visualised in the figure 9 below. There was a large range of length variation among the pea varieties intercropped with oats. On the first measurement at 50 DAS, the length ranged from 41 cm (Concordia) to 59 cm (Pelusk från Dalarna). On the last measurement at 100 DAS the height ranged from 40 cm (Concordia) to 83 cm (Solberga). As seen in figure 9, Solberga, Brattebräcka, Pelusk från Dalarna, Ringeriksert, Östgötagulärt, Timo, Jaerert and Concordia all measured slightly shorter on the last measurement than the previous measurement. On the last measurement, Solberga had a standard deviation of 82 ± 9, Maglaby of 70 ± 12, Brattebräcka of 21 ± 21, Bjurholmsmåärt of 52 ± 9, Concordia of 40 ± 10, Pelusk från Dalarna of 72 ± 24, Ringeriksert of 62 ± 14, Timo of 52 ± 6, Jaerert of 52 ± 8 and Östgötagulärt of 61 ± 12. Apart from Timo, all the peas had quite high standard deviations. Brattebräcka and Pelusk från Dalarna had particularly high standard deviations.

In the early stage of the growing period, Brattebräcka and Solberga did not grow much faster than the other pea varieties, however they did grow faster in the later stages, and they reached a longer length than the other pea varieties. They were also the slowest maturing pea varieties for both biomass and see harvest. The same can be said for Durum nr. 6A (significantly tall whilst also being the slowest maturing).

4.4 Cereal seed yield

The cereal seed yield is visualised in figure 10 below. The highest yielding varieties were Esperanza (wheat) at 4024kg per hectare, Diskett (wheat) at 3918kg per hectare and Saludo (wheat) at 3873kg per hectare. Esperanza is an organic variety from Dottenfelder Hof in Germany, which means it has been developed in an organic plant breeding program. Esperanza was a medium high wheat, with an average height of 86cm across the growing period. It usually had a low standard deviation (apart from on one measurement where it had 7) at an average of 4 across the measurements. For both biomass yield and seed yield, Esperanza's maturity times were in the middle of the range of the varieties. Vinjett (wheat yielding at 3752kg per hectare) Diskett and RGT Planet (barley yielding at 3621kg per hectare) are all modern conventional varieties. Galant (oat, 2392kg per hectare) and Widre (barley, 2946kg per hectare) however, are also both modern conventional varieties but were not amongst the highest yielding varieties. Widre was also the shortest variety and the variety with the lowest standard deviation. Ölandsvete (wheat) was the highest yielding landrace, yielding at 3435kg per hectare. Ölandsvete is quite tall, with average height of 96 ± 8cm.

Talkunar (oat) had the second to lowest yield at 1504kg per hectare and Gutekorn (barley) had the lowest at 1267kg per hectare. Talkunar is also an organic variety from Cultivari in Germany, meaning it was developed in an organic plant breeding program. It did not lodge and had a medium to high height averaging at 90 ± 5 across the growing period. In terms of maturity time, Talkunar was on the faster side for both biomass and seed yield but not the fastest. Gutekorn is an old variety of Barley. It had completely lodged by harvest and had maturity times in the middle of the range.

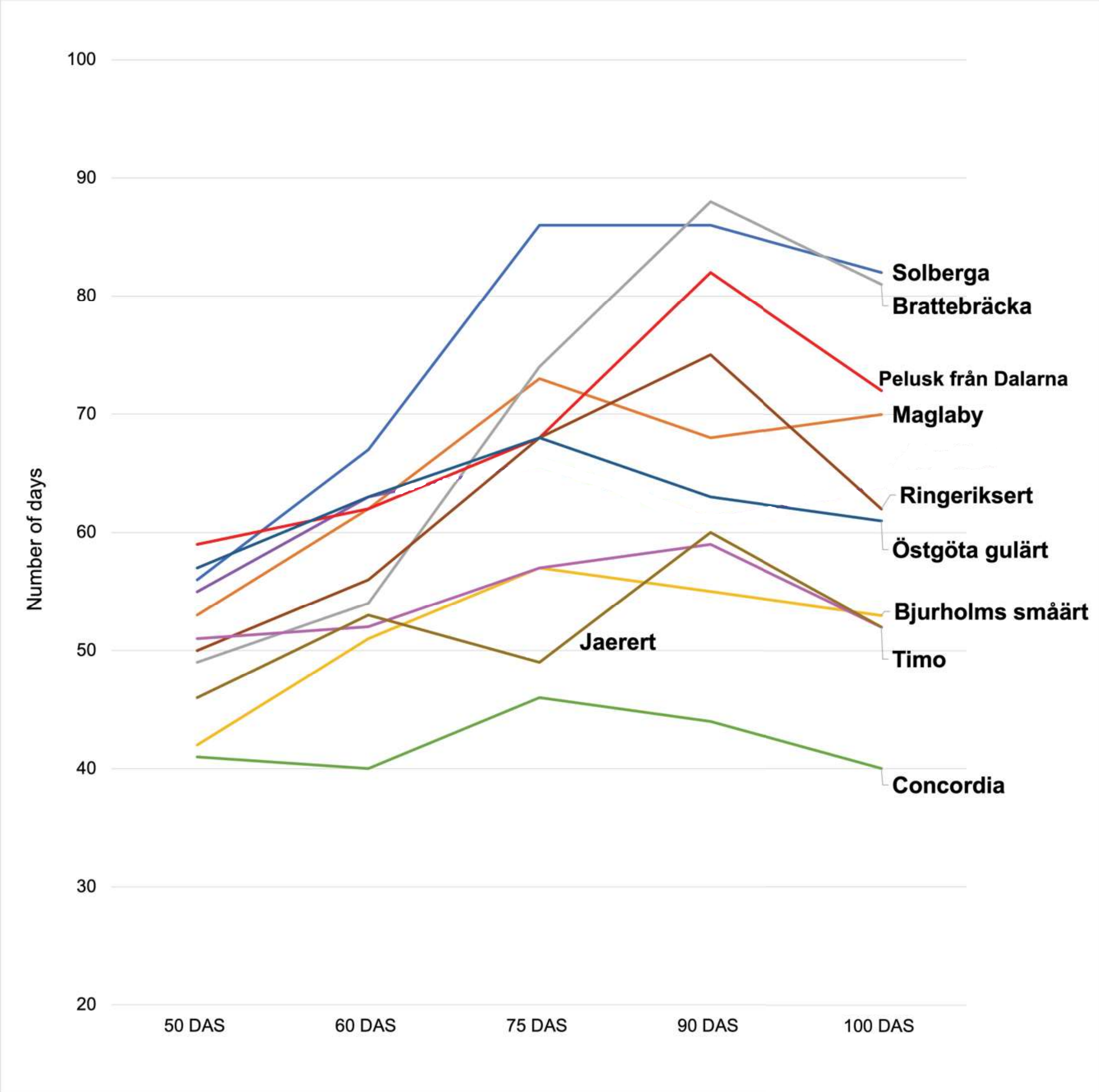

Figure 9. Length of peas with oats in intercrop trials at 50, 60, 75, 90 and 100 DAS.

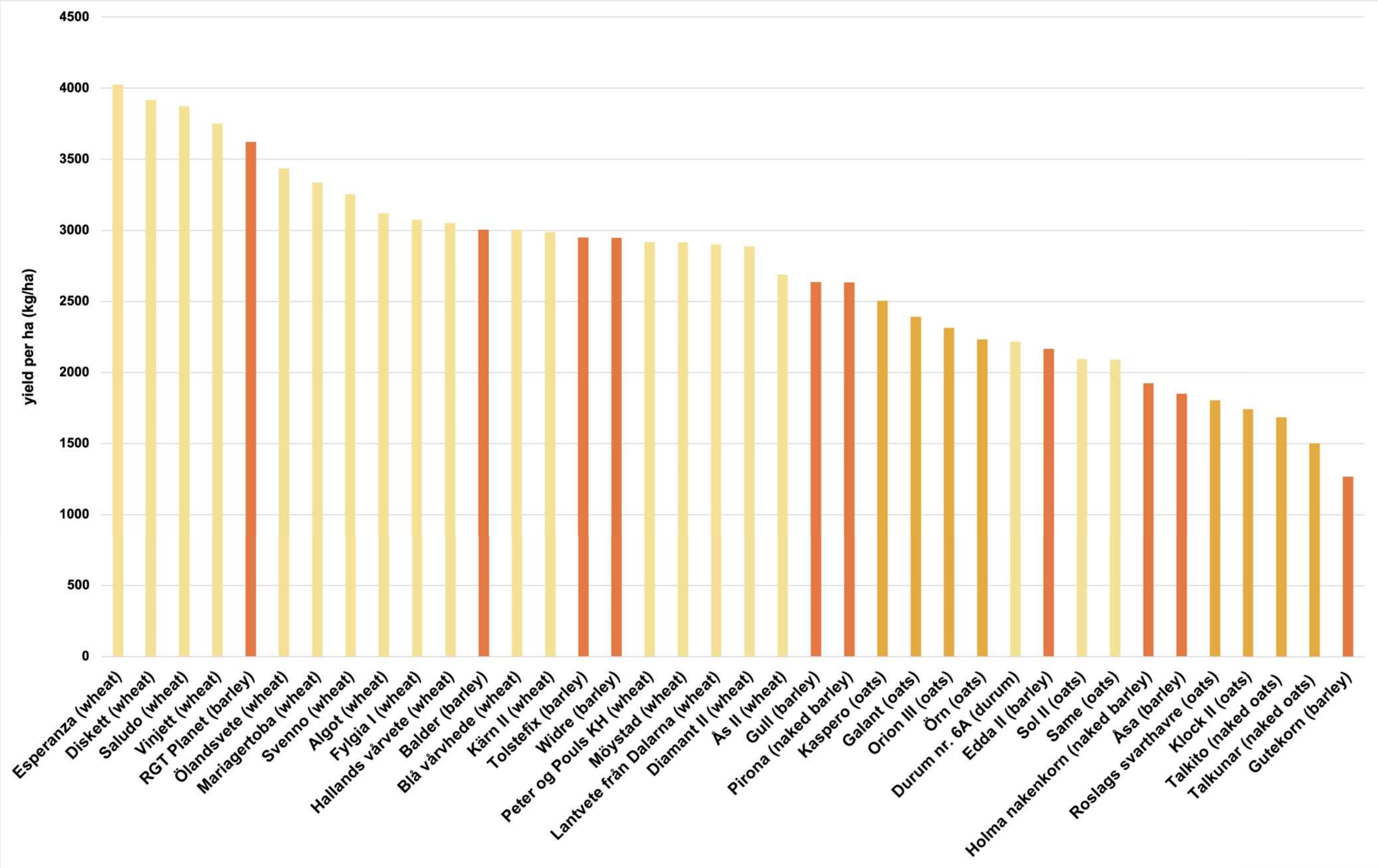

Figure 10. Bar chart showing the seed yield. Kg/hectar of all the cereal varieties.

4.5 Farmers views

Data was informally collected on farmers perspectives on two different occasions. Several of the farmers had livestock on their farms. From the first occasion, a visit of the field trials, the following views were expressed.

Traits relevant for farmers when selecting a variety:

- Deep root system that provides additional organic matter to the soil – farmers had the perception that deep roots were beneficial for soil and improved outcomes in drought.
- High nitrogen fixing ability.
- Tolerant to drought – famers had the perception that drought/dry weather is becoming more common and extreme and will continue to intensify.
- Competitive to weeds.
- High biomass yield which can be left on the soil to build up organic matter.
- Has a local Swedish origin.
- Seeds produced on organic farms.
- Can stand up at time of harvest.

From the second occasions, a meet up for people/farmers interested in grey peas, the following views were expressed:

Reasons farmers are interested in growing grey peas:

- Searching for alternative crops – farmers wanted to find ways to diversify income and access new and novel markets – struggling to make enough profit.
- Interested in alternative protein sources for animals – the farmers found it expensive and problematic to buy protein for animals – they wanted to be able to meet their animal's protein needs themselves.
- Interested in intercropping – farmers wanted to diversify their cropping systems to spread risk and to diversify income.
- Want to increase/conserve diversity – farmers were aware of the reduction in agro and biodiversity and wished to combat this.
- Grey pea interesting because there are many varieties and so can be grown all over Sweden/in many different soil types.
- Interested in improving soil health – farmers found synthetic inputs like fertilizer expensive and were worried about shortages in supply.

- Want to increase personal and national self-sufficiency/food security.

The opportunities and limitations of grey peas:

- Swedish story makes product more attractive.
- New culinary traits interesting to consumers.
- Lack of processing facilities for grain legumes in Sweden.
- Lack of awareness amongst consumers about grey peas.

Additional comments:

A farmer who had intercropped oats and grey peas reported that he had observed similar results of the oat appearing to outcompete the grey pea.

5. Discussion

5.1 Difference in lodging resistance in the cereals

In figure 6, we can see that Klock II lodged completely by harvest. In figure 7, we can see that Gutekorn, Widre and Gull had completely lodged by harvest. In figure 8, we can see that Fyglia I had significantly lodged by harvest time and that Lantvete från Dalarna, Diamant II, Durum nr. 6A, Algot and Ås II were quite low by harvest but not fully lodged. Åsa, Edda II and Orion III partially lodged but then raised again, due to them being weighed down by rain. The lodging is due to a weak stem being unable to support the weight of the plant when it matures. Cereals that grow taller are more prone to lodging (Khobra et al., 2019; Jinger et al., 2018), on the other hand, although Navabi et al (2006) also found that in most cases shorter plants were less prone to lodging, they also observed variation in lodging in taller wheat varieties, suggesting that susceptibility to lodging is not always related to plant height. Lodging occurs in particular with access to nutrient rich soil; therefore, tall cereals may not be ideal for a conventional setting where synthetic nitrogen is used but may not be a problem in organic low-input systems where there is a lower availability of nutrients. Furthermore, cereals prone to lodging would not be ideal for intercropping with vigorous peas as their purpose is to support the pea, so they must have strong straw. Height of the cereals was measured because it is an important factor in weed competition, as taller cereals stop light reaching potential weeds (found by Kunz & Karutz, 1991; Eisele & Köpke, 1997; Müller, 1998; cited in Lammerts Van Bueren et al, 2002). It is possible that the cereals were slightly taller than presented in figures 6, 7 and 8 as we measured height instead of length. They may have begun lodging before the peak value. However, it is likely that the highest values in these figures approximately represent the total length of each variety.

5.2 Differential height of cereals and its implications

It was found that there was a large variation in height amongst the cereals. Different heights could have different advantages in different cropping designs. It was expected that the landraces and old varieties would grow taller than the modern varieties. However, the results have provided a more detailed overview of their growth pattern. Konvalina et al (2013) argues that tall cereal varieties are preferred in organic farming for more efficient weed suppression (found by Kunz & Karutz, 1991; Eisele & Köpke, 1997; Müller, 1998; cited in Lammerts Van Bueren et al, 2002), and suggests this can result in a higher straw production which is important in organic farming as organic matter for soil improvement. Konvalina et al (2013) also describe modern wheat varieties to have major shortcomings, one being short plant height. Short plant height improves lodging resistance (Verma et al., 2005 cited in Lammerts van Bueren et al., 2011) but has been shown to increase susceptibility to diseases such as powdery mildew and Septoria (Simon et al., 2004 cited in Lammerts van Bueren et al., 2011). Furthermore, short plant height in cereals results in not only decreased competitiveness against weeds but also decreased robustness against mechanical weed control and therefore greater reliance on herbicides (Lammerts Van Bueren et al., 2002).

Cereal landraces have been shown to have more developed root systems than modern varieties (Newton et al, 2011) and as seen in the results of this study, old varieties and landraces of cereal are often much taller than modern varieties (figure 6, 7 and 8). Mäder et al (2002 cited in Lammerts van Bueren et al., 2011) found that short plant height in cereals resulted in reduced size and depth of root systems. Root development is important for finding and taking up nutrients which is particularly important in organic systems (Lammerts Van Bueren et al, 2002), and is also important for finding moisture in dry conditions (Lammerts Van Bueren et al, 2002). Drought tolerance is something farmers desired from varieties, as discovered through contact with farmers in relationship to this thesis. The cereals grew at different speeds. Some began slower and caught up, and some began faster but slowed down. There could be several advantages or disadvantages of this for organic intercropping. A cereal that grows slowly in the beginning may allow for the development of a companion crop such as peas without too much competition. A cereal that grows slowly in the beginning may also be more resistant to a dry early spring period. A cereal that grows quickly in the beginning, however, may have a better ability to supress weed growth (Van Der Weide et al., 2002, cited in Lammerts Van Bueren et al, 2002), a trait useful in an organic setting – but might pose too much competition for a companion crop.

The cereal height results showed a variation in standard deviation. As seen above, some of the cereals had a consistently high standard deviation (such as Lantvete från Dalarna and Åsa). One could speculate that this could indicate a significant variation in height between individual plants within a variety. If so, the perhaps a cereal with a large standard deviation may be more genetically diverse, which could influence its ability to buffer natural perturbations. On the other hand, a low standard deviation, (such as Widre), could indicate that there was not a large variation in height amongst individual plants within the variety. In this case, the variety may be more uniform, which, as is underscored by the requirements of new registered varieties to be uniform (Newton et al, 2011), may be beneficial for farmers in that the variety is more predictable. A more predictable and uniform crop is understood to be important because it ensures fair trade, in that the variety can be correctly described and is stable over time, ensuring the buyer of seeds knows what they are getting and can choose according to their requirements (Geves, 2023). This however is only relevant for farmers who buy seeds, not farmers who wish to save seeds. Standard deviation differences could also be a result of human error/bias, if the person measuring chooses to measure the most different plants or the most similar, depending on what result they want to confer.

5.3 Differential length of peas and its implications

The peas in the intercrops varied quite widely in length from relatively short to very long. This variation can have different advantages and disadvantages for different cropping designs. Acikbas (2022) found that pea varieties with the highest seed reserve utilization and vigorous seedling growth, had the highest total root length and number. This could suggest that very vigorous pea varieties have vigorous roots, beneficial for nutrient and water uptake, and therefore well suited to organic settings or dry weather. Wallace and Yan (1998) in Gill and Boisvert (2020) argue that determinate, dwarf-statured, reduced-leaf cultivars can be considered ideal for intercropping, however, it could be argued that this depends on the purpose of the intercropping. For peas in forage production, a leafy plant might be preferred, because a high leaf-to-stem ratio is associated with a higher nutritional value as the leaves and pods account for most of the digestible dry matter (Collins et al., 1995), furthermore, taller cultivars are also considered more suitable for forage (Feedipedia, 2015).

These reflections point to the significance of research on intercropping cereals with peas, particularly tall leafy varieties with high biomass. In addition, Woolly and

Davis (1991, in Anil et al., 1998) noted that practices that favour more vigorous crop growth increase crop competition with weeds and reduce the need for frequent direct control. This suggests that not only intercropping but selecting vigorous varieties such as ‘Solberga’ and ‘Brattebräcka’ can be beneficial for weed suppression, which is especially important in organic cropping systems (where herbicides are not used). On the other hand, peas which produce a lot of biomass may devote more resources to shoots and less on grains, resulting in a lower seed yield (Tran, C. T, 2022) making them less optimal for a situation where seed production is the priority. As for the cereals, there was also a variation in standard deviation of pea length, with the same possible implications as mentioned in section 5.3.

5.4 Implications of height and length for intercropping

The peas did not grow as tall as expected in the pea with oat intercrops. It is possible that the oats outcompeted the peas, which could be something that occurred specifically in this case because of the variety of oat used. It could also be that oat’s in general (or this variety of oats) fairs particularly well in dry weather compared to the peas, allowing the oats to outcompete the peas, since the first half of the growing period was extremely dry. Baxevanos et al (2017) found that results of oat-pea intercropping trials were different depending on cultivars of oat and pea used. They put forward that cultivar screening can contribute significantly to increased productivity of intercropping systems by investigating and exploiting the genetic variability for intercrop adaptation. As mentioned in the results, one of the farmers also reported that in his pea and oat intercrop the oats outcompeted the pea. This result could also be because of the varieties used– perhaps different pea or cereal varieties would have behaved differently. This shows again the importance of testing these varieties and others in an organic intercrop setting.

It is unclear whether differences in height of crops is disadvantageous or not for intercropping. Maitra et al (2021) highlight that if crops with a shorter canopy structure are intercropped with tall crops, the shorter will be affected by shading. However, they found that in this situation, more sunlight will be used together by the crops in association. They contend that it is preferable to choose crops with a dissimilar type of morphological character when intercropping, to ensure complementarity among the species. It is therefore not yet clear how the different heights of crops in intercropping affect each other, even though logically one may assume that very short crops would be outcompeted by very tall crops. As explained in the results, several cereals (Edda II, Orion III, Algot, Åsa and Durum nr. 6A) grew (in terms of height) much faster than other cereals. In a pea and cereal intercrop, it may be beneficial for weed suppression to select one of these varieties. The results have shown that the chosen variations may contain traits varieties which could be relevant for organic intercropping, which has the potential to further agroecological development.

5.5 Differential maturity times of cereals and peas and its implications

The maturation time important for human consumption is different for that of animal feed. As explained in the background section, it was chosen to analyse time for biomass harvest based on peas reaching pod fill and cereals reaching soft dough, and for seed data based on peas reaching dry stems, and cereals reaching ripening. The results show that amongst the crops, there was a variation in maturation times and that many of the cereals had similar maturation times to the peas for biomass harvest and for seed harvest. Different maturation times could have advantages or disadvantages for organic intercropping. Vanhala et al (2016), when studying Swedish pea landraces, including several of those included in this study, found that in general Swedish pea landraces flowered significantly later and had more variable flowering times than European cultivars and landraces, arguably because the Swedish peas have adapted to specific sunlight conditions found in Sweden. Although this thesis study focused on time to reach pod fill, pod mature and dry stems rather than flowering time, it also found significant variability in the peas. Vanhala et al (2016) discus that delayed flowering such as in these accessions could lead to a larger harvest and a larger production of total biomass.

A difference in maturation times between crops in intercrops might result in a better resource use efficiency, since the crops are not competing with each other. However, the crops should still reach a suitable stage for harvest at relatively similar times. Stelling (1997) argued that mixed crops should not differ dramatically in ripening, and Steen Jensen et al (2015) believe that cultivars suitable for organic intercropping should be developed with particular reference to matching cultivars which are appropriate for simultaneous harvest. On the other hand, Stelling (1997) found that peas could wait for a companion crop to finish maturing without the pods shattering. It is also possible that the weather (very dry spring and a wet late summer) affected the maturation speed of the crops.

It was also found that ‘Lantvete från Dalarna’, ‘Holma nakenkorn’ and ‘Blå vårvhede’ had a variation of maturation times within the variety. Lanteve från Dalarna is a landrace, and Holma nakenkorn and Blå vårvhede are heterogenous varieties. They all contain a significant amount of genetic diversity which contributes to uneven ripening. The implications of uneven ripening might be different for various end uses as quality requirements are different depending on for animal feed or grains for human food. A higher level of diversity in the crop, could be associated with several benefits such as a better tendency to buffer against natural perturbations like pests or diseases (Newton et al, 2011). Therefore, pros and cons related to production benefits and end use requirements should be considered when choosing a variety for organic farming.

5.6 Cereal seed yield and its implications

The cereal varieties did differentiate in yields under organic growing conditions. The yield ranged from 1250 kg per hectare (Gutekorn) to approximately 4000 kg per hectare. The highest yielding wheats were Esperanza and Saludo, modern organic varieties the organic plant breeding company Dottenfelder Hof, and Diskett and Vinjett, modern Swedish varieties from local conventional breeding programmes. Arguably, it is unsurprising that these were among the highest yielding as these varieties have been developed in breeding programmes, which typically results in higher yielding varieties than landraces (Dotlacil et al., 2002; Serpolay et al., 2011; Konvalina et al., 2012 cited in Konvalina et al., 2013). It could also be seen as curious that Diskett and Vinjett, the modern conventional varieties, yielded higher than the other organic varieties and landraces, since this study is based partly on the reflection that modern conventional varieties may not be best suited to organic systems. However, when planning this study, it was assumed that the field would resemble a low-input organic farming system, but it turned out to be more fertile than expected, considering that no fertilisers were applied. This might explain the lodging of certain varieties and the high yield of others. The nitrogen levels were evidently too high for some of the old varieties, whereas the modern varieties were able to adapt to the high nitrogen levels. These results show how important it is to select varieties adapted to the environment – considering temporal placement in the crop rotation as well as fertilization scheme and farming method (i.e intercropping).

Gutekorn, the cereal with the lowest yield, was the first variety to completely lodge out of all the varieties. Klock II also had one of the lowest yields and lodged by the end of the growing period, however Gull and Balder had significant lodging but medium yields. One might argue that other traits are more important in organic intercropping than high yield. In organic systems, yield stability may be equally (or more) as important as yield, a German study by Macholdt and Honermeier (2017) found that 48% of farmers considered yield stability to be more important than yield in wheat. Yield stability in cereals has shown to be better in old varieties and landraces (Migliorini et al., 2016). Without repeating this study for further years, the yield stability of these varieties is unknown. Traits such as high diversity, as discussed earlier could result in better responses to pests and diseases and extensive root structure may lead to better drought tolerance. Furthermore, if the cereal's purpose is mainly to support a pea plant in an intercrop, it may be beneficial for the cereal to be lower yielding, if this means it is less competitive towards the pea crop. In the intercropping trial, Galant was used, a modern Swedish variety. One could speculate that repeating this trial with a lower yielding variety could result in a higher yield for the peas.

5.7 Limitations of the research

This study would have significantly benefitted from including results of the seed yield from the pea and oat intercrops, biomass yield and weed biomass yield. Unfortunately, time constraints meant that these results fell beyond the scope of the thesis. Similarly, there are many other aspects of the cropping system that could be explored such as pest and disease instance, presence of natural enemies, and below ground interactions. However, the results from this study can be seen as a first step in paving the way for further research to be done with similar trials.

A significant factor influencing the results is that the spring and early summer was very dry, there was almost no rain for the whole of May. Then from July, the summer was extremely wet, with rain almost every day. In April it rained 22mm (normal is 34mm), in May it rained 13mm (normal is 41mm), in June it rained 22mm, (normal is 64mm), and in August it rained 157mm (normal is 73mm) (SMHI, 2023). It is not yet clear without comparing to previous years how this may have affected the results. It would have been useful to also explore weed coverage and extent of pests and diseases in the crops, as from visual observations these seemed quite low. The same could be said for nitrogen and carbon flows and content in the soil, it would have been interesting to correlate the yield levels with soil fertility. However, the trials were planned with a limited budget and with the primary purpose of seed multiplication. This research and the techniques used, could be extended (with replications) to investigate more intercropping designs, including more species and varieties, to further the development of organic and agroecological farming.

A further limitation of these results and this thesis is the small scale of the trials. It is difficult to conclude how these systems would work on larger scales in different environments, and with different management. This makes it difficult to confer information about or recommend these cropping systems to real farmers, who take on risk when they adopt new practices. Even if the farmers are interested in adoption, they usually require a demand from consumers and other actors in the value food chain. During the grey pea stakeholder meeting, a large Swedish grain legume company mentioned that although there is a desire to increase grain legume production and consumption, there is a lack of processing facilities in Sweden to process the produce. This agrees with Röös et al's (2020) findings that Sweden faces a lack of processing facilities to supply functional legume-based ingredients to food industries.

5.8 Further implications of research

An increased level of knowledge about the varieties in this trial could make organic legume production in Sweden more feasible, sustainable, and profitable. An increase in consumption of legumes in Sweden would reduce the climate impact of the average Swedish diet, and a transition to more legume production/consumption would also reduce agricultural land requirement, which could then be used for nature conservation or bioenergy for example (Röös et al., 2020). Not only this, but according to Röös et al (2020), an increase in legumes in Swedish diets would provide an increase in dietary fibre and an increase in folate intake, which are currently below recommended levels. Growing legumes also has the potential to improve the ecological, social, and economic sustainability of meat products, through providing a more sustainable source of protein rich animal feed. As highlighted by the Federation of Swedish Farmers (LRF), there is a need to increase Sweden's level of self-sufficiency, which today stands at 50%, but is less, since Swedish production relies on imports of inputs, such as animal feed (Berg, 2022). Therefore, results of this study could not only be significant in developing production of animal feed in Sweden but could also contribute to improving Sweden's self-sufficiency and food security, a paramount aspect of agroecology.

Due to meat production contributing a large percentage of the greenhouse gas emissions resulting in climate change (Livsmedelsverket, 2022), there is a call for an increase of plant-based protein production and consumption. Agronomic research on legume cultivation is necessary for this increase in plant-based protein production to happen in an efficient and sustainable way. Similarly, with chemical nitrogen fertilizers being unsustainable and facing the potential of continued shortages, there is increasing interest in growing legumes due to their ability to naturally fix nitrogen from the atmosphere and therefore have less of a need for fertilizer. Increasing legume cultivation therefore also could have an impact on the sustainability of soil management in Sweden and a reduction of external inputs, a further aspect of agroecological farming.

The results of this study show that there is potential for the varieties used in this trial to be successfully farmed in commercial organic settings. These varieties being cultivated on a wider scale could be instrumental in the conservation of genetic and agro biodiversity, something central to agroecology (Altieri, 1995). Conserving genetic diversity is important for developing varieties more resilient to climate change (Andersen, 2012). De Toro et al's report (2015) found that climate change is already affecting farmers in Sweden. They found that in the last 80 years, most years with very low yields were associated with a prolonged dry period, and/or a high level of precipitation during the harvesting period. This report also found that during the study period, precipitation during summer months appeared to increase over time, and concluded that if this persists, it will increase the risk of rainy harvesting periods, however, may also reduce the risk of drought periods. As mentioned previously, the first part of the growing season was unusually dry and the second part particularly wet. Extreme weather and the effects of climate change are expected to intensify in the years to come (EEA., 2020). Considering this, there is a need for consideration of adaption to climate change in cropping system design and crop variety selection and development. At the stakeholder meetings, not only did farmers identify drought tolerance as a desirable trait in crop varieties, but also commented that this year had been a very bad year for crops due to the heavy rain. The farmers clearly had concerns over dry weather and drought, and were therefore interested in varieties with deep root systems

This thesis has contributed to increasing knowledge on fundamental aspects relevant for optimizing intercropping systems. As such, it has the potential to contribute to facilitating an increase in intercropping in Sweden. Intercropping, an agroecological practice, also plays a part in adaptation to climate change. Lynam et al (1986, in Anil et al., 1998) contend that in regions where water is limiting, intercropping is widely practised by farmers as the most efficient strategy for reducing the probability of crop failure, as northern regions face climate change induced extreme weather, this could become more relevant for temperate climates as well. When water is a limiting resource, improvement in the efficiency of water resource use because of intercropping may also lead to enhanced use of other resources (Hook and Gascho, 1988) which makes intercropping particularly important for organic farming where no synthetic nutrients are added to the soil. Danquah and Barrett (2002) note when evaluating evolutionary participatory plant breeding, that yield during periods of drought tends to favour bulk populations over commercial cultivars selected under high input conditions. Some of the landraces and heterogeneous varieties used in this project are basically evolutionary populations, which could add another layer of climate change adaptation, if they are included in the intercropping combinations. Intercropping is an important contribution to more sustainable farming in general, which is why understanding more about intercropping and suitable varieties for intercropping is significant.

From the results of the stakeholder meetings with farmers, it was apparent that there was plenty of interest in these varieties from organic farmers. Their interest reflects Perales' (1998, in Murphy et al., 2005) claim, that many small-scale and low-input farmers have not wholly embraced homogenous modern cultivars and choose instead to rely on a diverse collection of local varieties and landraces. It was observed in this study that the farmers had a deep understanding of the challenges and needs of their farms echoing Murphy et al's findings (2005) that in Syria, traditional low-input barley farmers were shown to be uniquely capable of identifying and selecting the highest yielding varieties for their own farms. Moreover, the farmers at the stakeholder meetings were aware that using inputs of synthetic fertilizer is not economically or environmentally sustainable in the long run, and so they desired crops with a high nitrogen fixing ability.

Öhnfeldt (2019) found that Swedish farmers grew heritage crops because the farmers were greatly interested in agricultural history and had an intimate relationship with plants and conservation that was tied to their identities, memories, and sense of place. Therefore, it's possible that facilitating the cultivation of historical varieties not only contributes to environmental sustainability but protects Swedish farming culture and the welfare of farmers, possibly vital in achieving the desired level of Swedish food production. The varieties used in this study are free for any farmer to use and not protected by intellectual property rights. This makes these varieties agroecologically significant, in that farmers can save the seeds to plant again, which Garcia-Lopez et al (2019) argue 'generates new peasant identities and ways of life'. Ensuring that farmers, who otherwise often plant varieties that have been selected under conventional practice (Murphy et al., 2015), can select locally adapted varieties that have significance to them, and to not be dependent on oligarchic seed/agrochemical companies, contributes to food sovereignty amongst farmers and communities and perpetuates traditional knowledge, fundamental to agroecology.

Peas and cereal landraces are traditional and culturally significant crops in Sweden. Enriching their cultivation preserves cultural heritage and Scandinavian food security and sovereignty, again a core principle of agroecology. Due to climate change, it may become possible to cultivate peas further north in Sweden than previously possible (Carlson-Nilsson et al., 2021; Olesen and Bindi, 2002) which increases the significance of this research. Bindi and Olesen (2002) argue that encouraging the flexibility of land use, crop production and farming systems is necessary for adapting European agriculture to climate change. Paradigm shifts are needed for food production to continue to meet our needs, and this involves challenging the current status quo in agriculture, not just focusing on higher yields (De Schutter and Vanloqueren, 2011). A varied selection of tested organic varieties is missing for current farmers, and further development of organic varieties is needed (Wolfe et al., 2008). This hinders the success of organic farming and the conservation of agrobiodiversity, important factors in a resilient food system (Gliessman, 2015). Understanding more about the varieties in this study is important for Swedish agriculture.

5.9 Recommendations for further research

Based on the results of this study, it is possible to recommend some combinations of pea and cereal that may be appropriate for future organic intercropping trials. It is important to note that these recommendations are based on speculation and are not necessarily optimal, nevertheless could arguably be the most suitable to pursue. The recommendations are based on the pea and cereal reaching maturity for biomass or seed harvest at similar times and based on the pea and cereal being either similar length (pea) and height (cereal) or very dissimilar length (pea) or height (cereal), based on the recommendations mentioned earlier in the discussion. Since it is unclear whether a high or low yielding cereal is optimal in a pea-cereal intercrop, yield has not been taken into consideration. The recommendations do not include the modern varieties from the trial, since growing these varieties would not specifically fulfil the purpose of conserving genetic diversity. For biomass (animal feed) harvest, and when choosing varieties with similar lengths/heights, the following combinations could be of interest: Maglaby (pea) with Talkito (oat), Holma nakenkorn (barley), or Tolstefix (barley); Bjurholms småärt (pea) or Jaerert (pea) with Pirona (barley); Pelusk från Dalarna (pea) with Kaspero (oat); Östgötagulärt (pea) with Talkito, Holma nakenkorn, or Tolstefix; Ringeriksert (pea) with Balder (barley); Brattebräcka (pea) or Solberga (pea) with Algot (wheat), Mariagertoba (wheat) or Durum nr.6A (durum wheat).

For biomass harvest when choosing varieties with very dissimilar lengths/heights, the following combinations could be of interest: Timo (pea) with Same (black oat), or Orion III (black oat); Concordia (pea) with Åsa (barley), Edda II (barley) or Orion III; Maglaby with Talkunar (oat), Örn (oat), Diamant II (wheat), Roslags svarthavre (black oat); Bjurholms småärt or Jaerert with Esperanza (wheat) or Sol II (oat); Östgötagulärt with Talkunar, Örn, Esperanza, Diamant II or Sol II; Ringeriksert with Peter og Pouls KH (wheat), Ås II (wheat), Fyglia II (wheat), Ölandsvete (wheat) or Hallands vårvete (wheat).

For seed harvest when choosing varieties with similar lengths/heights, the following combinations could be of interest: Timo with Talkito or Pirona; Östgötagulärt with Balder or Tolstefix; Maglaby with Balder or Tolstefix; Pelusk från Dalarna with Esperanza; Ringeriksert with Balder; Brattebräcka or Solberga with Durum nr.6A. For seed harvest when choosing varieties with very dissimilar length/height, the following combinations could be of interest: Timo with Orion III, Talkunar, Blå vårvhede (wheat – organic heterogenous population) or Lantvete från Dalarna (wheat); Concordia with Möystad (wheat), Esperanza, Diamant II, Sol II or Ölandsvete; Jaerert with Roslags svarthavre.

From an agroecological perspective, farmer participation and perspective are crucial to developing varieties for organic farming. Going forward, this research could be developed into something that resembles evolutionary participatory breeding (EPB) or participatory variety selection (PVS). EPB emphasizes the utilization of natural selection on genetically diverse populations (Murphy, 2004). The EPB method is uniquely suited to improving crop varieties for the low-input and organic farmer. It utilizes the skills and knowledge of both breeders and farmers to develop heterogenous landrace populations (Murphy, 2004). The diversity of bulk populations and the economy of the breeding methods make evolutionary breeding methods uniquely suited for farmer participation to develop varieties for low-input and organic farming systems (Murphy, 2004). PVS is a breeding approach that brings breeders, social scientists, farmers, and extension personnel together in a field setting to prioritize and target traits of importance. It also helps to identify and assess traits that are important to small scale farmers and is especially successful in assessing subjective traits such as taste, aroma, appearance, texture, storage quality and other culinary qualities, which are difficult to measure quantitatively (Bellon 2002, in Kolech et al., 2017).

It is possible that these methods could be used to develop varieties even more fit for these systems than the current dominant breeding methods. With reference to Murphy (2004) and Röös (2020) and considering the importance of co-creation of knowledge for agroecology, this thesis recommends that these varieties be tested on real farms, managed by real farmers, with a continual dialogue between farmers and researchers in terms of observations about the crops and recommendations for future trials. Bedoussac et al (2014) argue that the development of intercrops cannot take place without the participation of all the actors in the value chain. Carton et al (2022) discovered that on farm experiments and the discussions associated with them indicated complementarity between farmers and researchers' measurements, observations, and interpretations, which were valuable for reaching conclusions that could be generalized across the different context of the participating farmers. Furthermore, this thesis recommends continuing with the intercrop trials for a further two years, replicated and in different locations, to discover whether the results of this trial are reliable. In addition, it recommends that other cereal varieties from this trial be tested in organic intercrops with the pea varieties from the intercrops, in further field trials, based on the results on the maturity time in this study. The length of cereals should be measured as well as height, as this would give a more detailed and accurate picture of lodging resistance in the cereals. This would allow a better understanding of the competitiveness of the oats and peas, and how this is affected by variety choice and weather.

6. Conclusion

After recording data from two field trials with pea and oat intercrops and sole crops of wheat, barley and oat, this study found a large range in length and maturity times of the eleven varieties of peas, and a large range of height and maturity times of the 38 varieties of cereals. The study also found that there was a wide range in yield across the varieties. Many of the crops had similar maturation times for the purposes of both biomass and seed harvest, offering a good opportunity to select combinations for further intercropping trials. This project has given a more detailed overview of the growth pattern of these varieties, facilitating a better variety selection for future research projects. The results showed that there was variation in lodging resistance amongst the cereals. From informal interviews with growers, it was found that there are farmers interested in alternative varieties for organic farming, where there is potential to produce protein rich animal feed. The aim of this research was to gain more information on these crops, mostly old varieties, and landraces, to provide more insight into which varieties of pea and cereals that are particularly well suited for further research on organic intercropping systems. The results were discussed in relation to agroecological knowledge and development, and the facilitation of organic farming and intercropping. As such, they have potentially wide practical applications and implications, including facilitating an increase in production and consumption of Swedish produced legumes an cereals, potentially contributing to a reduction in (or a more sustainable) meat production and consumption, and helping conserve agro-genetic diversity and aid in diversification of cropping systems, all of which are necessary for mitigating and adapting to climate change and for transitioning to a more sustainable food system.

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Popular science summary

In the pursuit of sustainable and resilient agriculture, organic farming, intercropping – where multiple crops are grown in the same field, and the conservation of traditional, ‘heritage’ crops emerge as promising strategies. Despite this potential, a gap exists in our understanding of suitable crop varieties for organic intercropping, hindering the progress towards more sustainable agricultural practices. The Swedish government has aimed for 30% of farms to be organic by 2030, so efforts should be made to facilitate the success of organic farming. Recognizing this, research field trials were conducted at the Swedish University of Agricultural Sciences, campus Alnarp, to reveal more information about which varieties are suitable for intercropping under organic conditions. This research is important because aside from the general sustainability issues associated with agriculture, we have lost 75% of crop plant genetic diversity in the last century, and this diversity is important for addressing challenges such as climate change.

The study investigated 10 intercrops with different varieties of peas planted with oat, and 38 different old varieties of wheat, barley, and oats. The trials measured height, length, maturity times and yield, revealing significant variations across the varieties. The outcomes offer potential combinations for further trials, which can help us know more about how to transition to a more sustainable agriculture, whilst preserving our agri-cultural heritage. Farmer participation was highlighted as essential in this process and the research suggested a shift towards plant breeding that involves collaboration between breeders, scientists, and farmers. The study recommends testing the varieties and farming practices on real farms, managed by real farmers, with a close dialogue between farmers and researchers. The implications of the study extend widely, potentially facilitating a reduction in meat production and consumption in Sweden, conserving biodiversity and helping to create farming systems that benefit people and planet.

I jakt av hållbart och motståndskraftigt jordbruk framstår ekologisk odling, samodling (där flera grödor odlas på samma fält), samt bevarandet av traditionella ’kulturarvs’ grödor som lovande strategier. Trots denna potential, finns det en lucka i vår förståelse av lämpliga sorter för ekologisk samodling, vilket hindrar framstegen mot ett mer hållbart jordbrukssystem. Den svenska regeringen har som *mål att 30% av våra odlingar ska vara ekologiska år 2030, så vi måste hjälpas åt för att underlätta framgången för ekologisk odling. Med detta i åtanke utfördes forskningsfältförsök vid Sveriges Lantbruksuniversitet, campus Alnarp, för att avslöja mer information om vilka sorter som är lämpliga för samodling under ekologiska förhållanden. Denna forskning är viktig eftersom, förutom de allmänna hållbarhetsfrågorna som är förknippade med jordbruk, har vi förlorat 75% av den genetiska mångfalden hos grödor under det senaste århundradet, och denna mångfald är viktig för att hantera utmaningar som klimatförändringar.*

Studien undersökte 10 samodlingar med olika sorter ärtor som planterats med havre, och 38 olika gamla sorter av vete, korn och havre. Vi mätte höjd, längd, mognadstider och avkastning, vilket avslöjade betydande variationer mellan sorterna. Resultaten erbjuder potentiella kombinationer för ytterligare försök, vilket kan hjälpa oss att veta mer om hur man övergår till ett mer hållbart jordbruk samtidigt som man bevarar vårt jordbruks-kulturarv. Deltagande av lantbrukare framhävdes som väsentligt i denna process, och studien förslog en övergång mot växtförädling som innefattar samarbete mellan förädlare, forskare och odlare. Studien rekommenderar att testa sorterna och odlingstekniker på riktiga gårdar, driven av riktiga odlare, med nära dialog mellan lantbrukare och forskare. Studiens implikationer sträcker sig brett och kan potentiellt underlätta en minskning av köttproduktionen och konsumtionen i Sverige, bevara biologisk mångfald och bidra till att skapa jordbrukssystem som gynnar människor och planeten.

An investigation of pea and cereal varieties

For organic intercropping in Sweden.

A FACT SHEET AIMED TOWARDS CROPPING SYSTEMS ECOLOGY RESEARCHERS

Organic farming, intercropping and the conservation of landraces are agroecological methods of transitioning to a sustainable and resilient agricultural system, however there is a lack of data on varieties suitable for organic intercropping. Therefore, farmers may benefit from increased knowledge in this area. Field trials were conducted to assist further variety selections for intercropping trials at the Swedish University of Agricultural Sciences, campus Alnarp.

PROBLEM STATEMENT

There is an acute need for a transition to more sustainable agriculture. in 2017, a plan was put in place by the Swedish government to increase the total proportion of organic farming in Sweden to 30% by 2030 (Jordbruksverket, 2022). There are numerous barriers to expanding organic agriculture and one of them is a lack of varieties adapted to organic conditions (Wolfe et al., 2008). According to FAO (2001), it is estimated that 75% of the genetic diversity of crop plants was lost in the last century. This is a problem because diverse genetic material is important for plant adapting agriculture to conditions such as climate change (Andersen, 2012). Modern varieties are bred for high input farming with increased yield levels (Newton et al, 2011) and these varieties are not always suitable for low-input or organic farming (Löschenberger et al., 2008, cited in Konvalina et al., 2013). Therefore, there is a need to develop and select varieties and cropping systems suitable for organic and agroecological farmers.

DESCRIPTION OF THE RESEARCH PROJECT

Intercrops of 11 older pea varieties with oat, and 38 varieties of cereals, mostly landraces, were planted in sole crops. Length and maturity times of the intercrop trials were measured and analysed at regular time intervals for around 15 weeks, for the cereals the same was done with height and maturity times. Yield was also recorded for the cereal trial.

Figure 1. Photograph of part of the cereal trial showing strips of different cereal varieties

RESEARCH QUESTIONS

- **Are there similar maturity times for biomass harvest/grain harvest among the cereal and pea varieties?**
- **Is there a variation in lodging resistance between the cereal varieties?**
- **Are there differences in height (cereal) and length (pea) development between the different varieties?**
- **Do the cereal varieties differentiate in yield under organic growing conditions?**

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Results and recommendations.

RESULTS

The results showed a variation in height, length, and maturity times across the varieties, which in many cases overlapped or were similar, offering a possibility to select combinations for further trials.

Figure 2. Photograph of one of the pea and oat intercrops.

At harvest, height of cereals ranged from 41 - 116cm. 6 of the cereals had partially or fully lodged. Length of the peasat harvest ranged from 40 - 83cm. Yield ranged from approx 1250-4000kg per hectar. The variations in height, length, maturity times and yield could have different advantages and disadvantages in an organic intercrop setting.

RECOMMENDATIONS

Farmer participation and perspective are crucial to developing varieties for organic farming. Going forward, this research could be developed into something that resembles evolutionary participatory breeding (EPB) or participatory variety selection (PVS). EPB emphasizes the utilization of natural selection on genetically diverse populations, and utilizes the skills and knowledge of both breeders and farmers to develop heterogenous landrace populations (Murphy, 2004). PVS is a breeding approach that brings breeders, social scientists and farmers together in a field setting in order to prioritize and target traits of importance. It also helps to identify and assess traits that are important to small scale farmers (Bellon 2002, in Kolech et al., 2017). It is possible that these methods could be used to develop varieties even more fit for these systems than the current dominant breeding methods. We recommend that these varieties and cropping systems be tested on real farms, managed by real farmers, with a continual dialogue between farmers and researchers in terms of observations about the crops and recommendations for future trials. Furthermore, we recommend continuing with the intercrop trials for a further two years, in different locations, to discover whether the results of this trial are reliable. In addition, we recommend that other cereal varieties from this trial be tested in organic intercrops with the pea varieties from the intercrops, in further field trials, based on the results on the maturity time in this study.

Figure 3. Pea flowers of variety Maglaby.

IMPLICATIONS

These recommendadions have potentially wide practical applications and implications, including facilitating a more feasible, sustainable and profitable legume production in Sweden, potentially contributing to a reduction in meat production and consumption, and helping conserve agro-genetic diversity and aid in diversification of cropping systems, all of which are necessary for mitigating and adapting to climate change.

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