Comparative analysis of Faba bean (*Vicia faba*) genotype-phenotype relationships in pure versus mixed culture with cereals

Assessing predictability and performance

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Comparative analysis of Faba bean (*Vicia faba*) genotype-phenotype relationships in pure versus mixed culture with cereals. Assessing predictability and performance.

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Abstract

There is a growing interest in diversifying agricultural systems both in Sweden and globally, particularly through the use of intercropping systems with legumes and cereals. These types of systems provide potential benefits such as increased biodiversity, reduced dependency on nitrogen fertilizer, and increased resource-use efficiency. Legumes, such as faba bean, are particularly promising due to the plant's ability to form symbiotic relationships with nitrogen-fixating bacteria, thereby reducing input needs and improving soil fertility. However, the success of these intercropping systems are dependent on functional compatibility and complex inter- and intraspecific plant-plant interactions, which in turn are strongly influenced by the phenotypic plasticity of the crop components of the intercrop.

The aim of this thesis was to examine whether or not trait plasticity of faba bean is different when it is grown in pure and mixed cultures, and whether different neighbouring crops affect the faba bean differently. Finally, to determine whether or not it is possible to predict traits and phenotypes of faba bean grown in mixed cultures from their corresponding phenotypes found when grown in pure culture. The study was conducted based on data from a field trial in Uppsala 2024 (Sweden), where two varieties of faba bean ('Stella' and 'Vertigo') were grown as pure cultures and as mixed cultures with spring oat and spring wheat, with two different fertilizer treatments (no N and +N).

Grain yield showed significant differences both between pure and mixed cultures, and with different neighbours, with faba bean overall having higher yields compared to cereals. The land equivalent ratio showed a significant difference between the no N and +N treatments, with mixture grown with no N being able to utilize a smaller land area to produce the same yield of aboveground dry biomass. Trait plasticity analysis, especially for later stages, showed significant differences for faba bean in trait plasticity of aboveground dry biomass under different fertilizer treatments for different neighbours (faba bean, spring oat and spring wheat) as well as mixtures grown with no N tending to exhibit an increased trait responsiveness to intercropping. In biomass traits for cereals, although no significant difference was seen between different neighbours or fertilizer treatments, mixed cultures tended to exhibit a decrease or suppression in trait responsiveness to intercropping.

This thesis concluded that significant effects on trait plasticity were more frequently observed later into the growing season, especially under no N treatments. This suggests a stronger contribution due to environmental factors increasing over time.

Keywords: faba bean, *Vicia faba*, trait plasticity, intercropping, mixed cultures, cereals, land equivalent ratio, phenotypic traits, Sweden

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Abbreviations

%Ndfa	Proportion of Nitrogen Derived from the Atmosphere
BNF	Biological Nitrogen Fixation
DAS	Days After Sowing
fun	Fixation Under Nitrate
LER	Land Equivalent Ratio
N	Nitrogen
N_2	Nitrogen gas
NH_3	Ammonia
SDG	Sustainable Development Goal
SNF	Symbiotic Nitrogen Fixation
SPAD	Soil Plant Analysis Development

1. Introduction

There is a growing interest in diversifying agriculture globally, both through the crops being grown, different types of cropping systems and cultivation practices. This shift has been caused by a combination of environmental, social and economic factors – ranging from biodiversity loss and climate change to the increasing need for alternative protein sources, more stable yields and sustainable agricultural practices (Röös et al. 2018). In organic farming systems, intercropping has been a common practice to reduce the need of inputs commonly used in conventional farming systems, such as mineral fertilizers and pesticides. Willey (1979) defines intercropping as "a method of crop diversification, where two or more crops are cultivated simultaneously on the same plot of land", where intercropping is considered to be an umbrella term that includes many different cropping systems, with both spatial and temporal variations. Through the introduction of crops such as legumes and new ecological mechanisms, the use of nitrogen fertilizer could be reduced through biological nitrogen fixation (BNF). In addition, pest and disease pressure could be reduced through increased spacing and species diversity which breaks up pathways of transmission and disruption of pest movement (Brooker et al. 2015, Fogelfors 2015, Yu et al. 2022).

In Sweden, legume-cereal intercropping systems are among the systems that have seen the most interest as a strategy to increase biodiversity, resource-use efficiency, and resilience in agriculture. Through the combination of BNF of the legume crop and the high productivity of the cereals, intercropping between these two crop types can enhance soil fertility, reduce dependency of mineral fertilizers, and possibly promote ecological intensification (Fogelfors 2015, Hauggaard-Nielsen & Jensen 2001, Jensen et al. 2020). However, the success of an intercropping system is heavily dependent of functional compatibility and plant-plant interactions between the different crops. Traits including plant architecture, nutrient uptake strategies and stress responses all contribute to the performance of an intercrop, where the traits are inherently tied to the genotypes of the crops involved. A central challenge in the design of these systems is therefore to understand how different genotypes of the same crop interact with different neighbour when placed under conditions with mixed cultivation practices. These genotype-phenotype relationships are modulated by the plant's phenotypic plasticity, which is the ability of the plant to alter form, function and development in response to the surrounding environment (Bradshaw 1965, Demie et al. 2022, Hauggaard-Nielsen & Jensen 2001, Nicotra & Davidson 2010).

To facilitate the increasing interest in the adaptation of intercropping systems in Swedish conditions, there is a need to further investigate how these systems work, how different crops and varieties interact with each other, and how these interactions affect the overall growth, performance and predictability of these intercropping systems in comparison to the corresponding monocultures.

1.1 Faba bean

Faba bean (*Vicia faba* L.) is an annual, self-pollinating leguminous plant of the Fabaceae family which originates from the Middle East, believed to have been domesticated as early as the 11th millennium cal BP (Caracuta et al. 2015, Caracuta et al. 2016, Fogelfors 2015). It is one of the most cultivated grain legume crops around the world and used for both human consumption as a grain legume and animal feed as a forage crop (Caracuta et al. 2016, Patrik & Stoddard 2010). The crop is typically divided into three main varietal groups: *major* (broad bean), *equina* (horse beans and field beans), and *minor* (tic beans), based on seed size (Fogelfors 2015, Inés Mínguez & Rubiales 2021).

The faba bean has a root system consisting of a taproot with secondary lateral roots, where nodules typically develop in the root hairs of the upper lateral roots. The majority of the roots can be found in the topsoil, but meter-deep root systems have been observed in well-structured soils (Fogelfors 2015, Inés Mínguez & Rubiales 2021). Aboveground, the faba bean grows with robust, but hollow stems. Branching could occur from the basal leaf axils, but is variable due to cultivar, nutrient and water supply as well as sowing density. The canopy height similarly varies with environment and growing conditions but generally ranges between 0.5-1.80 m (Inés Mínguez & Rubiales 2021). Each plant can produce between 50-150 flowers throughout the growing season, where the flowering begins at the lower part of the plant and works its way up the nodes over a period of approximately four weeks (Fogelfors 2015, Inés Mínguez & Rubiales 2021, Patrick & Stoddard 2010). The flowers are self-pollinating but yield greatly benefits from cross-pollination by insects (Fogelfors 2015, Raderschall et al. 2020). When flowering is completed, the faba bean produces seed pods that contain 2-10 seeds depending on varietal group and cultivar, with seed sizes ranging from 0.15-3.5 g per seed (Fogelfors 2015, Inés Mínguez & Rubiales 2021).

1.1.1 Symbiotic nitrogen fixation

One of the most important ecosystem services that faba bean and other legumes provide is BNF, where legumes form symbiotic relationships with nitrogen-fixating bacteria, so called rhizobia. This process is also known as symbiotic nitrogen fixation or SNF (Fogelfors 2015, Jensen et al. 2010). The legume-rhizobia symbiotic relationship is a mutualistic relationship where the rhizobia provide the legume with plant-available N in the form of NH_3, whilst the legume provides the rhizobia with carbon in the form of sugars. This interaction takes place in the nodules of the legume, where an anaerobic environment is formed necessary for housing the rhizobia using leghaemoglobins to regulate oxygen levels. In the nodules, the rhizobia capture atmospheric N in the form of N_2 and then reduce it to NH_3, a process possible through catalysation by the enzyme nitrogenase (Jensen et al. 2010, Hoffman et al. 2014, Mus et al. 2016).

In faba bean, the capacity of forming symbiotic relationships for BNF is dependent on both environmental factors and management practices, where the use of fertilizer has a major impact (Jensen et al. 2010, Fogelfors 2015). In unfertilized cropping systems, faba bean is able to cover 60-92 % of its N requirements using BNF, reducing the need for N fertilizer (Jensen et al. 2020, Fogelfors 2015). In traditional intercropping systems of legume-cereals, faba bean is considered less competitive in acquiring N from the soil compared to cereals. As a result, the faba bean is stimulated to increase N uptake through BNF, unless the system is fertilized in which case BNF efficiency could be inhibited, especially under high levels of N application (Fan et al. 2006, Hauggaard-Nielsen & Jensen 2001, Jensen et al. 2020, Zhang et al. 2024).

1.1.2 Legume and faba bean production in Sweden

Since the year 2000, legume production in Sweden has been increasing and reached its peak so far in 2016. At that time, the total area of legume production covered 65,000 ha, where approximately 11,000 ha were organically cultivated (Jordbruksverket 2022, Jordbruksverket 2024a). In 2024, legume production in Sweden covered 49,100 ha, where faba bean accounted for 33 % of the total production area, covering an area of approximately 16,200 ha (Jordbruksverket 2024a). Additionally, Sweden imports more than 40,000 tonnes of pulses (including canned) per year and the import has been steadily increasing during the last decade. To replace these imports with locally produced equivalents, the land used for legumes cultivation would need to increase by 8,000 ha. To replace the total import of legumes including soybean products, the necessary increase would measure at 140,000 ha, which would equal an area larger than Öland (Jordbruksverket 2022).

Currently, only a small percentage of legumes produced locally in Sweden enters the public market. Instead, the majority is directly used by the producing companies through captive consumption. This is especially true for faba bean production, where most of the harvest is used for animal feed. In 2020, the total consumption of legume and soy products in Sweden reached 423,300 tonnes, with around 11 % used for human consumption. This number is expected to rise with the increased demand for plant-based food products (Jordbruksverket 2022). With growing concerns over climate change, there has been an increased demand for alternative and locally produced protein sources. In Röös et al. (2018), a scenario is described where half of the meat consumption is replaced with legumes and pulses. To achieve this, an additional 26,500 ha of land would need to be converted to legume production. The study also highlights the need for furthering research in agricultural practises and breeding efforts for legumes to better suit Swedish conditions. Another vital part of legume production that Sweden lacks are local processing facilities. Major investments are needed to expand the relatively new industry of processing and refining plant-based proteins and meat alternatives that began to emerge with companies including Färsodlarna, Lupinta and GroPro (Jordbruksverket 2022).

Promoting domestic legume production could represent a more climate-adapted, resilient and self-sufficient food security system. By increasing the use of legumes in crop rotations, the agricultural landscape in Sweden would see a reduced need of using synthetic N fertilizers as well as reducing the need for importing protein crops, lowering greenhouse gas emissions in the process (Fogelfors 2015, Jordbruksverket 2022, Röös et al. 2018). This aligns with several of the United Nations Sustainable Development Goals (SDG), such as SDG2 – *Zero Hunger*, SDG12 – *Responsible Consumption and Production*, SDG13 – *Climate Action*, and SDG15 – *Life on Land* (UN 2025).

1.2 Plant-plant interactions

Interactions between plants can be divided into intra- and interspecific interactions, which can be further divided into competitive, facilitative or complementary depending on negative or positive effects on the respective plants. Competitive interactions include competition for resources including light, water and soil nutrient. Facilitative interactions refer to supportive mechanisms between plants that include resource enrichment, pest protection and microclimate modifications, through the creation of habitats and resources for predators, barriers, and release of root exudates. Complementary interactions include niche differentiation between different plants, such as differences in height and light requirements that in turn promote light interception and use efficiency, or resource partitioning (Brooker 2006, Brooker et al 2015, Lambers et al. 2008, Wendling et al. 2017, Yu et al. 2022).

1.2.1 Phenotypic plasticity

Plasticity or phenotypic plasticity is defined as the ability of a single genotype to express multiple alternative phenotypes based on environmental conditions

(Bradshaw 1965). This flexibility in phenotype expression of key traits allows for plants to optimize growth and survivability under various conditions and across different environments (Bradshaw 1965, Nicotra & Davidson 2010).

Phenotypic plasticity can be divided into two main categories: morphological plasticity and physiological plasticity (Bradshaw 1965). Morphological plasticity refers to changes in plant structures. Such acclimations include alterations of root architecture in response to nutrient or water deficiencies in the soil, changing leaf shape and orientation to improve light capture, and stem elongation as a shade avoidance mechanism. Physiological plasticity refers to acclimations in metabolic and physiological processes. Acclimations in this context include high transpiration rates in response to warm weather and the ability to adjust stomatal conductance to fluctuating weather conditions (Nicotra & Davidson 2010). Sometimes a third category is included, namely reproductive plasticity. Acclimations in reproductive traits include variable flowering time as a response to temperature changes, as well as seed number and size as a response to stress or competition (Guo et al. 2020).

Phenotypic plasticity is driven by combinations of genetic and environmental factors and the degree of plasticity a plant can express is largely controlled by its genetic makeup (Hauggaard-Nielsen & Jensen 2001, Demie et al. 2022). There are genotypes that have a higher capacity for plasticity compared to others due to specific gene expressions responsible for regulating stress responses, metabolic adjustments, growth regulation, as well as hormone signalling pathways for hormones such as auxins and gibberellins, which play a key role in mediating plastic responses (Jia et al. 2022, Lambers et al. 2008, Nakayama et al. 2017). There is mixed evidence for whether or not a greater plasticity is correlated with costly trade-offs for the plant. If plasticity was cost-free, every organism would express optimal traits in every environment, which has not been observed in nature (Schneider 2022). The ability to regulate growth and trait expression based on environmental conditions requires maintenance costs of sensory and regulatory processes compared to species with more fixed traits. However, for many traits, these costs are difficult to detect, vary by environment, and may be only become apparent under stress or competition with other plants (DeWitt et al. 1998, Schneider 2022).

In plant breeding, there are two concepts known as robustness and canalization (Alseekh et al. 2025). Robustness refers to a focus on the breeding of high-plasticity cultivars that give consistent yields across different environments, where yields often are lower. Whilst canalization is defined as “the ability to produce a consistent phenotype in spite of variable genetic and/or environmental features” or the 1990’s re-defined “the genetic capacity to buffer phenotypes against mutational or environmental perturbation”. Canalization focuses on breeding low-plasticity cultivars with consistently high yields in specific environments (ibid.).

1.2.2 Intercropping

In intercropping systems, crops are required to adjust growth and resource allocation for both above- and belowground biomass in response to neighbouring cultivars or species. This leads to complex dynamics of intra- or interspecific plant-plant interactions, which shape the productivity of the system, where successful intercropping systems typically focus on crops with different functional traits, to allow for complementary interactions, rather than competition (Ajal et al. 2022, Bargaz et al. 2021, Bedoussac et al. 2015, Benmrid et al. 2024, Zhang et al. 2024).

Traditional intercropping systems, such as cereal-legume systems, are expected to have a higher land-use efficiency compared to monocultures, to increase yields and to increase yield-stability with less input into the system (Bedoussac et al. 2015, Fogelfors 2015, Li et al. 2023, Yang et al. 2025). This is due to complementary growth patterns in canopy and root systems, as well as nutrient acquisition strategies and water uptake. The cereal being more competitive in acquiring N from the soil would stimulate the legumes to move over to acquiring N to BNF, resulting in a more efficient N use compared to respective monoculture (Benmrid et al. 2024, Fogelfors 2015, Hauggaard-Nielsen & Jensen 2001, Jensen et al. 2020, Pelzer et al. 2014). In addition to the expectation of a reduced need for fertilizer, intercropping systems could provide additional advantages compared to monocultures through reduced weed, pest and disease pressure (Fogelfors 2015, Li et al. 2023). Intercropping systems affect weed species differently especially when including factors such as different fertilizer treatments, where systems with N fertilizer added show a stronger response in weed biomass accumulation compared to N-limited systems (Jäck et al. 2021).

In a study investigating wheat-faba bean intercropping Xiao et al. (2018) found interspecific competition to be dominant during the early growing season, resulting in lower biomass accumulation especially for the faba bean component. Contrary, during mid- to late growing season, competition and complementation co-existed and rather increased the wheat biomass accumulation compared to the monoculture.

In another study reported by Fan et al. (2006), the growth pattern of a faba bean-wheat intercropping systems was substantially different compared to respective monocultures, where faba bean was supressed. There was a decrease in grain yield in the intercropping system regardless of N supply and LER decrease compared to respective monocultures. In addition, the study by Fan et al. (2006) also found that the percentage of N derived from the atmosphere (%Ndfa) increased in the intercrop compared to the faba bean monoculture.

Grain yields increased for both components of a faba bean-wheat intercrop compared to respective monocultures in a study by Zhang et al. (2024), where the biomass of the faba bean in the intercrop was also higher compared to the monoculture, specifically during mid- to late growing stages. The study by Zhang et al. (2024) also compared different fertilizer treatments and found that increased

N rates resulted in decreased LER, suggesting that the level of fertilizer use plays a major role in the performance of the intercrop and its competitive advantage to monocultures.

A common measure used to compare monocultures with intercrops is the concept of overyielding (Wendling et al. 2017, Yang et al. 2022). Overyielding occurs in a mixture when the biomass production of the mixture is greater than that of the average of the corresponding monocultures of the species in the mixture (Schmid et al. 2008). Whilst overyielding generally is a measure used in ecology and biodiversity experiments, to farmers interested in achieving high yields and remaining economically competitive, it is not the best approach. Contrary, by definition overyielding mixtures could have higher yields than the combined average of the crops in the mixtures but still be worse that the average of the best performing crop in mixture. An extension of the concept of overyielding is the use of transgressive overyielding, which occurs when a mixture's biomass (or yield) production is greater than the biomass (or yield) of the most productive monoculture contained in the mixture (Loreau & Hector 2008, Gravel et al. 2012, Schmid et al. 2008).

1.3 Aims and hypotheses

The aim of this thesis was to study two contrasting faba bean varieties when grown in pure versus mixed culture with cereals (spring wheat and spring oat). The following research questions and hypotheses were addressed:

(1) RQ1 Is it possible to predict phenotypic expression of faba beans grown in mixed cultures based on traits and phenotypes found in faba beans grown in monoculture?
Hypothesis 1: Traits and phenotypes of faba bean grown in mixed culture can be predicted from their corresponding phenotypes found when grown in pure culture.
$H1_0$: It is not possible to predict traits and phenotype expression in faba bean grown in mixed culture based on corresponding phenotypes found in pure culture.

(2) RQ2 Is trait plasticity of faba bean different for plants grown in monoculture compared to plants grown in mixed cultures with cereals?
Hypothesis 2: Plasticity in faba bean differs between plants grown in pure culture and plants grown in mixed culture with cereals.
$H2_0$: There is no difference in plasticity between faba bean grown in pure versus mixed culture.

(3) RQ3 Is trait plasticity in faba bean affected differently by having different neighbouring plants?
Hypothesis 3: Different neighbours affect traits and phenotypes differently, resulting in differential plant-plant interactions.
$H3_0$: There is no difference in plasticity between faba bean grown in mixed culture with different neighbours.

The overarching purpose of this study and following results is to further the knowledge into differences in plasticity of faba bean between pure and mixed culture, and to understand mechanisms behind crop responses to being cultivated in these types of systems. Finally, the study aims to provide insight needed for future field trials regarding the *fun* mutant (fixation under nitrogen), a mutant of the faba bean cultivar 'Vertigo' bred for the purpose of being able to perform BNF in conditions with +N fertilizer use, for the N2CROP project. The N2CROP project aims to use legume SNF as a foundation for producing high-quality and nutritious plant-based protein in sustainable agri-food systems, through enhancing legume N-fixation and output, especially in intercrops (N2CROP 2025).

2. Methodology

2.1 Research site

The N2CROP field trial was conducted at the Säby field trial site of the Swedish University of Agricultural Sciences (latitude: 59°50'33.1", longitude: 17°42'02.3"), in Uppsala, Sweden. The soil at the trial site is a mmh ML (SWE: måttligt mullhaltig mellanlera), where the topsoil at 0-20 cm depth has a pH of 6.4 and a soil organic matter content of 5.5 %.

The crop growing season in the area ranges from April to September, with an average annual temperature of 7.1°C and an annual average precipitation of 563 mm. The weather conditions for the 2024 field season were warmer and drier compared to the most current Climatological Standard Normals for the period 1991-2020 for Uppsala (Figure 2.1).

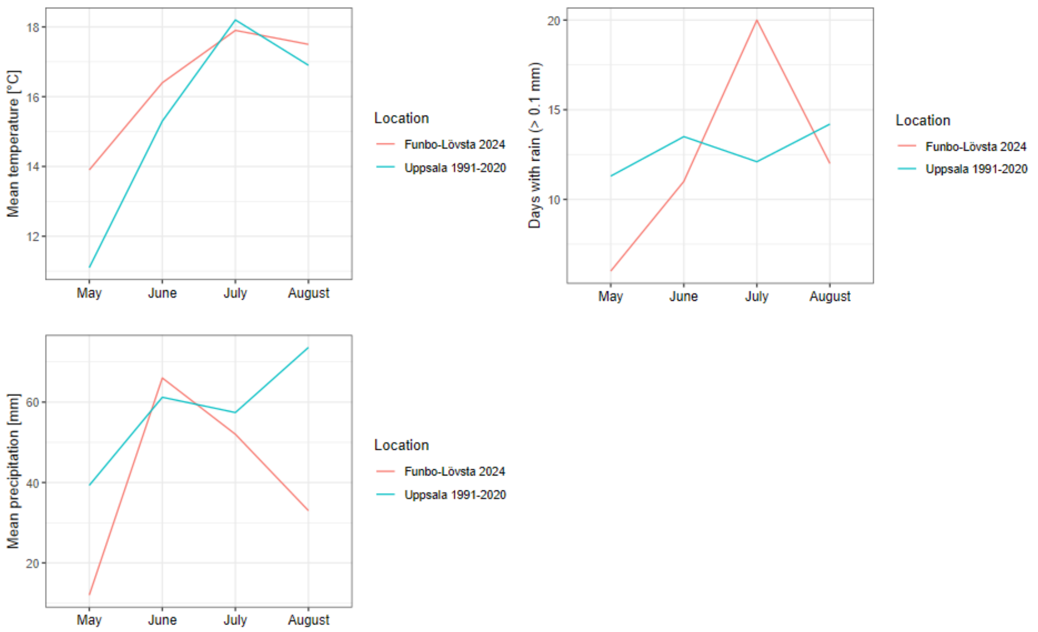

Figure 2.1 Comparison of weather conditions for May-August 2024 at the field trial site in Säby with the Climatological Standard Normals for the period 1991-2020 for Uppsala. *Weather data from Lantmet (Funbo-Lövsta weather station) for (a) mean monthly temperature in degrees Celsius,*

(b) mean monthly precipitation, as well as (c) average number of days with >0.1 mm rain for Uppsala (SMHI 2024). Data from: Lantmet 2025, SMHI 2024, SMHI 2025.

2.2 Field trial and experimental design

The field trial was planned at the N2CROP consortium in 2023. The crops were sown on the 7th of May 2024, with final harvest occurring on the 29th of August 2024. A split plot randomized block design was used (Appendix 1), with the experimental factors including two N applications (0 kg N ha^{-1} and 140 kg N ha^{-1}) and eight different cropping systems including two varieties of faba bean (*V. faba* cv. 'Stella' and *V. faba* cv. 'Vertigo'), spring wheat (*T. aestivum* cv. 'Thorus') and spring oat (*A. sativa* cv. 'Delfin'), and further described in Table 2.1 and Figure 2.2-2.3. The 'Vertigo' variety was chosen as it was the origin of the *fun* mutant, whilst the other varieties were chosen for their high yields and popularity. In Sweden, 'Thorus' is not known for high yields, but is popular in organic farming. Both faba bean varieties are also early in maturity, which is a prerequisite for having a functioning intercropping system with cereals.

***Table 2.1 Description of cropping systems used in the field trial**. Type of cropping system (pure or mixed culture), cultivars used for each crop and seed rate per square meter.*

		Seed rate (seeds/m^2)	
Type	**Crop or crop mixture**	**Faba bean**	**Cereals**
Monoculture	Faba bean cv. 'Stella'	40	-
Monoculture	Faba bean cv. 'Vertigo'	40	-
Monoculture	Spring wheat cv. 'Thorus'	-	520
Monoculture	Spring oat cv. 'Delfin'	-	400
Mixed culture	Faba bean cv. 'Stella' x Spring wheat cv. 'Thorus'	20	260
Mixed culture	Faba bean cv. 'Stella' x Spring oat cv. 'Delfin'	20	200
Mixed culture	Faba bean cv. 'Vertigo' x Spring wheat cv. 'Thorus'	20	260
Mixed culture	Faba bean cv. 'Vertigo' x Spring oat cv. 'Delfin'	20	200

The field trial was divided into 104 plots of 1.75 m x 12 m. There were four replicates of each combination of fertilizer x cropping system including buffer zones/border plots. During autumn 2023, the trial site was ploughed and tilled prior to catch crops being sown and fertilized with PK 11-21 (218 kg ha^{-1}). Before the start of the field trial in spring 2024, the plots used for growing spring crops were tilled twice before sowing. Crops were sown with a sowing distance of 12.5 cm (Table 2.1). The plots with the +N fertilizer treatment were fertilized with Axan (520 kg ha^{-1}). No additional pesticide or fertilizer treatments were used prior to harvest.

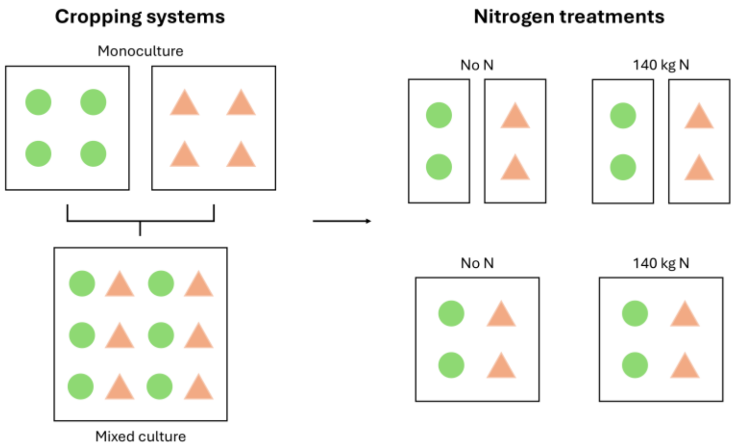

Figure 2.2 Conceptual figure of cropping systems and fertilizer treatments included in the experimental design.

In addition to the spring crops, a combination of winter faba bean (*V. faba* cv. 'Arabella') and winter wheat (*T. aestivum* cv. 'Pondus') were included in the original experimental design (both as pure and mixed cultures). However, the winter faba bean crop did not survive the April weather conditions and thus neither the winter faba bean nor the winter wheat were further considered in this report. Plot 63 ('Stella' + 'Delfin') was excluded from calculations due to not being sown properly.

Figure 2.3 Field trial in Säby, Uppsala (6/8-2024). *Examples of growth in plots from (a) plot 3-4, (b) plot 9, (c) plot 19, and (d) plot 22-23. Photo credit: Electra Lennartsson (used with permission).*

2.3 Measurements of phenotypic traits

2.3.1 Sampling

The samplings were conducted at 50 days after sowing (DAS) on June 25th (before faba bean flowering, BBCH 58 for faba bean and BBCH 59 for cereals), 73 DAS on June 19th (after faba bean flowering) and 92 DAS on August 6th (before faba bean pod maturity). During the second sampling the fourth replicate (plots 79 through 104) were mistakenly left in the field and were therefore not included in the calculations.

The growth stage of both faba bean and cereals were approximated at 50 DAS using the BBCH scale according to a field trial protocol developed within the EU project DIVERSify (Kiær et al. 2020). No data was available for 73 and 92 DAS. At each sampling occasion, weed coverage was noted in accordance with a scale from 0-5, with 0 being having no weeds.

For each plot, all aboveground biomass (incl. weeds) within a 0.25 m^2 square was collected, cut at approximately 1.5 cm above ground. Weeds and crops were separated, and the crops further divided into stem, leaves and pods/heads. Faba beans and cereals were measured for fresh weight separately, both for monocultures and mixed cultures. Additionally, the number of pods/heads were counted.

2.3.2 Measurements for nitrogen content

At 50, 73 and 92 DAS, the leaf chlorophyll content was measured on the uppermost, fully developed leaf (excluding flag leaf on cereals) for five plants per variety for each plot of the field trial using a chlorophyll meter (SPAD-502, Konica Minolta Sensing Inc., Japan). The chlorophyll meter measures absorbance at 650 and 940 nm (near-red to red wavelengths) of the leaves and calculates a dimensionless SPAD-value. This value is proportional to the amount of chlorophyll in the leaves, which is proportional to the N content in the leaves (Kiær et al. 2020, Konica Minolta Inc. 2009)

The measurements for 92 DAS were excluded from the analysis as several cereal plants had reached maturity.

2.3.3 Dry biomass of stem, leaves and pods/heads

The plant samples were stored in individual paper bags according to crop and plant part (stem, leaves, pods/heads or weeds) and dried for up to four days in an oven at 60°C. Samples were kept in the ovens until right before being weighted, where the samples were measured in grams with an accuracy of two decimals.

2.3.4 Harvest and grain yield

The final harvest was conducted on the 30th of August where 10.5 m^2 (1.75 x 6 m) of the total area of each plot was harvested. For each plot the combined total of the grain yield was measured in kg with an accuracy of three decimals. The samples were cleaned and dried.

Grain yield was compared to standard yields from Jordbruksverket (2024b).

2.4 Defining and quantifying plasticity

Trait plasticity in this study was defined using Yang et al. (2022), where trait plasticity (dimensionless) was defined as:

$$Trait\ plasticity = \frac{trait_{inter} - trait_{mono}}{trait_{mono}} \tag{1}$$

Where positive values indicate an increase in a specific trait when the crop is grown in a mixed culture compared to the same trait assessed in a monoculture, and negative values indicate a reduction of the trait when grown in mixed culture compared to monoculture. Values close to zero instead indicate that the trait remains largely unchanged by the crop being grown in a mixed culture, which would suggest that plasticity is minimal or that the environment does not significantly affect the trait. A higher absolute value (positive or negative) would suggest that the specific trait responds more strongly to intercropping, but whether or not that would imply a higher grade of plasticity depends on if the crop has the ability to consistently adjust when exposed to different contexts.

Plasticity was also evaluated through the concept of land equivalent ratio (LER) as defined by Mead & Willey (1980), which compares the performance of intercrops to the pure cultures of the crops used in the intercropping system (Equation 2).

$$LER = L_A + L_B = \frac{Y_{ia}}{Y_{sa}} + \frac{Y_{ib}}{Y_{sb}} \tag{2}$$

In Equation 2, Y is commonly a harvest trait such as yield or biomass, where ia and ib is crop a and b in the intercropping system, whilst sa and sb is crop a and b as a sole crops or monocultures. In systems where LER > 1, the intercrop has an advantage whilst the opposite is the case for systems where LER < 1. The advantage would imply that the intercrop would need less land area to produce the same amount of yield compared to the corresponding monocultures. Contrary, a disadvantage would mean that the intercrop would need an increased land area compared to the corresponding monocultures to produce the same amount of yield. Overyielding and transgressive overyielding were also considered as measures of trait plasticity in combination with LER. In this study, overyielding was defined as LER > 1, and transgressive overyielding was defined as when LER was greater than the highest of the two corresponding partial LER value (L_A or L_B).

To further describe the effect of fertilizer on trait plasticity, two versions of a fertilizer factor was used. For grain yield, weed biomass and LER, the fertilizer factor was calculated using Equation 3. For plasticity of biomass traits and SPAD, the fertilizer effect was calculated using Equation 4.

$$Fertilizer\ factor = \frac{trait_{+N}}{trait_{noN}} \quad (3)$$

$$Fertilizer\ factor = trait_{+N} - trait_{noN} \quad (4)$$

2.5 Data handling, statistics and data visualization

The statistical software program R with RStudio (version 4.4.1) was used to conduct data processing, statistical calculations and data visualization (R Core Team 2024, Posit team (2025).

To account for the differences in sowing density of pure versus mixed cultures (i.e. density of faba bean in mixed cultures were 50 % of that in pure cultures), the raw data for crop specific data was doubled for mixed cultures prior to analysis.

The data was checked for normality using the Shapiro-Wilk test and visually assessed using Q-Q plots. Homogeneity of variance was evaluated using Levene's test. Due to the limited number of replicates (maximum four replicates per treatment), the robustness of the parametric tests may have been affected as a small number of deviations from homoscedasticity was observed. The model below was constructed to compare variance of different plots as affected by block effects and type of cropping system:

$$\begin{aligned} &model1 \leftarrow lm(trait \sim type + rep, data = data) \\ &model2 \leftarrow gls(trait \sim type + rep, weights \\ &\qquad = varIdent(form = 1|type), data = data) \\ &aov(model2, model1) \end{aligned}$$

Where data for the two varieties 'Stella' and 'Vertigo', as well as the two cereals were separated into different datasets, which were then split into different fertilizer treatments. As per earlier tests, the small number of replicates impacted the overall capability of the model, but the conclusion was that block effects had little to no effect on the variance. Packages used include: *tidyverse* (version 2.0.0) (Wickham et al. 2019), *nlme* (version 3.1-167) (Pinheiro et al. 2025), and *lme4* (version 1.1-37) (Bates et al. 2015).

Statistical comparisons of independent variables and interaction effects were made using a two-way ANOVA, where independent variables were fertilizer treatment (no N and +N), and cropping system/neighbouring plants (type), as well as interaction effects between fertilizer and cropping system/neighbour. The usage of this linear model with fixed effects was chosen as a result of the minimal block effects. The results were then evaluated in post-hoc analysis using Tukey's range test to determine whether or not comparisons within (crop with different neighbours) and between groups (corresponding monocultures and intercrops) were relevant to this study. When conducting statistical comparisons for trait plasticity and LER, additional one-sample t-test was used to compare results to a baseline of zero for trait plasticity and one for LER, which would indicate no change in plasticity in the intercrop compared to pure cultures. In addition, variance components were extracted from the ANOVA mean squares to quantify the genetic (V_g), environmental (V_e), genotype-by-environment interactions (V_{gxe}), and residuals (V_{res}) sources to the total phenotypic variance (V_{tot}) according to Scheiner & Lyman (1989). The variance components were then used to calculate plasticity ($PL = (V_e + V_{gxe})/V_{tot}$), broad-sense heritability ($H = (V_g + V_{gxe})/V_{tot}$), and the heritability component of the plastic variation ($H_{pl} = V_{gxe}/V_{tot}$).

The data was visualized using the R packages *tidyverse*, *patchwork* (version 1.3.0) (Pedersen 2024), and *cowplot* (1.1.3) (Wilke 2024).

3. Results

3.1 Phenotypic traits

3.1.1 Faba bean biomass of leaves, stems and pods

No statistically significant effects on the total aboveground dry biomass were found for any of the experimental factors for neither 'Stella' nor 'Vertigo' (Appendix 3: Table 5.16). Both faba bean varieties generally tended to show a similar aboveground dry biomass between pure culture and corresponding mixtures for both fertilizer treatments at 50 DAS (before flowering) and 73 DAS (after flowering). At 92 DAS (before pod maturity), 'Stella' and 'Vertigo' tended to exhibit a higher aboveground dry biomass in their corresponding mixed cultures compared to the pure cultures for treatments without N. In the +N treatments at 92 DAS, pure cultures tended to exhibit higher aboveground dry biomass, with the exception of the mixed culture of 'Stella' and spring wheat where mean values were similar compared to the corresponding pure cultures (Figure 3.1, Appendix 2: Table 5.2).

Overall, 'Vertigo' tended to perform better in pure culture and in mixed cultures with spring wheat compared to 'Stella', with the exception at 92 DAS for the +N treatments, where 'Stella' tended to perform better than 'Vertigo' (Figure 3.1, Appendix 2: Table 5.2).

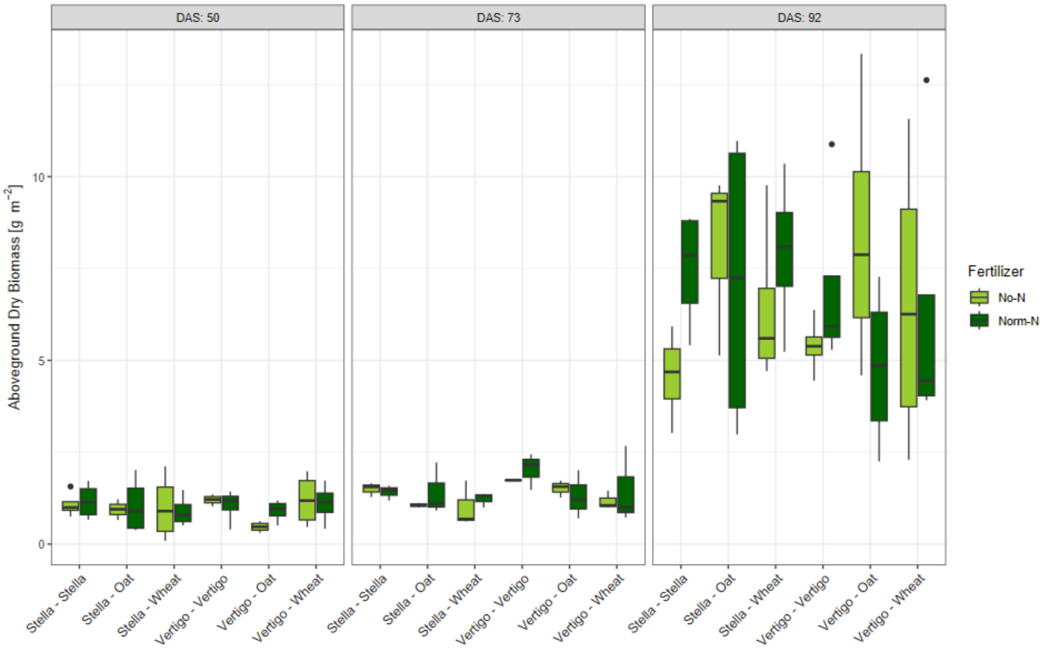

Figure 3.1 Aboveground dry biomass for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of total aboveground dry biomass per square meter for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Black dots indicate outliers, and black lines indicate median values.*

No significant effects on dry biomass of leaves, stems or pods were found for any of the experimental factors for either variety (Appendix 3: Table 5.17-5.19). Overall, the dry biomass of leaves, stems and pods followed a similar pattern to the total aboveground dry biomass, with 'Vertigo' tending to higher mean values in treatments with no N, whilst 'Stella' tended to exhibit higher mean values in +N treatments. 'Vertigo' consistently tended to exhibit the highest values for both leaves, stems and pods in the pure cultures, especially at 73 and 92 DAS (Figure 3.2, Appendix 2: Table 5.1-5.2).

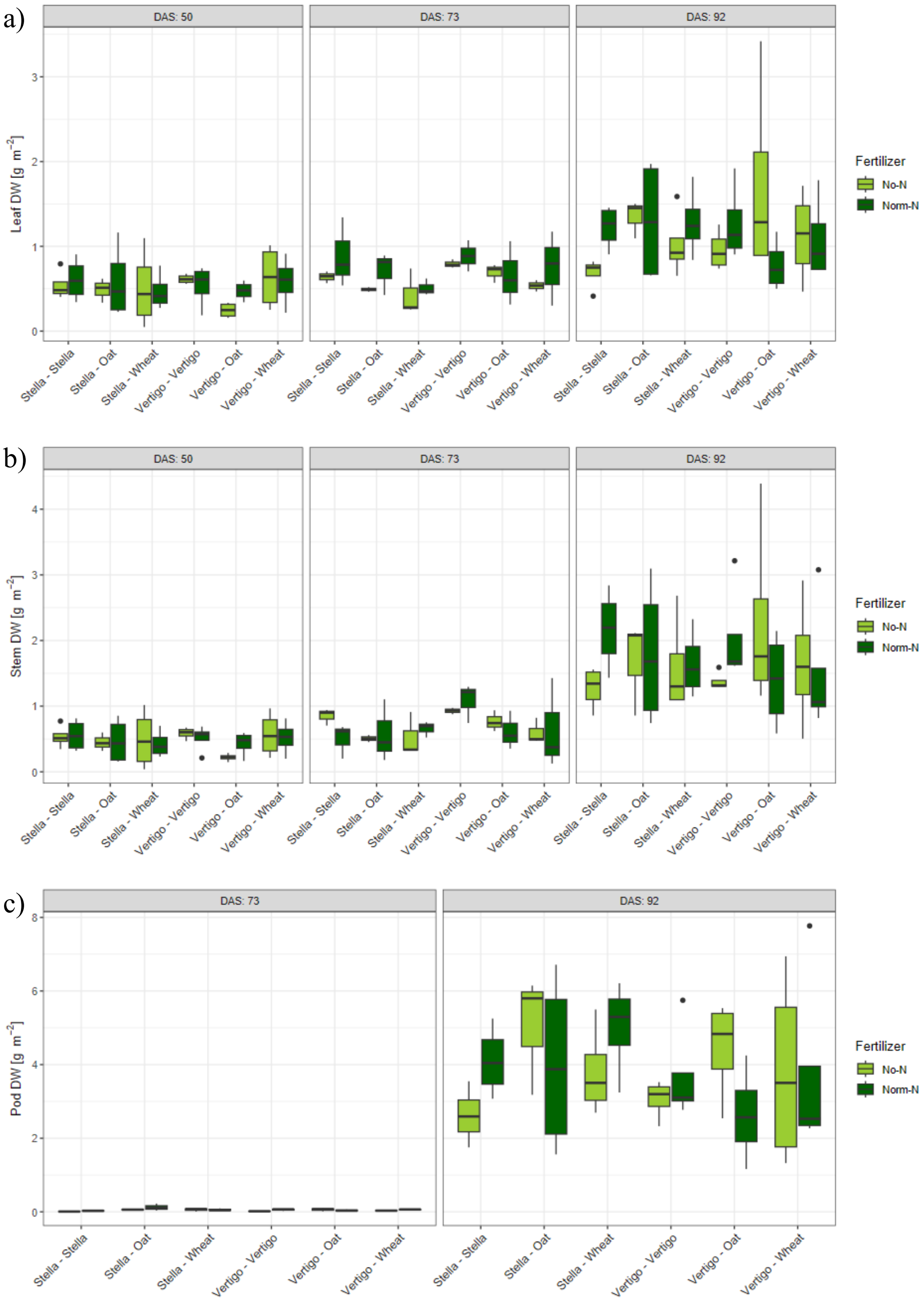

Figure 3.2 Dry leaf, stem and pod biomass for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of dry biomass of (a) leaves, (b) stems, and (c) pods per square meter for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Black dots indicate outliers, and black lines indicate median values. Note the differing scales.*

3.1.2 Faba bean leaf nitrogen content

No statistically significant effects on leaf chlorophyll content (SPAD) were found for any of the experimental factors (Appendix 3: Table 5.20). 'Stella' consistently tended to exhibit higher SPAD-values compared to 'Vertigo' across all sampling dates (Figure 3.3, Appendix 2: Table 5.3).

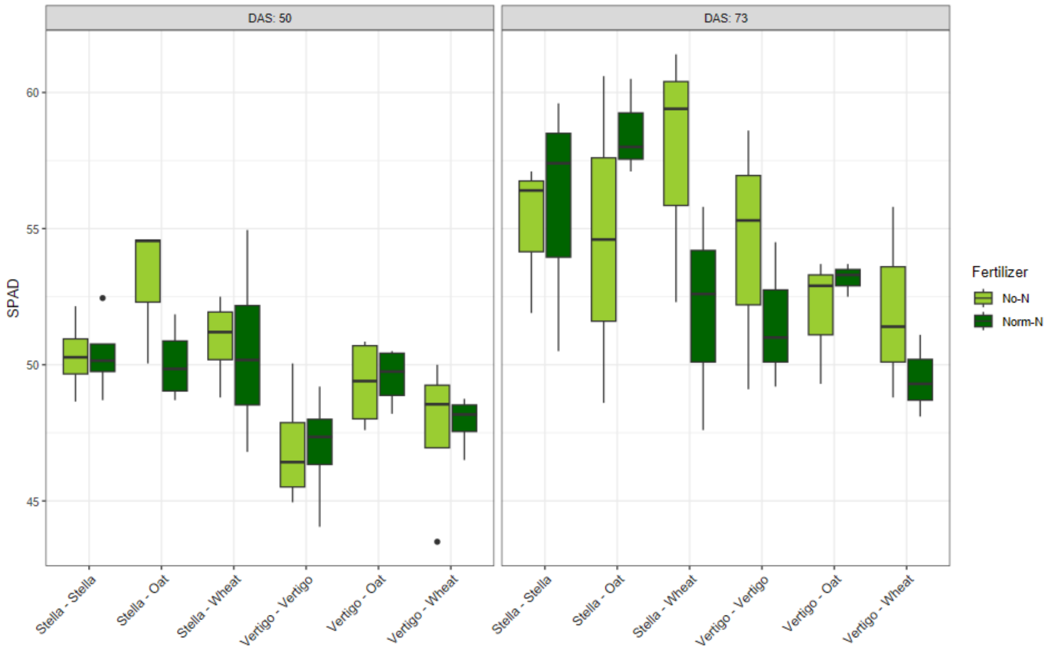

Figure 3.3 SPAD readings for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of SPAD readings for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50 and 73 days after sowing. Black dots indicate outliers, and black lines indicate median values.*

3.1.3 Cereal biomass of leaves, stems and heads

For the spring oat, no statistically significant effects on the total aboveground dry biomass were found for any of the experimental factors. Spring wheat showed a significant difference between the pure culture and the mixed cultures with both faba bean cultivars at 92 DAS, but not in regard to any other experimental factor (Appendix 3: Table 5.21), where mixtures with 'Vertigo' had higher mean values of aboveground dry biomass (Figure 3.4, Appendix 2: Table 5.5). Spring oat tended to exhibit the overall highest aboveground dry biomass regardless of experimental factor, with the exception for the no N treatments when comparing between pure cultures at 50 DAS and between mixtures with 'Stella' at 92 DAS, where spring wheat had the higher mean values of aboveground dry biomass (Figure 3.4, Appendix 2: Table 5.5).

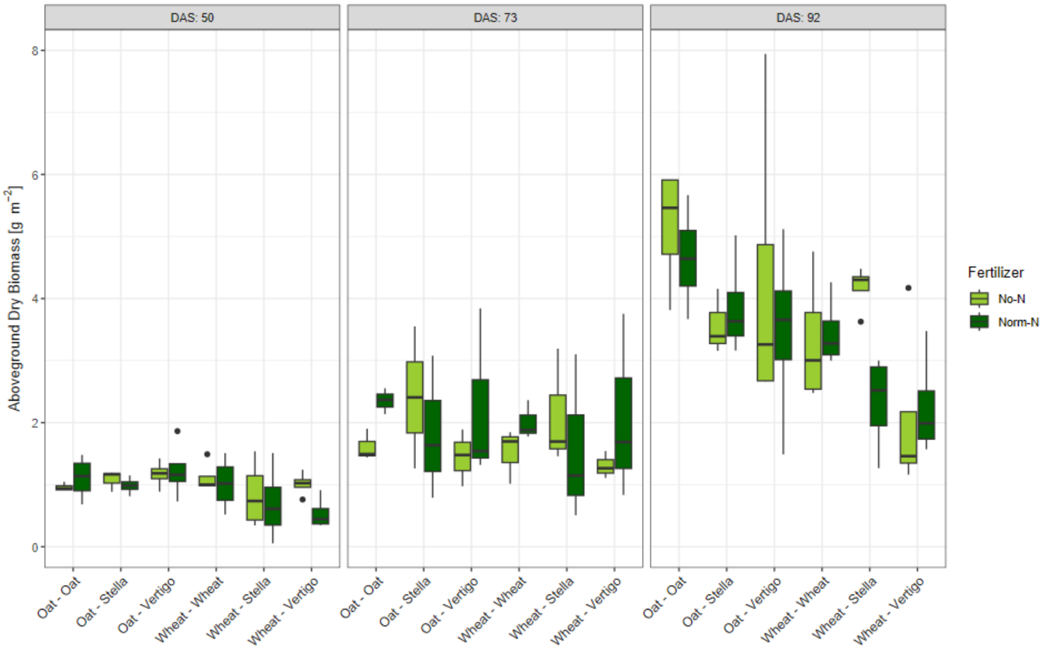

Figure 3.4 Aboveground dry biomass for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of total aboveground dry biomass per square meter for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo,) for two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Black dots indicate outliers, and black lines indicate median values.*

For spring oat, and similar to the results for the aboveground biomass, no statistically significant effects on the dry biomass of leaves, steams and heads were found for any of the experimental factors (Appendix 3: Table 5.22-5.24). At 92 DAS, spring wheat showed statistically significant effects on dry biomass of leaves and stems in no N treatments when grown with different faba bean varieties (Appendix 3: Table 5.22-5.23), where mixtures with 'Stella' had higher mean values, with the exception of mixtures with 'Vertigo' for dry biomass of stems (Figure 3.5, Appendix 2: Table 5.4). In spring wheat, there was also a statistically significant positive fertilization effect on dry biomass of leaves and stems when grown in mixed cultures with 'Vertigo' at 92 DAS (Appendix 2: Table 5.4, Appendix 3: Table 5.22-5.23). Additionally, in regard to dry biomass of heads at 92 DAS, there was also a statistically significant mixing effect found for the spring wheat pure culture compared to its mixture with 'Vertigo' (Appendix 3: Table 5.24), where the pure culture produced higher head biomass than the mixtures (Figure 3.5, Appendix 2: Table 5.5).

Overall, spring oat had the highest mean values for dry biomass of leaves, stems and heads, with most exceptions occurring at 73 DAS, in no N treatments and/or in mixtures with 'Stella' (Figure 3.5, Appendix 2: Table 5.4-5.5).

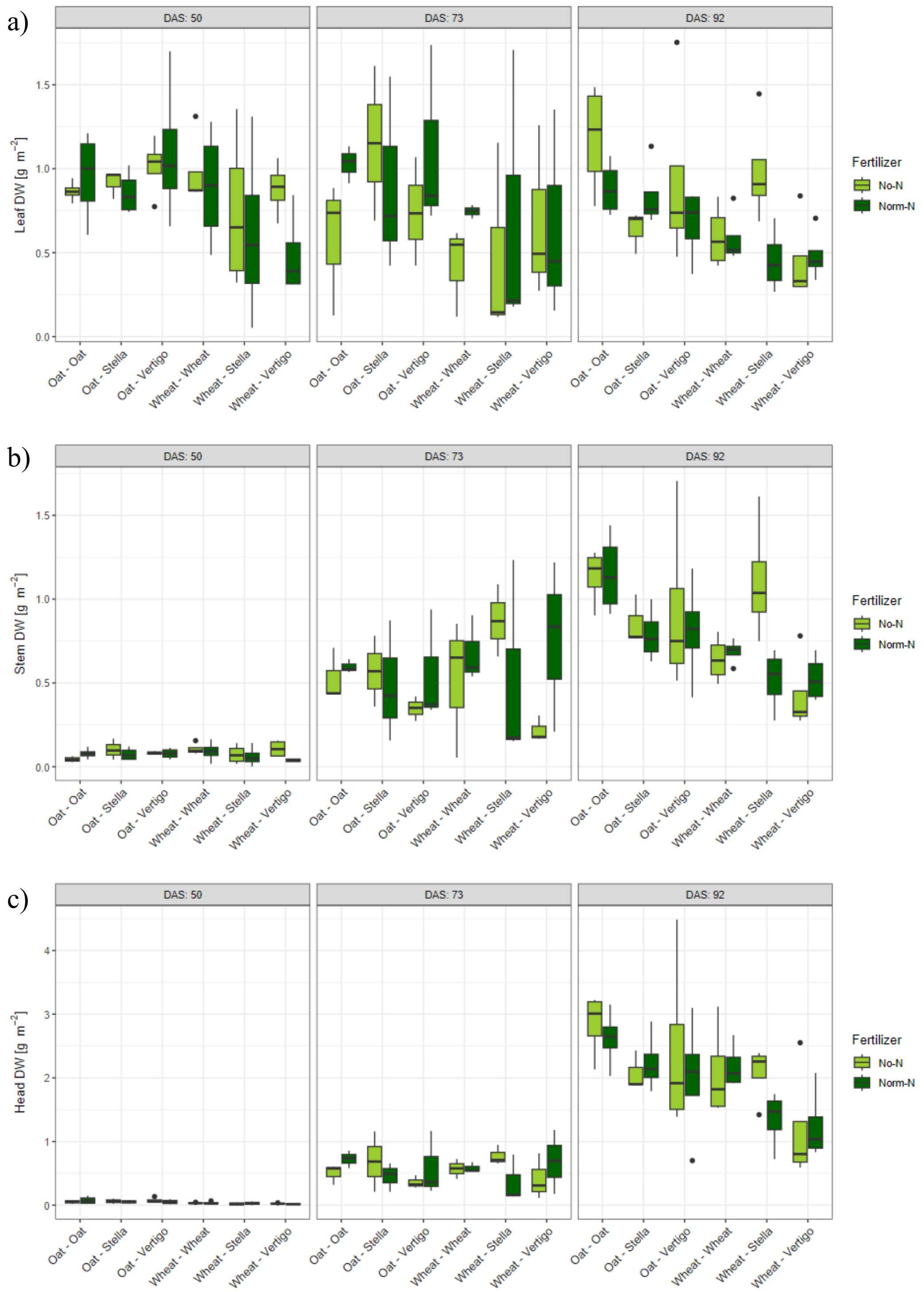

Figure 3.5 Dry leaf, stem and head biomass for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of dry biomass of (a) leaves, (b) stems, and (c) heads per square meter for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo,) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Black dots indicate outliers, and black lines indicate median values.*

3.1.4 Cereal leaf nitrogen contents

No statistically significant effects on SPAD were found for any of the experimental factors (Appendix 3:Table 5.25). Spring oat consistently tended to exhibit higher mean values of SPAD compared to spring wheat across all sampling dates and regardless of experimental factors (Figure 3.6, Appendix 2: Table 5.6).

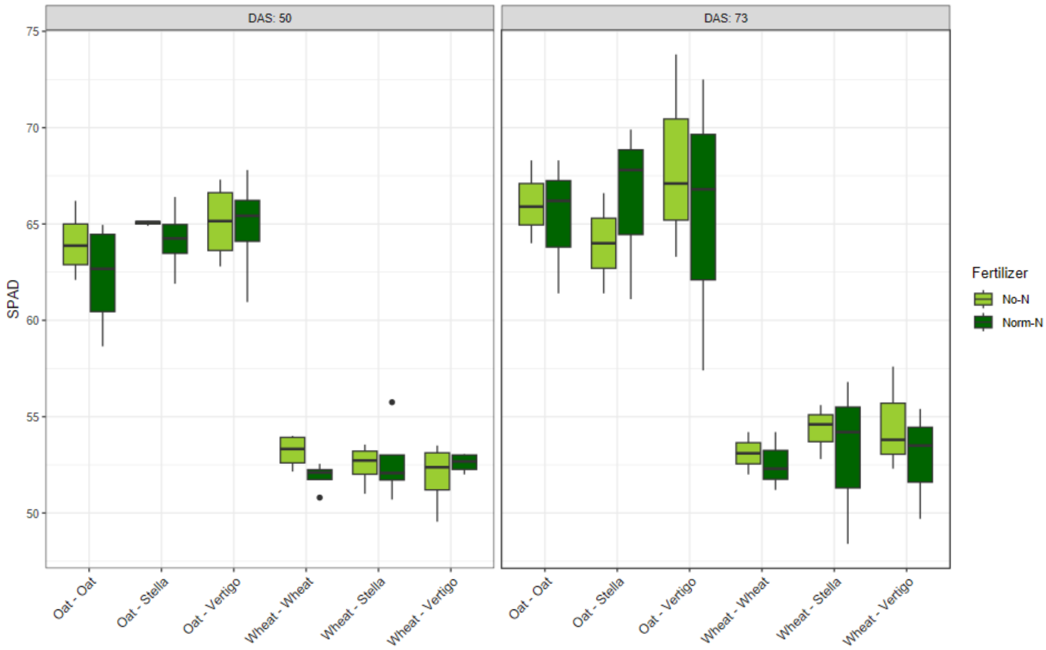

Figure 3.6 SPAD readings for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Box plots visualize the raw data of SPAD readings for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo,) for the two fertilizer treatments (no N and +N) at 50 and 73 days after sowing. Black dots indicate outliers, and black lines indicate median values.*

3.2 Faba bean and cereal yields

Statistically significant differences were found between pure and mixed cultures (Appendix 3: Table 5.26), where pure cultures of both faba bean varieties 'Stella' and 'Vertigo', as well as the spring oat had the highest grain yields regardless of fertilizer treatment (Figure 3.7, Appendix 2: Table 5.7). Spring wheat tended to have the lowest grain yields, for all combinations of experimental factors (Figure 3.7, Appendix 2: Table 5.7). The +N fertilizer treatment tended to produce higher grain yields in the pure cultures of 'Vertigo' and spring oat, as well as the mixed culture of the two (Table 3.1).

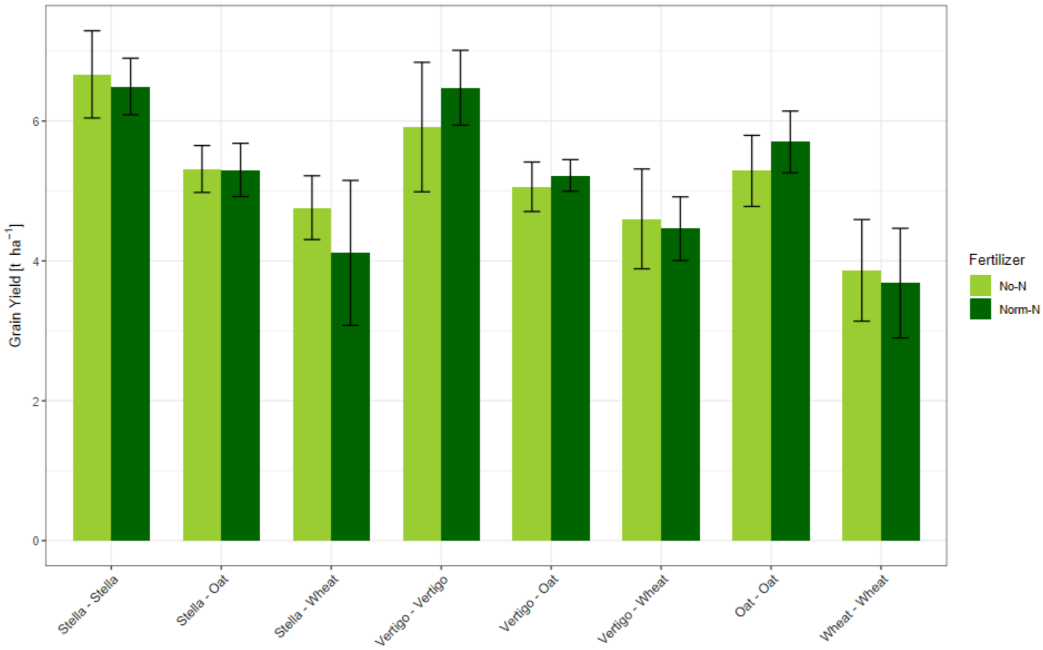

Figure 3.7 Grain yield for faba bean varieties 'Stella' and 'Vertigo', spring oat 'Delfin', and spring wheat 'Thorus' when grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean grain yield in tonnes per hectare for pure cultures of Stella, Vertigo, spring oat and spring wheat, as well as mixtures (Stella-Spring oat, Stella-Spring wheat, Vertigo-Spring oat, and Vertigo-Spring wheat) for the two fertilizer treatments (no N and +N) harvested the 30th of August 2024. The values represent the total grain yield base on total harvest from the field trial plot as a combined total. Error bars show the standard deviation of the raw data.*

Note that the data on grain yield presented in Figure 3.7 and Appendix 2: Table 5.7 are total grain yields of the mixed cultures, and no yield data from the separate crops in the mixtures were available. This hindered further examination into how and if the faba bean and cereal components contributed differently to the final grain yields for the mixed cultures.

Table 3.1 Effect of fertilizer treatment on grain yield. *Fertilizer factor calculated by dividing the +N treatment with the no N treatment for the different cropping systems of pure and mixed cultures with the faba bean varieties 'Stella' and 'Vertigo', as well as the cereals spring oat 'Delfin' and spring wheat 'Thorus'(Appendix 2: Table 5.7).*

Cropping system	+N/No-N
Stella	0.9739
Vertigo	1.0951
Oat	1.0783
Wheat	0.9528
Stella – Oat	0.9976
Stella – Wheat	0.8642
Vertigo – Oat	1.0321
Vertigo – Wheat	0.9697

3.3 Land equivalent ratio

3.3.1 Aboveground dry biomass

Significant effects on Land Equivalent Ratios (LER) were found only between fertilizer treatments at 92 DAS (Appendix 3:Table 5.27), where mixed cultures in treatments with no N generated higher LER compared to the corresponding pure cultures (Figure 3.8, Appendix 2: Table 5.8). There were no instances where +N treatments showed higher LER compared to no N treatments at 92 DAS (Table 3.2).

At 50 and 73 DAS, the mixed cultures tended to have LER < 1, with exceptions for the no N treatments of 'Stella' and spring oat at 50 and 73 DAS, 'Stella' and spring wheat at 73 DAS, and for the +N treatment of 'Vertigo' and spring oat at 50 DAS (Figure 3.8, Appendix 2: Table 5.8). Overall, indicating slight disadvantage compared to the corresponding pure cultures. This implies that an increased land area would be needed to produce the same amount of aboveground dry biomass, especially for systems with the +N treatment. At 92 DAS, the mixed cultures in the no N treatment instead tended to have LER > 1, which indicates an advantage compared to the corresponding pure culture (Figure 3.8, Appendix 2: Table 5.8). This implies that a reduced land area could be used to produce the same amount of aboveground dry biomass.

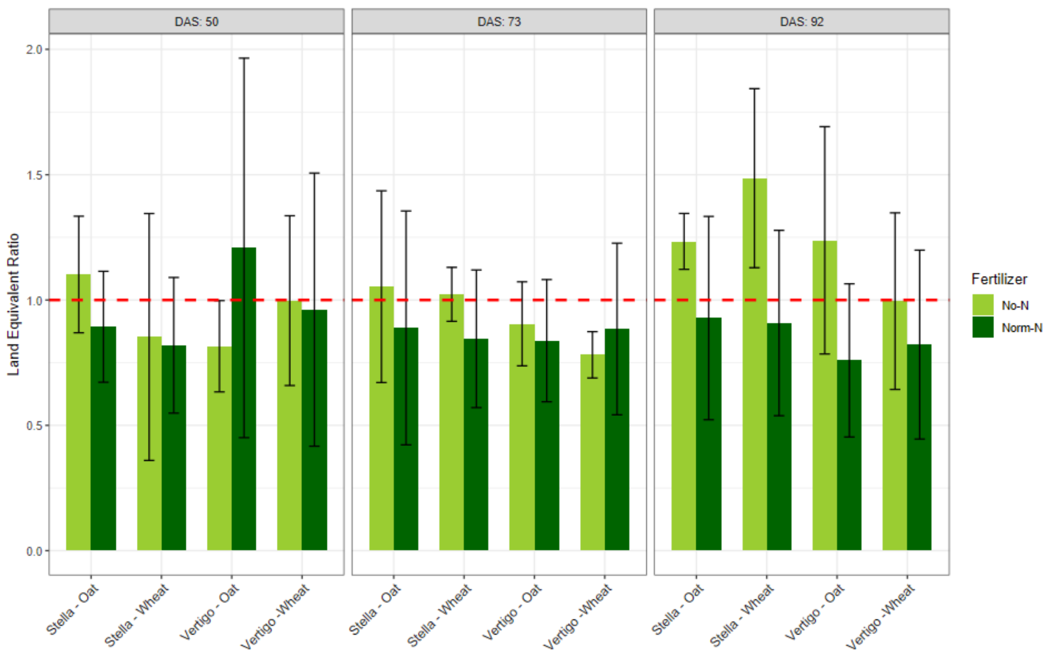

Figure 3.8 Land equivalent ratio for aboveground dry biomass. *Bar plots visualize the mean LER for the total aboveground dry biomass of the different mixed cultures (Stella-Spring oat, Stella-Spring wheat, Vertigo-Spring oat, and Vertigo-Spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Values above the red line (LER > 1) implies overyielding and that the mixture is advantageous, whilst a value below the red line (LER < 1) implies a lower yield and that the mixture is disadvantageous compared to a pure culture.*

There were instances where mixed cultures were overyielding compared to pure cultures. For no N treatments, ‘Stella’ with spring oat at 50, 73 and 92 DAS, ‘Stella’ with spring wheat at 50 and 73 DAS, as well as ‘Vertigo’ with spring oat at 92 DAS were all considered to be overyielding. ‘Stella’ with spring oat at 50 DAS was the only mixture with no N that exhibited transgressive overyielding. For treatments with +N, ‘Vertigo’ with spring oat at 50 DAS was the only system that was considered to be overyielding, where the same mixture also exhibited transgressive overyielding (Figure 3.8, Appendix 2: Table 5.8).

Table 3.2 Effect of fertilizer treatment on land equivalent ratio. *Fertilizer factor calculated by dividing the +N treatment with the no N treatment for mixed cultures of the faba bean varieties ‘Stella’ and ‘Vertigo’ with the cereals spring oat ‘Delfin’ and spring wheat ‘Thorus’ at 92 DAS (Appendix 2: Table 5.8).*

DAS	Mixture	+N/No-N
92	Stella – Oat	0.7520
92	Stella – Wheat	0.6112
92	Vertigo – Oat	0.6132
92	Vertigo – Wheat	0.8257

3.4 Weed biomass

No statistically significant effects on weed biomass were found for any of the experimental factors (Appendix 3: Table 5.28), and similarly there was no apparent pattern in weed prevalence between pure and mixed cultures or with different neighbours (Figure 3.9, Appendix 2: Table 5.9). Pure cultures and mixtures with ‘Vertigo’ tended to have lower dry biomass of weeds in +N treatments compared to treatments with no N. Pure cultures with ‘Stella’, spring oat and spring wheat instead tended to exhibit an increase in +N treatments compared to treatments with no N (Table 3.3).

Table 3.3 Effect of fertilizer treatment on dry biomass of weeds. *Fertilizer factor calculated by dividing the +N treatment with the no N treatment for the different cropping systems of pure and mixed cultures with the faba bean varieties ‘Stella’ and ‘Vertigo’, as well as the cereals spring oat ‘Delfin’ and spring wheat ‘Thorus’ at 92 DAS (Appendix 2: Table 5.9).*

DAS	Mixture	+N/No-N
92	Stella – Stella	1.0771
92	Stella – Oat	0.6809
92	Stella – Wheat	3.3975
92	Vertigo – Vertigo	0.5712
92	Vertigo – Oat	0.8505
92	Vertigo – Wheat	0.7087
92	Oat – Oat	1.2895
92	Wheat – Wheat	1.2188

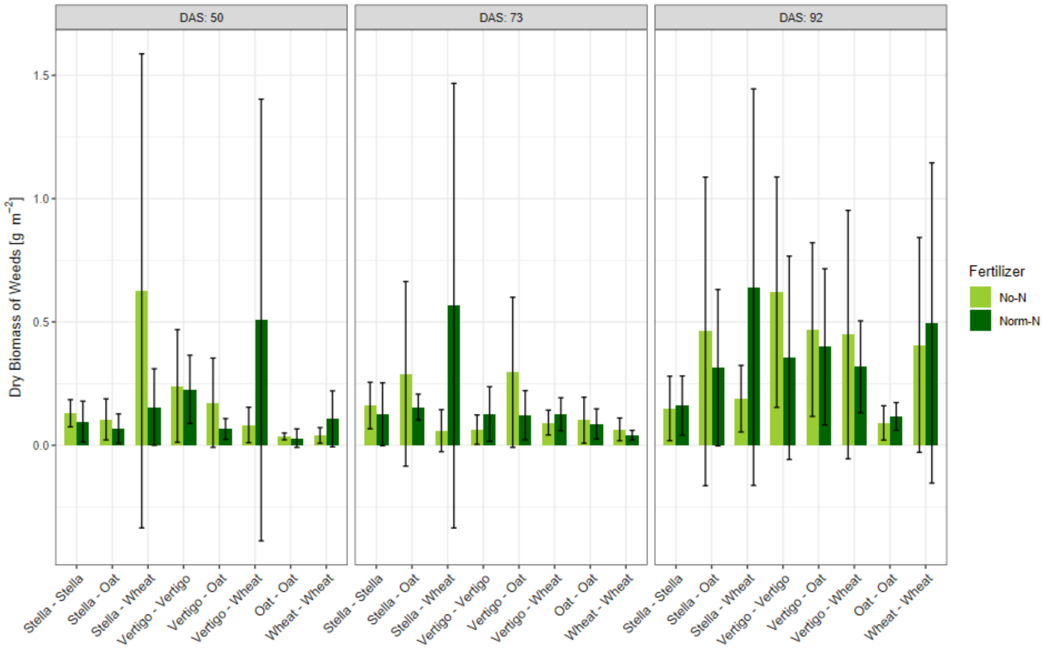

Figure 3.9 Dry biomass of weeds. *Bar plots visualize the mean dry biomass of weeds of the different pure and mixed cultures (Stella-Stella, Stella-Spring oat, Stella-Spring wheat, Vertigo-Vertigo, Vertigo-Spring oat, Vertigo-Spring wheat, spring oat-spring oat, and spring wheat-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data.*

3.5 Plasticity

3.5.1 Trait plasticity

In this section, higher plasticity values for a trait indicate positive plastic responses (or that the trait was upregulated or enhanced) in mixed culture compared to the corresponding pure culture. Lower trait plasticity values indicate negative plastic responses (or that the trait was suppressed or limited) in mixed culture compared to the corresponding pure culture.

Plasticity in faba bean traits

Statistically significant effects on trait plasticity of total aboveground dry biomass were found using two-way ANOVA for fertilizer treatment at 92 DAS (Appendix 3: Table 5.30), where treatments with no N exhibited higher positive trait plasticity values compared to +N treatments (Figure 3.10, Table 3.4, Appendix 2: Table 5.11).

Statistically significant differences in trait plasticity were also found using one-sample t-tests between mixed cultures and corresponding pure cultures of 'Vertigo' with spring oat at 50 DAS (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.10, Appendix 2: Table 5.11), and 'Stella' with spring oat at 92 DAS (Appendix 3: Table 5.29), where the mixed culture exhibited a positive plastic response (Figure 3.10, Appendix 2: Table 5.11). At 73 DAS, the trait plasticity values tended to be negative for all mixtures and fertilizer treatments but was not statistically significant for different neighbours or fertilizer treatments (Figure 3.10, Appendix 2: Table 5.11, Appendix 3: Table 5.29 and 5.30).

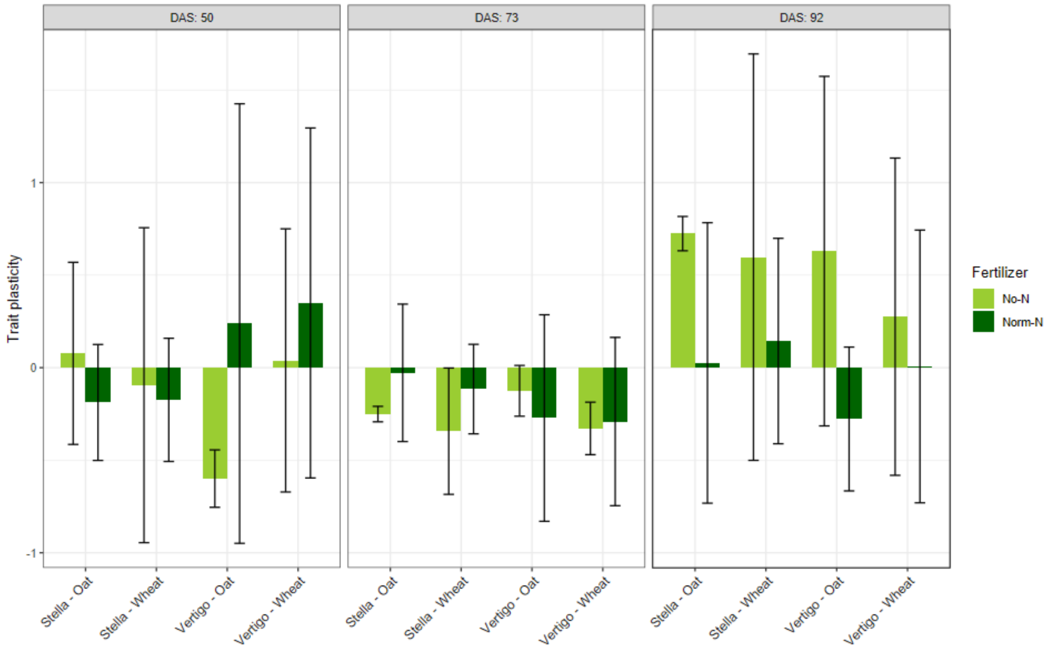

Figure 3.10 Trait plasticity of aboveground dry biomass for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of total aboveground dry biomass for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping.*

Statistically significant effects on trait plasticity of dry biomass of leaves and stems were found using two-way ANOVA for fertilizer treatment at 92 DAS (Appendix 3: Table 5.31-5.32), where no N treatments exhibited higher positive trait plasticity values compared to +N treatments (Figure 3.11, Table 3.4, Appendix 2: Table 5.10). No statistically significant effects on trait plasticity of dry biomass of pods were found using two-way ANOVA for different neighbours or fertilizer treatments (Appendix 3: Table 5.33).

Statistically significant differences in trait plasticity were also found using one-sample t-tests between mixed cultures and the corresponding pure cultures for dry biomass of leaves in treatments with no N at 50 DAS for 'Vertigo' with spring oat (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.11, Appendix 2: Table 5.10). At 73 DAS for 'Stella' and spring oat (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.11, Appendix 2: Table 5.10), and 'Vertigo' with spring wheat (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.11, Appendix 2: Table 5.10). At 92 DAS for 'Stella' with spring oat (Appendix 3: Table 5.29), the mixed culture exhibited a positive plastic response (Figure 3.11, Appendix 2: Table 5.10).

Statistically significant differences in trait plasticity were also found using one-sample t-tests between mixed cultures and corresponding pure cultures for dry biomass of stems in treatments with no N at 50 DAS for 'Vertigo' with spring oat (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.11, Appendix 2: Table 5.10), and at 73 DAS for 'Stella' with spring oat (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.11, Appendix 2: Table 5.10).

Additionally, statistically significant differences in trait plasticity were found using one-sample t-tests between mixed cultures and the corresponding pure cultures in treatments with no N for dry biomass of pods at 73 DAS for 'Vertigo' with spring wheat (Appendix 3: Table 5.29), where the mixed culture exhibited a positive plastic response (Figure 3.11, Appendix 2: Table 5.11), and at 92 DAS for 'Stella' with spring oat (Appendix 3: Table 5.29), where the mixed culture exhibited a positive plastic response (Figure 3.11, Appendix 2: Table 5.11).

Table 3.4 Effect of fertilizer treatment on trait plasticity of faba bean traits. *Fertilizer effect calculated using the difference between the +N treatment and the no N. Includes the difference in trait plasticity for dry biomass of leaves, stem, pods and combined total, as well as SPAD of the faba bean component at 92 DAS based on previous calculations form Equation 1 (Appendix 2: Table 5.10-5.11). Effects on trait plasticity for SPAD was calculated for 73 DAS, as opposed to biomass traits which were calculated for 92 DAS.*

DAS	Cropping system	Biomass traits				SPAD
		Leaves	**Stem**	**Pods**	**Total**	
92 (73*)	Stella – Oat	-1.0296	-0.3630	-0.7884	-0.6987	0.0907*
92 (73*)	Stella – Wheat	-0.6311	-0.5789	-0.3357	-0.4533	-0.1145*
92 (73*)	Vertigo – Oat	-1.2651	-0.9670	-0.7441	-0.9069	0.0715*
92 (73*)	Vertigo – Wheat	-0.3961	-0.3987	-0.1563	-0.2688	-0.0032*

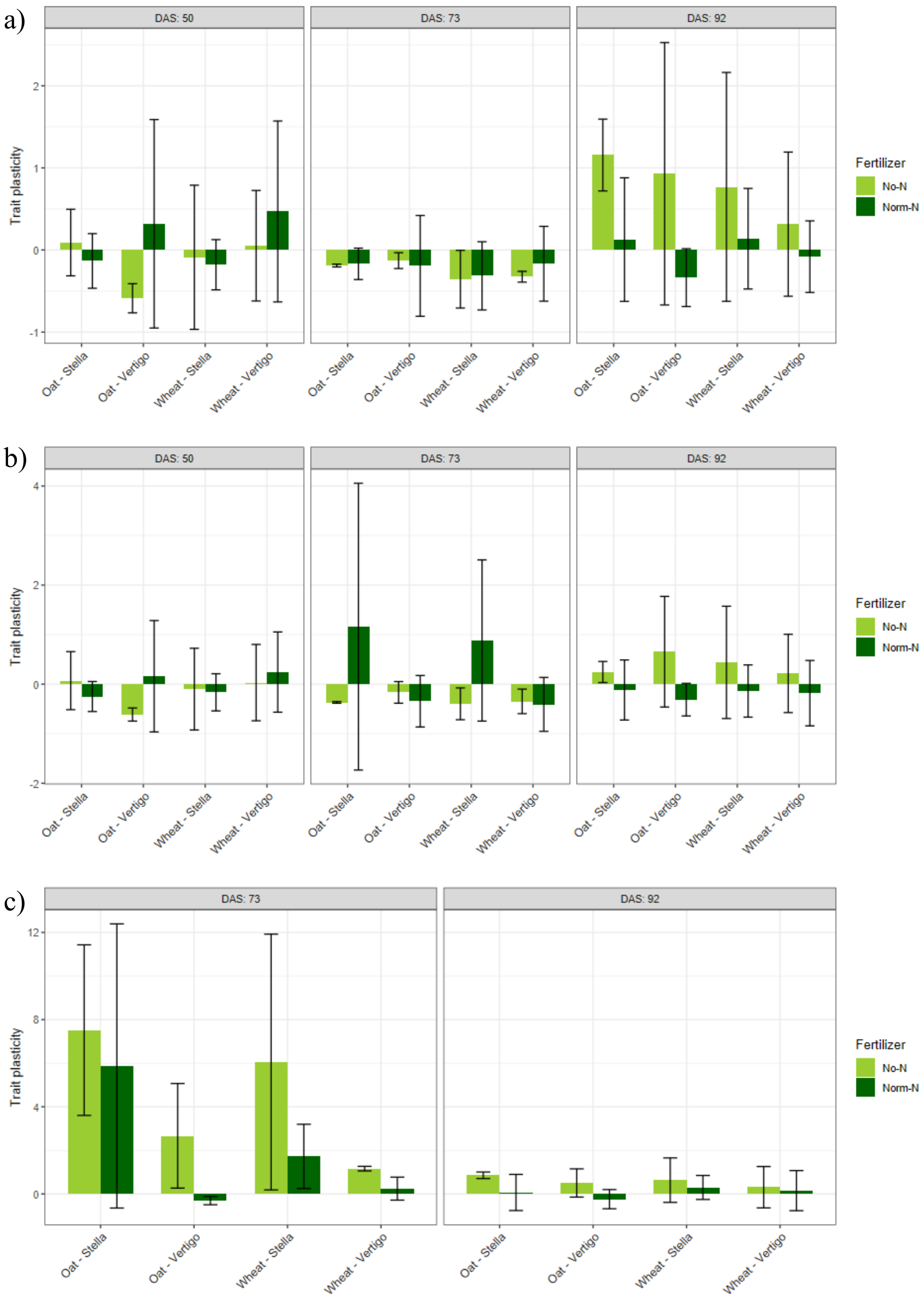

Figure 3.11 Trait plasticity of dry leaf, stem and pod biomass for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of dry biomass of (a) leaves, (b) stems, and (c) pods for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping. Note the differing scales.*

No statistically significant effects on trait plasticity of SPAD were found using two-way ANOVA for different neighbours or fertilizer treatments for faba bean (Appendix 3: Table 5.34).

The only instance with a statistically significant difference found using one-sample t-tests between mixed cultures and the corresponding pure cultures was at 50 DAS for 'Vertigo' with spring oat in the no N treatment (Appendix 3: Table 5.29), where the mixed culture exhibited a positive plastic response (Figure 3.12, Appendix 2:Table 5.14). For both faba bean varieties, mixed cultures with spring oat tended to show higher trait plasticity values in N+ treatments compared to the treatments without N, whilst mixed cultures with spring wheat tended to show lower trait plasticity values in N+ treatments compared to the treatments without N (Table 3.4).

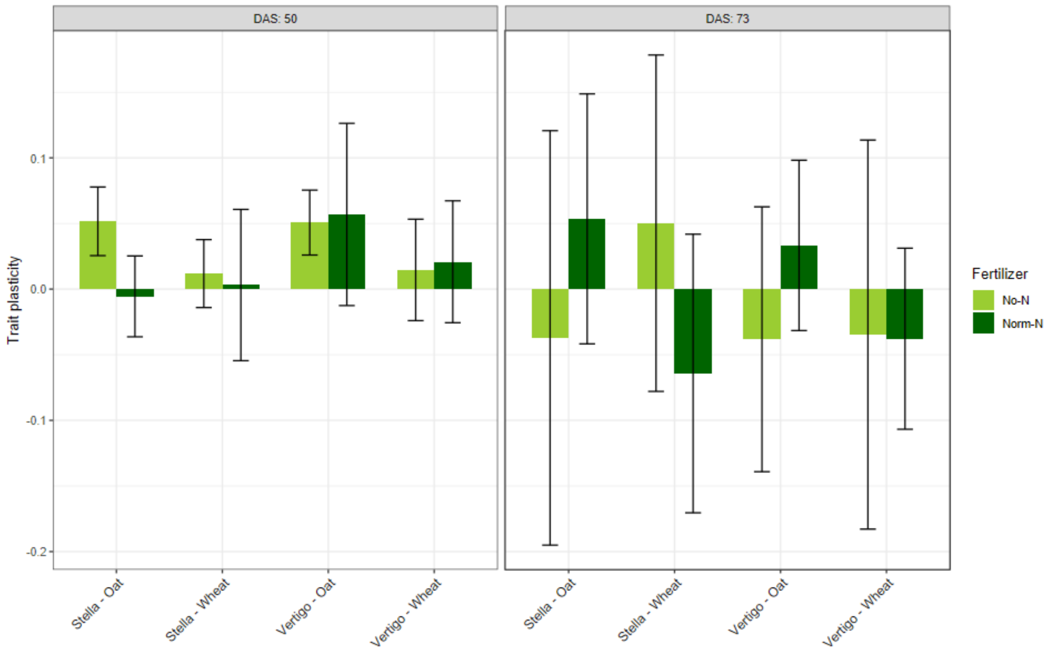

Figure 3.12 Trait plasticity of SPAD for faba bean varieties 'Stella' and 'Vertigo' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of SPAD for the faba bean component in the different cropping systems (Stella-Stella, Stella-spring oat, Stella-spring wheat, Vertigo-Vertigo, Vertigo-spring oat, and Vertigo-spring wheat) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping.*

Plasticity in cereal traits

No statistically significant effects on trait plasticity of total aboveground dry biomass were found using two-way ANOVA for different neighbours (spring oat-spring oat, spring oat-'Stella' and spring oat-'Vertigo', and corresponding combinations for spring wheat) or fertilizer treatments (Appendix 3: Table 5.35).

Statistically significant differences in trait plasticity were found using one-sample t-tests between mixed cultures and the corresponding pure cultures for aboveground dry biomass at 50 and 92 DAS for spring wheat with 'Vertigo' (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3. 13, Appendix 2: Table 5.13), and at 92 DAS for spring oat with 'Stella' (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3. 13, Appendix 2: Table 5.13). Treatments with +N generally showed lower trait plasticity values for total aboveground dry biomass compared to treatments with no N (Table 3.5).

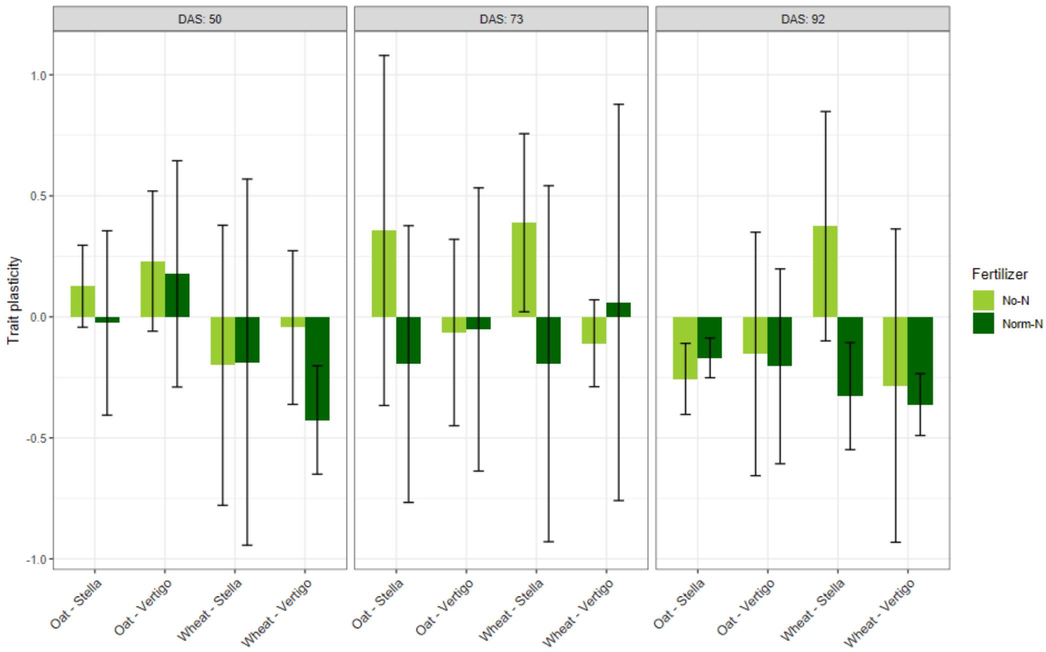

Figure 3.13 Trait plasticity of aboveground dry biomass for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of total aboveground dry biomass for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping.*

No statistically significant effects on trait plasticity of dry biomass of leaves, stems or heads were found using a two-way ANOVA for different neighbours or fertilizer treatments (Appendix 3: Table 5.36-5.58).

Statistically significant differences in trait plasticity were found using one-sample t-tests between mixed cultures and corresponding pure cultures for dry biomass of leaves at 50 and 92 DAS in +N treatments for spring wheat with 'Vertigo' (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.12), and at 92 DAS in no N treatments for spring oat with ‘Stella’ (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.12).

Statistically significant differences in trait plasticity were also found using one-sample t-tests between mixed cultures and the corresponding pure cultures for dry biomass of stems at 73 DAS in no N treatments for spring oat and ‘Vertigo’ (Appendix 3: Table 5.29), where the mixed culture exhibited a positive plastic response (Figure 3.14, Appendix 2: Table 5.12); at 92 DAS in +N treatments for spring oat with ‘Stella’ (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.12); and for spring wheat with ‘Vertigo’ (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.12).

Statistically significant differences in trait plasticity were found using one-sample t-tests between mixed cultures and corresponding pure cultures for dry biomass of heads at 92 DAS in +N treatments for spring oat with ‘Stella’ (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.13); for spring wheat with ‘Stella’ (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Appendix 3: Table 5.13); and for spring wheat with ‘Vertigo (Appendix 3: Table 5.29), where the mixed culture exhibited a negative plastic response (Figure 3.14, Appendix 2: Table 5.13).

The +N fertilizer treatment tended to show lower trait plasticity values for trait plasticity of dry biomass of leaves, stems and heads, with the exceptions of leaves and heads for spring oat with ‘Stella’, and heads for spring wheat with ‘Vertigo’ (Table 3.5).

Table 3.5 Effect of fertilizer treatment on trait plasticity of cereal traits. *Fertilizer effect calculated using the difference between the +N treatment and the no N treatment. Includes the difference in trait plasticity for dry biomass of leaves, stem, pods and combined total, as well as SPAD of the cereal component based on previous calculations form Equation 1 (Appendix 2: Table 5.12-5.13). Effects on trait plasticity for SPAD was calculated for 73 DAS, as opposed to biomass traits which were calculated for 92 DAS.*

		Biomass Trait				
DAS	**Cropping system**	**Leaves**	**Stem**	**Heads**	**Total**	**SPAD**
92 (73*)	Oat – Stella	0.3558	-0.1031	0.0721	0.0867	0.0292*
92 (73*)	Oat – Vertigo	-0.0101	-0.0710	-0.0586	-0.0510	-0.0302*
92 (73*)	Wheat – Stella	-1.0800	-1.1370	-0.4533	-0.7023	-0.0102*
92 (73*)	Wheat – Vertigo	-0.0568	0.0256	-0.1101	-0.0782	-0.0286*

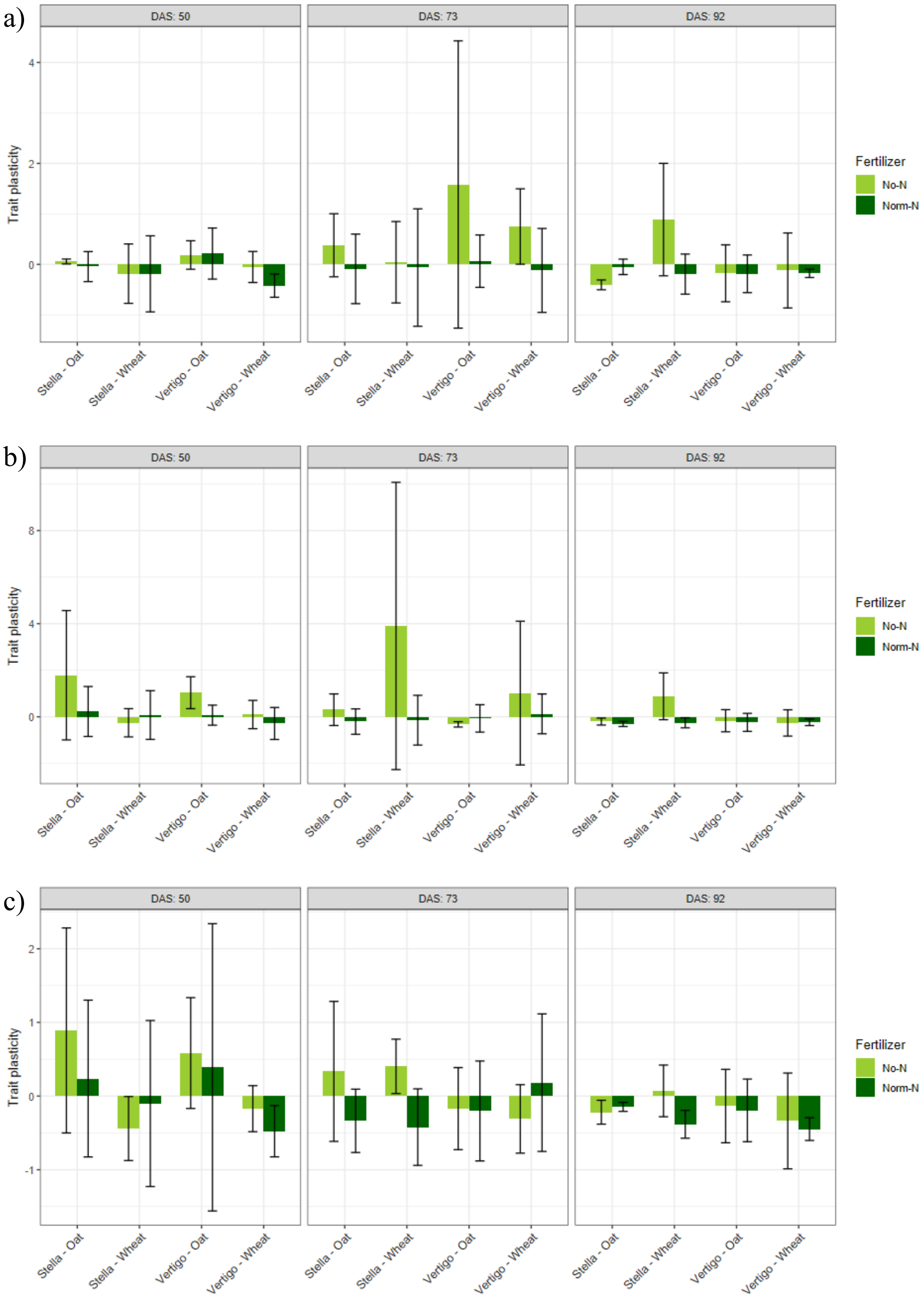

Figure 3.14 Trait plasticity of dry leaf, stem and head biomass for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of (a) leaves, (b) stems, and (c) heads for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo) for the two fertilizer treatments (no N and +N) at 50, 73 and 92 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping. Note the differing scales.*

No statistically significant effects on trait plasticity of SPAD for any of the experimental factors for neither cereal (Appendix 3: Table 5.29 and Table 5.39). The +N treatment tended to show a slight increase in trait plasticity values of SPAD at 50 DAS compared to the no N treatment, but the opposite at 73 DAS (Table 3.4).

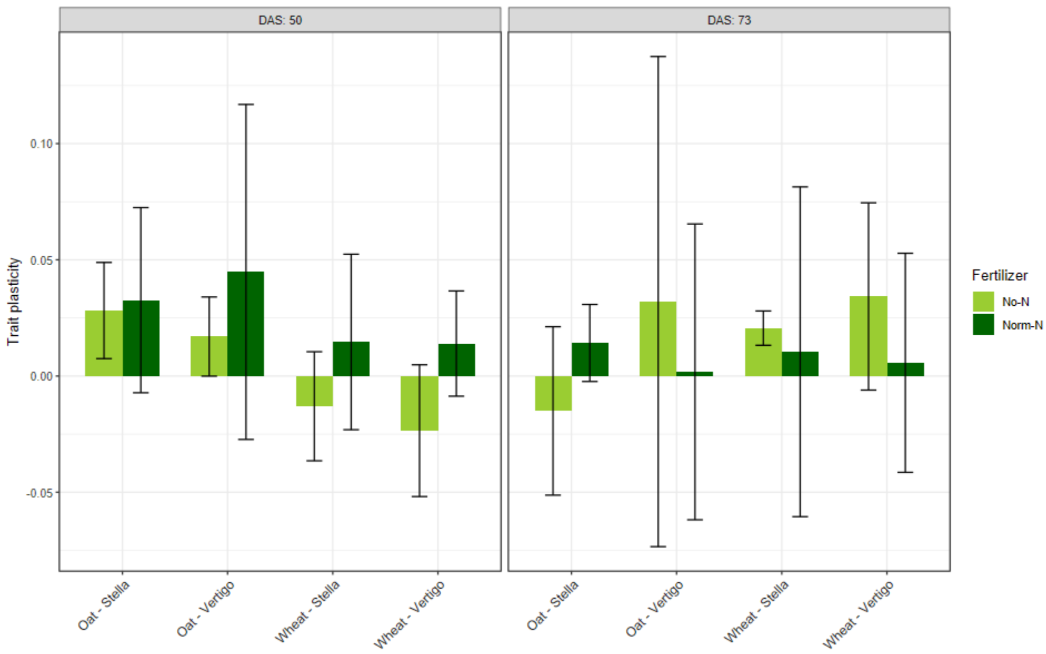

Figure 3.15 Trait plasticity of SPAD for spring oat 'Delfin' and spring wheat 'Thorus' grown as pure and mixed cultures under different fertilizer treatments. *Bar plots visualize the mean trait plasticity as per Equation 1 of SPAD for the cereal component in the different cropping systems (spring oat-spring oat, spring oat-Stella, spring oat-Vertigo, spring wheat-spring wheat, spring wheat-Stella, and spring wheat-Vertigo) for the two fertilizer treatments (no N and +N) at 50 and 73 days after sowing. Error bars show the standard deviation of the raw data. Positive values indicate an increase in the trait and negative values indicate a reduction, with higher absolute values suggesting a stronger response to intercropping.*

3.5.2 Plasticity and heritability

Faba bean showed a greater response to genetic factors in plasticity at 50 DAS, which declined over time (Fig. 3.16, Appendix 2: Table 5.15). At 92 DAS, environmental factors dominated the plastic responses. Broad-sense heritability was highest for SPAD overall and was moderate for other traits at 50 and 73 DAS, but low at 92 DAS. The heritable plasticity was relatively low across all sampling dates, with higher values at 50 DAS and for SPAD in particular at 73 DAS. The cereals showed a similar pattern in terms of plasticity but showed an increase earlier at 73 DAS. The cereals were also more consistent in regard to broad-sense heritability, with moderate to high values across all sampling dates. The heritable plasticity increased over time for cereals (Figure 3.16, Appendix 2: Table 5.15).

Figure 3.16 Variance components for aboveground dry biomass and SPAD traits for faba bean and cereals. *Bar plots visualize the variance ratio for the variance components plasticity (PL), heritability (H) and heritable plasticity (Hpl) of the traits as per Scheiner & Lyman (1989). Note the differing scales.*

4. Discussion

There is a growing interest in diversification of cropping systems in Sweden, where intercrops with legumes and specifically faba bean would be a potential candidate crop with its ability for BNF (Jordbruksverket 2022, Röös et al. 2018). To meet this growing interest, there is a need to understand how crops in these types of systems would interact with each other, how the intercropping systems would perform, and whether or not it is possible to predict the crop performance in an intercrop based on the corresponding performance in monoculture.

In this study, two faba bean varieties were grown as pure cultures and as mixed cultures with the cereals spring oat and spring wheat under two different fertilizer treatments. No conclusive evidence was found in support of the second hypothesis, regarding plasticity for faba beans differing between pure and mixed culture. Although, there were instances where statistically significant differences were found in biomass traits between pure and mixed culture, there was no evident pattern across sampling dates related to a certain variety or mixture, with the exception of significant effects related to fertilizer treatment only occurring in the no N treatments. In these treatments there was a positive effect on trait plasticity, which is accordance to results reported in previous research (Zhang et al. 2014). In regard to the cereals, similar to the faba bean, significant differences between pure and mixed cultures only occurred sporadically and only for biomass traits. However, contrary to the faba bean, significant differences for cereals were generally seen in treatments with +N and for spring wheat consistently showed negative effects on trait plasticity at 92 DAS for all biomass traits in mixtures with 'Vertigo'. These results for the cereal component is contradictory to results of earlier research, where cereal biomass tended to be positively affected by being grown as an intercrop (Bargaz et al. 2021). Grain yield showed a significant difference between pure and mixed cultures for both faba bean varieties and cereals, where pure cultures had higher yields compared to mixed cultures, which is contradictory to results reported in previous research (Xiao et al. 2018, Zhang et al. 2024). However, considering the inability to further analyse individual crop components of grain yield due to lab results not arriving in time for the conclusion of this study, it is impossible to know the contribution of the different crops to the grain yield in mixtures. Therefore, when considering whether or not the results support the rejection of the second hypothesis, it was deemed less reliable compared to other traits. As a consequence, my study did not find sufficient support to reject the second hypothesis as evidence was inconclusive for biomass traits and not significantly different between pure and mixed cultures overall in terms of trait plasticity related to N content in the leaves (SPAD). Following this, no conclusive evidence was found in support of the third hypothesis, regarding different neighbours affecting traits and phenotypes differently. No significant effects due to different neighbours were found for any trait (biomass, N content in the leaves, grain yield and LER) for neither faba bean variety nor cereal. Consequently, my study also did not find sufficient support to reject the null hypothesis for third hypotheses.

However, insufficient evidence to reject the second and third hypotheses lends support to the first hypothesis, which states that traits and phenotypes of faba beans grown in mixed culture can be predicted from their corresponding phenotypes found when grown in pure culture. Especially when considering specific individual traits, rather than estimates such as land equivalent ratio, where there were statistically significant differences between pure and mixed cultures at 92 DAS in the no N treatment. In these treatments, mixed cultures required less land area to produce the same amount of biomass yield, which is both in accordance (Xiao et al. 2018) and contradictory (Fan et al. 2008) to the results in previous research. Hence, following the insufficient support to reject the second and third null hypotheses, but there being significant differences in grain yield and LER, the conclusion regarding the first hypothesis is that it finds support when considering specific individual traits throughout the growing season, but when considering yield traits there is insufficient support to reject the null hypothesis.

4.1 Effects of cropping system and neighbour interactions on plasticity and yield

In this study, there were few instances where significant effects on trait plasticity could be found between pure and mixed cultures for specific trait components (especially biomass traits). In the majority of occurrences when there were significant differences between pure and mixed cultures, spring oat was the neighbouring crop. The spring oat as a neighbour tended to have positive effects on the trait plasticity, especially at 92 DAS and in mixtures with ‘Stella’. However, whilst this was the case for the faba bean, the spring oat tended to be negatively affected in terms of trait plasticity when grown in mixtures. This suggests that the faba bean exerts a higher pressure (interspecific plant-plant interactions such as competition) on the spring oat compared to that of the intraspecific interactions in monoculture, especially in +N treatments. Both of the faba bean varieties showed similar plastic responses when accompanied by spring wheat to that of their corresponding pure cultures, indicating that spring wheat exerted a similar pressure to the faba bean intraspecific plant-plant interactions. Whilst the faba bean tended to have an advantage in intercropping systems, it appears to have been to the detriment of the cereals, especially at the last sampling and when N fertilizer was added to the system. This is in accordance a study of faba bean-wheat intercrops, where biomass of faba bean increased in intercrops with wheat compared to the monoculture (Zhang et al. 2024), but contrary to the expected complimentary and facilitative interactions described in literature, where faba bean is expected to act as a secondary crop and to be less competitive in terms of N uptake from the soil (Fogelfors 2015, Hauggaard-Nielsen & Jensen 2001, Jensen et al. 2020, Pelzer et al. 2014). The results were also contradictory to those of others addressing the biomass of cereals in intercrops, where wheat shoot dry weight (per plant) was found to significantly increase in intercrops compared to monocultures (Bargaz et al. 2021).

In this study, there were significant differences between pure and mixed cultures in terms of grain yield, where pure cultures of both faba bean varieties and spring oat had higher yields compared to mixed cultures, whilst the pure culture of spring wheat had the lowest grain yield. This is contradictory to another study on faba bean-cereal mixtures, where grain yields increased for both faba bean and cereals when grown as a mixture compared to the respective monocultures (Zhang et al. 2024). Similarly, it also contradicts a study by where there was a yield advantage in a faba bean-wheat intercrop compared to respective monocultures. In this study, there was also an advantage in LER, but the yield of faba bean was lower in the intercrop compared to corresponding monoculture, indicating the wheat component saw a great positive effect to being grown in the intercropping system compared to as a monoculture (Xiao et al. 2018). The advantage in LER is in accordance with the results of the present study, but where the opposite effect was seen for the wheat component and faba bean was instead positively affected by being grown as an intercrop. The LER result of the present study is also contradictory to the results of the study by Fan et al. (2008), where a decrease in LER was seen compared to monocultures.

Reasons behind the low grain yield of spring wheat compared to the other crops was thought to be due to 2024 being a particularly bad year for spring wheat, with a slightly warmer and drier early growing season compared to the 1991-2020 Climatological Standard Normal period (Figure 2.1). Dry weather in combination with higher temperatures may negatively affect a number of developmental process, including sprouting, tillering, shoot differentiation and early maturation, leading to fewer spikelets and fertile flowers which in turn results in fewer and smaller kernels (Fogelfors 2015). The low grain yield could also be a result of the chosen variety ('Thorus') not being a high-yielding variety and most commonly used in organic farming systems. However, when comparing to standard yields for Uppsala in 2024, yields in the spring wheat monocultures were similar to those in Jordbruksverket (2024b), with a standard yield of 3.95 tonnes ha^{-1} compared to this study's mean grain yield of 3.86 tonnes ha^{-1} (no N) and 3.68 tonnes ha^{-1} (+N). On the other hand, the mean faba bean yields in this study were almost twice as high as the standard yields for faba bean in Uppsala 2024 which was 2.78 tonnes ha^{-1} (Jordbruksverket 2024b).

4.2 Effects of fertilizer treatment on plasticity and yield

The effects of different fertilizer treatments on plasticity and yield in intercropping systems are influenced by both resource availability and changes over time in plant development (Jensen et al. 2020). In systems with limited N (no N treatment in the present study), faba bean showed a lower plasticity in biomass traits in mixed cultures at early sampling stages compared to pure cultures. Competition for resources likely decreased the plastic responses, as the plants had to adjust their growth to optimize resource capture when in competition with cereals which were expected to be more competitive earlier in the season based on the previous results reported by others (Hauggaard-Nielsen & Jensen 2001, Jensen et al. 2020, Pelzer et al. 2014). The opposite was found in the present study further into the growing season. Possible explanations for this could be that the competition for N with cereals early in the growing season increased the need for BNF, which later into the season gave the faba bean an advantage as nutrient resources in the soil were expected to decrease as the crops continued their nutrient uptake. For cereals in mixed cultures with +N treatments, there tended to be negative effect on plasticity of all dry biomass traits of the cereal component when compared to pure cultures. This may reflect a suppression of biomass allocation under competitive conditions where resource availability is higher, or where competition is more symmetric. In general, the addition of N fertilizer generally showed a negative effect on trait plasticity for all biomass traits and mixtures for faba bean, and in the majority of biomass traits and mixtures for cereals. However, no consistent pattern of neighbour-specific effects could be identified, indicating that plastic responses were more strongly shaped by nutrient availability and sampling stage rather than the identity of the neighbouring species.

Following the negative effects of the +N treatment on biomass traits, the same pattern was reflected in LER, where the addition of N fertilizer generally showed a negative effect on LER. The mixed cultures with no N tended to initially exhibit LER values <1 at 50 and 73 DAS, indicating a disadvantage compared to pure cultures. However, at 92 DAS, the mixed cultures instead tended to exhibit LER >1 in the no N treatment, suggesting a late-stage advantage of intercropping under N limited conditions. This pattern supports the notion that interspecific competition dynamics shifted over time, with potential complementarity or facilitation effects becoming more pronounced later in the growing season. Significant differences in LER between fertilizer treatments further reinforced the importance of N availability in shaping intercrop performance. In terms of grain yield, both faba bean varieties consistently outperformed cereals in pure cultures, regardless of fertilizer. However, the addition of N fertilizer generally showed a negative effect on grain yield, with the exception of grain yield for pure cultures of 'Vertigo', spring oat and the mixture of the two. When considering the results for both LER and grain yield, there is an indication that N availability was a major driver of intercrop performance. However, although biomass accumulation improved over time in the mixed cultures without N, it did not always translate into higher grain yields, and *vice versa*. Here, the fact that faba bean had high grain yields even when LER < 1 in early sampling, could indicate an efficient allocation to reproductive plant parts despite suppression early in the season. It could also indicate that reproductive plasticity was greater than the plasticity of vegetative growth. The mixed cultures that had late biomass advantages (LER >1) but not equal benefit in terms of grain yield could be explained by competition for resources (light, space) that may have had limiting effects on grain filling. In a study of faba bean-wheat intercrops, LER values were lower compared to monocultures regardless of fertilizer treatments (Fan et al. 2006), which partly agrees with the results of this study, at least for the treatments with +N. However, in the present study LER values were higher for the treatments with no N compared to monocultures.

The presence of weeds was also considered as a reason for the discrepancies in results related to the different fertilizer treatments. However, there were no significant differences in dry biomass of weeds due any of the experimental factors. In addition, as half of the systems tended to have an increased dry weed biomass due to the +N treatment (pure cultures of 'Stella', spring oat and spring wheat, as well as mixed culture of 'Stella' with spring wheat). These tendencies coincide with grain yields being lower in +N treatments compared to treatments with no N for pure cultures of 'Stella' and spring wheat, as well as the mixture of the two but not the pure culture of spring oat. These tendencies also coincides with total aboveground dry biomass for the pure cultures of spring wheat and the faba bean component of the mixed culture of 'Stella' with spring wheat. However, the tendencies do not coincide with total aboveground dry biomass for the pure culture of 'Stella', spring oat or the cereal component of the mixed culture between 'Stella' and spring wheat, where the +N treatment has higher mean values compared to the no N treatment. Therefore, no conclusive support could be found for the effects of weed dry biomass on grain yield and total aboveground dry biomass. With this, the results in regard to the effect of weeds on biomass especially, are in line with the results of the study by Jäck et al. (2021).

4.3 Predictability

This study found support for the idea that it is possible to predict traits and phenotypic expression in mixed cultures based on those found in pure cultures to a certain extent. There were traits, specifically N content of leaves (SPAD), which tended to remain unchanged between pure and mixed cultures, with the exception of one instance in the no N treatment for faba bean, indicating a strong physiological regulation in both faba bean and cereals for the trait. The relatively fixed aspect of the trait reflects the essential function that N content in the leaves has for the plants, as it is connected to photosynthetic capacity. Hence, even under deficiencies, the trait would have priority in resource allocation (Lambers et al. 2008). In connection to this, it could be expected that rather than sacrificing photosynthetic capacity, the plants would alter its growth pattern to compensate for plant-plant interactions such as shading (i.e. competition), by adjusting positioning and structure of the leaves. However, in relation to this study, it would be necessary to know N levels in the soil prior to sowing and post-harvest to know whether or not N was a limiting factor.

In terms of biomass traits, although there were differences in plasticity, they were inconsistent and without apparent pattern, resulting in the conclusion that there was support for predictability in mixed cultures based on trait expression found in pure culture. However, with the cumulative differences that did exist, it was not surprising that the statistically significant difference in LER between pure and mixed cultures contradicted the notion that it would be possible to predict results based on the pure culture.

For farmers looking to implement intercrops, having predictable results would be crucial for the sustainability of these systems, especially in regard to the economic aspects related to yield. Hence, further studies are necessary to provide additional evidence to whether or not intercropping systems could be a competitive and sustainable alternative to monoculture systems.

4.3.1 Heritability of traits

The only trait that consistently exhibited a high broad-sense heritability for both faba bean and cereals was N content in the leaves (SPAD), which supports the notion of the trait having a strong genetic determination and its potential as a reliable selection trait in intercropping systems (Lambers et al. 2008).

In faba bean, the plastic responses to environmental conditions were more strongly influenced by genetic factors at earlier sampling dates, ascribed to high broad-sense heritability and moderate levels of heritable plasticity. This influence appeared to decrease overtime, shifting to environmental factors becoming the predominant driver of plastic responses. This shift suggests that there is a temporal shift in the control of trait expression, with earlier growth being more dependent on genetics whilst later development is increasingly shaped by environmental conditions. This in turn could be ascribed to nutrient and water availability, shading or interactions such as competition. The cereals showed similar trends in plasticity dynamics, but with an earlier increase of plastic responses. This may be ascribed to the development of tillers early in development for cereals, increasing the flexibility of the plastic responses compared to faba beans, which are limited to branching (Fogelfors 2015). The cereals overall maintained both higher and more stable levels of broad-sense heritability throughout samplings, which would suggest a stronger genetic control over trait expression throughout plant development or be a result of cereals having a longer breeding history (ibid.) compared to faba bean. In terms of heritable plasticity, the cereals also showed an increase over time, suggesting a greater capacity for genetically influenced plastic responses.

Overall, the patterns observed emphasize the importance of considering both the specific traits being measured as well as the differences between crops (both species and cultivars) when assessing heritability and plasticity in intercropping systems.

4.4 Sources of errors and areas of improvements

Sampling and experimental design

Both sampling, grading and measuring/weighting of the samples for the field trial were conducted by several different people without noting whom performed what. This could lead to a number of different sources of error in the raw data, such as through variability in sampling techniques, observer bias, equipment handling differences, and communication gaps. To account for this in the future, steps should be taken so that sampler or experimenter could be treated as a random factor.

With only four replicates and sampling performed on an area basis, the statistical groundwork could be improved by increasing the number of replicates and introduce sampling on an individual plant basis, for a more powerful statistical analysis and possibly increasing instances with significance results.

The field design includes border plots between replicates to reduce interaction effects between blocks. To further reduce effects of neighbouring plots in a field setting, increasing plot size and only sampling from the centre part is an option. Additionally, similar studies could be performed in separate pots in greenhouse conditions to reduce both interactions between plots and cost factors but would instead lose the much needed field condition part of the experiment.

A good idea for future studies would also be to look closer at specific traits and not only on dry biomass. Here number of leaves, leaf area, plant height, number of tillers/shoots, root length, number of nodules and rhizobia are some of the traits that could be further looked into.

Considering the prospect of using these results of this type of study for modelling, where the main goal is to show difference over time, the addition of more trait specific sampling and possibly additional sampling dates would be necessary to provide ample data for model building.

Single year-experiment

Due to the experiment set-up only running for a single year so far, it is impossible to determine whether or not the results in this study are in accordance with the norm or if they are outliers due to weather conditions, etc. In terms of actual conditions, 2024 was both slightly warmer and drier throughout the growing season compared to the most recent normal period (Figure 2.1). As there is only single year to compare with, it is impossible to determine to what extent the climatic factors affected the results of this study. However, as this experiment will run during the 2025 growing season as well, adding year and climatic factors connected to this will be possible for similar studies in the future. An additional factor that would be good to include would be trials at different location to consider environmental factors into account, such as soil properties and climate.

Statistical limitations

The biggest limitation in this study is connected to the limited statistical tools available for rigorously testing differences in phenotypic plasticity between varieties and treatments, particularly in the context of a multi-factorial field trial such as the one in this study. The most commonly used metrics used to measure plasticity, such as plasticity index (PI), coefficient of variation (CV) and the ANOVA-based approach in this study, provide only a narrow and trait-specific view of plastic responses and does not include the nature of plant-environment interactions.

The measures used in this study primarily relied on comparisons between pure and mixed cultures with the additional factors of different neighbours and fertilizer treatments, across different points in time. Hence, whilst this approach has the ability to highlight certain interaction effects, it is highly sensitive to variability and lacks robustness in its ability to determine plasticity from other sources such as genotypic performance or sampling errors, as well as environmental heterogeneity. The pairwise comparisons and simple difference measures makes it difficult to account for non-linear or multi-trait plastic responses, which are likely to operate simultaneously and to be driven by different underlying mechanisms.

An additional issue with this approach is that plasticity measures are rarely designed to accommodate for repeated measures data or hierarchical designs, which limits the ability to model trait plasticity over time or across nested experimental units such as blocks and plots, where random effects can be significant. Thus, increasing the risk of type I and type II errors.

When comparing the results of this study to those of previous research, the lack of standardized thresholds for interpreting plastic capacity and response was another issue that was raised. The lack of easily comparable studies can lead to ambiguous interpretations, especially in context-dependent research.

Future studies would benefit from a more thorough and flexible statistical framework, potentially through mixed-effects models and multivariate plasticity indices, which could offer a clearer insight into plasticity. Additionally, including more precise environmental data may help isolate environmental effects on plasticity that were not considered for this study.

5. Conclusions

In this study, to examine trait plasticity and predictability of mixed cultures compared to pure cultures of faba bean, two faba bean varieties were cultivated both as pure and mixed cultures with spring oat or with spring wheat in treatments with no N and +N. Significant differences in trait plasticity between pure and mixed cultures were more often observed in specific traits and conditions, particularly in no N treatments for both faba bean varieties and in mixtures with spring oat. Contrary, cereals and especially spring wheat, more often showed significant differences between pure and mixed cultures for treatments with +N. Within groups, a significant difference in trait plasticity was only observed for fertilizer treatments at 92 DAS for faba bean, not in regard to neighbours or neighbour x fertilizer interactions for neither faba bean nor cereals. SPAD was the trait that had the least difference in plastic response overall, which is accounted to the importance that N content in the leaves have in regard to photosynthetic capacity.

Similar results were found for land equivalent ratio, where significant differences within groups were only found for fertilizer treatment, where treatments without N outperformed those with +N. Contrary, grain yield had significant differences between pure and mixed cultures, but not for different neighbours or fertilizer treatments. However, results for grain yield should consider the fact that analysis into the different crops contribution to the grain yield was not possible due to data only describing total amounts and not individual crop components.

The final conclusion of this study is that for this experiment, fertilizer had a greater effect on trait plasticity and yield compared to whether the cropping system was a pure or a mixed culture, or what the neighbouring crop was. Hence, this study found insufficient support to reject the second and third hypotheses which suggested that there is no difference in plasticity between faba bean grown in pure culture versus mixed culture, or in mixed culture with different neighbours. This in turn supports the first hypothesis which suggests that traits and phenotypes of faba bean grown in mixed culture can be predicted from their corresponding phenotypes when grown in pure culture, especially when considering specific individual traits throughout the growing season, but when considering yield traits there is insufficient support to reject the null hypothesis. However, additional studies are needed to provide further insights into specific traits and to confirm whether or not these results are outliers for this particular growing season and location.

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Popular science summary

Intercrops with legumes are growing in popularity, especially when considering the legumes ability to form symbiosis with nitrogen-fixating bacteria which can reduce the need for nitrogen fertilizer in agricultural systems. One of the grain legumes that has seen a growing interest in Sweden is the faba bean. Currently, the faba bean production in Sweden has been mostly used for animal feed, but with concerns growing for climate change and people looking for locally produced alternatives to animal protein, faba bean could be one of the options. However, for intercropping systems with faba bean to truly reach the market, farmers need to see the potential and advantages of these types of cropping systems.

The purpose of this thesis was to examine and evaluate whether or not the growth and productivity of faba bean changes when it is grown in intercrops with different cereals compared to when it is grown as sole crops in monocultures. Additionally, the effects of two different nitrogen fertilizer treatments (no nitrogen and normal nitrogen) were looked at to consider if fertilizing affected the cropping systems differently.

The results showed that land equivalent ratio which describes how much land would be needed for intercrops to grow the same amount of yield compared to the monocultures. Here, the intercrops without nitrogen performed better compared to corresponding monocultures. This implies that less land area would be needed to have the same yield. In terms of trait plasticity, which describes how the plants change their growth according to different environments, there were no overall differences when faba bean was grown with different cereals. When instead looking at differences between monocultures and intercrops as a whole, there were a few instances where there were clear differences. However, these differences in general only appeared in cropping systems where there was no nitrogen fertilizer applied, and mostly in systems where faba bean was grown with spring oat.

The conclusion of the thesis was that the major source of differences in plasticity and yield for faba bean was different fertilizer treatments, rather than being grown in monoculture/intercrop or as a result of having different cereals as neighbours.

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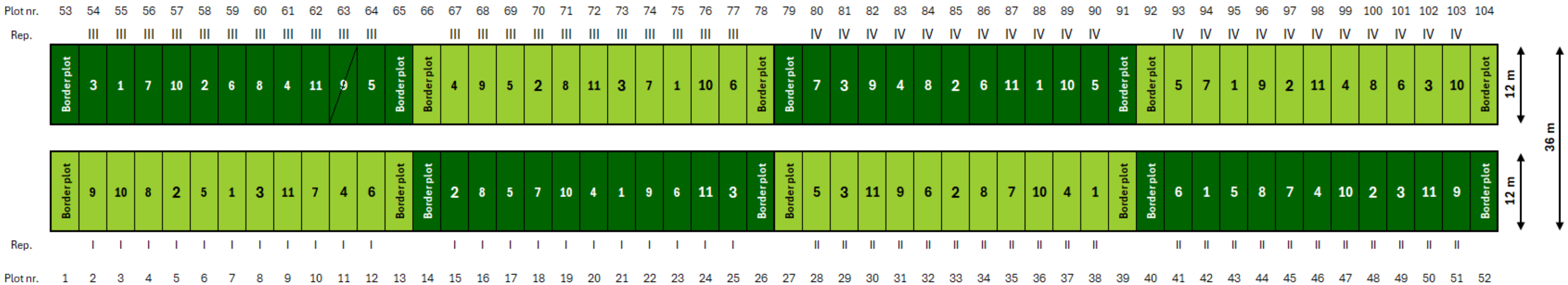
Appendix 1 – Field trial chart and cultivar descriptions



	Code	Crop
Monocultures	1	Winter bean (Arabella)
	2	Spring bean 1 (Stella)
	3	Spring bean 2 (Vertigo)
	4	Winter wheat (Pondus)
	5	Spring wheat (Thorus)
	6	Spring oat (Delfin)

	Code	Crop
Mixed cultures	7	Winter bean (Arabella) + Winter wheat (Pondus)
	8	Spring bean 1 (Stella) + Spring wheat (Thorus)
	9	Spring bean 1 (Stella) + Spring oat (Delfin)
	10	Spring bean 2 (Vertigo) + Spring wheat (Thorus)
	11	Spring bean 2 (Vertigo) + Spring oat (Delfin)

Color codes

N-	(24 kg P + 46 kg K per ha)
N+	(140 kg N + 24 kg P + 46 kg K per ha)

Figure 5.1 Field trial chart.

Appendix 2 – Supplementary Data

Aboveground biomass and SPAD of faba bean

Table 5.1 Mean values and standard deviation of dry biomass of leaves and stems faba bean. *The faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N).*

			Aboveground Dry Biomass (g/m^2)			
			Leaves		Stem	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Stella – Stella	No-N	0.5407	0.1739	0.5348	0.1767
50	Stella – Stella	Norm-N	0.6087	0.2540	0.5552	0.2424
50	Stella – Oat	No-N	0.4886	0.1423	0.4508	0.1402
50	Stella – Oat	Norm-N	0.5814	0.4382	0.4688	0.3509
50	Stella – Wheat	No-N	0.5050	0.4659	0.4938	0.4556
50	Stella – Wheat	Norm-N	0.4683	0.2195	0.4233	0.2089
50	Vertigo – Vertigo	No-N	0.6140	0.0540	0.5861	0.0895
50	Vertigo – Vertigo	Norm-N	0.5362	0.2502	0.5115	0.2075
50	Vertigo – Oat	No-N	0.2467	0.0888	0.2200	0.0575
50	Vertigo – Oat	Norm-N	0.4748	0.1123	0.4298	0.1901
50	Vertigo – Wheat	No-N	0.6348	0.3814	0.5667	0.3453
50	Vertigo – Wheat	Norm-N	0.5864	0.2913	0.5193	0.2555
73	Stella – Stella	No-N	0.6386	0.0690	0.8489	0.1268
73	Stella – Stella	Norm-N	0.8883	0.4115	0.4998	0.2608
73	Stella – Oat	No-N	0.4914	0.0364	0.5062	0.0748
73	Stella – Oat	Norm-N	0.7108	0.2498	0.5775	0.4752
73	Stella – Wheat	No-N	0.4244	0.2719	0.5254	0.3343
73	Stella – Wheat	Norm-N	0.5086	0.0981	0.6575	0.1200
73	Vertigo – Vertigo	No-N	0.7929	0.0494	0.9279	0.0485
73	Vertigo – Vertigo	Norm-N	0.8871	0.1833	1.0841	0.2978
73	Vertigo – Oat	No-N	0.6927	0.1084	0.7667	0.1595
73	Vertigo – Oat	Norm-N	0.6581	0.3768	0.6105	0.2930
73	Vertigo – Wheat	No-N	0.5352	0.0667	0.5978	0.1944
73	Vertigo – Wheat	Norm-N	0.7575	0.4376	0.6429	0.6908
92	Stella – Stella	No-N	0.6826	0.1837	1.2754	0.3248
92	Stella – Stella	Norm-N	1.2255	0.2575	2.1657	0.6172
92	Stella – Oat	No-N	1.3492	0.2221	1.6829	0.7153
92	Stella – Oat	Norm-N	1.3000	0.7320	1.8000	1.1182
92	Stella – Wheat	No-N	1.0224	0.3980	1.5948	0.7501
92	Stella – Wheat	Norm-N	1.2852	0.4069	1.6476	0.5203
92	Vertigo – Vertigo	No-N	0.9544	0.2379	1.3802	0.1406
92	Vertigo – Vertigo	Norm-N	1.2737	0.4565	2.0469	0.7795
92	Vertigo – Oat	No-N	1.7198	1.1917	2.2667	1.4629
92	Vertigo – Oat	Norm-N	0.7788	0.3033	1.3929	0.7306
92	Vertigo – Wheat	No-N	1.1217	0.5490	1.6545	0.9992
92	Vertigo – Wheat	Norm-N	1.0821	0.4966	1.5052	1.0543

Table 5.2 Mean values and standard deviation of dry biomass of pods and combined total of aboveground dry biomass (leaves + stems + pods) of faba bean. *The faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N).*

			Aboveground Dry Biomass (g/m^2)			
			Pods		Total	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Stella – Stella	No-N	-	-	1.0755	0.3471
50	Stella – Stella	Norm-N	-	-	1.1639	0.4949
50	Stella – Oat	No-N	-	-	0.9394	0.2805
50	Stella – Oat	Norm-N	-	-	1.0502	0.7822
50	Stella – Wheat	No-N	-	-	0.9988	0.9190
50	Stella – Wheat	Norm-N	-	-	0.8917	0.4278
50	Vertigo – Vertigo	No-N	-	-	1.2001	0.1417
50	Vertigo – Vertigo	Norm-N	-	-	1.0477	0.4530
50	Vertigo – Oat	No-N	-	-	0.4667	0.1418
50	Vertigo – Oat	Norm-N	-	-	0.9045	0.2997
50	Vertigo – Wheat	No-N	-	-	1.2014	0.7240
50	Vertigo – Wheat	Norm-N	-	-	1.1057	0.5467
73	Stella – Stella	No-N	0.0083	0.0020	1.4957	0.1959
73	Stella – Stella	Norm-N	0.0260	0.0171	1.4141	0.2059
73	Stella – Oat	No-N	0.0595	0.0222	1.0571	0.0889
73	Stella – Oat	Norm-N	0.1219	0.0952	1.4102	0.7071
73	Stella – Wheat	No-N	0.0565	0.0418	1.0063	0.6230
73	Stella – Wheat	Norm-N	0.0571	0.0319	1.2232	0.2019
73	Vertigo – Vertigo	No-N	0.0152	0.0027	1.7360	0.0062
73	Vertigo – Vertigo	Norm-N	0.0556	0.0269	2.0268	0.4987
73	Vertigo – Oat	No-N	0.0590	0.0407	1.5184	0.2352
73	Vertigo – Oat	Norm-N	0.0378	0.0219	1.3063	0.6601
73	Vertigo – Wheat	No-N	0.0330	0.0067	1.1660	0.2470
73	Vertigo – Wheat	Norm-N	0.0597	0.0122	1.4600	1.0561
92	Stella – Stella	No-N	2.6210	0.7680	4.5789	1.2404
92	Stella – Stella	Norm-N	4.1031	0.9625	7.4943	1.6474
92	Stella – Oat	No-N	5.0425	1.6222	8.0746	2.5579
92	Stella – Oat	Norm-N	4.0071	2.4726	7.1071	4.2263
92	Stella – Wheat	No-N	3.8002	1.2306	6.4174	2.2997
92	Stella – Wheat	Norm-N	5.0110	1.2853	7.9438	2.1347
92	Vertigo – Vertigo	No-N	3.0615	0.5285	5.3962	0.7859
92	Vertigo – Vertigo	Norm-N	3.6820	1.3859	7.0026	2.6066
92	Vertigo – Oat	No-N	4.4352	1.3700	8.4217	3.7553
92	Vertigo – Oat	Norm-N	2.6367	1.3060	4.8083	2.2517
92	Vertigo – Wheat	No-N	3.8186	2.6614	6.5948	4.1552
92	Vertigo – Wheat	Norm-N	3.7740	2.6695	6.3614	4.1958

Table 5.3 Mean values and standard deviation of SPAD reading for faba bean. *The faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N).*

			SPAD	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**
50	Stella – Stella	No-N	50.3375	1.4482
50	Stella – Stella	Norm-N	50.3625	1.5510
50	Stella – Oat	No-N	53.0667	2.6126
50	Stella – Oat	Norm-N	50.0625	1.4285
50	Stella – Wheat	No-N	50.9250	1.6075
50	Stella – Wheat	Norm-N	50.5250	3.4647
50	Vertigo – Vertigo	No-N	46.9625	2.2518
50	Vertigo – Vertigo	Norm-N	46.9875	2.1534

50	Vertigo – Oat	No-N	49.3125	1.6770
50	Vertigo – Oat	Norm-N	49.5500	1.1030
50	Vertigo – Wheat	No-N	47.6500	2.8734
50	Vertigo – Wheat	Norm-N	47.9000	0.9975
73	Stella – Stella	No-N	55.1333	2.8219
73	Stella – Stella	Norm-N	55.8333	4.7480
73	Stella – Oat	No-N	54.6000	8.4853
73	Stella – Oat	Norm-N	58.5333	1.7616
73	Stella – Wheat	No-N	57.7000	4.7823
73	Stella – Wheat	Norm-N	52.0000	4.1328
73	Vertigo – Vertigo	No-N	54.3333	4.8232
73	Vertigo – Vertigo	Norm-N	51.5667	2.6951
73	Vertigo – Oat	No-N	51.9667	2.3438
73	Vertigo – Oat	Norm-N	53.1667	0.6110
73	Vertigo – Wheat	No-N	52.0000	3.5384
73	Vertigo – Wheat	Norm-N	49.5000	1.5100

Aboveground biomass and SPAD of cereals

Table 5.4 Mean values and standard deviation of dry biomass of leaves and stems of cereals. *Spring oat ('Delfin') and spring wheat ('Thorus') grown as pure culture and as mixed cultures with faba bean varieties 'Stella' and 'Vertigo' under two different fertilizer treatments (no N and +N).*

			Aboveground Dry Biomass (g/m^2)			
			Leaves		Stem	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Oat – Oat	No-N	0.8656	0.0614	0.0444	0.0155
50	Oat – Oat	Norm-N	0.9545	0.2727	0.0788	0.0312
50	Oat – Stella	No-N	0.9168	0.0839	0.1025	0.0626
50	Oat – Stella	Norm-N	0.8564	0.1305	0.0755	0.0375
50	Oat – Vertigo	No-N	1.0138	0.1754	0.0824	0.0093
50	Oat – Vertigo	Norm-N	1.0979	0.4382	0.0790	0.0315
50	Wheat – Wheat	No-N	0.9793	0.2215	0.1064	0.0339
50	Wheat – Wheat	Norm-N	0.8913	0.3574	0.0912	0.0596
50	Wheat – Stella	No-N	0.7445	0.4758	0.0738	0.0567
50	Wheat – Stella	Norm-N	0.6133	0.5319	0.0612	0.0591
50	Wheat – Vertigo	No-N	0.8805	0.1617	0.1071	0.0508
50	Wheat – Vertigo	Norm-N	0.4836	0.2497	0.0386	0.0088
73	Oat – Oat	No-N	0.5830	0.4025	0.5279	0.1573
73	Oat – Oat	Norm-N	1.0305	0.1107	0.5970	0.0399
73	Oat – Stella	No-N	1.1519	0.6512	0.5700	0.2983
73	Oat – Stella	Norm-N	0.8965	0.5837	0.4851	0.3619
73	Oat – Vertigo	No-N	0.7422	0.3225	0.3483	0.0734
73	Oat – Vertigo	Norm-N	1.0990	0.5558	0.5495	0.3369
73	Wheat – Wheat	No-N	0.4275	0.2697	0.5197	0.4150
73	Wheat – Wheat	Norm-N	0.7454	0.0399	0.6781	0.1976
73	Wheat – Stella	No-N	0.4724	0.5915	0.8717	0.2153
73	Wheat – Stella	Norm-N	0.7003	0.8725	0.5197	0.6181
73	Wheat – Vertigo	No-N	0.6752	0.5174	0.2175	0.0766
73	Wheat – Vertigo	Norm-N	0.6521	0.6240	0.7546	0.5096
92	Oat – Oat	No-N	1.1825	0.3299	1.1365	0.1676
92	Oat – Oat	Norm-N	0.8826	0.1637	1.1529	0.2445
92	Oat – Stella	No-N	0.6384	0.1260	0.8559	0.1488
92	Oat – Stella	Norm-N	0.8357	0.2009	0.7881	0.1615
92	Oat – Vertigo	No-N	0.9257	0.5655	0.9298	0.5347
92	Oat – Vertigo	Norm-N	0.6726	0.2168	0.8105	0.3143

92	Wheat – Wheat	No-N	0.5967	0.1904	0.6418	0.1379
92	Wheat – Wheat	Norm-N	0.5838	0.1611	0.6874	0.0751
92	Wheat – Stella	No-N	0.9871	0.3233	1.1090	0.3648
92	Wheat – Stella	Norm-N	0.4557	0.1908	0.5195	0.1847
92	Wheat – Vertigo	No-N	0.4486	0.2615	0.4276	0.2371
92	Wheat – Vertigo	Norm-N	0.4838	0.1559	0.5274	0.1396

***Table 5.5 Mean values and standard deviation of dry biomass of heads and combined total of aboveground dry biomass (leaves + stems + heads) of the cereals**. Spring oat ('Delfin') and spring wheat ('Thorus') grown as pure culture and as mixed cultures with faba bean varieties 'Stella' and 'Vertigo' under two different fertilizer treatments (no N and +N).*

			Aboveground Dry Biomass (g/m^2)			
			Heads		Total	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Oat – Oat	No-N	0.0502	0.0240	0.9602	0.0615
50	Oat – Oat	Norm-N	0.0758	0.0600	1.1092	0.3530
50	Oat – Stella	No-N	0.0616	0.0405	1.0810	0.1704
50	Oat – Stella	Norm-N	0.0524	0.0239	0.9843	0.1380
50	Oat – Vertigo	No-N	0.0731	0.0420	1.1693	0.2199
50	Oat – Vertigo	Norm-N	0.0514	0.0349	1.2283	0.4690
50	Wheat – Wheat	No-N	0.0325	0.0096	1.1182	0.2484
50	Wheat – Wheat	Norm-N	0.0333	0.0227	1.0158	0.4342
50	Wheat – Stella	No-N	0.0200	0.0182	0.8383	0.5500
50	Wheat – Stella	Norm-N	0.0292	0.0281	0.6964	0.6170
50	Wheat – Vertigo	No-N	0.0252	0.0074	1.0129	0.1968
50	Wheat – Vertigo	Norm-N	0.0148	0.0088	0.5369	0.2603
73	Oat – Oat	No-N	0.4998	0.1571	1.6108	0.2527
73	Oat – Oat	Norm-N	0.7246	0.1371	2.3521	0.2089
73	Oat – Stella	No-N	0.6848	0.6694	2.4067	1.6189
73	Oat – Stella	Norm-N	0.4530	0.2264	1.8346	1.1577
73	Oat – Vertigo	No-N	0.3568	0.1004	1.4473	0.4584
73	Oat – Vertigo	Norm-N	0.5848	0.5078	2.2333	1.3967
73	Wheat – Wheat	No-N	0.5719	0.1560	1.5190	0.4421
73	Wheat – Wheat	Norm-N	0.5833	0.0797	2.0068	0.3129
73	Wheat – Stella	No-N	0.7714	0.1557	2.1156	0.9400
73	Wheat – Stella	Norm-N	0.3651	0.3727	1.5851	1.3511
73	Wheat – Vertigo	No-N	0.4124	0.3607	1.3051	0.2195
73	Wheat – Vertigo	Norm-N	0.6851	0.5025	2.0917	1.5006
92	Oat – Oat	No-N	2.8439	0.5056	5.1630	0.9940
92	Oat – Oat	Norm-N	2.6200	0.4600	4.6555	0.8444
92	Oat – Stella	No-N	2.0749	0.3063	3.5692	0.5225
92	Oat – Stella	Norm-N	2.2381	0.4646	3.8619	0.8130
92	Oat – Vertigo	No-N	2.4274	1.4275	4.2829	2.5017
92	Oat – Vertigo	Norm-N	1.9969	0.9861	3.4800	1.5001
92	Wheat – Wheat	No-N	2.0723	0.7424	3.3107	1.0595
92	Wheat – Wheat	Norm-N	2.1827	0.3521	3.4539	0.5681
92	Wheat – Stella	No-N	2.0812	0.4479	4.1774	0.3766
92	Wheat – Stella	Norm-N	1.3519	0.4511	2.3271	0.7932
92	Wheat – Vertigo	No-N	1.1871	0.9191	2.0633	1.4130
92	Wheat – Vertigo	Norm-N	1.2452	0.5707	2.2564	0.8526

Table 5.6 Mean values and standard deviation of SPAD reading for the two cereals. *Spring oat ('Delfin') and spring wheat ('Thorus') grown as pure culture and as mixed cultures with faba bean varieties 'Stella' and 'Vertigo' under two different fertilizer treatments (no N and +N).*

			SPAD	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**
50	Oat – Oat	No-N	64.0125	1.7825
50	Oat – Oat	Norm-N	62.2375	2.9378
50	Oat – Stella	No-N	65.0500	0.1323
50	Oat – Stella	Norm-N	64.2000	1.8493
50	Oat – Vertigo	No-N	65.1000	2.1024
50	Oat – Vertigo	Norm-N	64.9000	2.8702
50	Wheat – Wheat	No-N	53.2000	0.9009
50	Wheat – Wheat	Norm-N	51.8875	0.7565
50	Wheat – Stella	No-N	52.5000	1.1158
50	Wheat – Stella	Norm-N	52.6500	2.1660
50	Wheat – Vertigo	No-N	51.9500	1.7612
50	Wheat – Vertigo	Norm-N	52.6000	0.5115
73	Oat – Oat	No-N	66.0667	2.1548
73	Oat – Oat	Norm-N	65.3000	3.5369
73	Oat – Stella	No-N	64.0000	3.6770
73	Oat – Stella	Norm-N	66.2667	4.5960
73	Oat – Vertigo	No-N	68.0667	5.3163
73	Oat – Vertigo	Norm-N	65.5667	7.6252
73	Wheat – Wheat	No-N	53.1000	1.5556
73	Wheat – Wheat	Norm-N	52.5667	1.5177
73	Wheat – Stella	No-N	54.3333	1.4189
73	Wheat – Stella	Norm-N	53.1333	4.3004
73	Wheat – Vertigo	No-N	54.5667	2.7319
73	Wheat – Vertigo	Norm-N	52.8667	2.9023

Yield

Table 5.7 Means and standard deviation of grain yield. *Yields in tonnes per hectare for the two faba bean varities 'Stella' and 'Vertigo', and the two cereals spring oat ('Delfin') and spring wheat ('Thorus'), when grown as pure culture and as mixed cultures under two different fertilizer treatments (no N and +N).*

		Grain yield (t/ha)	
Type	**Fertilizer**	**Mean**	**SD**
Stella – Stella	No-N	6.6674	0.6235
Stella – Stella	Norm-N	6.4936	0.4040
Stella – Oat	No-N	5.3146	0.3354
Stella – Oat	Norm-N	5.3017	0.3805
Stella – Wheat	No-N	4.7614	0.4561
Stella – Wheat	Norm-N	4.1150	1.0363
Vertigo – Vertigo	No-N	5.9140	0.9261
Vertigo – Vertigo	Norm-N	6.4767	0.5349
Vertigo – Oat	No-N	5.0600	0.3538
Vertigo – Oat	Norm-N	5.2224	0.2251
Vertigo – Wheat	No-N	4.6010	0.7141
Vertigo – Wheat	Norm-N	4.4617	0.4553
Oat – Oat	No-N	5.2874	0.5082
Oat – Oat	Norm-N	5.7014	0.4418
Wheat – Wheat	No-N	3.8650	0.7260
Wheat – Wheat	Norm-N	3.6824	0.7833

Land equivalent ratio

Table 5.8 Means and standard deviation of land equivalent ratio for aboveground dry biomass. *LER for the two faba bean varities 'Stella' and 'Vertigo', and the two cereals spring oat ('Delfin') and spring wheat ('Thorus'), when grown as mixed cultures under two different fertilizer treatments (no N and +N).*

			Partial LER values		Land equivalent ratio Aboveground biomass	
DAS	**Type**	**Fertilizer**	**Faba bean**	**Cereal**	**Mean**	**SD**
50	Stella – Oat	No-N	0.9121	0.9602	1.1018	0.2325
50	Stella – Oat	Norm-N	1.1639	1.1092	0.8932	0.2213
50	Stella – Wheat	No-N	1.0755	1.1182	0.8525	0.4926
50	Stella – Wheat	Norm-N	1.1639	1.0158	0.8193	0.2706
50	Vertigo – Oat	No-N	1.2001	0.9602	0.8154	0.1821
50	Vertigo – Oat	Norm-N	1.0477	1.1092	1.2079	0.7571
50	Vertigo – Wheat	No-N	1.2001	1.1182	0.9975	0.3386
50	Vertigo – Wheat	Norm-N	1.0477	1.0158	0.9616	0.5449
73	Stella – Oat	No-N	1.4164	1.6967	1.0531	0.3825
73	Stella – Oat	Norm-N	1.4141	2.3521	0.8885	0.4666
73	Stella – Wheat	No-N	1.4957	1.5190	1.0227	0.1077
73	Stella – Wheat	Norm-N	1.4141	2.0068	0.8453	0.2745
73	Vertigo – Oat	No-N	1.7360	1.6108	0.9050	0.1676
73	Vertigo – Oat	Norm-N	2.0268	2.3521	0.8378	0.2439
73	Vertigo – Wheat	No-N	1.7360	1.5190	0.7812	0.0924
73	Vertigo – Wheat	Norm-N	2.0268	2.0068	0.8842	0.3424
92	Stella – Oat	No-N	4.6846	4.9125	1.2340	0.1115
92	Stella – Oat	Norm-N	7.4943	4.6555	0.9280	0.4056
92	Stella – Wheat	No-N	4.5789	3.3107	1.4860	0.3571
92	Stella – Wheat	Norm-N	7.4943	3.4539	0.9081	0.3699
92	Vertigo – Oat	No-N	5.3962	5.1630	1.2381	0.4535
92	Vertigo – Oat	Norm-N	7.0026	4.6555	0.7591	0.3056
92	Vertigo – Wheat	No-N	5.3962	3.3107	0.9955	0.3523
92	Vertigo – Wheat	Norm-N	7.0026	3.4539	0.8220	0.3768

Weed biomass

Table 5.9 Means and standard deviation of dry biomass of weeds. *From the different cropping systems containing the two faba bean varities 'Stella' and 'Vertigo', and the two cereals spring oat ('Delfin') and spring wheat ('Thorus'), when grown as pure culture and as mixed cultures under two different fertilizer treatments (no N and +N), measured in grams per square meter.*

			Weed coverage (g/m^2)	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**
50	Stella – Stella	No-N	0.1296	0.0551
50	Stella – Stella	Norm-N	0.0956	0.0830
50	Stella – Oat	No-N	0.1048	0.0831
50	Stella – Oat	Norm-N	0.0675	0.0595
50	Stella – Wheat	No-N	0.6260	0.9614
50	Stella – Wheat	Norm-N	0.1548	0.1552
50	Vertigo – Vertigo	No-N	0.2402	0.2282
50	Vertigo – Vertigo	Norm-N	0.2263	0.1385
50	Vertigo – Oat	No-N	0.1721	0.1810
50	Vertigo – Oat	Norm-N	0.0660	0.0420
50	Vertigo – Wheat	No-N	0.0820	0.0719
50	Vertigo – Wheat	Norm-N	0.5077	0.8956

50	Oat – Oat	No-N	0.0357	0.0139
50	Oat – Oat	Norm-N	0.0287	0.0376
50	Wheat – Wheat	No-N	0.0398	0.0317
50	Wheat – Wheat	Norm-N	0.1068	0.1135
73	Stella – Stella	No-N	0.1610	0.0942
73	Stella – Stella	Norm-N	0.1256	0.1275
73	Stella – Oat	No-N	0.2895	0.3744
73	Stella – Oat	Norm-N	0.1548	0.0523
73	Stella – Wheat	No-N	0.0589	0.0852
73	Stella – Wheat	Norm-N	0.5657	0.9015
73	Vertigo – Vertigo	No-N	0.0632	0.0595
73	Vertigo – Vertigo	Norm-N	0.1267	0.1104
73	Vertigo – Oat	No-N	0.2957	0.3044
73	Vertigo – Oat	Norm-N	0.1214	0.0999
73	Vertigo – Wheat	No-N	0.0917	0.0505
73	Vertigo – Wheat	Norm-N	0.1256	0.0670
73	Oat – Oat	No-N	0.1013	0.0934
73	Oat – Oat	Norm-N	0.0862	0.0612
73	Wheat – Wheat	No-N	0.0641	0.0459
73	Wheat – Wheat	Norm-N	0.0406	0.0196
92	Stella – Stella	No-N	0.1492	0.1308
92	Stella – Stella	Norm-N	0.1607	0.1202
92	Stella – Oat	No-N	0.4616	0.6257
92	Stella – Oat	Norm-N	0.3143	0.3170
92	Stella – Wheat	No-N	0.1887	0.1349
92	Stella – Wheat	Norm-N	0.6411	0.8040
92	Vertigo – Vertigo	No-N	0.6206	0.4672
92	Vertigo – Vertigo	Norm-N	0.3545	0.4124
92	Vertigo – Oat	No-N	0.4689	0.3521
92	Vertigo – Oat	Norm-N	0.3988	0.3167
92	Vertigo – Wheat	No-N	0.4487	0.5037
92	Vertigo – Wheat	Norm-N	0.3180	0.1863
92	Oat – Oat	No-N	0.0905	0.0694
92	Oat – Oat	Norm-N	0.1167	0.0562
92	Wheat – Wheat	No-N	0.4067	0.4357
92	Wheat – Wheat	Norm-N	0.4957	0.6494

Trait plasticity

Table 5.10 Means and standard deviation of trait plasticity in dry biomass of leaves and stem for faba bean. *Faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N). Calculated according to Equation 1.*

			Aboveground Dry Biomass (g)			
			Leaves		Stem	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Stella – Oat	No-N	0.0908	0.4052	0.0708	0.5860
50	Stella – Oat	Norm-N	-0.1332	0.3326	-0.2495	0.3026
50	Stella – Wheat	No-N	-0.0885	0.8778	-0.1004	0.8255
50	Stella – Wheat	Norm-N	-0.1792	0.3058	-0.1648	0.3750
50	Vertigo – Oat	No-N	-0.5876	0.1775	-0.6131	0.1322
50	Vertigo – Oat	Norm-N	0.3193	1.2698	0.1596	1.1243
50	Vertigo – Wheat	No-N	0.0518	0.6730	0.0316	0.7702
50	Vertigo – Wheat	Norm-N	0.4696	1.1017	0.2438	0.8098
73	Stella – Oat	No-N	-0.1888	0.0171	-0.3681	0.0166

73	Stella – Oat	Norm-N	-0.1686	0.1913	1.1613	2.8945
73	Stella – Wheat	No-N	-0.3553	0.3513	-0.3964	0.3213
73	Stella – Wheat	Norm-N	-0.3146	0.4154	0.8814	1.6273
73	Vertigo – Oat	No-N	-0.1290	0.0964	-0.1662	0.2179
73	Vertigo – Oat	Norm-N	-0.1935	0.6138	-0.3449	0.5199
73	Vertigo – Wheat	No-N	-0.3254	0.0658	-0.3477	0.2476
73	Vertigo – Wheat	Norm-N	-0.1675	0.4556	-0.4078	0.5441
92	Stella – Oat	No-N	1.1565	0.4372	0.2456	0.2130
92	Stella – Oat	Norm-N	0.1268	0.7525	-0.1173	0.6068
92	Stella – Wheat	No-N	0.7688	1.3936	0.4401	1.1334
92	Stella – Wheat	Norm-N	0.1377	0.6122	-0.1388	0.5274
92	Vertigo – Oat	No-N	0.9289	1.5976	0.6545	1.1169
92	Vertigo – Oat	Norm-N	-0.3362	0.3522	-0.3126	0.3291
92	Vertigo – Wheat	No-N	0.3151	0.8778	0.2165	0.7901
92	Vertigo – Wheat	Norm-N	-0.0810	0.4360	-0.1822	0.6599

Table 5.11 Means and standard deviation of trait plasticity in dry biomass of pods and total aboveground dry biomass (leaves + stem + pods) for faba bean. *Faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N). Calculated according to Equation 1.*

			Aboveground Dry Biomass (g)			
			Pods		Total	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Stella – Oat	No-N	-	-	0.0771	0.4918
50	Stella – Oat	Norm-N	-	-	-0.1882	0.3133
50	Stella – Wheat	No-N	-	-	-0.0948	0.8508
50	Stella – Wheat	Norm-N	-	-	-0.1741	0.3329
50	Vertigo – Oat	No-N	-	-	-0.5995	0.1549
50	Vertigo – Oat	Norm-N	-	-	0.2383	1.1877
50	Vertigo – Wheat	No-N	-	-	0.0392	0.7109
50	Vertigo – Wheat	Norm-N	-	-	0.3494	0.9455
73	Stella – Oat	No-N	7.5179	3.9143	-0.2507	0.0418
73	Stella – Oat	Norm-N	5.8718	6.5189	-0.0279	0.3713
73	Stella – Wheat	No-N	6.0547	5.8671	-0.3434	0.3412
73	Stella – Wheat	Norm-N	1.7230	1.4743	-0.1157	0.2419
73	Vertigo – Oat	No-N	2.6677	2.4011	-0.1252	0.1370
73	Vertigo – Oat	Norm-N	-0.3062	0.1889	-0.2723	0.5581
73	Vertigo – Wheat	No-N	1.1616	0.1050	-0.3284	0.1419
73	Vertigo – Wheat	Norm-N	0.2440	0.5263	-0.2911	0.4546
92	Stella – Oat	No-N	0.8563	0.1492	0.7242	0.0928
92	Stella – Oat	Norm-N	0.0679	0.8304	0.0255	0.7578
92	Stella – Wheat	No-N	0.6338	1.0204	0.5972	1.0980
92	Stella – Wheat	Norm-N	0.2981	0.5503	0.1439	0.5550
92	Vertigo – Oat	No-N	0.5047	0.6473	0.6295	0.9443
92	Vertigo – Oat	Norm-N	-0.2394	0.4411	-0.2774	0.3886
92	Vertigo – Wheat	No-N	0.3096	0.9499	0.2752	0.8570
92	Vertigo – Wheat	Norm-N	0.1533	0.9210	0.0064	0.7368

Table 5.12 Means and standard deviation of trait plasticity in dry biomass of leaves and stem) for cereals. *Spring oat 'Delfin' and spring wheat 'Thorus' grown as pure culture and as mixed cultures*

with faba bean varieties 'Stella' and 'Vertigo' under two different fertilizer treatments (no N and +N). Calculated according to Equation 1.

			Aboveground Dry Biomass (g)			
			Leaves		Stem	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Oat – Stella	No-N	0.1265	0.0484	0.0570	2.7780
50	Oat – Stella	Norm-N	-0.0254	0.2974	-0.0437	1.0739
50	Oat – Vertigo	No-N	-0.2002	0.2818	-0.1832	0.6848
50	Oat – Vertigo	Norm-N	-0.1872	0.5061	-0.1871	0.4303
50	Wheat – Stella	No-N	0.2304	0.5885	0.1862	0.6055
50	Wheat – Stella	Norm-N	0.1775	0.7536	0.2150	1.0455
50	Wheat – Vertigo	No-N	-0.0442	0.3070	-0.0516	0.6071
50	Wheat – Vertigo	Norm-N	-0.4262	0.2299	-0.4214	0.6873
73	Oat – Stella	No-N	0.3569	0.6240	0.3792	0.6784
73	Oat – Stella	Norm-N	-0.1950	0.6887	-0.0887	0.5468
73	Oat – Vertigo	No-N	0.3887	2.8447	0.0424	0.1153
73	Oat – Vertigo	Norm-N	-0.1937	0.5190	-0.0624	0.5885
73	Wheat – Stella	No-N	-0.0647	0.8066	1.5823	6.1705
73	Wheat – Stella	Norm-N	-0.0520	1.1629	0.0641	1.0688
73	Wheat – Vertigo	No-N	-0.1091	0.7468	0.7498	3.0882
73	Wheat – Vertigo	Norm-N	0.0595	0.8307	-0.1197	0.8551
92	Oat – Stella	No-N	-0.2563	0.0966	-0.4048	0.1492
92	Oat – Stella	Norm-N	-0.1696	0.1525	-0.0490	0.1101
92	Oat – Vertigo	No-N	0.3747	0.5637	0.8877	0.4755
92	Oat – Vertigo	Norm-N	-0.3276	0.3730	-0.1923	0.3877
92	Wheat – Stella	No-N	-0.1533	1.1132	-0.1761	1.1132
92	Wheat – Stella	Norm-N	-0.2043	0.3973	-0.1863	0.3973
92	Wheat – Vertigo	No-N	-0.2842	0.7424	-0.1203	0.5643
92	Wheat – Vertigo	Norm-N	-0.3624	0.0821	-0.1771	0.1402

Table 5.13 Means and standard deviation of trait plasticity in dry biomass of heads and total aboveground dry biomass (leaves + stem + heads) for cereals. *Spring oat 'Delfin' and spring wheat 'Thorus' grown as pure culture and as mixed cultures with faba bean varieties 'Stella' and 'Vertigo' under two different fertilizer treatments (no N and +N). Calculated according to Equation 1.*

			Aboveground Dry Biomass (g)			
			Heads		Total	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Oat – Stella	No-N	1.7842	0.1694	0.8907	1.3915
50	Oat – Stella	Norm-N	0.2266	0.3809	0.2378	1.0637
50	Oat – Vertigo	No-N	-0.2578	0.2895	-0.4406	0.7524
50	Oat – Vertigo	Norm-N	0.0740	0.4676	-0.1011	1.9496
50	Wheat – Stella	No-N	1.0342	0.5785	0.5836	0.4347
50	Wheat – Stella	Norm-N	0.0687	0.7565	0.3897	1.1269
50	Wheat – Vertigo	No-N	0.0956	0.3120	-0.1712	0.3173
50	Wheat – Vertigo	Norm-N	-0.2886	0.3475	-0.4773	0.2238
73	Oat – Stella	No-N	0.3029	0.9503	0.3346	0.7231
73	Oat – Stella	Norm-N	-0.2064	0.4298	-0.3366	0.5717
73	Oat – Vertigo	No-N	3.9023	0.3851	0.4032	0.5568
73	Oat – Vertigo	Norm-N	-0.1460	0.5852	-0.4214	0.6781
73	Wheat – Stella	No-N	-0.3262	0.3680	-0.1705	0.3690
73	Wheat – Stella	Norm-N	-0.0713	0.7355	-0.2023	0.5191
73	Wheat – Vertigo	No-N	1.0167	0.4646	-0.3106	0.1794
73	Wheat – Vertigo	Norm-N	0.1251	0.9334	0.1815	0.8187
92	Oat – Stella	No-N	-0.2056	0.1618	-0.2189	0.1469
92	Oat – Stella	Norm-N	-0.3087	0.0608	-0.1469	0.0820
92	Oat – Vertigo	No-N	0.8794	0.5031	0.0703	0.4984
92	Oat – Vertigo	Norm-N	-0.2575	0.4025	-0.3830	0.4254

92	Wheat – Stella	No-N	-0.1701	0.4739	-0.1358	0.3507
92	Wheat – Stella	Norm-N	-0.2411	0.2212	-0.1944	0.1893
92	Wheat – Vertigo	No-N	-0.2648	0.6473	-0.3376	0.6501
92	Wheat – Vertigo	Norm-N	-0.2392	0.1277	-0.4477	0.1547

Table 5.14 Means and standard deviation of trait plasticity in SPAD for faba bean and cereal components. *For faba bean varieties 'Stella' and 'Vertigo' grown as pure culture and as mixed cultures with spring oat or spring wheat under two different fertilizer treatments (no N and +N). Calculated according to Equation 1.*

			SPAD			
			Faba bean		Cereal	
DAS	**Type**	**Fertilizer**	**Mean**	**SD**	**Mean**	**SD**
50	Stella – Oat	No-N	0.0516	0.0261	0.0282	0.0207
50	Stella – Oat	Norm-N	-0.0056	0.0308	0.0326	0.0398
50	Stella – Wheat	No-N	0.0118	0.0259	-0.0130	0.0235
50	Stella – Wheat	Norm-N	0.0031	0.0576	0.0147	0.0377
50	Vertigo – Oat	No-N	0.0507	0.0247	0.0170	0.0170
50	Vertigo – Oat	Norm-N	0.0569	0.0694	0.0448	0.0721
50	Vertigo – Wheat	No-N	0.0146	0.0387	-0.0235	0.0283
50	Vertigo – Wheat	Norm-N	0.0208	0.0464	0.0140	0.0226
73	Stella – Oat	No-N	-0.0372	0.1579	-0.0150	0.0362
73	Stella – Oat	Norm-N	0.0535	0.0952	0.0142	0.0166
73	Stella – Wheat	No-N	0.0502	0.1282	0.0206	0.0074
73	Stella – Wheat	Norm-N	-0.0643	0.1062	0.0105	0.0709
73	Vertigo – Oat	No-N	-0.0382	0.1009	0.0320	0.1054
73	Vertigo – Oat	Norm-N	0.0333	0.0649	0.0018	0.0636
73	Vertigo – Wheat	No-N	-0.0347	0.1482	0.0342	0.0403
73	Vertigo – Wheat	Norm-N	-0.0378	0.0690	0.0057	0.0471

Plasticity and heritability

Table 5.15 Values of variance components for aboveground dry biomass and SPAD traits calculated from ANOVA tables for each trait. *For the cropping systems containing two faba bean varities 'Stella' and 'Vertigo', and the two cereals spring oat ('Delfin') and spring wheat ('Thorus'), when grown as pure culture and as mixed cultures under two different fertilizer treatments (no N and +N).*

DAS	Trait	Crop	PL	H	H_{pl}
50	Leaves	Faba bean	0.5575	0.4102	0.2653
50	Stem	Faba bean	0.4851	0.4677	0.3195
50	Total	Faba bean	0.5269	0.4358	0.2914
50	SPAD	Faba bean	0.3429	0.6223	0.2065
73	Leaves	Faba bean	0.1177	0.2704	0.0689
73	Stem	Faba bean	0.4309	0.4698	0.0365
73	Pods	Faba bean	0.5444	0.3722	0.1914
73	Total	Faba bean	0.3474	0.3485	0.1979
73	SPAD	Faba bean	0.4604	0.5496	0.4503
92	Leaves	Faba bean	0.8267	0.0887	0.0450
92	Stem	Faba bean	0.7318	0.1304	0.0648
92	Pods	Faba bean	0.8185	0.0575	0.0436
92	Total	Faba bean	0.8019	0.0743	0.0454
50	Leaves	Cereals	0.2416	0.5665	0.0976
50	Stem	Cereals	0.1815	0.5783	0.0867
50	Heads	Cereals	0.5748	0.4274	0.1717
50	Total	Cereals	0.2889	0.5266	0.0792

50	SPAD	Cereals	0.5534	0.3369	0.0377
73	Leaves	Cereals	0.6077	0.2164	0.0870
73	Stem	Cereals	0.6708	0.4455	0.4194
73	Heads	Cereals	0.5672	0.3817	0.1939
73	Total	Cereals	0.5810	0.2829	0.2504
73	SPAD	Cereals	0.2858	0.2163	0.1722
92	Leaves	Cereals	0.5593	0.6503	0.3719
92	Stem	Cereals	0.5187	0.3978	0.1926
92	Heads	Cereals	0.6301	0.5276	0.2611
92	Total	Cereals	0.6301	0.4760	0.2813

Appendix 3 – Statistical data

To facilitate an easier reading experience and to showcase values that are significant, values where p < 0.05 are in bold font. In ANOVA tables for tables 5.16-5.28, "type" in Source refers to both different neighbours and different cropping systems (pure and mixed culture). In tables 5.29-5.39, "type" only refers to different neighbours – as a separate statistical analysis using one-sample t-tests were necessary to compare between pure and mixed cultures.

Aboveground biomass and SPAD

Table 5.16 ANOVA table for aboveground dry biomass for faba bean.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Stella	50	type	2	0.126	0.063	0.174	0.842
Stella	50	fertilizer	1	0.004	0.0041	0.011	0.917
Stella	50	type:fertilizer	2	0.056	0.0278	0.077	0.927
Stella	50	residuals	17	6.172	0.3631		
Stella	73	type	2	0.348	0.17401	0.944	0.418
Stella	73	fertilizer	1	0.0934	0.09345	0.507	0.491
Stella	73	type:fertilizer	2	0.1366	0.0683	0.371	0.699
Stella	73	residuals	11	2.0272	0.18429		
Stella	92	type	2	9.30	4.648	0.725	0.499
Stella	92	fertilizer	1	9.14	9.135	1.425	0.249
Stella	92	type:fertilizer	2	14.13	7.064	1.102	0.355
Stella	92	residuals	17	108.96	6.41		
Vertigo	50	type	2	1.099	0.5494	2.846	0.0844
Vertigo	50	fertilizer	1	0.024	0.024	0.124	0.7285
Vertigo	50	type:fertilizer	2	0.424	0.2121	1.099	0.3547
Vertigo	50	residuals	18	3.475	0.1931		
Vertigo	73	type	2	1.106	0.553	1.732	0.218
Vertigo	73	fertilizer	1	0.069	0.0695	0.217	0.649
Vertigo	73	type:fertilizer	2	0.254	0.1272	0.398	0.680
Vertigo	73	residuals	12	3.832	0.3193		
Vertigo	92	type	2	0.72	0.359	0.035	0.966
Vertigo	92	fertilizer	1	3.30	3.346	0.327	0.575
Vertigo	92	type:fertilizer	2	28.04	14.018	1.369	0.280
Vertigo	92	residuals	18	184.36	10.242		

Table 5.17 ANOVA table for dry biomass of leaves for faba bean.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Stella	50	type	2	0.0316	0.01579	0.158	0.855
Stella	50	fertilizer	1	0.0086	0.00861	0.086	0.773
Stella	50	type:fertilizer	2	0.0181	0.00905	0.091	0.914

Stella	50	residuals	17	1.6968	0.09981		
Stella	73	type	2	0.2647	0.13234	2.270	0.150
Stella	73	fertilizer	1	0.1390	0.13896	2.383	0.151
Stella	73	type:fertilizer	2	0.0229	0.01146	0.197	0.824
Stella	73	residuals	11	0.6414	0.05831		
Stella	92	type	2	0.5072	0.2536	1.448	0.263
Stella	92	fertilizer	1	0.4081	0.4081	2.329	0.145
Stella	92	type:fertilizer	2	0.3236	0.1618	0.924	0.416
Stella	92	residuals	17	2.9782	0.1752		
Vertigo	50	type	2	0.2924	0.14622	2.773	0.0891
Vertigo	50	fertilizer	1	0.0069	0.00692	0.131	0.7213
Vertigo	50	type:fertilizer	2	0.1139	0.05696	1.080	0.3605
Vertigo	50	residuals	18	0.9491	0.05273		
Vertigo	73	type	2	0.1309	0.06544	1.018	0.391
Vertigo	73	fertilizer	1	0.0397	0.03974	0.618	0.447
Vertigo	73	type:fertilizer	2	0.0495	0.02473	0.385	0.689
Vertigo	73	residuals	12	0.7715	0.06429		
Vertigo	92	type	2	0.107	0.0535	0.138	0.872
Vertigo	92	fertilizer	2	0.0316	0.01579	0.158	0.855
Vertigo	92	type:fertilizer	1	0.0086	0.00861	0.086	0.773
Vertigo	92	residuals	2	0.0181	0.00905	0.091	0.914

Table 5.18 ANOVA table for dry biomass of stems for faba bean.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Stella	50	type	2	0.0379	0.01897	0.225	0.801
Stella	50	fertilizer	1	0.0008	0.00084	0.010	0.922
Stella	50	type:fertilizer	2	0.0105	0.00525	0.062	0.940
Stella	50	residuals	17	1.4321	0.08424		
Stella	73	type	2	0.0455	0.02275	0.285	0.757
Stella	73	fertilizer	1	0.0137	0.01371	0.172	0.686
Stella	73	type:fertilizer	2	0.2013	0.10065	1.261	0.321
Stella	73	residuals	11	0.8778	0.07980		
Stella	92	type	2	0.070	0.0349	0.068	0.935
Stella	92	fertilizer	1	0.762	0.7624	1.484	0.240
Stella	92	type:fertilizer	2	0.852	0.4261	0.829	0.543
Stella	92	residuals	17	8.734	0.5137		
Vertigo	50	type	2	0.2606	0.13032	2.843	0.0845
Vertigo	50	fertilizer	1	0.0051	0.00515	0.112	0.7415
Vertigo	50	type:fertilizer	2	0.0985	0.04923	1.074	0.3626
Vertigo	50	residuals	18	0.8251	0.04584		
Vertigo	73	type	2	0.5084	0.025422	2.2126	0.162
Vertigo	73	fertilizer	1	0.0010	0.00102	0.008	0.928
Vertigo	73	type:fertilizer	2	0.0752	0.03761	0.315	0.736
Vertigo	73	residuals	12	1.4348	0.11957		
Vertigo	92	type	2	0.250	0.1251	0.139	0.871
Vertigo	92	fertilizer	1	0.085	0.0847	0.094	0.763
Vertigo	92	type:fertilizer	2	2.376	1.1879	1.317	0.293
Vertigo	92	residuals	18	16.234	0.9019		

Table 5.19 ANOVA table for dry biomass of pods for faba bean.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Stella	73	type	2	0.017417	0.008708	3.871	0.0534
Stella	73	fertilizer	1	0.002500	0.002500	1.111	0.3144
Stella	73	type:fertilizer	2	0.002544	0.001322	0.588	0.5722
Stella	73	residuals	11	0.024746	0.002250		
Stella	92	type	2	5.92	2.961	1.337	0.289

Stella	92	fertilizer	1	2.28	2.282	1.030	0.324
Stella	92	type:fertilizer	2	6.88	3.441	1.553	0.240
Stella	92	residuals	17	37.65	2.215		
Vertigo	73	type	2	0.000587	0.000294	0.575	0.5774
Vertigo	73	fertilizer	1	0.001045	0.001045	2.047	0.1781
Vertigo	73	type:fertilizer	2	0.003139	0.001570	3.074	0.0836
Vertigo	73	residuals	12	0.006126	0.000511		
Vertigo	92	type	2	0.73	0.367	0.110	0.986
Vertigo	92	fertilizer	1	1.00	0.997	0.299	0.591
Vertigo	92	type:fertilizer	2	6.25	3.124	0.937	0.410
Vertigo	92	residuals	18	59.98	3.332		

Table 5.20 ANOVA table for SPAD for faba bean.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Stella	50	type	2	3.78	1.889	0.417	0.666
Stella	50	fertilizer	1	6.09	6.092	1.344	0.262
Stella	50	type:fertilizer	2	9.70	4.850	1.070	0.365
Stella	50	residuals	17	77.05	4.532		
Stella	73	type	2	12.55	6.28	0.315	0.736
Stella	73	fertilizer	1	1.84	1.84	0.092	0.767
Stella	73	type:fertilizer	2	66.20	33.10	1.662	0.234
Stella	73	residuals	11	219.12	19.92		
Vertigo	50	type	2	68.5	34.23	1.343	0.287
Vertigo	50	fertilizer	1	44.4	44.40	1.743	0.204
Vertigo	50	type:fertilizer	2	9.4	4.71	0.185	0.833
Vertigo	50	residuals	17	433.1	25.48		
Vertigo	73	type	2	25.11	12.555	3.277	0.0611
Vertigo	73	fertilizer	1	0.18	0.175	0.046	0.8331
Vertigo	73	type:fertilizer	2	0.06	0.032	0.008	0.9917
Vertigo	73	residuals	18	68.97	3.831		

Table 5.21 ANOVA table for aboveground dry biomass for cereals.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Oat	50	type	2	0.1481	0.07404	0.964	0.401
Oat	50	fertilizer	1	0.0110	0.01096	0.143	0.710
Oat	50	type:fertilizer	2	0.0564	0.02820	0.367	0.698
Oat	50	residuals	17	1.3053	0.07678		
Oat	73	type	2	0.142	0.0709	0.079	0.924
Oat	73	fertilizer	1	0.613	0.6129	0.685	0.425
Oat	73	type:fertilizer	2	1.531	0.7654	0.856	0.451
Oat	73	residuals	11	9.838	0.8944		
Oat	92	type	2	6.34	3.170	1.625	0.226
Oat	92	fertilizer	1	0.79	0.786	0.403	0.534
Oat	92	type:fertilizer	2	1.17	0.583	0.299	0.746
Oat	92	residuals	17	33.16	1.951		
Wheat	50	type	2	04672	0.2336	1.348	0.285
Wheat	50	fertilizer	1	0.3458	0.3458	1.995	0.175
Wheat	50	type:fertilizer	2	0.1685	0.0842	0.486	0.623
Wheat	50	residuals	18	3.1197	0.1733		
Wheat	73	type	2	0.070	0.0349	0.039	0.961
Wheat	73	fertilizer	1	0.277	0.2767	0.313	0.586
Wheat	73	type:fertilizer	2	1.431	0.7153	0.809	0.468
Wheat	73	residuals	12	10.605	0.8838		
Wheat	92	type	2	7.212	3.606	4.380	**0.0282**
Wheat	92	fertilizer	1	1.528	1.528	1.856	0.1899
Wheat	92	type:fertilizer	2	5.434	2.717	3.300	0.0601
Wheat	92	residuals	18	14.819	0.823		

Table 5.22 ANOVA table for dry biomass of leaves for cereals.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Oat	50	type	2	0.1343	0.06716	1.179	0.331
Oat	50	fertilizer	1	0.0103	0.01028	0.181	0.676
Oat	50	type:fertilizer	2	0.0259	0.01296	0.228	0.799
Oat	50	residuals	17	0.9681	0.05695		
Oat	73	type	2	0.1032	0.05161	0.249	0.784
Oat	73	fertilizer	1	0.1928	0.19284	0.930	0.355
Oat	73	type:fertilizer	2	0.3768	0.18838	0.909	0.431
Oat	73	residuals	11	2.2797	0.20724		
Oat	92	type	2	0.3500	0.17500	1.792	0.197
Oat	92	fertilizer	1	0.1031	0.10314	1.056	0.318
Oat	92	type:fertilizer	2	0.2716	0.13578	1.390	0.276
Oat	92	residuals	17	1.6601	0.09765		
Wheat	50	type	2	0.3464	0.17318	1.341	0.286
Wheat	50	fertilizer	1	0.2530	0.25303	1.960	0.179
Wheat	50	type:fertilizer	2	0.1119	0.05597	0.434	0.655
Wheat	50	residuals	18	2.3238	0.12910		
Wheat	73	type	2	0.024	0.01194	0.039	0.962
Wheat	73	fertilizer	1	0.137	0.13661	0.445	0.517
Wheat	73	type:fertilizer	2	0.094	0.04688	0.153	0.860
Wheat	73	residuals	12	3.685	0.30710		
Wheat	92	type	2	0.2607	0.1303	2.644	0.0985
Wheat	92	fertilizer	1	0.1728	0.1727	3.504	0.0776
Wheat	92	type:fertilizer	2	0.3949	0.1974	4.005	**0.0364**
Wheat	92	residuals	18	0.8874	0.0493		

Table 5.23 ANOVA table for dry biomass of stems for cereals.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Oat	50	type	2	0.002694	0.001347	1.211	0.322
Oat	50	fertilizer	1	0.000043	0.000043	0.039	0.846
Oat	50	type:fertilizer	2	0.003602	0.001801	1.619	0.227
Oat	50	residuals	17	0.018911	0.001112		
Oat	73	type	2	0.0393	0.01966	0.337	0.721
Oat	73	fertilizer	1	0.0219	0.02194	0.376	0.552
Oat	73	type:fertilizer	2	0.0546	0.02731	0.468	0.638
Oat	73	residuals	11	0.6413	0.05830		
Oat	92	type	2	0.4779	0.23894	2.637	0.101
Oat	92	fertilizer	1	0.0182	0.01816	0.200	0.660
Oat	92	type:fertilizer	2	0.0187	0.00935	0.103	0.902
Oat	92	residuals	17	1.5403	0.09060		
Wheat	50	type	2	0.00449	0.002243	0.957	0.403
Wheat	50	fertilizer	1	0.00620	0.006199	2.645	0.121
Wheat	50	type:fertilizer	2	0.00399	0.001994	0.851	0.444
Wheat	50	residuals	18	0.04219	0.002344		
Wheat	73	type	2	0.1322	0.06608	0.438	0.655
Wheat	73	fertilizer	1	0.0590	0.05899	0.391	0.543
Wheat	73	type:fertilizer	2	0.5974	0.29868	1.980	0.181
Wheat	73	residuals	12	1.8105	0.15087		
Wheat	92	type	2	0.4556	0.22778	5.108	**0.01750**
Wheat	92	fertilizer	1	0.1315	0.13152	2.949	0.10307
Wheat	92	type:fertilizer	2	0.5876	0.29381	6.588	**0.00713**
Wheat	92	residuals	18	0.8027	0.04459		

Table 5.24 ANOVA table for dry biomass of heads for cereals.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Oat	50	type	2	0.000197	0.000099	0.063	0.939
Oat	50	fertilizer	1	0.000011	0.000011	0.007	0.934
Oat	50	type:fertilizer	2	0.002383	0.001192	0.765	0.481
Oat	50	residuals	17	0.026491	0.001558		
Oat	73	type	2	0.0601	0.03003	0.282	0.760
Oat	73	fertilizer	1	0.0383	0.03828	0.359	0.561
Oat	73	type:fertilizer	2	0.1799	0.08994	0.843	0.456
Oat	73	residuals	11	1.1734	0.10667		
Oat	92	type	2	1.531	0.7653	1.155	0.339
Oat	92	fertilizer	1	0.0185	0.1853	0.280	0.604
Oat	92	type:fertilizer	2	0.331	0.1656	0.250	0.782
Oat	92	residuals	17	11.267	0.6628		
Wheat	50	type	2	0.000698	0.000349	1.237	0.315
Wheat	50	fertilizer	1	0.000002	0.000002	0.008	0.932
Wheat	50	type:fertilizer	2	0.000364	0.000182	0.645	0.537
Wheat	50	residuals	18	0.004798	0.000282		
Wheat	73	type	2	0.0026	0.00130	0.014	0.987
Wheat	73	fertilizer	1	0.0075	0.00747	0.078	0.785
Wheat	73	type:fertilizer	2	0.3520	0.17598	1.832	0.202
Wheat	73	residuals	12	1.1528	0.09607		
Wheat	92	type	2	3.333	1.6663	4.444	**0.027**
Wheat	92	fertilizer	1	0.210	0.2096	0.559	0.464
Wheat	92	type:fertilizer	2	0.885	0.4426	1.180	0.330
Wheat	92	residuals	18	6.749	0.3750		

Table 5.25 ANOVA table for SPAD for cereals.

Variety	DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
Oat	50	type	2	15.29	7.644	1.553	0.240
Oat	50	fertilizer	1	5.12	5.117	1.039	0.322
Oat	50	type:fertilizer	2	2.50	1.252	0.254	0.778
Oat	50	residuals	17	83.69	4.923		
Oat	73	type	2	6.65	3.324	0.139	0.872
Oat	73	fertilizer	1	.1.13	1.132	0.047	0.832
Oat	73	type:fertilizer	2	15.29	7.645	0.320	0.733
Oat	73	residuals	11	262.89	23.899		
Wheat	50	type	2	0.44	0.2176	0.122	0.886
Wheat	50	fertilizer	1	0.18	0.1751	0.098	0.757
Wheat	50	type:fertilizer	2	4.16	2.0801	1.168	0.333
Wheat	50	residuals	18	32.05	1.7807		
Wheat	73	type	2	3.15	1.576	0.217	0.808
Wheat	73	fertilizer	1	5.93	5.929	0.817	0.385
Wheat	73	type:fertilizer	2	0.91	0.454	0.063	0.940
Wheat	73	residuals	11	79.81	7.256		

Table 5.26 ANOVA table for grain yield.

Source	Df	Sum Sq	Mean Sq	F-value	P-value
type	7	48.44	6.921	19.073	**6.68e-12**
fertilizer	1	0.00	0.000	0.000	0.991
type:fertilizer	7	2.03	0.290	0.799	0.592
residuals	47	17.05	0.363		

Table 5.27 ANOVA table for land equivalent ratio.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.149	0.04963	0.268	0.848
50	fertilizer	1	0.011	0.01084	0.059	0.811
50	type:fertilizer	3	0.377	0.12556	0.678	0.574
50	residuals	23	4.256	0.18506		
73	type	3	0.0533	0.01777	0.226	0.877
73	fertilizer	1	0.0295	0.02948	0.374	0.550
73	type:fertilizer	3	0.0729	0.02429	0.308	0.819
73	residuals	15	1.1821	0.07881		
92	type	3	0.3513	0.1171	0.896	0.45830
92	fertilizer	1	1.1552	1.1552	8.836	**0.00682**
92	type:fertilizer	3	0.1921	0.0640	0.490	0.69275
92	residuals	23	3.0069	0.1307		

Table 5.28 ANOVA table for dry biomass of weeds.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	7	0.853	0.12192	0.986	0.453
50	fertilizer	1	0.008	0.00754	0.061	0.806
50	type:fertilizer	7	0.836	0.11938	0.966	0.467
50	residuals	46	5.685	0.12359		
73	type	7	0.3006	0.04295	0.629	0.728
73	fertilizer	1	0.0118	0.01183	0.173	0.680
73	type:fertilizer	7	0.4516	0.06452	0.945	0.487
73	residuals	31	2.1164	0.06827		
92	type	7	1.128	0.16108	0.979	0.458
92	fertilizer	1	0.000	0.00005	0.000	0.986

Trait plasticity

Table 5.29 One-sample t-test between pure and mixed cultures for all traits for trait plasticity. *Tested against 0 to show any statistically significant differences between pure and mixed cultures.*

				P-value		
Crop	**Trait**	**System**	**Fertilizer**	**50 DAS**	**73 DAS**	**92 DAS**
Faba	Total DW	Stella – Oat	No-N	0.81144	0.07469	**0.00543**
Faba	Total DW	Stella – Oat	Norm-N	0.31584	0.90823	0.95054
Faba	Total DW	Stella – Wheat	No-N	0.83802	0.22341	0.35622
Faba	Total DW	Stella – Wheat	Norm-N	0.37244	0.49445	0.63984
Faba	Total DW	Vertigo – Oat	No-N	**0.00449**	0.25439	0.27465
Faba	Total DW	Vertigo – Oat	Norm-N	0.71506	0.48702	0.24867
Faba	Total DW	Vertigo – Wheat	No-N	0.91916	0.05694	0.56639
Faba	Total DW	Vertigo – Wheat	Norm-N	0.51345	0.38284	0.98713
Faba	Leaf DW	Stella – Oat	No-N	0.73536	**0.04060**	**0.04449**
Faba	Leaf DW	Stella – Oat	Norm-N	0.48170	0.26644	0.75824
Faba	Leaf DW	Stella – Wheat	No-N	0.85313	0.22190	0.35044
Faba	Leaf DW	Stella – Wheat	Norm-N	0.32585	0.31986	0.68337
Faba	Leaf DW	Vertigo – Oat	No-N	**0.00702**	0.14625	0.32900
Faba	Leaf DW	Vertigo – Oat	Norm-N	0.64964	0.63984	0.15221
Faba	Leaf DW	Vertigo – Wheat	No-N	0.88739	**0.01335**	0.52468
Faba	Leaf DW	Vertigo – Wheat	Norm-N	0.45657	0.58931	0.73492
Faba	Stem DW	Stella – Oat	No-N	0.85361	**0.02031**	0.18391
Faba	Stem DW	Stella – Oat	Norm-N	0.19766	0.55899	0.72474
Faba	Stem DW	Stella – Wheat	No-N	0.82342	0.16611	0.49400
Faba	Stem DW	Stella – Wheat	Norm-N	0.44418	0.44720	0.63511

Faba	Stem DW	Vertigo – Oat	No-N	**0.00265**	0.31740	0.32583
Faba	Stem DW	Vertigo – Oat	Norm-N	0.79489	0.36938	0.15373
Faba	Stem DW	Vertigo – Wheat	No-N	0.93969	0.13554	0.62182
Faba	Stem DW	Vertigo – Wheat	Norm-N	0.58953	0.32379	0.61934
Faba	Pod DW	Stella – Oat	No-N	-	0.22458	**0.00997**
Faba	Pod DW	Stella – Oat	Norm-N	-	0.25910	0.88051
Faba	Pod DW	Stella – Wheat	No-N	-	0.21578	0.30241
Faba	Pod DW	Stella – Wheat	Norm-N	-	0.18026	0.35797
Faba	Pod DW	Vertigo – Oat	No-N	-	0.19419	0.21680
Faba	Pod DW	Vertigo – Oat	Norm-N	-	0.10689	0.35705
Faba	Pod DW	Vertigo – Wheat	No-N	-	**0.00271**	0.56102
Faba	Pod DW	Vertigo – Wheat	Norm-N	-	0.50622	0.76116
Faba	SPAD	Stella – Oat	No-N	0.07576	0.79529	-
Faba	SPAD	Stella – Oat	Norm-N	0.74234	0.43298	-
Faba	SPAD	Stella – Wheat	No-N	0.42754	0.56739	-
Faba	SPAD	Stella – Wheat	Norm-N	0.92151	0.40420	-
Faba	SPAD	Vertigo – Oat	No-N	**0.02627**	0.57901	-
Faba	SPAD	Vertigo – Oat	Norm-N	0.19976	0.46801	-
Faba	SPAD	Vertigo – Wheat	No-N	0.50431	0.72472	-
Faba	SPAD	Vertigo – Wheat	Norm-N	0.43540	0.44244	-
Cereal	Total DW	Oat – Stella	No-N	0.32496	0.61206	0.09434
Cereal	Total DW	Oat – Stella	Norm-N	0.90221	0.61462	**0.02563**
Cereal	Total DW	Oat – Vertigo	No-N	0.20969	0.79833	0.58521
Cereal	Total DW	Oat – Vertigo	Norm-N	0.50284	0.89172	0.38473
Cereal	Total DW	Wheat – Stella	No-N	0.53871	0.20882	0.21198
Cereal	Total DW	Wheat – Stella	Norm-N	0.65458	0.69305	0.05945
Cereal	Total DW	Wheat – Vertigo	No-N	0.79856	0.40275	0.44455
Cereal	Total DW	Wheat – Vertigo	Norm-N	**0.03183**	0.91128	**0.01083**
Cereal	Leaf DW	Oat – Stella	No-N	0.17827	0.54803	**0.01845**
Cereal	Leaf DW	Oat – Stella	Norm-N	0.78813	0.84418	0.56648
Cereal	Leaf DW	Oat – Vertigo	No-N	0.27803	0.43698	0.57631
Cereal	Leaf DW	Oat – Vertigo	Norm-N	0.45794	0.85034	0.39149
Cereal	Leaf DW	Wheat – Stella	No-N	0.57768	0.93580	0.20902
Cereal	Leaf DW	Wheat – Stella	Norm-N	0.65359	0.93441	0.40442
Cereal	Leaf DW	Wheat – Vertigo	No-N	0.75914	0.22415	0.76711
Cereal	Leaf DW	Wheat – Vertigo	Norm-N	**0.03511**	0.82626	**0.02291**
Cereal	Stem DW	Oat – Stella	No-N	0.38174	0.64149	0.13972
Cereal	Stem DW	Oat – Stella	Norm-N	0.70144	0.58037	**0.01122**
Cereal	Stem DW	Oat – Vertigo	No-N	0.05673	**0.03921**	0.52607
Cereal	Stem DW	Oat – Vertigo	Norm-N	0.77057	0.85324	0.30191
Cereal	Stem DW	Wheat – Stella	No-N	0.45714	0.38765	0.17853
Cereal	Stem DW	Wheat – Stella	Norm-N	0.89639	0.83503	0.09838
Cereal	Stem DW	Wheat – Vertigo	No-N	0.77349	0.62604	0.41712
Cereal	Stem DW	Wheat – Vertigo	Norm-N	0.46265	0.82367	**0.04211**
Cereal	Head DW	Oat – Stella	No-N	0.38305	0.70585	0.14383
Cereal	Head DW	Oat – Stella	Norm-N	0.68504	0.30782	**0.01689**
Cereal	Head DW	Oat – Vertigo	No-N	0.21863	0.64888	0.62374
Cereal	Head DW	Oat – Vertigo	Norm-N	0.71612	0.65679	0.42824
Cereal	Head DW	Wheat – Stella	No-N	0.13572	0.19895	0.71529
Cereal	Head DW	Wheat – Stella	Norm-N	0.89082	0.29493	**0.02719**
Cereal	Head DW	Wheat – Vertigo	No-N	0.35254	0.36653	0.37528
Cereal	Head DW	Wheat – Vertigo	Norm-N	0.07093	0.76834	**0.01025**
Cereal	SPAD	Oat – Stella	No-N	0.14225	0.66281	-
Cereal	SPAD	Oat – Stella	Norm-N	0.19974	0.27501	-
Cereal	SPAD	Oat – Vertigo	No-N	0.13982	0.65126	-
Cereal	SPAD	Oat – Vertigo	Norm-N	0.30214	0.96531	-
Cereal	SPAD	Wheat – Stella	No-N	0.34828	0.15802	-
Cereal	SPAD	Wheat – Stella	Norm-N	0.49395	0.82244	-

Cereal	SPAD	Wheat – Vertigo	No-N	0.19574	0.44162	-
Cereal	SPAD	Wheat – Vertigo	Norm-N	0.30492	0.85378	-

Table 5.30 ANOVA table for trait plasticity of aboveground dry biomass of faba bean.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.675	0.2250	0.439	0.727
50	fertilizer	1	0.367	0.3670	0.716	0.406
50	type:fertilizer	3	1.363	0.4542	0.887	0.463
50	residuals	23	11.784	0.5124		
73	type	3	0.1045	0.03483	0.300	0.825
73	fertilizer	1	0.0346	0.03458	0.298	0.593
73	type:fertilizer	3	0.1373	0.04576	0.394	0.759
73	residuals	15	1.7416	0.11610		
92	type	3	0.295	0.0982	0.171	0.9151
92	fertilizer	1	2.574	2.5738	4.471	**0.0455**
92	type:fertilizer	3	0.464	0.1545	0.268	0.8474
92	residuals	23	13.241	0.5757		

Table 5.31 ANOVA table for trait plasticity of dry biomass of leaves for faba bean.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.837	0.2792	0.487	0.695
50	fertilizer	1	0.561	0.5629	0.982	0.332
50	type:fertilizer	3	1.533	0.5111	0.892	0.460
50	residuals	23	13.184	0.5732		
73	type	3	0.1102	0.03672	0.296	0.828
73	fertilizer	1	0.0089	0.00890	0.072	0.792
73	type:fertilizer	3	0.0377	0.01255	0.101	0.958
73	residuals	15	1.8611	0.12407		
92	type	3	0.875	0.292	0.337	0.7991
92	fertilizer	1	5.226	5.226	6.028	**0.0221**
92	type:fertilizer	3	0.902	0.301	0.347	0.7917
92	residuals	23	19.943	0.867		

Table 5.32 ANOVA table for trait plasticity of dry biomass of stems for faba bean.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.581	0.1936	0.404	0.751
50	fertilizer	1	0.216	0.2164	0.452	0.508
50	type:fertilizer	3	1.252	0.4174	0.871	0.470
50	residuals	23	11.019	0.4791		
73	type	3	3.104	1.035	0.657	0.591
73	fertilizer	1	2.021	2.021	1.284	0.275
73	type:fertilizer	3	3.289	1.096	0.696	0.568
73	residuals	15	23.609	1.574		
92	type	3	0.142	0.0473	0.083	0.9687
92	fertilizer	1	2.638	2.6384	4.621	**0.0423**
92	type:fertilizer	3	0.446	0.1486	0.260	0.8532
92	residuals	23	13.131	0.5709		

Table 5.33 ANOVA table for trait plasticity of dry biomass of pods for faba bean.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
73	type	3	118.44	39.48	3.189	0.0543
73	fertilizer	1	35.93	35.93	2.902	0.1091
73	type:fertilizer	3	10.00	3.33	0.269	0.8465
73	residuals	15	185.68	12.38		
92	type	3	0.559	0.1864	0.324	0.8080
92	fertilizer	1	1.895	1.8954	3.293	0.0826
92	type:fertilizer	3	0.552	0.1840	0.320	0.8110
92	residuals	23	13.237	0.5755		

Table 5.34 ANOVA table for trait plasticity of SPAD for faba bean.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.00976	0.003255	1.724	0.190
50	fertilizer	1	0.00107	0.001068	0.566	0.460
50	type:fertilizer	3	0.00485	0.001616	0.856	0.478
50	residuals	23	0.04342	0.001888		
73	type	3	0.00815	0.002718	0.226	0.877
73	fertilizer	1	0.00028	0.000276	0.023	0.882
73	type:fertilizer	3	0.03696	0.012320	1.023	0.410
73	residuals	15	0.18069	0.012046		

Table 5.35 ANOVA table for trait plasticity of aboveground dry biomass of cereals.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	1.012	0.3373	1.696	0.196
50	fertilizer	1	0.158	0.1581	0.795	0.382
50	type:fertilizer	3	0.179	0.0597	0.300	0.825
50	residuals	23	4.573	0.1988		
73	type	3	0.083	0.0275	0.084	0.968
73	fertilizer	1	0.280	0.2802	0.855	0.370
73	type:fertilizer	3	0.637	0.2123	0.648	0.596
73	residuals	15	4.916	0.3277		
92	type	3	0.498	0.1659	1.111	0.365
92	fertilizer	1	0.297	0.2973	1.991	0.172
92	type:fertilizer	3	0.719	0.2398	1.606	0.215
92	residuals	23	3.435	0.1494		

Table 5.36 ANOVA table for trait plasticity of dry biomass of leaves for cereals.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.942	0.31408	1.619	0.212
50	fertilizer	1	0.096	0.09642	0.497	0.488
50	type:fertilizer	3	0.196	0.06539	0.337	0.799
50	residuals	23	4.461	0.19394		
73	type	3	2.418	0.806	0.492	0.693
73	fertilizer	1	3.244	3.244	1.981	0.180
73	type:fertilizer	3	1.626	0.542	0.331	0.803
73	residuals	15	24.563	1.638		
92	type	3	1.639	0.5463	1.716	0.192
92	fertilizer	1	0.368	0.3676	1.154	0.294
92	type:fertilizer	3	2.189	0.7296	2.291	0.105
92	residuals	23	7.324	0.3184		

Table 5.37 ANOVA table for trait plasticity of dry biomass of stems for cereals.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	5.463	1.821	1.509	0.239
50	fertilizer	1	2.871	2.871	2.379	0.137
50	type:fertilizer	3	3.668	1.223	1.013	0.405
50	residuals	23	27.758	1.207		
73	type	3	15.45	5.149	0.767	0.530
73	fertilizer	1	10.24	10.237	1.524	0.236
73	type:fertilizer	3	15.95	5.316	0.791	0.517
73	residuals	15	100.75	6.717		
92	type	3	1.814	0.6048	2.577	0.0784
92	fertilizer	1	0.837	0.8373	3.567	0.0716
92	type:fertilizer	3	1.778	0.5926	2.525	0.0827
92	residuals	23	5.398	0.2347		

Table 5.38 ANOVA table for trait plasticity of dry biomass of heads for cereals.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	4.949	1.6496	1.504	0.241
50	fertilizer	1	0.318	0.3181	0.290	0.596
50	type:fertilizer	3	0.873	0.2909	0.265	0.850
50	residuals	23	24.129	1.0968		
73	type	3	0.100	0.0333	0.086	0.966
73	fertilizer	1	0.321	0.3207	0.830	0.377
73	type:fertilizer	3	1.605	0.5348	1.384	0.286
73	residuals	15	5.798	0.3865		
92	type	3	0.307	0.10235	0.743	0.537
92	fertilizer	1	0.163	0.16270	1.181	0.288
92	type:fertilizer	3	0.288	0.09607	0.698	0.563
92	residuals	23	3.168	0.13773		

Table 5.39 ANOVA table for trait plasticity of SPAD for cereals.

DAS	Source	Df	Sum Sq	Mean Sq	F-value	P-value
50	type	3	0.00845	0.002817	2.029	0.1379
50	fertilizer	1	0.00485	0.004855	3.497	0.0743
50	type:fertilizer	3	0.00106	0.000355	0.256	0.8565
50	residuals	23	0.03193	0.001388		
73	type	3	0.00074	0.000245	0.066	0.977
73	fertilizer	1	0.00063	0.000631	0.170	0.687
73	type:fertilizer	3	0.00287	0.000956	0.257	0.855
73	residuals	15	0.04838	0.003721		

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