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Investigation of the Physiological Basis of Yield Differences in Norwegian Spring Wheat

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ABSTRACT

Norway has a total land area of 324,000 km^2 of which only 3% is arable. Moreover, the climate conditions allow a short growing season for agriculture. Despite these challenges, Government policies are directed towards increasing food production and sustainability.

Wheat is a major contributor to the food and feed nutrition of the country. Furthermore, for the past 40 years, plant breeding has improved the yields of the Norwegian spring wheat cultivars and this study is set to find the physiological reasons why the new cultivars yield higher than the older ones.

The experiment consisted of 24 spring wheat cultivars which represents the history of wheat breeding in Norway. The experiment took place at two locations (Ås and Staur) in the south eastern part of the country, between May and September 2017. Two nitrogen levels of fertilization were adopted in this study, 7.5kg/daa and 15kg/daa.

Some of the physiological traits measured were chlorophyll content, light interception, plant height, harvest index and phenological phases (days to heading and days to maturity), above ground biomass and the yield components. Images were taken and analysed for canopy spectral reflectance indices and were compared with traditional data.

Grain yield was found to be strongly correlated with the number of grains per square meter, grain weight and the length of grain filling. Light interception and chlorophyll content were poorly correlated to grain yield, but their relationship was responsible for a large part of the variation between the cultivars. Spectral indices like MERIS Terrestrial Chlorophyll index and NDVI were associated with Chlorophyll content and Light interception respectively.

Future experiments should, therefore, focus much on the period from heading to maturity and collecting much data to help predict yields.

Master thesis, Ås, August 15th, 2018

Abstrakt

Kun 3% av det totale landarealet (324,000 km^2) i Norge er dyrkbar jord. I tillegg bidrar de klimatiske forholdene til en kort vekstsesong . Til tross for disse utfordringene er den statlige politikken å øke matproduksjon og bærekraft. Hvete er en hovedkilde til mat og fôr i landet. I løpet av de siste 40 årene har planteforedling forbedret avlingen til norske vårhvetesorter og denne studien har som mål å finne de fysiologiske forklaringene på hvorfor de nye sortene har høyere avling enn de eldre sortene. Forsøket besto av 24 vårhvetesorter som representerer historisk hveteforedling i Norge. Forsøket ble utført på to steder (Ås og Staur) i den sørøstlige delen av Norge mellom mai og september 2017. To nivåer av nitrogengjødsling ble brukt i studien, 7.5 kg/daa og 15 kg/daa. Noen av de fysiologiske egenskapene som ble målt var klorofyllinnhold, lysoppfanging (light interception), strålengde, kornprosent (harvest index), fenologisk stadium (dager til skyting og dager til modning), overjordisk biomasse og avlingskomponenter. Det ble tatt bilder, og analyser av bladverkets spektralrefleksjon ble utført og sammenlignet med tradisjonelle data. Det ble funnet at kornavling var sterkt korrelert med antall korn per kvadratmeter, kornvekt og lengden på kornfyllingsperioden. Studien viser også at kornavling har økt med årene. Spektrale indekser som MERIS terrestrisk klorofyllindeks og NDVI var assosiert med henholdsvis klorofyllinnhold og lysoppfanging. Framtidige forsøk bør fokusere på perioden fra skyting til modning og samle mye data for å kunne predikere avling.

Master thesis, Ås, August 15th, 2018

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God is the Greatest

Master thesis, Ås, August 15th, 2018

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1. INTRODUCTION

1.1. BACKGROUND INFORMATION

Food and feed are the fuels that human beings and cultivated animals source their energy from. Chlorophyll containing plants harness radiation from the sun; CO_2 in the atmosphere; available water, and nutrients in the soil to provide these food and feed needs of the world. So, food production must increase and be diversified to offset demand due to proliferation in global population. The world's population is expected to grow to almost 10 billion by 2050, boosting agricultural demand – in a scenario of modest economic growth – by some 50 percent compared to 2013 (Bruinsma, 2017).

In view of this forthcoming situation, governments, and international organizations such as the Food and Agriculture Organisation (Fao) and International Maize and Wheat Improvement Center (CIMMYT) have executed several researches to ensure sustainable production and food security. The government of Norway has specific goals and strategies for increasing sustainable food production. These are policies are; continuous food production, sustainable management of resources for food production and a well-functioning trade system (Regjeringen, 2016).

1.1. PROBLEM STATEMENT AND JUSTIFICATION

Wheat is a very important food and feed crop in Norwegian agriculture. Its production needs to improve in relation to environmental conditions and other stress components.

Anne Kjersti Uhlen, a Professor within the group responsible for enhanced agronomic practices in the study, Agronomy for increased food production (Agropro) mentioned that (personal communication, September 19, 2017) yields in Norwegian spring wheat cultivars have increased over the past years. The genetic and physiological basis for these yield gains are however unknown. The increased yield in the latter cultivars than the former is evidence of great achievement in breeding over the years. Figure 1.1 by Uhlen (unpublished) shows the yield differences among cultivars.

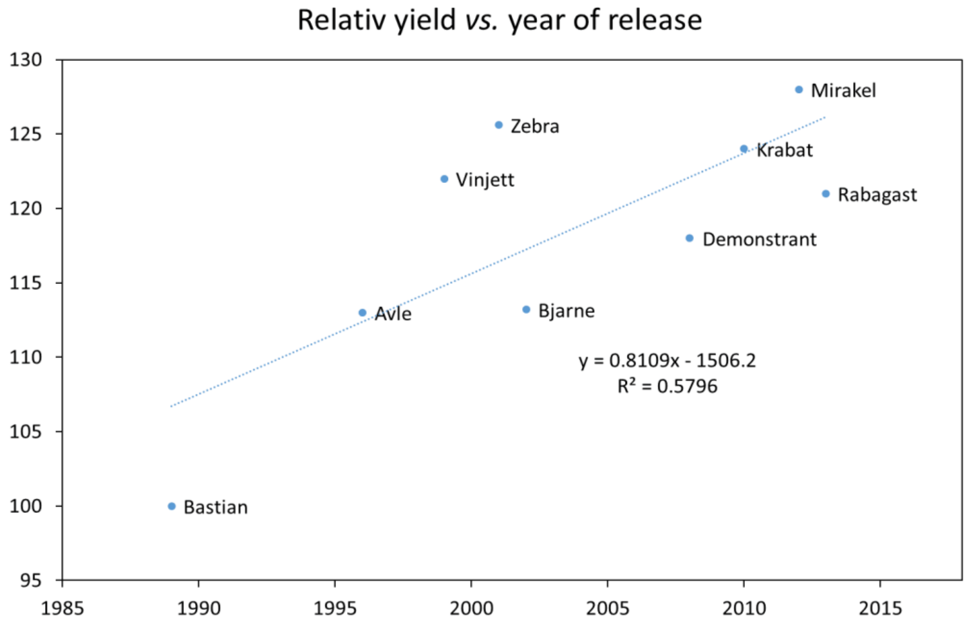


Figure 1.1 Relative yields and year of release describing the gains made by breeding in Norway

Basic plant breeding involves crossing varieties possessing complementary traits for propagation. After crossing and developing first offspring, selection throughout subsequent generations becomes a factor that delays the entire process. Phenotypic selection to find higher-yielding cultivars among the thousands of offspring from each cross is cumbersome and time-consuming. Knowledge of the physiological variables of cultivars within a specific environment throughout history can provide information that can be used to help the selection process. This study however is interested in understanding the reasons for variations relative to yield under the Norwegian climate.

Thus, to provide better intelligence in plant breeding, crop management, and sustainable production.

Potential yield of a cultivar is the maximum yield that can be obtained in an environment it is adapted to (Van Ittersum et al., 2013). The authors also explain actual yields to reflect the current state of soils and climate; which considers average skills of the farmers, and their average use of technology. The consideration for this study is the maximum crop yield determined by physiological limits to key process including biomass production and partitioning.

The assumption is that increased yields are due to increases in biomass before translocation of captured resources into grains; longer grain filling period before maturity; and improved ability to utilize high doses of nitrogen fertilizer without lodging. Studies of this sort have been done in other parts of the world like Mexico, Australia, etc., (Lopes et al., 2012; Perry & d'Antuono, 1989; Sayre, Rajaram, & Fischer, 1997; Siddique, Belford, Perry, & Tennant, 1989). However, we cannot depend on those results due to different growing conditions and types of cultivars.

In recent years, there is a continuous focus on the ability to predict yield prior harvest. Data collection based on low throughput traditional methods are time consuming and labour intensive. Innovation from other fields introduced technologies like drones and robots for image capture and computer analysis which has been integrated in agriculture. A few comparisons were made with canopy reflection indices in this project.

1.2. AIM AND SPECIFIC OBJECTIVES

The major goal for this project was to establish relationships between physiological variables and yield. These included light interception, chlorophyll concentration, above ground biomass, above ground coverage, plant height, lodging effects, phenology and the harvest components.

Specific goals were to:

- correlate the physiological variables of the cultivars to yield
- relate these correlations to the history of the cultivars and find reasons for the difference in yield
- compare traditional methods of data collection with image analysis methodology.

2. Literature Review

The fundamental concept behind this research was to estimate the correlations between basic indices that determine yield in wheat crops and the actual grain yield. Thus, this chapter reviews the various theories and concepts that predict or account for the development of wheat and results in the ultimate yield.

2.1. The wheat Crop

The wheat crop is a major contributor to the nutrition needs of the world and is the most widely cultivated food crop out of the three most produced cereal crops in the world. (Khan & Shewry, 2009) states that wheat, maize, and rice dominate world grain production. This is a fact which can be seen from data at (Fao, 2018)

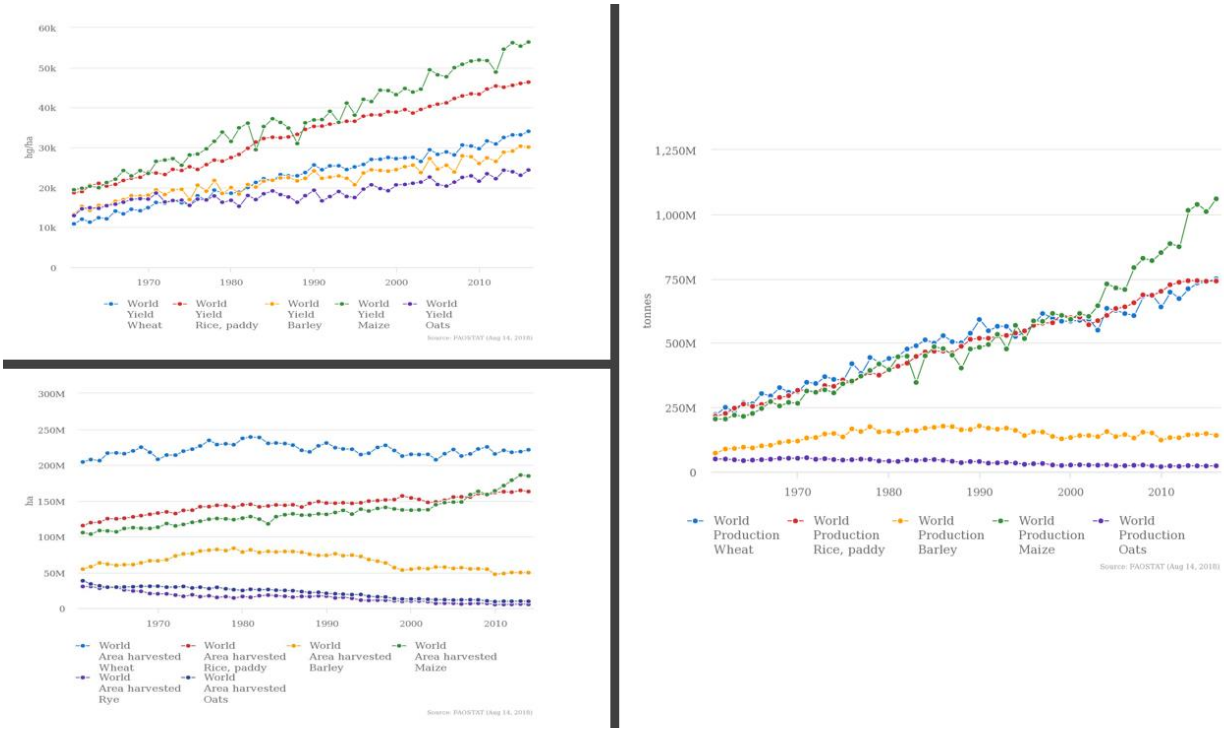


Figure 2.1 Graphs of Yield (top left), harvested area (down left) and production of major cereal crops in the world. Source: FAOSTAT, 2018

These crops are grasses in the family *Poaceae* and are cultivated mostly for their grain. The tribe *Triticeae* is the most economically important of the family, as it is responsible for cultivated wheats, barleys, ryes, oats, and several important grasses. The current wheat cultivars belong primarily to two species: (Jenner, Ugalde, & Aspinall) hexaploid bread wheat, *T. aestivum* (2n = 42 chromosomes), that accounts for more than 90% of the world's wheat production (Khan & Shewry, 2009) and (2) tetraploid, hard or durum-type wheat, *T.*

turgidum (2n = 28) responsible for the further 5% used for macaroni and low-rising bread. Thus, *T. aestivum* dominates the wheat species used for flour and bread. There has been changes in genetics throughout history in the evolution of wheat from the wild emmer, einkorn, and spelt varieties to the current bread wheat *T. aestivum*. Hybridization among genera within the tribe has allowed the exchange of genetic material and given rise to polyploidy (many chromosome sets) in the form of amphiploidy (at least one diploid chromosome set from each parent species) (Gustafson, Raskina, Ma, & Nevo, 2009). The wheats (genus *Triticum*) comprise a series of diploid, tetraploid, and hexaploid (current) forms, the polyploids having arisen by amphiploidy between *Triticum* species and diploid species of the genus *Aegilops (Caligari & Brandham, 2001; Feldman & Levy, 2012; Feldman et al., 1997; Van Slageren, 1994; Wang et al., 1994).*

Wheat even though originally has been a crop of the temperate regions has widely adapted to cover large areas of cultivated land than any other crop in the world. The crop is being grown from the Arctic Circle to the Equator, from see level to 3,000 m, and in areas with between 250 to 1,800 mm of rainfall (Khan, 2009 #1). The wide adaptability of wheat is achieved through adjustment of the life cycle to suit local seasonal climatic conditions (Bonjean & Angus, 2001) such as photoperiod and vernalisation need.

The various wheat varieties can be classified into winter wheat and spring wheat. The winter types are sown in autumn and receive continuous cold treatments in the winter before flowering and maturing in the summer. The spring types which we are interested in are grown from the spring period and are not subjected to cold temperatures Spring type alleles are dominant and are insensitive to cold treatment, meaning that they will initiate flowering irrespective of cold treatment, whilst the recessive winter alleles normally require at least six weeks of vernalising temperatures before commencement of floral initiation (Bonjean & Angus, 2001).

Some importance of the crop extends from nutrition (both food and feed) to straw for roofing and bedding for animals. Per (Khan, 2009 #1), majority of the crop is used directly in products for human consumption and the remaining minority is used in animal rations. Dough making from flours to trap carbon dioxide liberated from fermentation distinguishes wheat from other cereals (Khan, 2009 #1). This resulted in the ability to bake leavened foods, of which bread is the most important. Other uses such as alcoholic beverage production, surface coating agent in paper and board manufacture and as a fermentation substrate in the production of antibiotics are all documented (Khan, 2009 #1).

2.1.1. The crop in Norway

Norway is a western Scandinavian country between latitudes $57^0$58’ and $71^0$10’N with 1,752 km from south to north. The total land area is about 324,000 km^2 but only 3% of this area is used as arable land. The climate is warmer compared to land areas with similar latitudes (i.e. Alaska) due to steady and warm ocean currents that approaches from the Gulf stream to most part of the coast. The main agricultural area is in the south-eastern part of the country (where the research took place) and is separated from the coast by high mountain ranges which give this area a more continental climate with less rainfall and higher temperature differences between summer and winter. The total amount of rainfall is mostly enough, with water limitations causing marginal problems but also varies annually. However, water deficits have been recorded in the months of June and July in Ås over the total wheat growing season (Lillemo & Dieseth, 2011) and results in yield reduction if not compensated by irrigation (Lillemo & Dieseth, 2011; Strand, 1984).

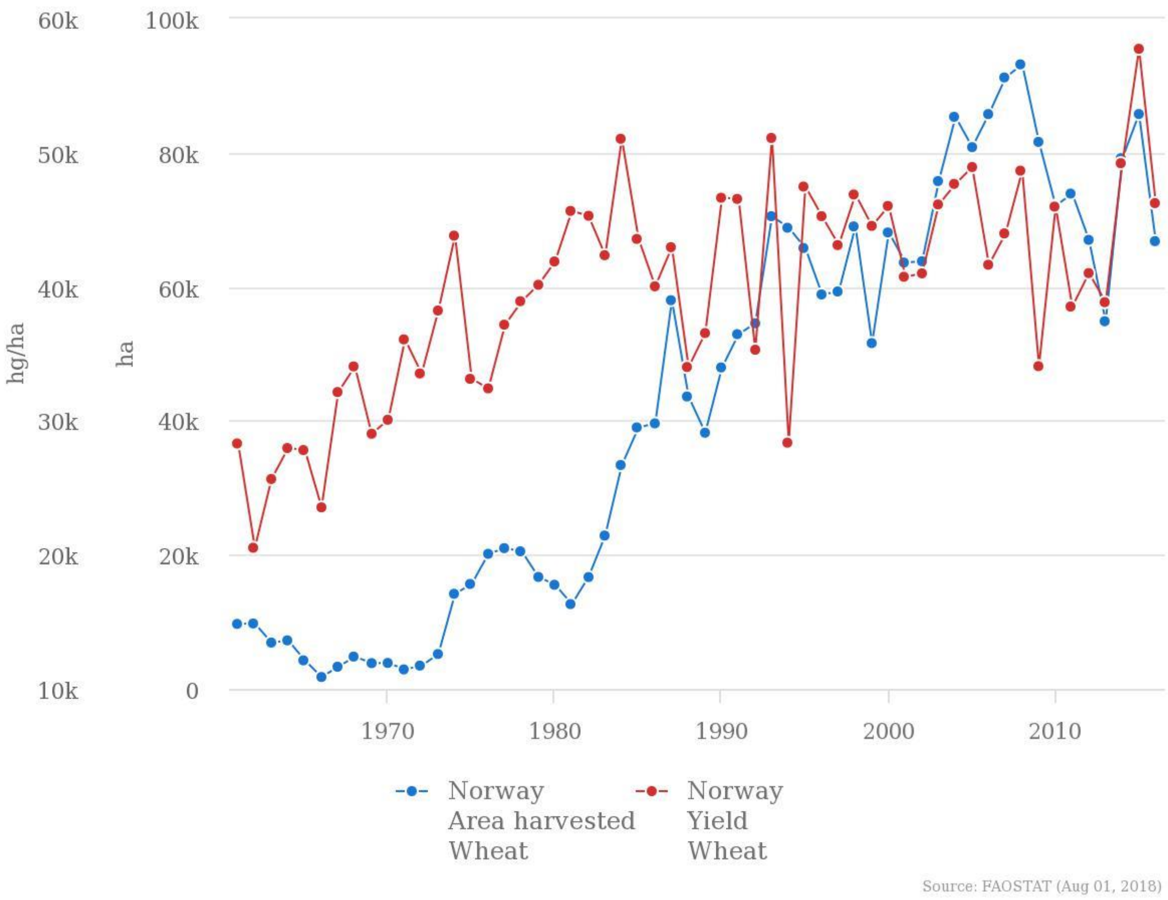


Figure 2.2 wheat yield trends in Norway from1961-2016 (FOASTAT, 2018

From figure 2.2, wheat production has been increasing since the 1970s until the 2000s where variations seem to be levelling up at between 40000 and 50000 hg/ha. But this is characterised by downwards trend in area of production in recent years. These variations are attributed to environmental conditions becoming less predictable in recent years.

2.2. Cultivation and Breeding

Figure 2.2 shows that wheat is cultivated on more land than any other food crop, also the average yields are lower than those of maize and rice; which explains the extensive cultivation over large areas where water availability limits production. Breeding has consecutively over the years contributed towards high yielding varieties that are cultivated presently.

One important factor that has changed drastically throughout the years is the stature or height of the wheat plant. Some shortcomings such as; tall plants being susceptible to lodging, and the fraction of grain to straw being less than short straw wheat were identified. The expressions are termed lodging and harvest index (HI) respectively. These assertions had been long appreciated in the 1800s by (Khan, 2009 #1). There are complicated relationships relating to yield, (Jenner et al.) canopies are intended to be sufficiently large enough to intercept majority of the available light for photosynthesis and, (2) resources captured during growth and development are expected to be translocated to the grains before maturity. However, (Austin, 1980; Austin et al., 1980) attested that grain yield was closely and negatively associated with straw dry weight. Which meant that improving HI with reduction of height could account for improvement in yield potential.

Several reduced height (*Rht*) genes were identified even though with polygenic characters. The *Rht* genes were expected to improve HI or lodging resistance, but only few are utilised because others were not able to compensate for reduced biomass production, therefore causing yield reduction. Khan et al., 2009 explained that those *Rht* genes that effected increase in HI, did that mostly through improved spikelet fertility while maintaining sufficent biomass production.

Norwegian spring wheat has undergone transformations through breeding. Breeding simply is the crossing of existing crop varieties to improve certain pre-determined traits of economic importance and quality. Yield and earliness have been the major driving forces for breeding in Norway. So are resistance to disease, good agronomic performance, and good quality. Early maturity was the most important character for local adaptation to Norwegian growing conditions (Lillemo & Dieseth, 2011). The trend in the Norwegian wheat yields indicates that yield levels have tripled during the last 80 years. About half of this increase is due to successive introduction of new varieties, while the rest has come from improvements in the cultivation techniques (Lillemo & Dieseth, 2011; Strand, 1984).

2.3. Yields of wheat

The definition and focus of yield have for many years transformed from the energy used in acquiring food compared to energy gained, at the time of hunting and gathering; to a more refined and empirical estimation of amounts per area of land in a year or season. Potential yield is the yield of a current cultivar “when grown in environments to which it is adapted; with nutrients and water non-limiting; and with pests, diseases, weeds, lodging, and other stresses effectively controlled” (L. Evans & Fischer, 1999).

Wheat, as all green plants, converts intercepted solar irradiance into chemical potential energy which is partitioned into various sink components like the harvested parts (grains) and other parts. The yield depends on the quantity of solar radiation available (depends on daylength, weather influence like cloudiness and diurnal pattern of irradiance), the fraction intercepted by the plant (a function of leaf area index, leaf angle, and canopy architecture), the efficiency of conversion to chemical potential energy (photosynthesis, respiration, and photorespiration), and the net result of assimilate partitioning also known as Harvest index (grain biomass per total aboveground biomass). (Hay & Porter, 2006) gives more insight on these transformations in their book, physiology of crop yield. They also describe resource capture as the most important component of yield.

Furthermore, to expand on the yield of wheat in terms of grain mass per unit area, we consider the approach which examines yield in terms of yield components;

$$Grain\ yield = \frac{mass}{grain} * \frac{grain\ number}{head} * Number\ of\ heads/area \qquad \text{.... } Equation\ 1$$

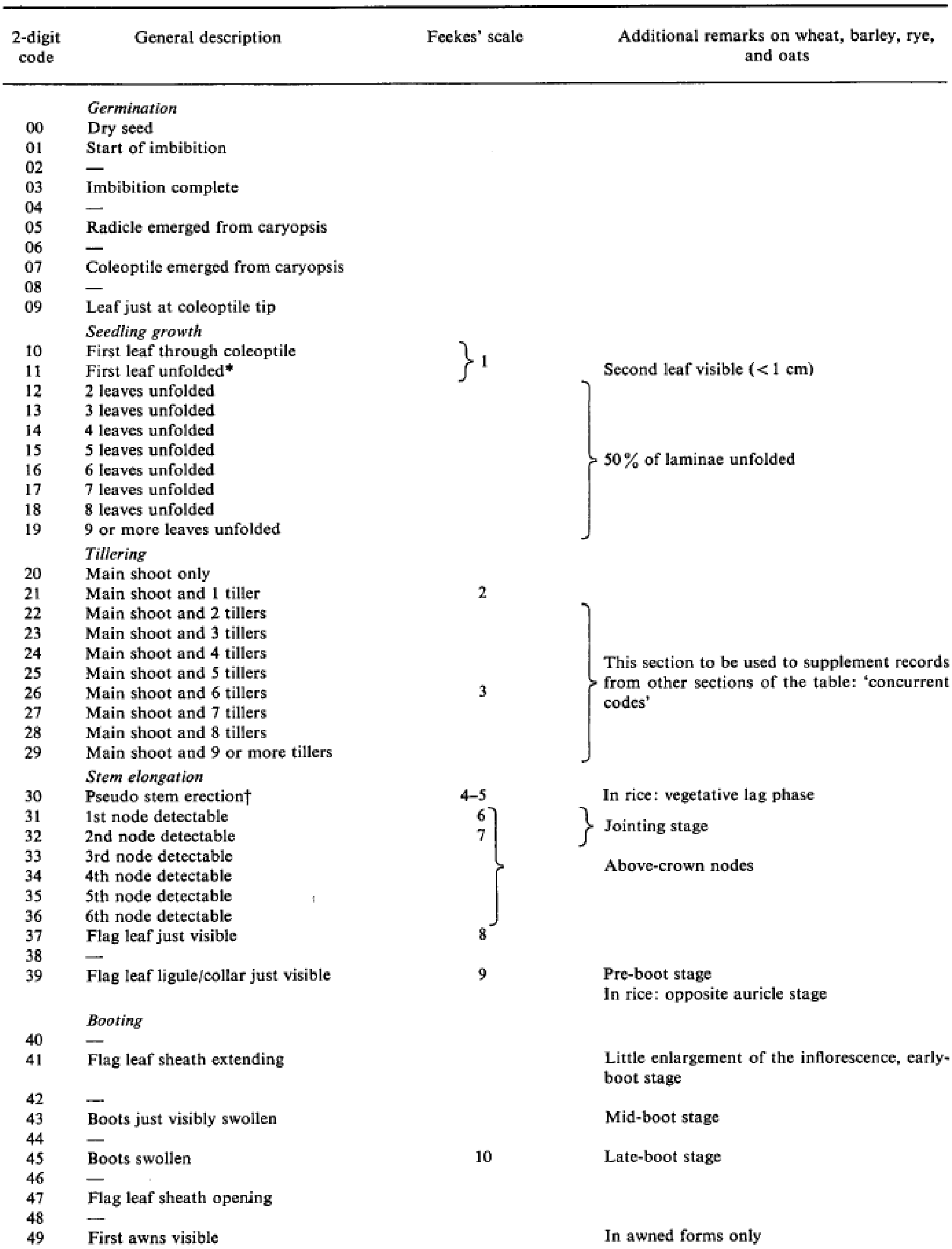
This is simply a function of the grain numbers produced per area and average grain weight. The process of energy capture, energy transformation and accumulation of assimilates are explored in the next section.

2.4. Growth and Development

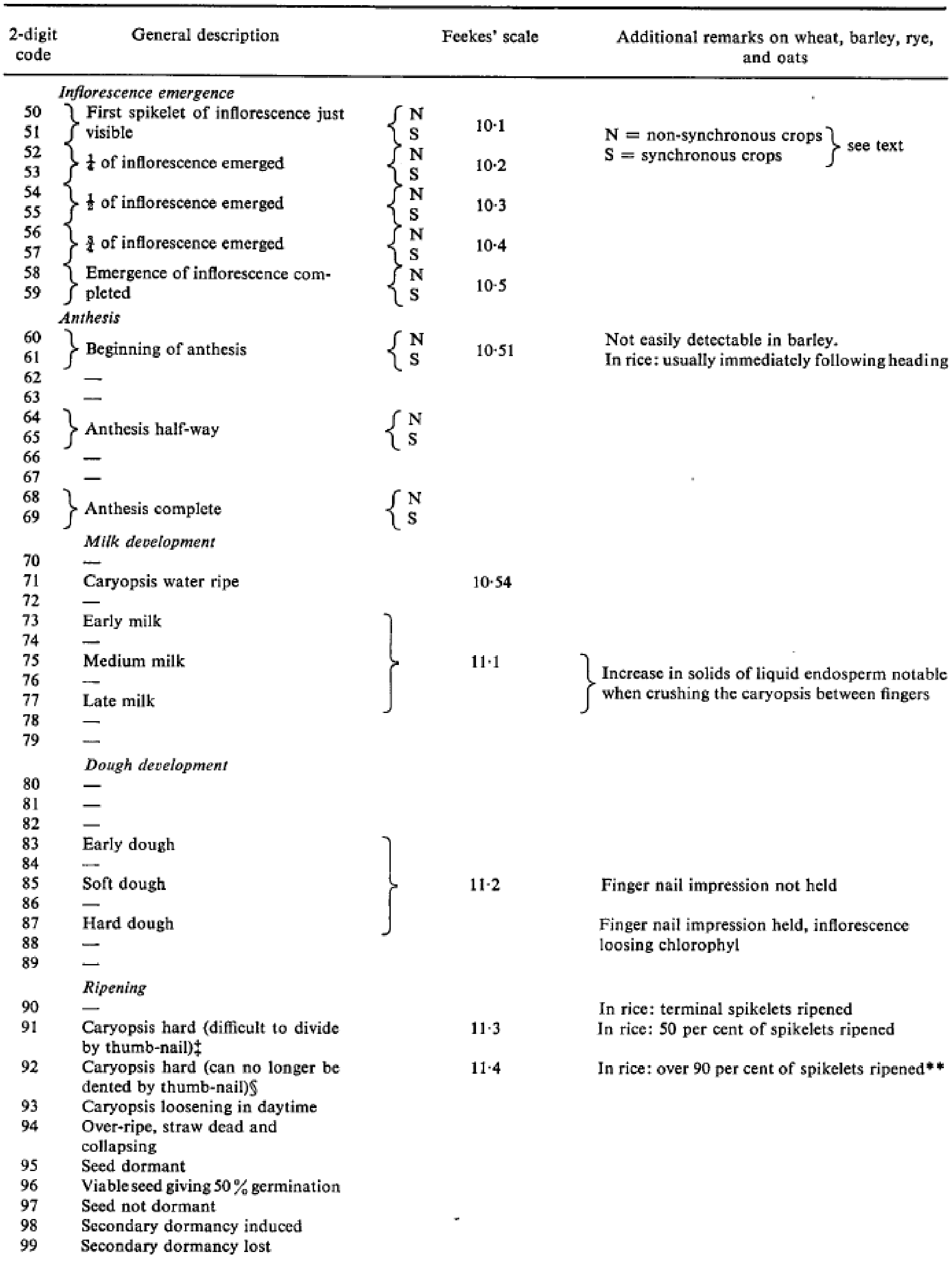
Wheat, like other annual grasses, exhibits observable phases of development. These are identified from germination; through leaf proliferation; tillering; stem elongation; heading; Flowering; grain filling to Maturity. The phases of development of the wheat crop have been very well defined (Zadoks, Chang, & Konzak, 1974), based on external appearance of the crop. The vegetative phase commences with germination, followed by appearances of leaves from the apical meristem and appearance of more stems or tillers on each plant, whereas the reproductive phase begins when the stem apex starts producing ear or spike while still close to the ground level (Khan & Shewry, 2009).

The wheat crop just as most plants intercept solar radiation and assimilate CO_2 for the synthesis of carbohydrates for growth and development. However, the rates of emergence and development are not much depending on light intensity, but temperature, photoperiod nutrient availability and variety (Khan & Shewry, 2009). The crop accumulates nutrients and sugars pending anthesis, then translocate it into the grains after fertilisation. Thus, I considered physiological variables that can explain the absorption of these products from emergence, leaf proliferation, stem elongation until heading and the grain filling period. The biomass amount, crop ground coverage, Chlorophyll concentration, and canopy light interception were important for the study.

Table 2.1 A decimal code for growth stages (Zadoks et al., 1974)



2-digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Germination		
00	Dry seed		
01	Start of imbibition		
02	—		
03	Imbibition complete		
04	—		
05	Radicle emerged from caryopsis		
06	—		
07	Coleoptile emerged from caryopsis		
08	—		
09	Leaf just at coleoptile tip		
	Seedling growth		
10	First leaf through coleoptile	1	
11	First leaf unfolded*		Second leaf visible (< 1 cm)
12	2 leaves unfolded		50 % of laminae unfolded
13	3 leaves unfolded		
14	4 leaves unfolded		
15	5 leaves unfolded		
16	6 leaves unfolded		
17	7 leaves unfolded		
18	8 leaves unfolded		
19	9 or more leaves unfolded		
	Tillering		
20	Main shoot only		
21	Main shoot and 1 tiller	2	
22	Main shoot and 2 tillers		This section to be used to supplement records from other sections of the table: 'concurrent codes'
23	Main shoot and 3 tillers		
24	Main shoot and 4 tillers		
25	Main shoot and 5 tillers		
26	Main shoot and 6 tillers	3	
27	Main shoot and 7 tillers		
28	Main shoot and 8 tillers		
29	Main shoot and 9 or more tillers		
	Stem elongation		
30	Pseudo stem erection†	4–5	In rice: vegetative lag phase
31	1st node detectable	6	Jointing stage
32	2nd node detectable	7	
33	3rd node detectable		Above-crown nodes
34	4th node detectable		
35	5th node detectable		
36	6th node detectable		
37	Flag leaf just visible	8	
38	—		
39	Flag leaf ligule/collar just visible	9	Pre-boot stage In rice: opposite auricle stage
	Booting		
40	—		
41	Flag leaf sheath extending		Little enlargement of the inflorescence, early-boot stage
42	—		
43	Boots just visibly swollen		Mid-boot stage
44	—		
45	Boots swollen	10	Late-boot stage
46	—		
47	Flag leaf sheath opening		
48	—		
49	First awns visible		In awned forms only



2-digit code	General description		Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Inflorescence emergence			
50	First spikelet of inflorescence just visible	N	10·1	
51		S		N = non-synchronous crops S = synchronous crops see text
52	¼ of inflorescence emerged	N	10·2	
53		S		
54	½ of inflorescence emerged	N	10·3	
55		S		
56	¾ of inflorescence emerged	N	10·4	
57		S		
58	Emergence of inflorescence completed	N	10·5	
59		S		
	Anthesis			
60	Beginning of anthesis	N	10·51	Not easily detectable in barley. In rice: usually immediately following heading
61		S		
62	—			
63	—			
64	Anthesis half-way	N		
65		S		
66	—			
67	—			
68	Anthesis complete	N		
69		S		
	Milk development			
70	—			
71	Caryopsis water ripe		10·54	
72	—			
73	Early milk			
74	—			
75	Medium milk		11·1	Increase in solids of liquid endosperm notable when crushing the caryopsis between fingers
76	—			
77	Late milk			
78	—			
79	—			
	Dough development			
80	—			
81	—			
82	—			
83	Early dough			
84	—			
85	Soft dough		11·2	Finger nail impression not held
86	—			
87	Hard dough			Finger nail impression held, inflorescence loosing chlorophyl
88	—			
89	—			
	Ripening			
90	—			In rice: terminal spikelets ripened
91	Caryopsis hard (difficult to divide by thumb-nail)‡		11·3	In rice: 50 per cent of spikelets ripened
92	Caryopsis hard (can no longer be dented by thumb-nail)§		11·4	In rice: over 90 per cent of spikelets ripened**
93	Caryopsis loosening in daytime			
94	Over-ripe, straw dead and collapsing			
95	Seed dormant			
96	Viable seed giving 50% germination			
97	Seed not dormant			
98	Secondary dormancy induced			
99	Secondary dormancy lost			

2.4.1. Phenology

Under this section, we look at the various events in the development of spring wheat and the environmental influences associated with them.

2.4.1.1. *Emergence*

The vegetative growth of the wheat crop proceeds after seed dormancy has been broken and germination has taken place. Germination begins with coleorhiza emergence from seed coat and rapturing, followed by seminal and lateral roots before the plumule. The coleoptile, which covers the plumule emerges as a pale tube-like structure protecting the first leaf and the ultimate length is determined by exposure to light, reserves available and cultivar.

2.4.1.2. *Leaf development*

The leaves are the primary site for photosynthesis and must provide optimum surface area for light interception to produce energy molecules, ATP, and NADPH during the light dependent reaction. The first true leaf emerges from the coleoptile, followed by others. The leaves appear in two sections; the sheath which is attached to and makes up the stem, and the blade that elongates away from the straw with some number of veins. Evans et al., (1975), states that the rate of leaf formation, emergence, and expanssion to final size and shape depends on the temperature (essentially), nutrients available, light intensity, day-length and variety.

2.4.1.3. *Tillering*

The wheat plant usually produces tillers (lateral branches) that arise from buds of the axils where leaf sheath is attached to the stem. Based on the population densities and type of cultivar, tiller production can vary, but tillering increases with increasing light and nitrogen availability (Khan & Shewry, 2009). Even though they can compensate for poor establishment in bad conditions, excess tiller production results in uneven crop with tillers at different developmental stages, at the end of the season. Also, shading and competition for assimilates lead to death of tillers when there is excessive proliferation. (Sparkes, Holme, & Gaju, 2006) proclaims the start of tiller death can be associated with low red to far-red light at the base of canopies and low leaf nitrogen content.

2.4.1.4. *Stem elongation*

Nutrient availability and plant protection are very important factors during stem elongation. This phase is characterized by rapid extension of the internodes and is visualised as the crop increase in height. Dry matter accumulation is also rapid at this stage. Most of the important elements (especially nitrogen) are taken up in high quantities during this phase. The period from onset of elongation until flag leaf emergence is when demand for nitrogen is highest and risk of nitrogen loss is reduced if fertilization coincides with it (Khan et al., 2009). The end of stem elongation is characterized by the emergence of the spike or head. Though the ultimate length is not realised until anthesis or after, PAR interception does not change much after spike emergence.

2.4.1.5. *Anthesis*

Anthesis is one of the most important phases of the development of wheat. Fertilization and development of zygote is what the phase is about. This involves production, transfer, and unity of viable pollen grains to serviceable oocyte (cell in the ovary) to allow for seed set. It is important to note that wheat is essentially a self-pollinated crop with occasional cross pollination (Khan et al., 2009). Anthesis begins from the centre of the spike (Identified by the oozing out of anthers from spikelet) and proceeds downwards and upwards. The process under this phase is basically temperature dependent (Optimum 18-24 ^{0}C) and effectiveness is promoted by good nutrition (especially boron). Three to eight days after ear emergence is common for the inception of anthesis and it elapses two to three days for a spike but may take up to ten days for a whole crop due to variations in tiller development (Khan et al., 2009).

2.4.1.6. *Grain Development*

Another delicate period before maturity is the grain filling period and spans from the flowering phase till physiological maturity (time of maximum dry matter). During this stage, grains are loaded with dry matter. As discussed earlier under the topic of yield, this is the period when the partitioned assimilates are translocated to the harvested part which is the grains. The grains enlarge as their cells multiply and are filled with water. The endosperm development continues by taking in starch granules (A- types first before B-types) before storage proteins. The process advances until the maximum dry mater content per grain in attained. The processes are in three phases best described by; (Jenner et al., 1991; Pepler, Gooding, & Ellis, 2006; Stoddard, 2003). They also give the impression that the end of the grain filling period is in tandem with senescence of flag leaf but not always. This stage is very much dependent on temperature. Grain filling with carbohydrate is ultimately a function of concurrent post anthesis photosynthesis with 40% from the flag leaf (Khan et al., 2009). This can change if the photosythesis is somehow curtailed. Also protein (nitrogen accumulation) in grains is mostly remobilized nitrogen accumulated before anthesis, and accouts for 50-70% of grain nitrogen at harvest with the remaining derived from post anthesis up take (Khan et al., 2009). As pointed out in the section on yield, even though partitioning is not fully understood, the 'rules' are very well known (Hay and Porter 2010).

2.5. Nutrition

The wheat crop relies on some essential elements to undertake optimum growth and development. Nitrogen (N), phosphorus (P), sulphur (S), and potassium (K) are some of the macro (major) nutrients supplied by fertilization. Magnesium (Mg) and Calcium are important too but are available through liming. The others like oxygen Hydrogen and Carbon are acquired from the atmosphere and/or soil. These and other micronutrients are required for growth. This research is purposefully interested in Nitrogen and the reasons are given below.

2.5.1. Nitrogen

Wheat is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. Nitrogen is present in protein structures (enzymes and nucleic acids) and makes the bulk of chlorophyll (the green colouring pigments of leaves). Over 50% of nitrogen in the plant can be attributed to RUBISCO (Khan et al., 2009) and ultimately chlorophyll makes very strong corellation with nitrogen content. Chlorophyll molecules absorbs light energy from photons to facilitate biosynthesis. Due to the influence on amount of protein, protoplasm and chlorophyll formed, nitrogen impacts the cell size, leaf area, and photosynthetic activity. Hence, nitrogen plays a key role in canopy size, light capture and number of grain set per area (Khan et al., 2009). The variety, previous crop, manure application, soil type and rainfall are key to nitrogen fertilization and management.

2.6. Lodging

The falling of the culms of the crop is attributed to various reasons and courses significant reduction in yield. The two forms lodging takes are stem lodging and root lodging where external forces acting on the crop renders a failure at the lower internodes or at the root anchorage respectively. The phenomenon is most likely to be seen after anthesis due to weight exerted by the spike and is triggered by rain and wind events (Berry et al., 2004).

2.7. Parameters for measurement

The previous sections described how growth and development, and their associate accumulation, translocation and remobilizations of assimilates occur during different stages. I now turn to the physiological variables that explain grain yield. The actual procedure and devices used are described in the next chapter, but the logic behind those measurement is explained here.

As stated earlier, light interception is basic to providing chemical potential energy for biochemical processes and biosynthesis, and therefore it is important to measure. As leaf is important for the capture of light, it is important to look at the canopy ground coverage and its relation to light interception. Nitrogen drives the expansion and growth of the plant and with its linear relation to chlorophyll content, the concentration of chlorophyll provides an easy route to investigating nitrogen status of the crop. The height of the crop has also been described to have significant effect on yield earlier when detailing the journey of the crop through generations. At the end, the actual yield, above ground biomass, protein content, grain weight and test weight were used to describe resource distribution. Their relationships were investigated.

Phenotyping with traditional methods as will be outlined in the next chapter are time consuming labour intensive and sometimes destructive. Therefore, there has been an introduction of high throughput measures such as image capturing and analysis. The reflectance of electromagnetic energy by the crop canopy at different wavelengths is predictive of important physiological traits such as leaf nitrogen content, photosynthetically active biomass, leaf chlorophyll and plant water status (Burud et al., 2017; Wahabzada et al., 2016). For these reasons, we combined both the traditional methods and the high throughput data capturing methods to establish some relationships for future research.

This employs the use of high spectral cameras fixed on drones flying at an altitude to capture images for analysis. The indices to be analysed from reflectance are Normalized Difference Vegetation Index (NDVI), MERIS Terrestrial Chlorophyll Index (MTCI) and leaf area index

3. Materials and methods

3.1. Introduction

The project incorporated several measurements, observations, and estimations. Thus, the methodology for taking individual and collective data were crucial to producing this inquiry. The materials, equipment and methods that were used in collecting data; including all processes undergone to analyse and process data to arrive at our results and conclusion are elaborated systematically in this chapter. This is to facilitate repetition of this experiment and provide basis for further improvements in the future.

3.2. Plant materials and Field orientation

Norwegian historical spring wheat cultivars were the priority in this research. Recent lines in addition to presently used and old cultivars totalling 24 in all were used (Table 3.1). The nursery was made up of 18 lines that were used in official variety trials in 2016, plus six major historical cultivars. Altogether, the set represent the breeding history of spring wheat in Norway since the beginning of the 1970s. As shown in the table 3.1, some of the breeding lines were rejected or withdrawn after the research had concluded, but the results for those lines were still included. The planting materials were sourced from previous yield experiment in 2016, and the seeding rate was 185 grams of seeds per plot.

In section 2.2 I explained the work of the height reducing semi dwarfing gene *Rht*. In the bread wheat, the signal mediator proteins (DELLA) are encoded by the homeoloci; *Rht-A1, Rht-B1 and Rht-D1.* The allele *Rht-1a* encodes for wild type (tall) wheat plants with proteins (DELLA) that are gibberellin (GA) sensitive. The plants with reduced height possess the allele *Rht-1b* and encodes for GA insensitivity (Wilhelm et al., 2013).

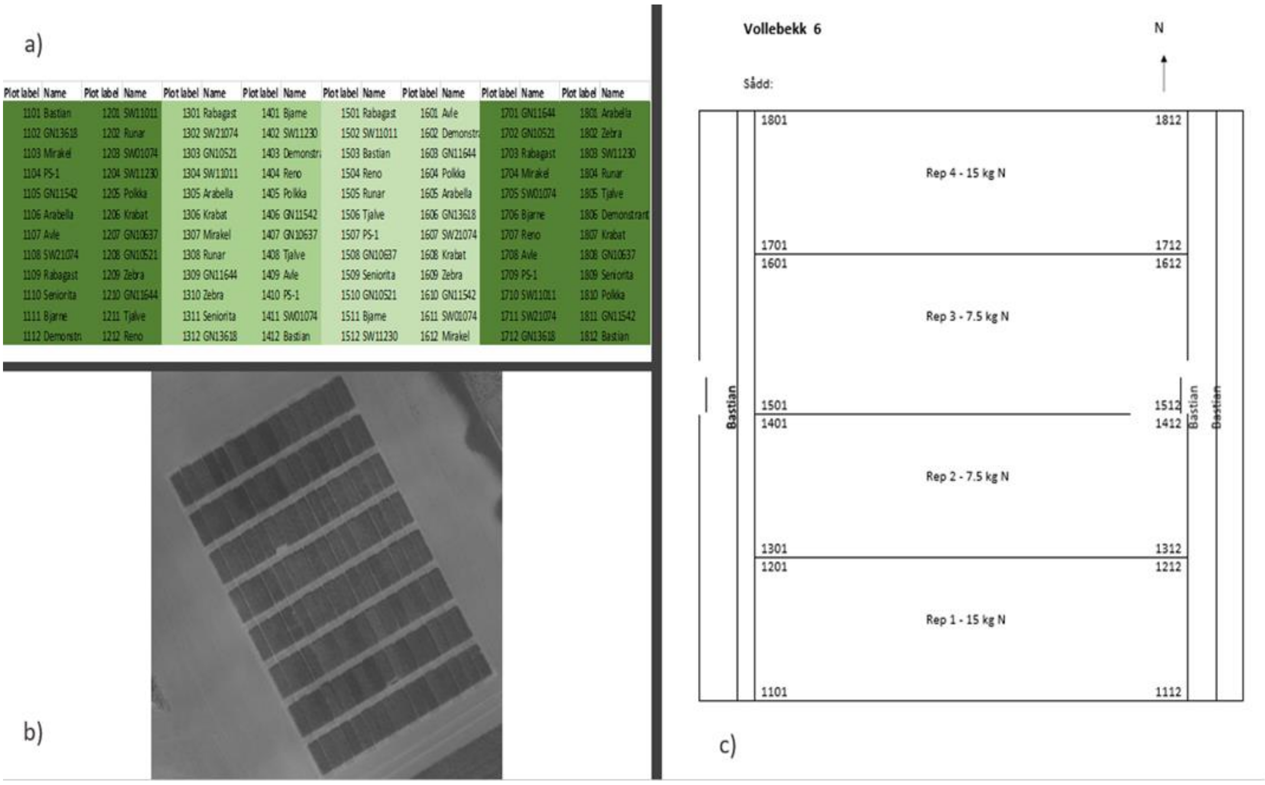
Grain protein content is a quality trait which is controlled by the gene (*Gpc).* In the case of *Gpc*, *Gpc-B1a* is a non-functional allele while *Gpc-B1b* accelerates leaf senescence and increased protein content and based on gene-specific KASP marker.
These and the cultivars are listed in the table below.

Table 3.1 Norwegian spring wheat cultivars that are included in this experiment, Year of release and genes controlling height (Rht, a =tall, b = reduced height) and grain protein content (Gpc, a = non-functional allele, b = accelerated leaf senescence and increased protein content and based on gene-specific KASP marker)

Cultivar/line	Entry	Released Year	*Rht-B1*	*Rht-D1*	*Gpc-B1*
Bjarne	1	2002	a	b	a
Zebra	2	2001	a	a	a
Demonstrant	3	2008	b	a	a
Krabat	4	2010	b	a	a
Mirakel	5	2012	a	a	b
Rabagast	6	2013	b	a	b
Seniorita	7	2014	a	b	a
Zombi (GN11644)	8	2018	a	b	a
GN11542	9	tested 2years	a	a	a
GN13618	10	tested 2years	b	a	a
Arabella	11	2014	a	a	a
Willy (GN10521)	12	2016	b	a	a
Cares (SW01074)	13	2017	a	a	a
GN10637	14	withdrawn	a	b	a
SW11230	15	rejected	a	a	a
PS-1	16	rejected	a	a	a
SW11011	17	tested 2years	a	a	a
SW21074	18	tested 2years	a	a	a
Tjalve	19	1987	a	a	a
Avle	20	1996	a	a	a
Bastian	21	1989	a	b	a
Runar	22	1972	a	a	a
Reno	23	1975	a	a	a
Polkka	24	1992	a	a	b

Out of the 24 cultivars used in the experiment 13 contains the *Rht- 1a* type allele that codes for tall wild types and 11 contains the *Rht- 1b type that reduces height.*

The project took place at two different locations, Vollebekk research station, Ås (planted on the 24th May,2017) and Graminor's research area at Staur, Hamar (planted on the 9th May 2017). At Ås, a split plot field design was adopted with two levels of nitrogen fertilization; 7.5 kg daa^{-1} and 15 kg daa^{-1} representing low and high nitrogen levels respectively. There were two replications of each nitrogen level making up 96 different plots in total. At sowing, each plot was prepared, 5 meters long and 1.5 meters wide. After emergence, an alley of 1 meter between the plots were cleared by spraying with glyphosate. At Staur, the design had a single nitrogen fertilization level, 15 kg daa^{-1}, and three replications. The plot size was 6 x 1.5 meters at sowing and was harvested at 5 x 1.5 due to the cleared alley like at Ås.



a)

Plot label	Name	Plot label	Name	Plot label	Name	Plot label	Name	Plot label	Name	Plot label	Name	Plot label	Name	Plot label	Name
1101	Bastian	1201	SW11011	1301	Rabagast	1401	Bjarne	1501	Rabagast	1601	Avle	1701	GN11644	1801	Arabella
1102	GN13618	1202	Runar	1302	SW21074	1402	SW11230	1502	SW11011	1602	Demonstr	1702	GN10521	1802	Zebra
1103	Mirakel	1203	SW01074	1303	GN10521	1403	Demonstr	1503	Bastian	1603	GN11644	1703	Rabagast	1803	SW11230
1104	PS-1	1204	SW11230	1304	SW11011	1404	Reno	1504	Reno	1604	Polkka	1704	Mirakel	1804	Runar
1105	GN11542	1205	Polkka	1305	Arabella	1405	Polkka	1505	Runar	1605	Arabella	1705	SW01074	1805	Tjalve
1106	Arabella	1206	Krabat	1306	Krabat	1406	GN11542	1506	Tjalve	1606	GN13618	1706	Bjarne	1806	Demonstrant
1107	Avle	1207	GN10637	1307	Mirakel	1407	GN10637	1507	PS-1	1607	SW21074	1707	Reno	1807	Krabat
1108	SW21074	1208	GN10521	1308	Runar	1408	Tjalve	1508	GN10637	1608	Krabat	1708	Avle	1808	GN10637
1109	Rabagast	1209	Zebra	1309	GN11644	1409	Avle	1509	Seniorita	1609	Zebra	1709	PS-1	1809	Seniorita
1110	Seniorita	1210	GN11644	1310	Zebra	1410	PS-1	1510	GN10521	1610	GN11542	1710	SW11011	1810	Polkka
1111	Bjarne	1211	Tjalve	1311	Seniorita	1411	SW01074	1511	Bjarne	1611	SW01074	1711	SW21074	1811	GN11542
1112	Demonstr	1212	Reno	1312	GN13618	1412	Bastian	1512	SW11230	1612	Mirakel	1712	GN13618	1812	Bastian

Figure 3.1 Field orientation at Ås. a) Plot labels with cultivar planted, b) Field image in the green band from multi spectral camera, and c) Field Map

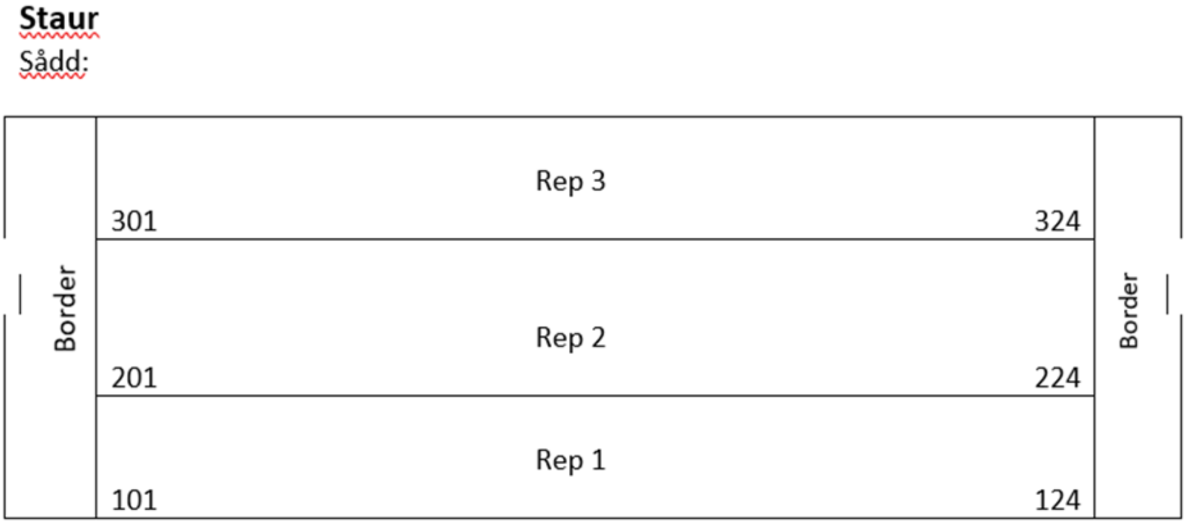


Figure 3.2 Field Map at Staur

Standard agronomic practices in management and disease control of wheat fields were adopted, e.g. pesticide treatments were administered immediately at about growth stage 31. Data on planting, phenological stages, and component’s resource capture were taken and will be explained further below. Data collection was done throughout the whole growing season of field trial and all variables measured are represented in Table 3.2 below.

Table 3.2 Physiological variables measured at both research stations

Data index

Ås	**Staur**
Light interception	Light interception
Chlorophyll content	Chlorophyll content
Plant ground coverage	-
Plant height	Plant height
Leaf angle	Leaf angle
Lodging	Lodging
Biomass ammount	-
Grain yield	Grain yield
Thousand kernel wight	Thousad kernel wight
Test weight	Test weight
Phenological stages	Phenological stages
Harvest index	
-	Starch Content
Protein Content	Protein Content
Image data	-

3.3. Phenological stages

The various phases of development and their rates were interesting to observe as they provide essential information about genetic variation between cultivars and environmental conditions within the growing period. Beginning from emergence until physiological maturity, a measure of 50% and above was used as an indication for realisation of a stage. Heading date and date of maturity were taken. This two will be critical for biomass accumulation and grain filling.

3.4. Light interception

Energy needed to drive photosynthesis is basically derived from solar radiation (light). As well known, the range of the light spectrum contributing this energy is between wavelengths 400 nm to 700 nm. Photosynthetically active radiation (PAR) is the term given to this range of the light spectrum. The Sun scan canopy analysis system was used in the measurement of the amount of light transmited through the canopy. Measurement were taken when there was clear sky and little wind, between 12:00 noon to 15:00 pm. I started taking measurements weekly, from stem elongation to heading at Ås. At Staur, light interception was measured on the 17th and 31st of July 2017. At both locations, five readings were taken for each plot and averaged for analysis. Further measurements could not be taken due to technical issues that developed with the device.

3.4.1. SunScan

The sun scan is made up of two devices; a probe with an array of 64 sensors embedded in its 1-meter length, connected through an RS-232 cable to a handheld personal digital assistant (PDA), and a sunshine beam fraction sensor (BFS) type-1, with unique features of measuring both direct and diffuse components of incident light. The sun scan measures incident and transmitted PAR in plant canopies and is suited for cloudy, clear, and changeable conditions.

3.4.2. Procedure

The BFS was set on a tripod and established a level plane with an internal spirit level. One of the two domes on top of the surface was covered with the shadow of the overhead handle to recognize diffuse radiation. The probe was set below the canopy, also ensuring a level plane. Date and location were set as PDA is turned on. As light photons travels through the canopy, it is either intercepted or reflected, thus the remaining light is transmitted to lower leaves. This means at any point in time, the probe's measurement of incident radiation was dependent on the green area index (GAI) and the architecture of the canopy. The probe thus measures the transmitted light through the canopy and the BFS measures the total available incoming radiation at the press of a button on the probe and data is estimated and displayed from both devices onto the PDA.

Figure 3.3 Measuring light transmission with a Sun scan comprising of a probe(left), PDA (centre), and (BFS1) right

3.4.3. Data and calculations

After going through the plots and repeating same procedures, the data was stored in the sun software in the PDA and uploaded to my computer running on windows 10 operating system. The display was a WordPad file and I transferred them onto an excel file. A test sample of the first three plots produced the output displayed in the table below.

Table 3.3 Typical output from a sun scan measuring PAR from both below and above canopy (Unit-µmol $m^{-2}s^{-1}$).

```
Created by SunData for Windows Mobile v2.0.0.2

Title     :    lab testghygfmj
Location  :    AAs

2017-06-17
SunScan probe v0.36 (C) JGW 1996/06/06

Ext Sensor: BFS
Group    1 :

Time          Plot       Sample   PAR  Spread   Total  Diffuse

13:22:33         1        1       1029.6  0.29    1672.4  266.1
13:23:35         1        2       917.4   0.51    1745.6  274.7
13:24:33         1        3       1041.1  0.26    1521.0  268.6
13:25:15         1        4       984.3   0.21    1355.0  268.6
13:25:52         1        5       696.6   0.49    1475.8  268.6
13:29:00         2        1       929.2   0.39    1516.1  285.6
13:29:42         2        2       1015.4  0.38    1608.9  289.3
13:30:17         2        3       941.9   0.44    1591.8  289.3
13:31:00         2        4       906.5   0.33    1501.5  279.5
13:31:35         2        5       905.7   0.39    1567.4  271.0
13:33:04         3        1       874.2   0.46    1684.6  246.6
13:33:47         3        2       1041.2  0.40    1718.8  239.3
13:34:25         3        3       1041.2  0.34    1726.1  231.9
13:35:09         3        4       967.9   0.44    1709.0  225.8
13:35:49         3        5       1037.2  0.34    1712.6  219.7
```

The fraction of light intercepted is therefore estimated with the equation;

$$Interception = 1- (PAR/Total)$$ …*Equation 2*

3.5. Leaf angle

Leaf angle refers to the angle leaves are held relative to the vertical axis. This is most obvious on the flag leaves. It leads to an architecture of either an 'open' or 'closed' canopy. The former allows light to penetrate to the lower leaves (for erect or pendant leaves) and the latter grants the upper leaves to capture most of the incident light (for horizontal leaves or erect leaves which flop mid-way) (Pask, Pietragalla, Mullan, & Reynolds, 2012).

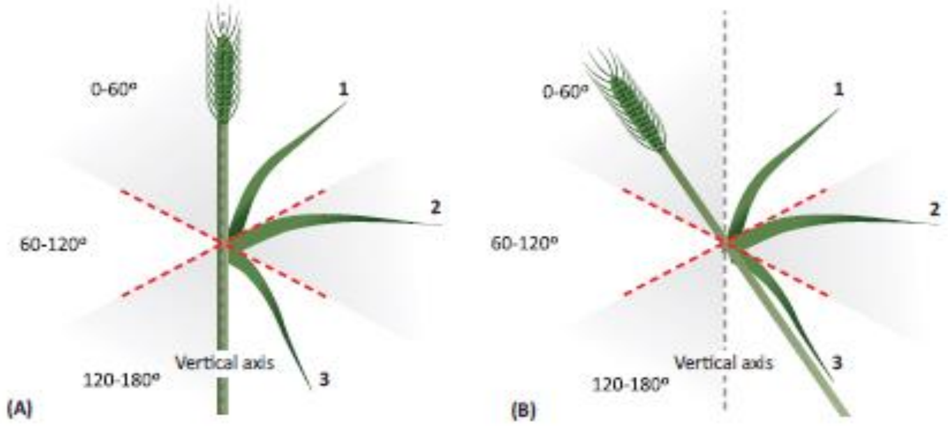


Figure 3.4 Scoring of leaf angle. measure the angle at which the leaves are held: (A) relative to the vertical axis; (B) rather than to the stem axis (Pask et al., 2012).

3.5.1. Procedure

The scoring was done by dividing the vertical plane into three sectors of approximately 60^0. As shown in figure 2 above, erect leaves were scored with the integer 1 which stood for angles from $0\text{-}60^0$ to the vertical axis. Horizontal leaves were labelled 2 (60^0-120^0) and 3 was allocated to pendant leaves ($120\text{-}180^0$).

3.6. Chlorophyll content

Chlorophyll is the green photosynthetic pigment that is responsible for the absorption of PAR and assist the transformation of its energy into chemical energy for the use of plants to respire and build biomass. It is usually found in leaves and stems but chiefly in leaves. Photosynthetic potential is indicated by the amounts in leaves and related to the nitrogen concentration. One of the simple and non-destructive approach to measure chlorophyll content is the use of a chlorophyll content meter.

3.6.1. Chlorophyll content meter

The chlorophyll content measurement system used was a device produced by a company called Hansatech Instruments and had the name “chlorophyll content meter” with a Model code CL-01. The CL-01 as shown in is a portable hand-held device that determines relative chlorophyll content using dual wavelength optical absorbance (red light at 620nm and infrared light at 940nm) measurements from leaf samples. Relative chlorophyll content is displayed in the range 0 – 2000 units. It must be noted that chlorophyll meters give only ‘point’ readings, therefore more measurements need to be taken and integrated within a canopy or use an instrument that measures whole crop canopy reflectance.

Figure 3.5Hansatech Chlorophyll content meter with two buttons and a display screen

Figure 3.6 Field use of the Hansatech Chlorophyll content

3.6.2. Procedure

The enlisted procedure describes how measurement is taken using the Hansatech CL-01 chlorophyll meter.

First, I took the meter, field form, and a clipboard to the field. Typical measurement is done on flag leaf as they are fully expanded, unless the aim is to assess canopy chlorophyll profile (Pask et al., 2012). I made sure the leaves were clean, dry, green, and with no sign of disease. Upon turning it on by a sustained hold on the mode button, it auto calibrates and equilibrates with ambient temperature. I randomly selected five flag leaves from different plants, placed a third to half way of the length of a leaf from the bottom in the sensor chamber and verified that their adaxial (upper) surface faced upwards. The enter button was used in taking the measurements and there is a display of chlorophyll concentration index (CCI) on the screen. After five measurements on different leaves the mode button allows to review and average the readings. The average was recorded, deleted, and repeated to provide three average readings per plot.

3.6.3. Data and calculations

Data was recorded directly on the field form. After the recordings, the data was typed into Microsoft Excel and used to calculate a mean CCI for each plot. From here they were transferred to the single document for analysis.

3.7. Plant height

The height of wheat plants varies a lot with variety as expressed earlier in the literature. This is so because it is strongly controlled by genes (height reducing genes, Rht) and highly heritable. The expectation is to correlate plant height with above ground biomass (AGB) and Harvest index (HI).

3.7.1. Measurement procedure

The length of ten individual culms were measured from the soil surface to the tip of the spike. Data was recorded to the nearest centimetre. The awns were not included, and the rule was flat on soil surface to avoid mounds and cracks.

3.8. Ground Coverage

The crop's ground cover can be explained as the percentage of soil surface covered by plant foliage.

This measure can be essential in crop establishment and early vigour. The greater the early cover may provide an advantage to better intercept incident radiation, thereby increasing soil shading, decreasing soil evaporation, increase water use efficiency, and may increase competitiveness with weeds. The accurate method to measure ground cover is however destructive and time consuming. Therefore, high throughput approaches like: visual assessment, digital analysis of photographs, or

normalized difference vegetation index is lately used. Visual assessment (the approach used) allows a rapid and low technology approach but is subjective and may not have the resolution to distinguish between genotypes, whilst digital analysis of photographs enables a more quantitative and objective measurement (Pask et al, 2012).

3.8.1. Procedure

3.8.1.1. *Visual assessment*

This measure depends on experience. It is important that ratings are consistent due to subjectivity.

I stood along the side of the plot so that I can look down directly over the crop. Observation of the crop was made, and the rating was a scale from (0%) to (100%). More on the experience of this procedure is given by Pask et al, 2012.

3.9. Lodging

I first recorded the type of lodging. Secondly, the fraction of culms within the plot that is affected was recorded. The scale for registering was from 0% to 100%. Furthermore, the mean angle of the culms in relation to the vertical was registered. The lodging score was the estimated by the equation below.

*Lodging score = proportion of plot affected * degree of lodging …Equation 3*

3.10. Biomass and yield components

The total quantity (weight) of the crop in the planted area is what is termed biomass. The interest for this study was the above ground biomass. Generally, the dry weight is considered. If sampling is done in season, there are lots of possibilities, such as identifying growth rates, organ size, leaf area, dry mass partitioning between canopy components and many more (Pask et al., 2012). While these are important, our goal was to use non-destructive procedures, therefore we only looked at the final harvest biomass. Note that the measurement for biomass presented in this project is the biomass of the crop between physiological maturity and harvest maturity.

3.10.1. Field measurements

A representative area (0.25 m^2) was harvested by cutting above-ground biomass and avoiding border rows. This area biomass was put into either labelled textile or paper bags and brought to the lab. The sample was then weighed to obtain the fresh weight (FW). The sample was then dried in an oven at 60^0C for 48 hours and dry weight (Wilhelm et al.) taken. Threshing followed, and grain weight (GW) taken to end the measurements. Harvest index is therefore GW/DW.

3.11. Yield and quality

This section basically describes measurements of the grain yield at harvest maturity and some quality measures like protein content, starch content and test weight. In the case of grain yield, the procedure is very similar to that used in the previous section for GW. The quality measures had specific processes in taking their data.

3.11.1. Grain yield

A combine harvester was involved in amassing practically all grains from every single plot into netlike sacs. An extra winnowing process, by a different thresher, was involved to clean the kernels from unwanted impurities. All 96 sacs were put in a drying cabinet (30-35^{0}C) to allow the grains to dry for 72 hours. This was to allow for a uniform moisture content before dry weight is taken. The dry weight then represents the weight of the total number of grains in every single plot.

Grain weight was deduced from thousand kernel weight (TKW) given in grams. TKWs of normally developed grains should be in the interval 30-45g between varieties. Some cultivars give small but well-filled grains and those samples may provide high test weights. TKW are not normally used as quality criteria for at the grain deliveries in Norway but important for weight-based analyses.

To measure the TKW, I counted 600 grains with an automatic seed counter, weighted the sample, and calculated the weight of 1000 grains. This was recorded and added to the rest of the data in an excel worksheet.

Grain numbers were calculated with these equations;

$$GN_t = (GW_t * 1000)/TKW \quad \text{.... } \textit{Equation 4}$$

Where $GN_t$is the total grain number, GW_t is the total grain weight from a plot, and TKW is the thousand kernel weight.

The grains per spike was;

$$GN_{/s} = \frac{GW_{50} * 1000}{50 * TKW} \quad \text{.... } \textit{Equation 5}$$

Where, $GN_{/s}$ is the grain number per spike, grain weight from 50 spikes.

3.11.2. Test weight

Test weight is the weight (in kg) of 1 hectolitre grain. This measure varies between the different cultivars and it records how well the grains are filled. Thus, shrivelled grains will show lower test weight. Also, high test weight indicates higher flour yields and higher feed value of the grains (higher energy concentration). The measure of grain filling is largely dependent on the environmental conditions during grain development (from anthesis to ripening). Severe drought or attack by diseases around this period may produce shrunken grains with lower test weight (Tw). All grains in Norway are priced according to the Test Weight.

3.11.2.1. *Procedure*

The procedure involved the use of a cylindrical grain sampler and an analogue weight balance. The sampler has as a filler, main cylinder (1/4 of a hectolitre) and a cutter bar. The filler which is situated in the upper part of the whole cylinder was filled with the grains. Thereafter the cutter bar was pulled out as quick as possible to allow the grain mass to drop into the lower half of the sampler (main cylinder) with a force that lets the grains bulk perfectly. The cutter bar is reinserted to divide the grain mass into two halves; the main cylinder and an excess. The excess grains were poured out and both the cutter bar and the filler were separated from the main cylinder. This was the staged on an analogue weight balance which has already been calibrated for wheat samples, and the corresponding weight in kilogram per hectolitre inscribed on it. Note that without a calibrated balance, you must proportionate the weight to a whole hectolitre (if using a ¼ hectolitre).

3.11.3. Protein content

The Kjeldahl-method is standard for measuring protein content in grains. This method is accurate and time consuming due to various processes involved. The use of NIR (Near Infrared Reflectance) or NIT (Near Infrared Transmission) methods is now commonly used for analysing protein content at the grain deliveries. This technology is now widely used and various grain analysers have been manufactured. The technology involves irradiating the samples with near infrared light of certain wavelengths. The analyser records the reflected and transmitted light and then compare with values from the Kjeldahl-method which was used in calibrating it. For all new samples analysed, reflected/transmitted light of different wavelength is recorded, and this is transformed to protein content with the help of the regression line from the calibration. NIR/NIT methods are fast and easy to use. The procedure can be used on flour (NIR) and on whole kernels (NIT).

3.11.3.1. *Procedure*

The method was very simple. I set the analyser to wheat (grains), fill the chamber with the kernels and press a button to start analysing. The kernels flow steadily into a basin below the chamber as it is being analysed and the result is displayed on the screen when done. The data was recorded and added to the rest.

3.12. Image analysis

Image analysis was hinged around two main apparatus; a multi-spectral camera and an unmanned aerial vehicle (UAV). The plan originally included an agricultural robot, but some unforeseen challenges rendered it not useable.

To obtain sensory data of the spectral bands, a multi-spectral camera from MicaSense called Parrot Sequoia was used. It consisted of five separate sensors, one for each spectral segment, being near infrared, red-edge, green, red, and usual RGB.

For the UAV, a predetermined route was set by a software application called Litchi for the DJI Phantom 3 drone.

Systematic deductions and practical analysis on these images were done with the program Pix4D, and are discribed in the master thesis of Grindbakken, 2018 (unpublished). Due to limited time to submit project, only two groups of data NDVI and MTCI for a single date (17.07.2017) around the period of heading were included in my analysis to find interesting correlations.

3.13. Statistical analysis

In accordance with the field trial layout at Ås (alpha lattice split plot design), the statistical program SAS was used to execute analysis of variance using a mixed model (PROC MIXED). The trial at Staur was a column design with a single N level fertilization thus, the code was different relative to that of Ås. The SAS codes for the two locations are included in appendix. The code returned least square means for three groups; 1) the 24 cultivars, and 2) the interaction between the cultivars and the fertilizer level for both 8 and 15 N kg/daa. Additionally, probability values were produced along with their degrees of freedom. Significance for the project was set at 0.05. The null- hypothesis tested was that there were no differences between the elements within a group. After obtaining the LS means, correlations were made between grain yield and yield components, also with all physiological traits measured. I first made correlation matrices and then make figures from those that were strongly correlated. These procedures were performed in Microsoft Excel

2016. Finally, a principal component analyses was operated on the variables and all the variations were exhibited on a figure in the results.

4. RESULTS

The experiment lasted about four months (from May to September 2017). The weather data for the two locations were sourced from the Meteorological institute of Norway's website, eklima.met.no. The breakdown of the conditions which were associated with the locations are given below.

Table 4.1 Data on the weather conditions over the trial period for both locations. Sourced from the Norwegian Meteorological Institute, eklima.met.no

Weather overview of experimental period		
May, June, July, August, September, 2017		
STATIONS: 17850 ÅS, 12290 HAMAR II		
Elements	**Ås**	**Staur**
Tm: Mean temperature °C	13.6	13.3
Dev: Mean temperature deviation from normal	0.3	
Txm: Mean maximum temperature °C	18.3	18.4
Tnm: Mean minimum temperature °C	9.1	8.8
Txa: Absolute maximum temp. °C	25.9	29
dt: Date of Txa	23-Jul	27-May
Tna: Absolute minimum temp. °C	-2.4	-2.3
dt: Date of Tna	09-May	01-May
Hum: Relative humidity	74	69
RR: Total precipitation	457.3	403.1
RR%: RR in % deviation from normal	120	
Rxa: Maximum daily precipitation	50.2	25.1
dt: Date of Rxa	10-Aug	16-Aug
T0: Number of days where Tmin < 0°C	2	3
T20: Number of days where Tmax >= 20°C	59	57
Rd1: Number of days with precipitation >= 1.0 mm	58	62
Hd: Heating degree days, base 17°C	537	580
Gd: Growing degree days, base 5°C	1319	1273

The average temperature throughout the season 13.6^{0}C at Ås and 13.3 at Staur. Mean high temperatures were 18.3^{0}C (Ås); and 18.4^{0}C (Staur) during the period. Total precipitation was 457.3mm and 403.1mm for Ås and Staur respectively. Overall the season was cold with fluctuating diurnal temperatures. Initially, the month of May was accompanied with cold temperatures and lots of erratic showers which delayed planting until the 24th. Later, the summer came along with interspersed showers and some dryness in the middle of both June and July, which meant we had to irrigate especially around the time of heading and anthesis.

The intensity of rains however increased towards the end of the season as is mostly the case under the Norwegian climate.

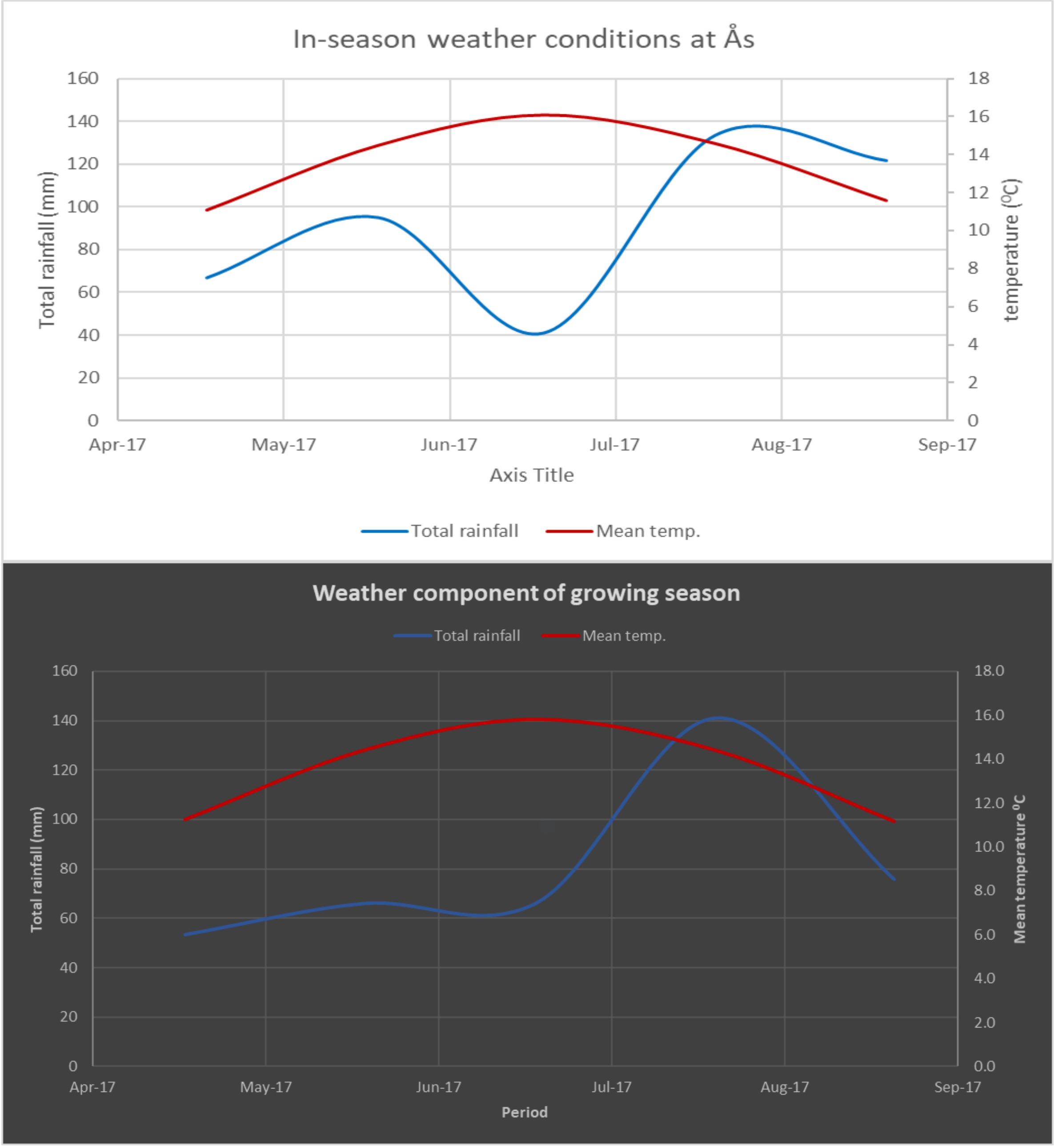


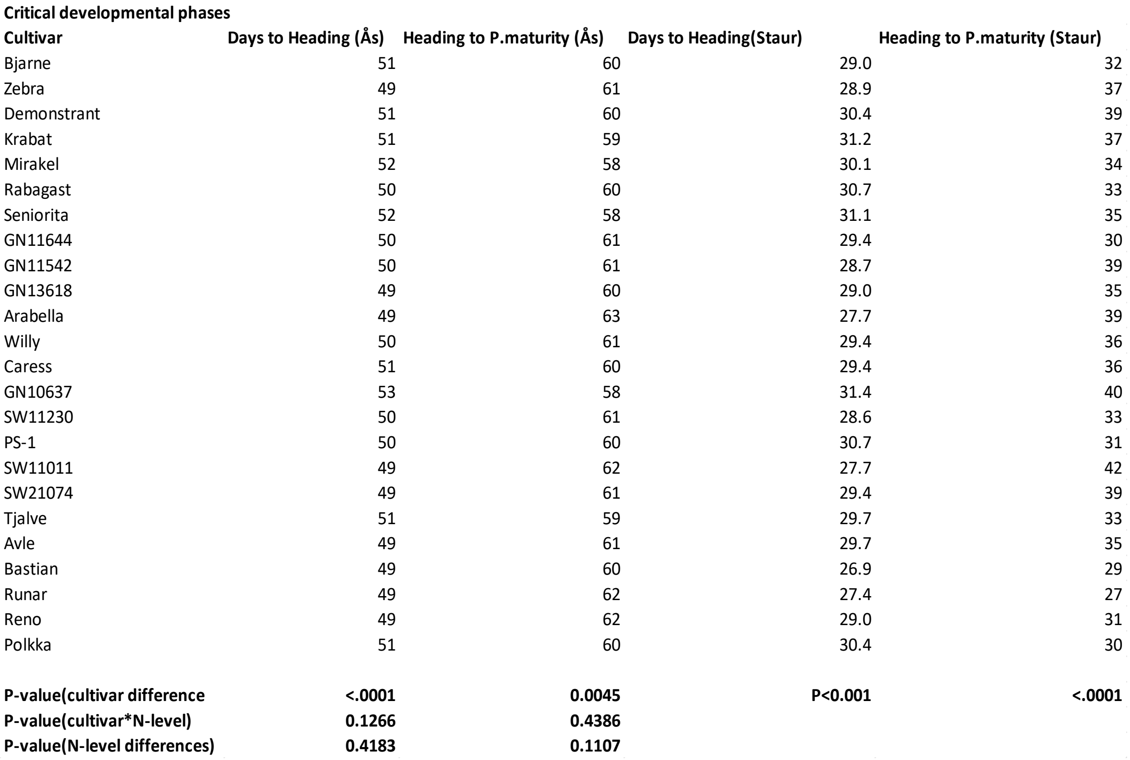
Figure 4.1 Mean temperature and rainfall pattern (total monthly rainfall) for both locations (Ås on top; Staur below) from May to September. Data used for this figure was sourced from *http://www.eklima.met.no*

Approaching the end of the season, there was an increased amount of rains which could have affected harvest timing and elicit sprouting. Although there was some incidence of sprouting, they were minimal and harvesting at Ås was on the 22th September 2017. That for Staur was later on the 28th September 2017.

4.1. Phenological development

First, changes in plant developmental phases observed were not greatly dissimilar before spike emergence. Along with a temperature sum of 106.4-degree days, the date of emergence from the ground was promptly observed 7 days from sowing (24th – 30th May 2017). Days from sowing until heading was generally over 40 days for all cultivars, meaning heading begun in the mid of July 2017. Lastly, days to heading was significantly different between cultivars (P<0.0001) and no significant interaction was found between cultivar and N-level (P=0.1266).

Table 4.2 Duration of different phenological phases



Critical developmental phases

Cultivar	**Days to Heading (Ås)**	**Heading to P.maturity (Ås)**	**Days to Heading(Staur)**	**Heading to P.maturity (Staur)**
Bjarne	51	60	29.0	32
Zebra	49	61	28.9	37
Demonstrant	51	60	30.4	39
Krabat	51	59	31.2	37
Mirakel	52	58	30.1	34
Rabagast	50	60	30.7	33
Seniorita	52	58	31.1	35
GN11644	50	61	29.4	30
GN11542	50	61	28.7	39
GN13618	49	60	29.0	35
Arabella	49	63	27.7	39
Willy	50	61	29.4	36
Caress	51	60	29.4	36
GN10637	53	58	31.4	40
SW11230	50	61	28.6	33
PS-1	50	60	30.7	31
SW11011	49	62	27.7	42
SW21074	49	61	29.4	39
Tjalve	51	59	29.7	33
Avle	49	61	29.7	35
Bastian	49	60	26.9	29
Runar	49	62	27.4	27
Reno	49	62	29.0	31
Polkka	51	60	30.4	30
P-value(cultivar difference	**<.0001**	**0.0045**	**P<0.001**	**<.0001**
P-value(cultivar*N-level)	**0.1266**	**0.4386**		
P-value(N-level differences)	**0.4183**	**0.1107**		

4.2. Grain yield and post-harvest data

Grain yield was high across all cultivars. They are presented in the unit, grams per square metre (gm^{-2}) which is equivalent to kilogram per decare, the unit mostly used throughout Norway. Figure 4.2 below, shows the yield levels relative to the nitrogen application. The cultivars, Demonstrant and Arabella showed superior grain yield relative to the other cultivars at both N levels.

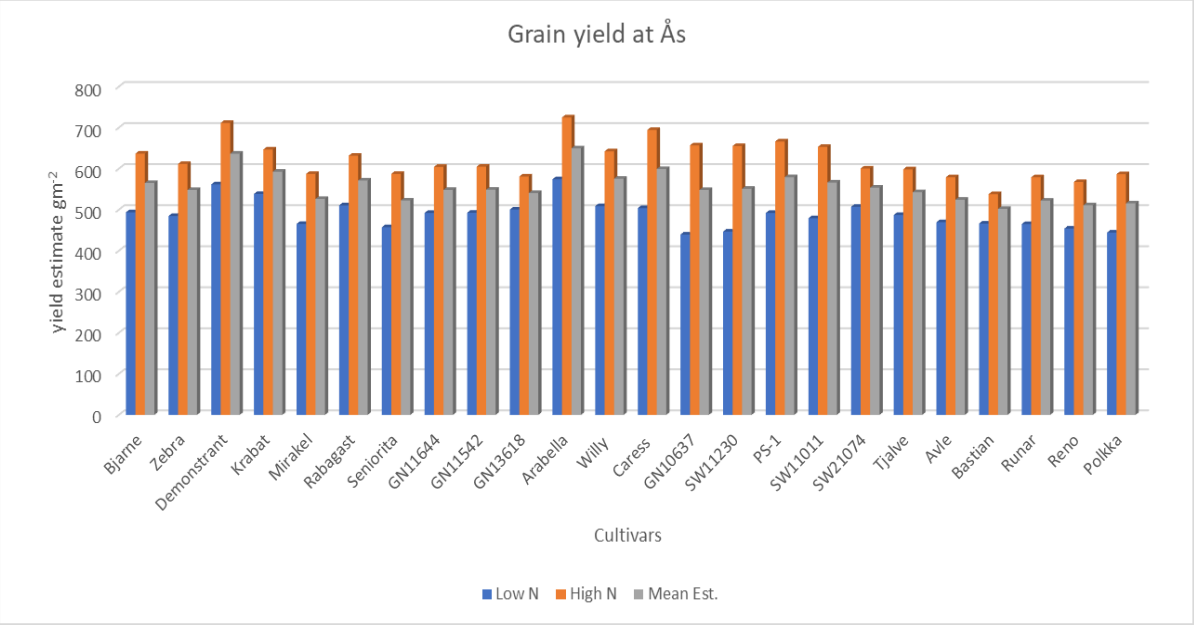


Figure 4.2 Grain yield across cultivars with probability value of <.0001 and for both nitrogen level 0.0002 which shows significance

There were significant differences between cultivars (P<0.0001) and a significant interaction between cultivars and N-level interaction (P= 0.0002), while differences across N level were also barely significant (P= 0.0531). All the cultivars responded to high N fertilization, with 27.3% increment on average. The cultivars/lines GN10637, SW11230 and Caress had the greatest response with 49%, 47% and 38% respectively. Those with the lowest response were SW21074, GN13618, and Bastian having 18%,16%, and 15% respectively.

As is evident in figure 4.3 below, the results were not the same at Staur research station. Line SW1011 was the highest yielding with 894.9 gm^{-2} followed by GN13618 with 821.11 gm^{-2}. Excluding Bastian, Runar, and Reno, all the cultivars yielded above 700 gm^{-2}. The average yield for the station (Staur) was ca.22% higher than the average yield of the high N fertilization counterpart at Ås.

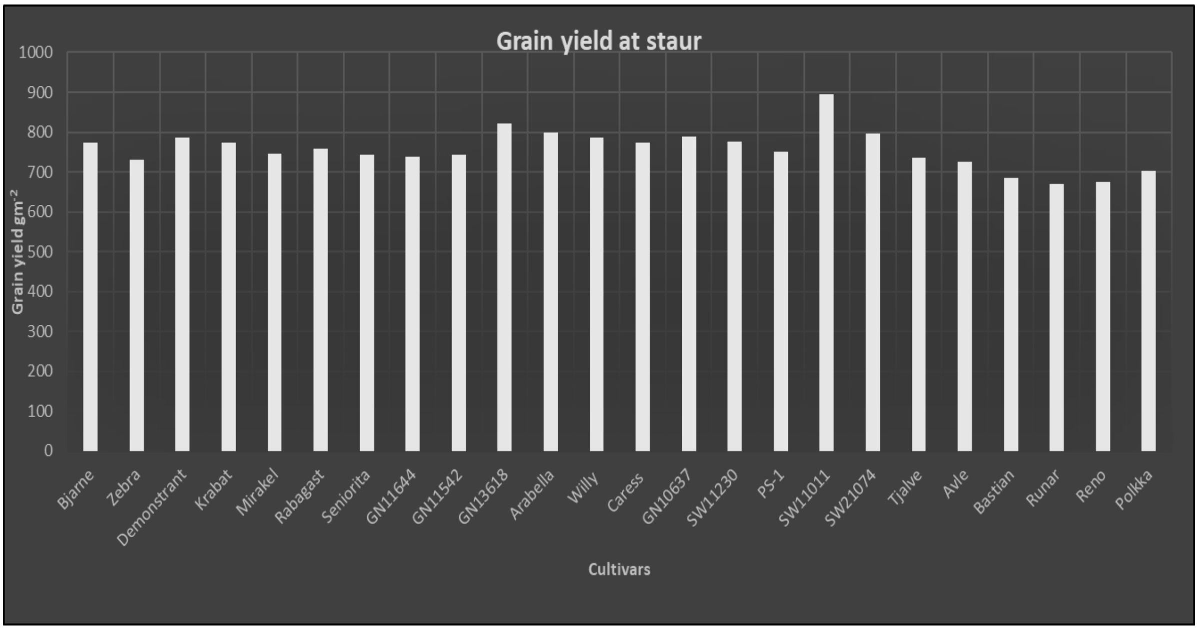


Figure 4.3 Grain yield at Staur research station with significant difference identified at probability level <0.0001

As intruded earlier that some cultivars were not yet released or had been rejected or withdrawn, I considered only released cultivars for comparisons with year of release (YOR). Figure 4.4 below, therefore reiterate the idea for the research and shows a linear positive relationship between year of release and cultivar grain yield. The trial at Staur shows a stronger relationship for cultivar and YOR but this could be because the trial is based on a higher N fertilization.

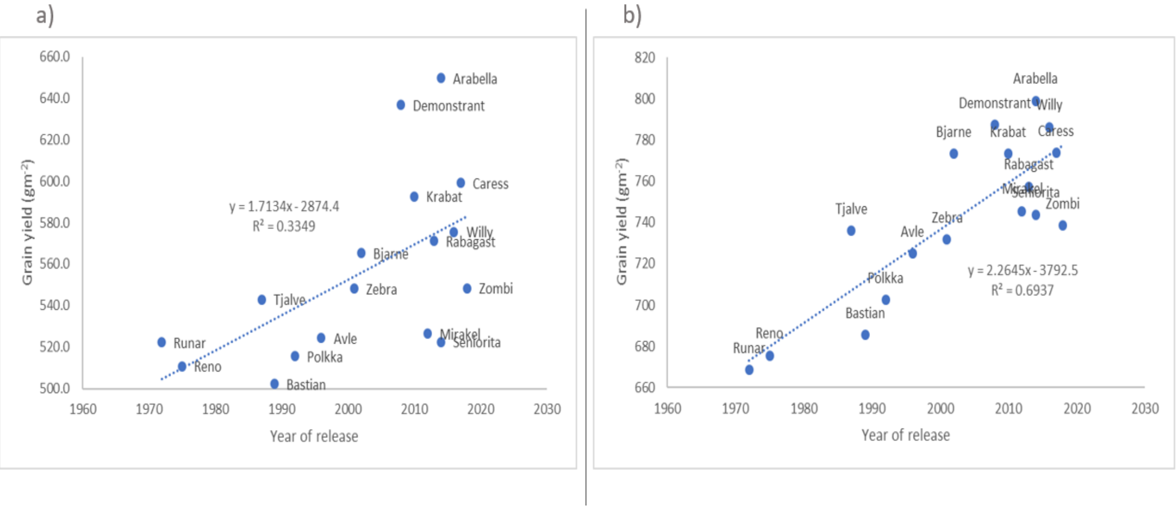


Figure 4.4Regression of year of release on a) grain yield at Ås, and b) grain yield at Staur

A correlation matrix was developed to find out yield components which were either linearly correlated with grain yield or other components. The result showed strong positive relationship between HI and grain yield, HI and Grains per spike, and grain yield and grain per spike. Strong negative relationship was observed for grain weight (GW) and grain per spike. Consideration of strength was 0.45 (decent) 0.7 and above (very strong).

Table 4.3 Correlation matrix for harvest components

	Grain yield	*Biomass*	*Harvest index*	*GW (mg)*	*Grains per m^2*	*Grains per spike*
Biomass	0.380					
Harvest index	0.721	0.040				
GW (mg)	0.337	0.098	0.129			
Grains per m^2	0.479	0.199	0.494	-0.658		
Grains per spike	0.512	0.427	0.619	-0.108	0.483	
spike per m^2	-0.055	-0.160	-0.260	-0.467	0.423	-0.568

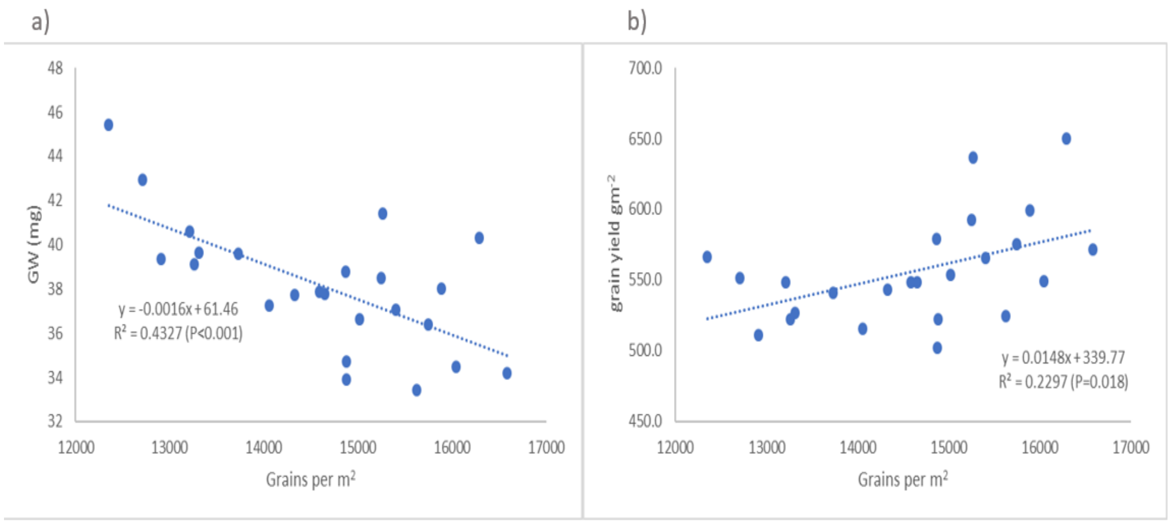


Figure 4.5Regression on a) grain weight and grain per m2, and b) grain yield and grain per m2

4.2.1. Biomass

The biomass produced by the crops were generally above 1000 gm^{-2} and showed significant difference between cultivars. This trait was highest for the cultivar Arabella, 1333.02 gm^{-2}, but Demonstrant, Mirakel, Polka and new lines like GN11542 and SW21074 also produced biomass around 1200 gm^{-2}. Figure 4.6 displays all cultivars and representative biomass amount. This trait was not measured at Staur research station.

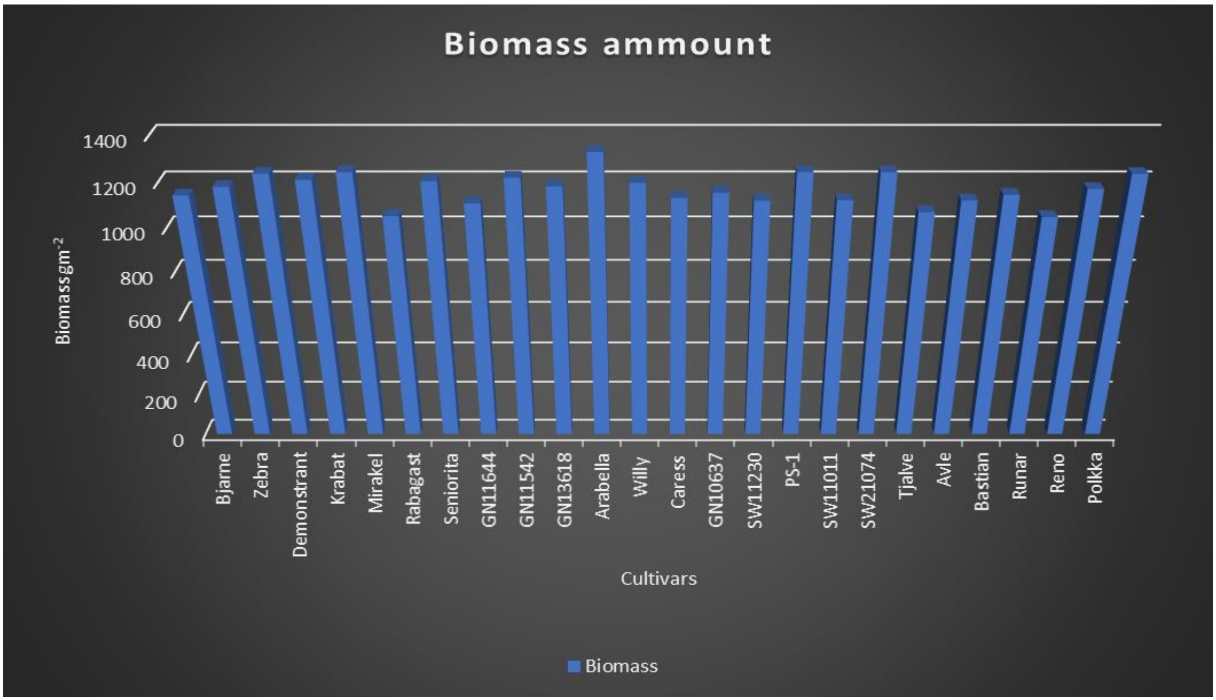


Figure 4.6Representation of biomass production of crops at Ås

4.2.2. Harvest index

At Ås, the estimation of harvest index provided results with Arabella displaying the highest HI followed by PS-1, Bjarne and Demonstrant respectively. Reno and GN13618 were amongst the cultivars with the lowest HI with line GN13618 being the lowest of all. Due to no data for biomass from Staur, there was no HI estimation either. Figure 12 shows the variation between the cultivars. This variation was significant (P= 0.015) unlike the interaction between N level and cultivar (P=0.592). The HI estimates for Runar and rabagast were intentionally removed because their values were outliers.

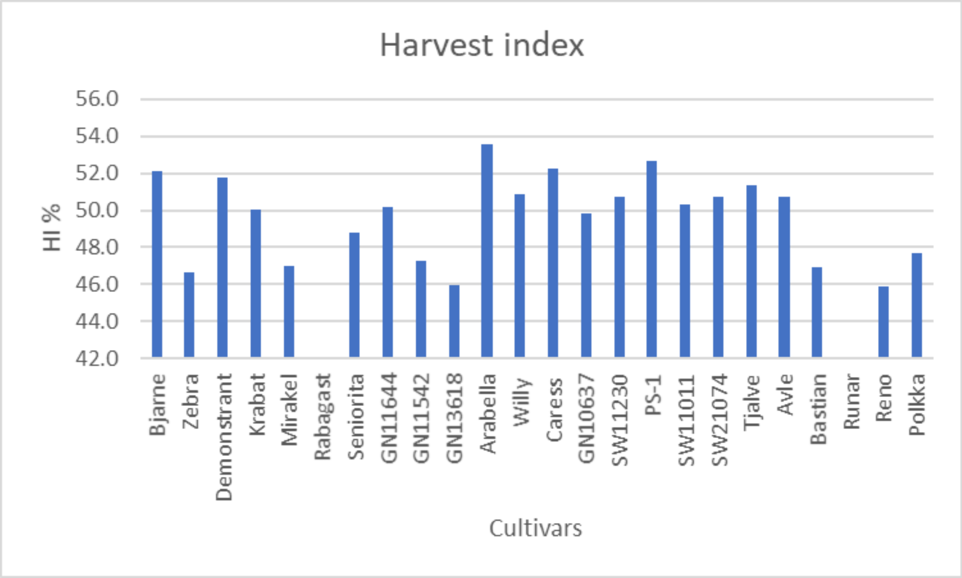


Figure 4.7Mean harvest index for all cultivars (P= 0.0153)

The mean HI showed a decent positive linear association with grain yield (R^2 =0.52) which was significant (P<0.001). The year of release had a weak positive relation with HI.

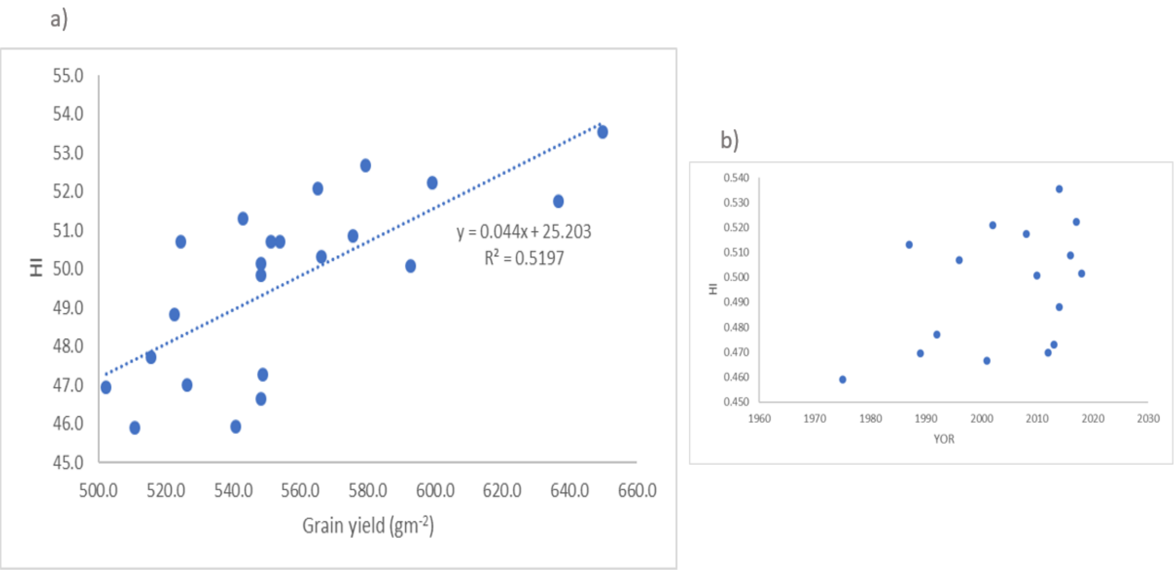


Figure 4.8Relationship between a) harvest index and grain yield, and b) HI and year of release

4.2.3. Thousand Kernel weight

The variety SW11011 had the highest grain weight (from 45 up to 50g) in relation to the rest and at every N fertilization level. Other high weight cultivars were Demonstrant, Arabella, Zebra, and the line SW11230 with weights being over 40g at both Nitrogen fertilization. Bastian, Avle and Seniorita belonged to the cultivars having the lowest grain weight across trials. In figure 4.9, we can also see slight variations which are due to N fertilization.

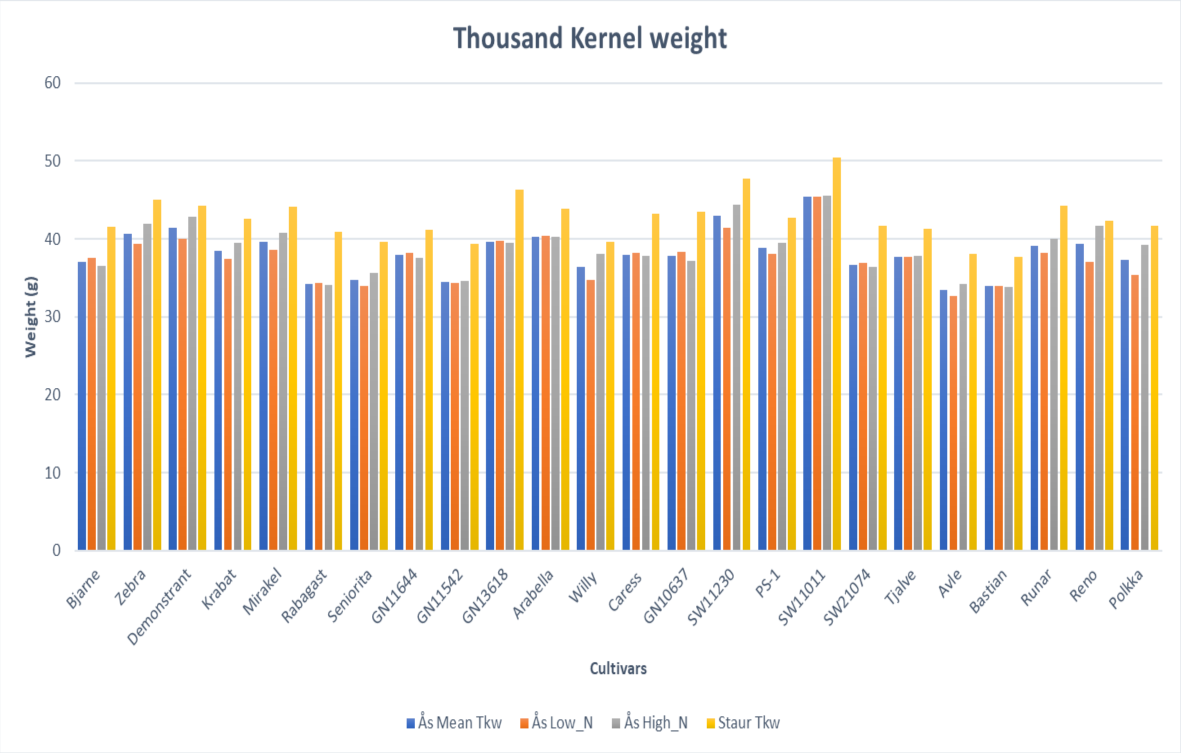


Figure 4.9 Thousand kernel weight displayed to be range between 30 and 45g, with some exceptions reaching 50g.

4.3. Quality Measures

4.3.1. Test weight

How well the grains were filled indicated strongly a cultivar variation. The cultivars demonstrated specificity in terms of how they were filled across both locations. The test weight of a cultivar like Bjarne was about 74 Kg/hl at both locations and even at both nitrogen fertilization.

Figure 4.10 Test weight for all cultivars presented for Ås and Staur, and N-level interaction with cultivar.

These similarities were identified generally with some few fluctuations basically for the trial at Staur. The results here therefore significantly suggest that test weight should be mainly cultivar dependent and may show slight increase due to environment and Nitrogen fertilization.

4.3.2. Starch content

Starch content has increased in association with yield over the years. The trait was estimated at Staur and not at Ås. Rabagast and breeding line SW11011 had the highest starch content (between 70 and 72 %DM) at the location. The lowest container was of starch was Tjavle.

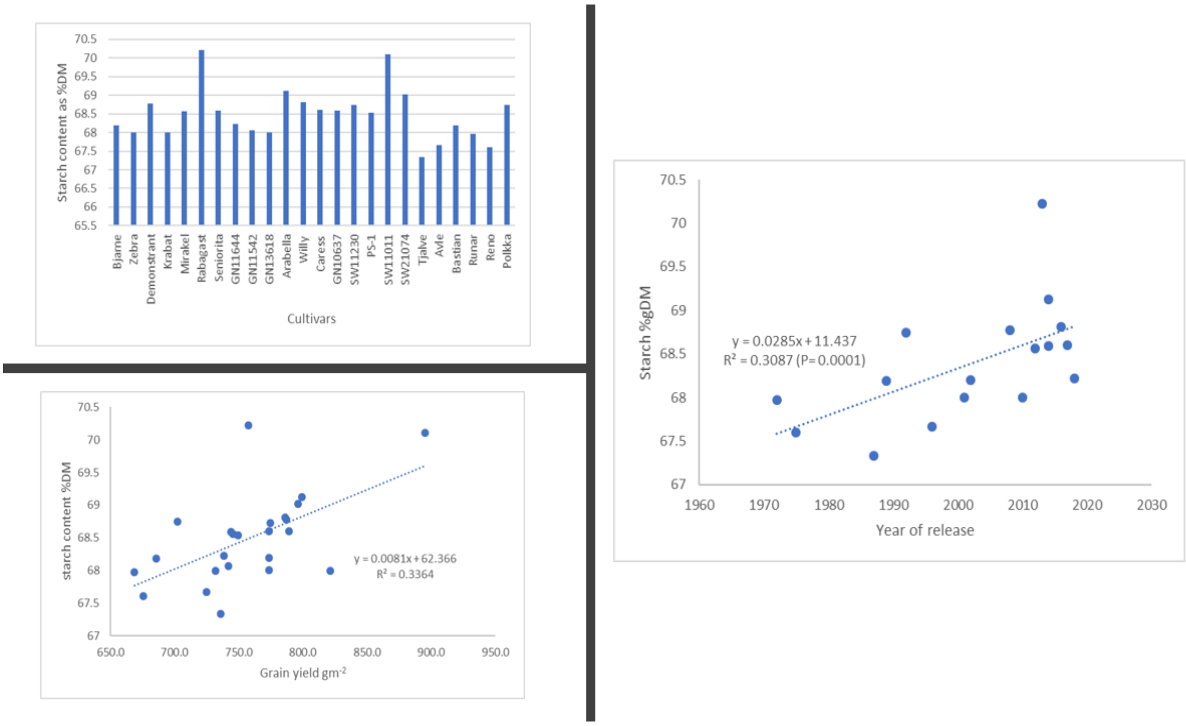


Figure 4.11 Starch content of cultivars (top left), relations with yield (down left) and year of release(left)

4.3.3. Protein content

The protein content of the crops were slightly higher in the trial held at Ås than that at Staur. Nitrogen fertilization showed differences in protein content but mean protein content of the varieties in Ås were still higher than those of Staur. Avle, Polkka and the line GN11644 were those with greater protein content and Demonstrant being the lowest.

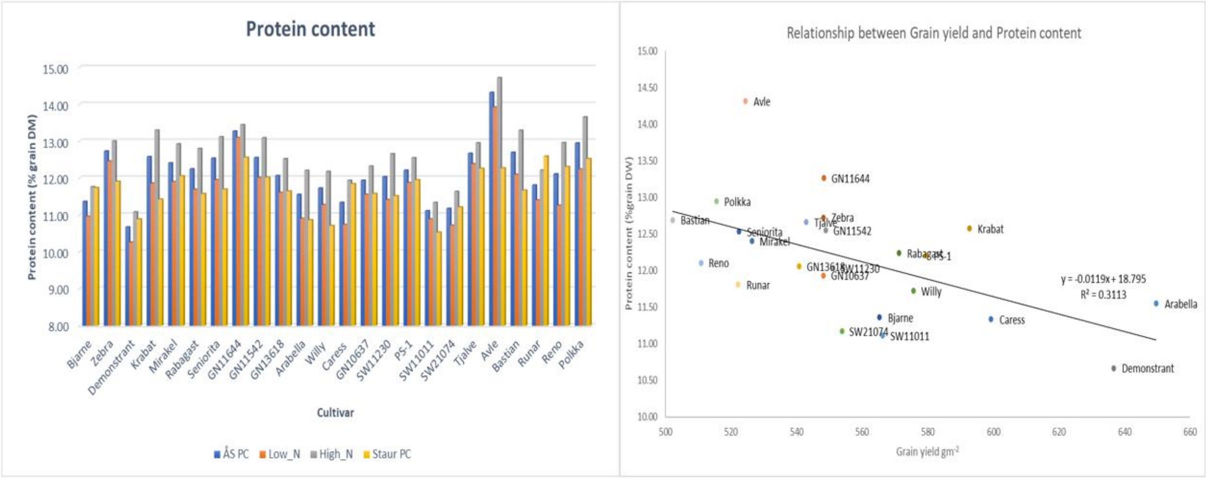


Figure 4.12 Protein distribution in cultivars at both Ås and Staur (left), and a graph of an inverse relationship between grain yield and protein content with regression coefficient (-0.0119) and percent explained variance (R^2= 0.3113).

4.4. Ground cover

The percentage of soil surface covered with foliage varied through the growth season. Data was collected on three different days during the season. As earlier explained, an observational scoring approach was used but data was integrated with the remaining data, making information displayed a result from the statistical analysis.

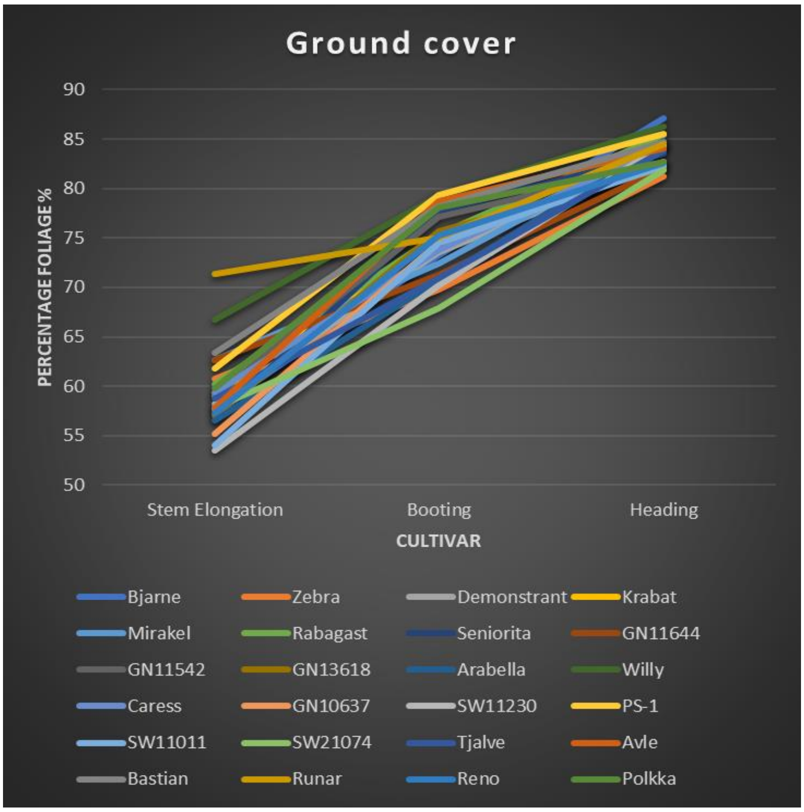


Figure 4.13 Mean ground cover for trials at Ås

The information as presented below shows ground cover at the beginning of stem elongation, mid elongation and heading. Runar showed the highest coverage 71%, which means an early vigour and establishment. This relates with its PAR interception, being the highest (0.64) at stem elongation. Bjarne was one of the lowest the initial stage but was the cultivar with the most coverage alongside Willy at heading.

4.5. Light interception

The cultivars at Ås displayed significant differences for PAR interception and showed increment in interception as the season progressed. *Table 4.4* below shows the increasing effect and differences between cultivars. This was observed from a lower fraction of 0.56 at the beginning of jointing to a high of 0.91 around heading in the case of Mirakel. Similar trends were identified in all the cultivars.

Table 4.4 Least square means, showing cultivar variations in fraction of light interception

Cultivar	19/06/2017	27/06/2017	05/07/2017	13/07/2017
Bjarne	0.53	0.78	0.85	0.89
Zebra	0.51	0.76	0.82	0.84
Demonstrant	0.57	0.76	0.86	0.88
Krabat	0.54	0.77	0.85	0.88
Mirakel	0.56	0.77	0.85	0.91
Rabagast	0.55	0.72	0.81	0.87
Seniorita	0.56	0.80	0.87	0.89
Zombi (GN11644)	0.57	0.79	0.85	0.91
GN11542	0.57	0.79	0.85	0.88
GN13618	0.49	0.77	0.84	0.88
Arabella	0.49	0.76	0.86	0.90
Willy (GN10521)	0.56	0.81	0.90	0.91
Caress (SW01074)	0.51	0.74	0.84	0.90
GN10637	0.55	0.77	0.82	0.89
SW11230	0.46	0.71	0.81	0.86
PS-1	0.54	0.80	0.84	0.90
SW11011	0.48	0.73	0.78	0.86
SW21074	0.47	0.71	0.80	0.87
Tjalve	0.54	0.72	0.83	0.87
Avle	0.51	0.78	0.84	0.87
Bastian	0.60	0.83	0.87	0.90
Runar	0.64	0.82	0.89	0.90
Reno	0.54	0.81	0.89	0.92
Polkka	0.61	0.84	0.88	0.91

Averagely, about a half of the total PAR available was intercepted at the beginning of stem elongation. Bastian, Runar, and Polka were cultivars showing higher fraction of interception with over 0.60. Lines SW11011, SW21074 and SW11230 were among those with the least fraction of interception with 0.48, 0.47, and 0.46, respectively. The week before and after heading shows a slight increase compared to the period of initiation of elongation. It should be noted that PAR reflected by plants is not included in the estimation of fraction intercepted.

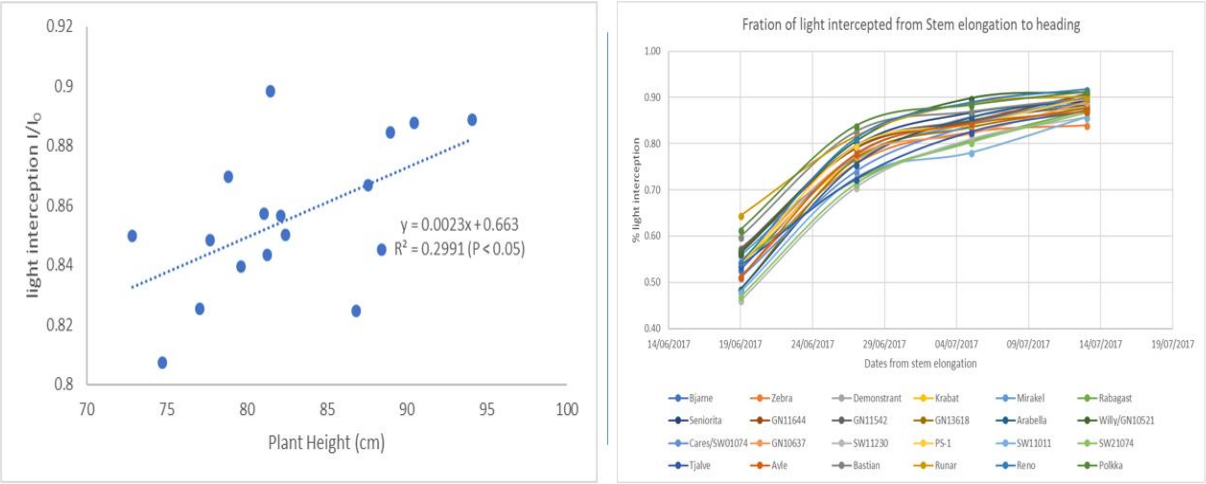


Figure 4.14 Fraction of light interception shown to be having a weak relation with plant height (left). And the patten it increases with from stem elongation to becoming more uniform as plant reaches heading (right).

There were no significant interactions between cultivars and nitrogen fertilization levels. However, the indication that higher nitrogen level plots intercepted greater PAR fraction at each date was evident.

4.6. Chlorophyll Content

In relation to chlorophyll content, the cultivars showed significant difference with probability values; <.0001, 0.0005, and 0.0081 for measurements taken on the 7th, 14th, and 25th of July 2017. Generally, cultivars were exhibiting increment of chlorophyll concentration except Bjarne, which dropped from 20.33 units to 17.55 units. All cultivars had headed at the time of taking the final chlorophyll data. Also, the variation in chlorophyll content in relation to nitrogen fertilization level is shown in figure 4.15, where all cultivars exhibited lower and higher CCI for nitrogen level 7.5 kg daa^{-1} and 15 kg daa^{-1} respectively.

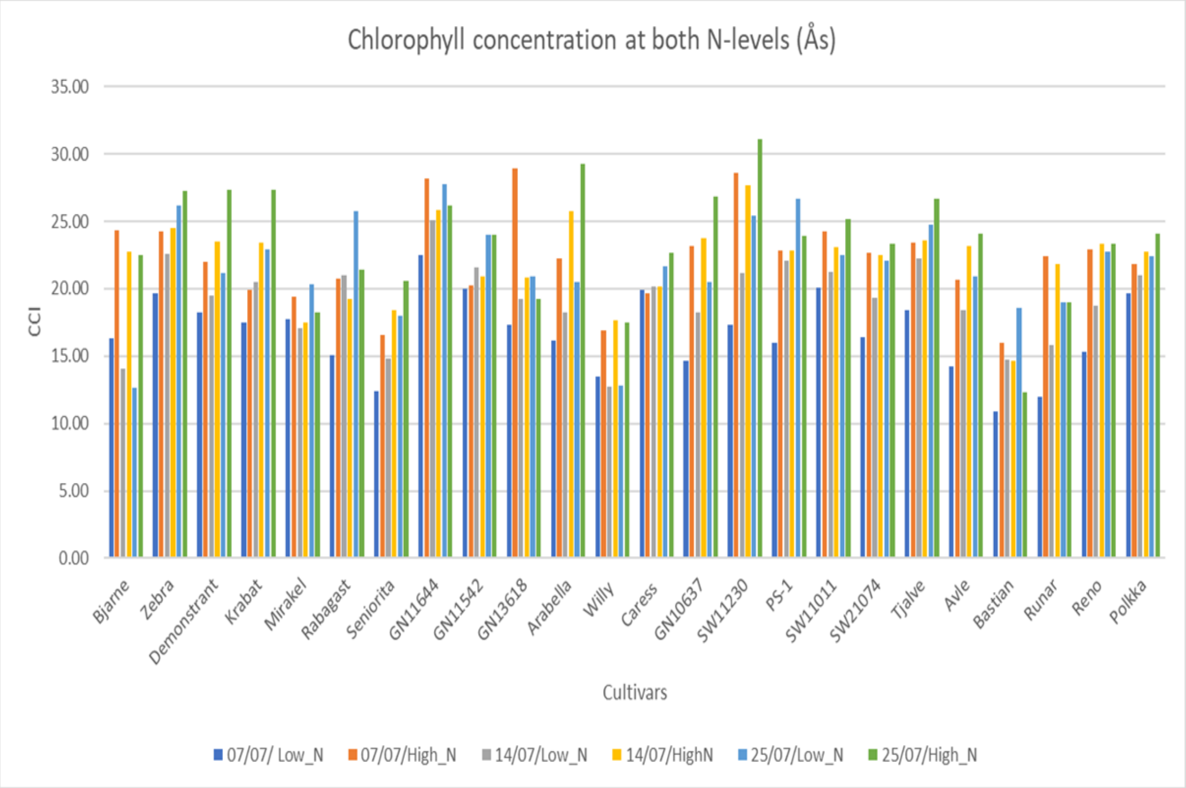


Figure 4.15 Mean distribution of chlorophyll concentration of cultivars across all plots (left), and the responses of chlorophyll content to N fertilization.

4.7. Plant Height

Plant height measure from both Ås and Staur are represented in the figure below. Mirakel, Runar, and Reno were the tallest cultivars at both locations. Differences in height were significant between cultivars and are presented in a table in the appendix. The trial at staur was based only on High N fertilization so, comparison can be made with the equivalent fertilization level at Ås. This comparison generally showed taller plants in Staur than in Ås but similar distribution.

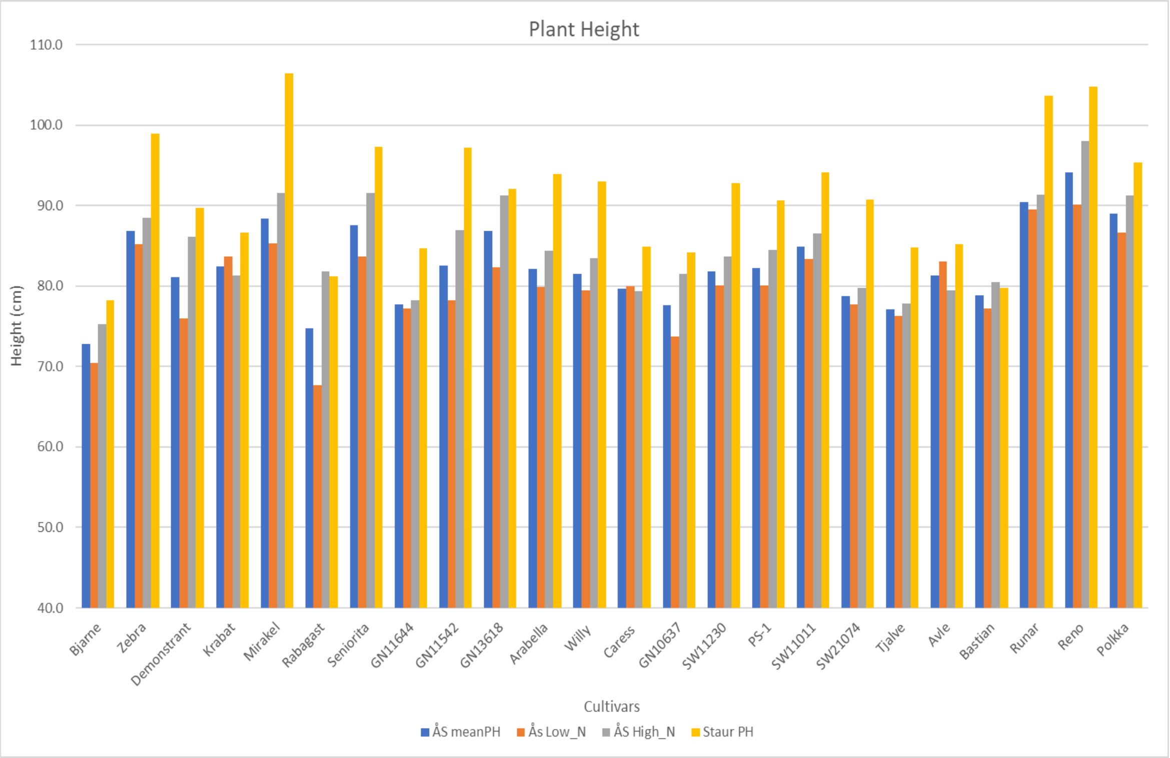


Figure 4.16 Plant height distribution for both locations.

4.8. Trait correlations

This section systematically presents the various relationships between traits that contribute to cultivar variance, especially those significant to yield at both locations.

4.8.1. At Ås

To find relationships between traits, I made a correlation matrix in Microsoft Excel. A multiple regression analysis (95%confiidence level) was carried out on the variables which were associated with grain yield (Positive; HI, GW, GNpm^2, Grains per spike, and AGB; Negative; PC, PH, Li,). The most significant of them were GNpm^2 and GW. Both together explained 98% of the variance of grain yield. And are displayed in table 4.5 and figure 4.11.

Table 4.5 Summary output from the regression analysis made in Excel displaying traits that are much associated with yield differences at Ås.

Multiple R	0.98983
R Square	0.97976
Adjusted R Square	0.97783
Standard Error	5.48666
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*P value*
Regression	2	30596.69038	15298.35	508.1924	1.64E-18
Residual	21	632.1724199	30.10345		
Total	23	31228.8628			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-559.07552	35.15171195	-15.9046	3.46E-13
GW (mg)	14.6249191	0.52427869	27.89531	4.43E-18
Grains per m2	0.03812265	0.001271822	29.97483	1.01E-18

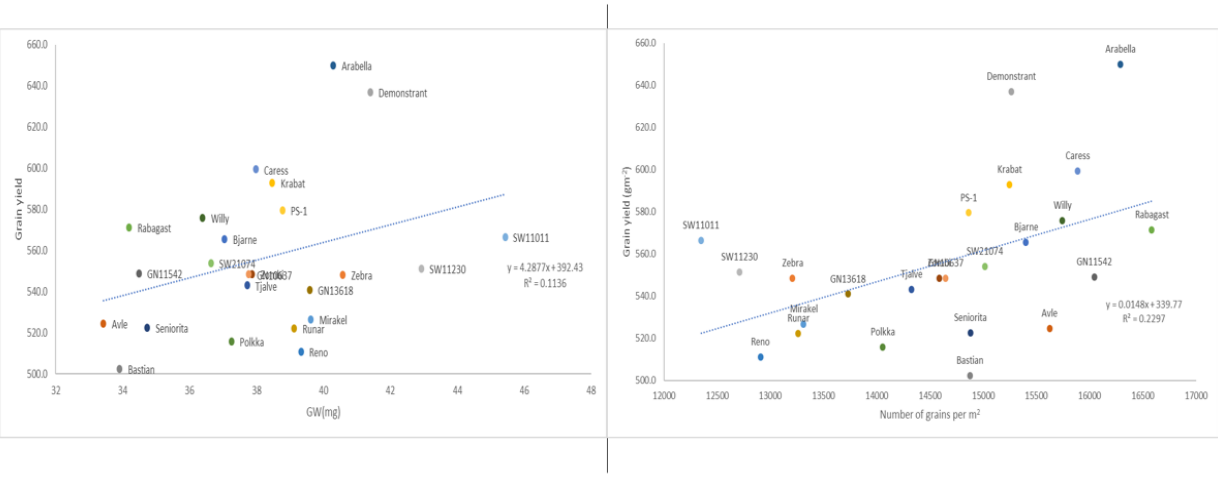
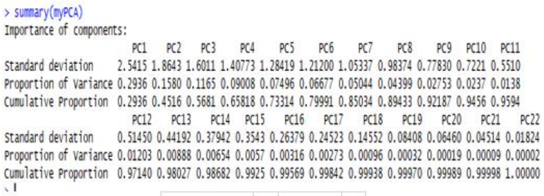


Figure 4.17 A graph showing relationships between GW and GY (left) and GNpm^2 and GY (right)

The principal component analysis biplot below shows the variations between all cultivars and their relationships with the physiological traits measured. PC1 is responsible for 29% of the variation and is driven by light interception and chlorophyll content. Line SW11230 (entry 15) and Bastian showed the most variation relative to chlorophyll and light interception respectively. Plant height and yield are very much varied in PC2. Reno and Arabella are accordingly varied.



```
> summary(myPCA)
Importance of components:
                          PC1    PC2    PC3     PC4     PC5     PC6     PC7     PC8     PC9   PC10   PC11
Standard deviation     2.5415 1.8643 1.6011 1.40773 1.28419 1.21200 1.05337 0.98374 0.77830 0.7221 0.5510
Proportion of Variance 0.2936 0.1580 0.1165 0.09008 0.07496 0.06677 0.05044 0.04399 0.02753 0.0237 0.0138
Cumulative Proportion  0.2936 0.4516 0.5681 0.65818 0.73314 0.79991 0.85034 0.89433 0.92187 0.9456 0.9594
                          PC12    PC13    PC14   PC15    PC16    PC17    PC18    PC19    PC20    PC21    PC22
Standard deviation     0.51450 0.44192 0.37942 0.3543 0.26379 0.24523 0.14552 0.08408 0.06460 0.04514 0.01824
Proportion of Variance 0.01203 0.00888 0.00654 0.0057 0.00316 0.00273 0.00096 0.00032 0.00019 0.00009 0.00002
Cumulative Proportion  0.97140 0.98027 0.98682 0.9925 0.99569 0.99842 0.99938 0.99970 0.99989 0.99998 1.00000
```

Bjame	1	Caress	13
Zebra	2	GN10637	14
Demonstrant	3	SW11230	15
Krabat	4	PS-1	16
Mirakel	5	SW11011	17
Rabagast	6	SW21074	18
Seniorita	7	Tjalve	19
Zombi	8	Avle	20
GN11542	9	Bastian	21
GN13618	10	Runar	22
Arabella	11	Reno	23
Willy	12	Polkka	24

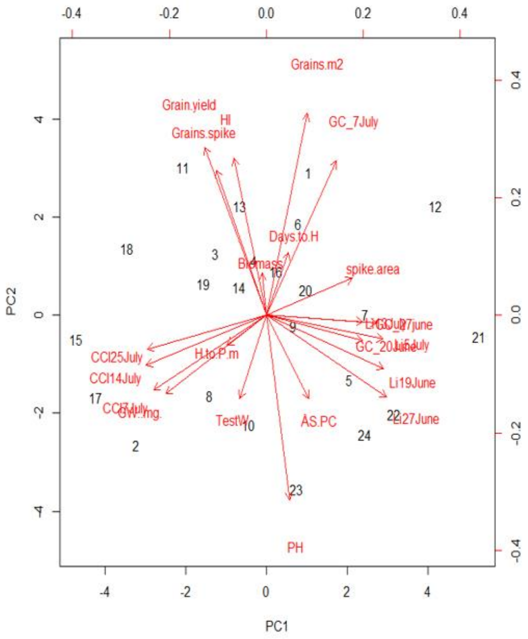


Figure 4.18A biplot Principal component analysis for cultivars and traits. Chat explanation (up left) Entry and cultivar names

4.8.2. At Staur

The format used in section 4.8.1 was used in this section. The Table 4.7 indicates that the grain filling period was highly associated with yield. Three other variables that were associated with yield were starch content, grain weight and chlorophyll content.

Table 4.6 correlation matrix for all variables from at Staur

	GY	***PH***	***HM***	***PC***	***StarchDM***	***TestWeight***	***GW***	***Li1707***	***Li 3107***
PH	-0.19673								
HM	0.753398	0.022804							
PC	-0.78636	0.144677	-0.69815						
StarchDM	0.580023	-0.08868	0.376829	-0.62103					
TestWeight	0.107908	0.314034	0.221809	0.048864	0.250852				
GW	0.563277	0.328596	0.308792	-0.32936	0.335038	0.3351245			
Li1707	0.092119	-0.24869	0.002596	-0.06234	0.141004	-0.2181495	-0.44195		
Li 3107	0.08426	-0.24091	0.147855	-0.11311	-0.00626	-0.1735453	-0.40109	0.530878	
CCI 1707	0.316528	-0.3025	0.41551	-0.09956	0.074108	0.0456741	0.193814	-0.39524	-0.04781
CCI 3107	0.335706	-0.06595	0.147625	0.151001	-0.04392	0.3453897	0.545711	-0.22484	-0.28611
DaystoH	0.05524	-0.14817	0.154032	0.077456	0.046922	0.0020193	-0.18971	0.390328	-0.06476

After establishing the relationships between the variables, I developed a multivariate regression table to identify significance and make systematic inferences. The initial table showed that grain weight and chlorophyll content were not significantly associated with yield. Thus, I made another regression table without those two. The findings from the new regression analysis are displayed in table 4.8.

Table 4.7 Summary output from the regression analysis made in Excel displaying traits that are much associated with yield at Staur.

Multiple R	0.818418325
R Square	0.669808554
Adjusted R^2	0.63836175
Standard Error	29.66433247
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*P-value*
Regression	2	37486.36476	18743.18	21.29973	8.85E-06
Residual	21	18479.42504	879.9726		
Total	23	55965.7898			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1210.4716	645.3063376	-1.87581	0.074653
HM	7.86156484	1.707304464	4.604665	0.000153
StarchDM	24.76258209	9.712792973	2.549481	0.018665

The period of grain filling was the most significant (P<0.001) and its relationship is displayed in figure 4.12.

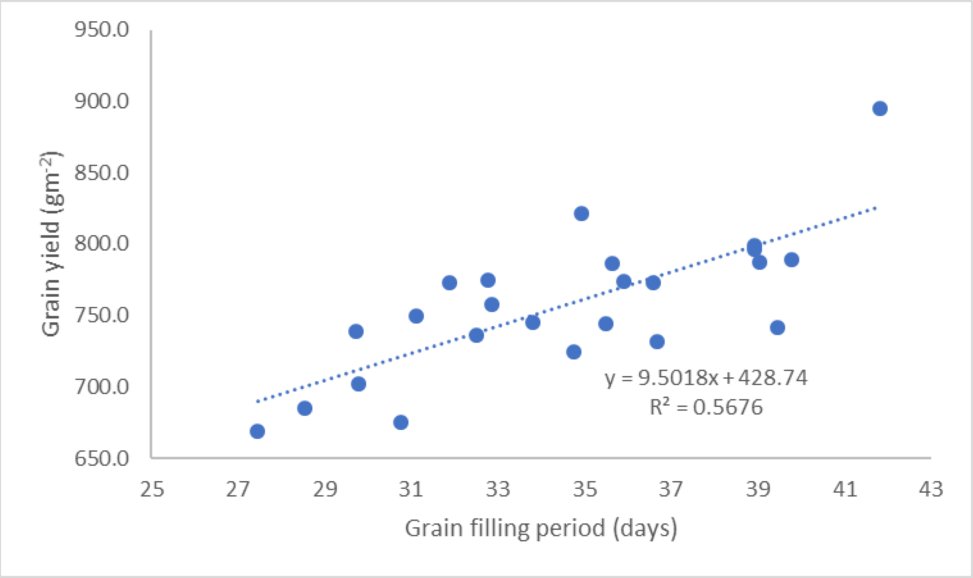


Figure 4.19 A graph showing the relationship between the grain filling period and grain yield

5. Discussion

Under this chapter, I first discussed the physiological basis of the genetic gains in yield and their related traits in the Norwegian spring wheat cultivars. Furthermore, the trends associated with resource capture throughout the breeding history are deliberated.

5.1. Progress in Grain Yield and Yield components

Grain yield of the Norwegian spring wheat cultivars have increased by 47% from 1992 (377.12 kgdaa^{-1}) to 2017 (555.9 kgdaa^{-1}) based on average yields of available cultivars in both years. This increase is however 10% higher than the increase calculated from a review by Uhlen, (unpublished) based on (Lillemo & Dieseth, 2011), which is 34% from 1992 (377.12 kgdaa^{-1}) to 2014 (504.2 kgdaa^{-1}). Uhlen's review shows a yield progress of 0.81% per year from 1989 to 2013. On the average however, my results suggest that even, though recently released cultivars like Willy and Caress produce high yields, the rate of genetic gains are decreasing.

In this study, the physiological traits that exhibited significant association with grain yield were; number of grains per square metre (GN) and grain weight (GW) at Ås, and the length grain filling at Staur. The quality trait, starch content was also highly related to the grain yield at Staur. GN and GW however, displayed an inverse relationship.

The results showed that GN had the better percentage of explaining the variance in the cultivars than GW. Furthermore, the situation is vice versa for coefficient of regression. Most of the previous studies (e.g., (Perry, 1989 #5) worldwide uphold the understanding that grain yield is a function of grain number. This is in contrary to recent findings in studies of CIMMYT advanced lines from 1977 to 2008, where grain yield progress was found to be associated with grain weight rather than the number of grains per square meter (Aisawi, Reynolds, Singh, & Foulkes, 2015; Lopes et al., 2012).

In my study, I found that the grain weight was a function of AGB, protein and starch relations, spike per area (which relates to tillers), plant height, grain number and chlorophyll content. However, grain number, was just significantly related to the grain weight. As a consequence, the dependency of GW on several variables favours grain number and affirms the reason why it explains the variances in the yield better. High GN by a cultivar also infers spikelet fertility.

Harvest index was correlated to grains per spike but not with above ground biomass. In addition, there was a trend with increased harvest index over the year of release. As well as a negative association between plant height and year of release.

The reduction in height or introduction of the *Rht* gene into cultivars beginning with Bastian in 1989 may partly explain why the heights yields being GN dependent. Earlier, Section 3.2 indicated that 14 out of the 24 cultivars had the wild type allele for *Rht* and furthermore section 2.2 explained that the reduction in height was related to increased spikelet fertility. Some of the high yielding cultivars from this study (e.g. Demonstrant at Ås, and line GN13628 at Staur) had the *Rht-1b type* allele. An early experiment (Waddington, Ransom, Osmanzai, & Saunders, 1986) shows that this explanation is true, as they also used both tall and semi dwarf cultivars. In the study by (Aisawi et al., 2015), all the cultivars were semi dwarf genotypes. So, if the assertion (Waddington et al., 1986) that the introduction of semidwarf cultivars reduced the grain weight due to distal positions in spikelet having low grain weight potential (GWP) is true, then I can speculate that through adaptation GWP can increase and contribute to genetic gains. This can be the reason for the significant correlation of GW to yield in my experiment. Currently, three of the four cultivars in trial to be released are tall varieties (without *Rht-1b*) and Caress which was released in 2017 is also tall.

The length of grain filling was associated with chlorophyll content and the relationship between protein and Starch content. Interestingly, this means longer grain filling periods could be promoted by availability of chlorophyll or nitrogen but reduces the protein content. Due to limited time I could not find literature to back or disprove this accession. I therefore left it in for further debate.

5.2. Progress in Physiological traits of grain yield

The results showed that the fraction light interception had a weak but significant positive association with plant height especially during mid stem elongation. Interestingly the association of light interception and biomass was not significant, and Likewise, the harvested above ground biomass did not show significant correlation to plant height. The explanation I thought of was that, the taller plants were intercepting more light, which is expected, but the light was not absorbed much or the conversion to increase biomass weight was low, hence a low radiation use efficiency. It could also be that the light was not intercepted but were reflected. (Pask et al., 2012) provided a description where some wheat plants had hollow culms while other were fully filled. (Siddique et al., 1989) showed in their experiment that their older tall cultivars intercepted more light but had low use efficiency.

Biomass itself made positive significant correlation with grain yield but was not significant. These relations even though not significant gives the idea that biomass amount could be a function of light interception. The method used in taking data may not have been appropriate since most studies measure the light interception, biomass increase and plant coverage at the same frequency on same dates relating to stages of development (Siddique et al., 1989). My data for above ground biomass was just at the end at the season but before harvest.

Chlorophyll content has been shown to be highly correlated with nitrogen content of plant leaves (Bojović & Marković, 2009; J. R. Evans, 1983, 1989). Due to the understanding of the role nitrogen plays in plant development (J. R. Evans, 1989), my expectation was that Chlorophyll content will be significantly to associated with biomass production and maybe protein content. The Chlorophyll Content measure was weakly correlated with yield at Staur (r=0.33) and at Ås (r=0.25). However, it was correlated with grain weight, which was significant (above r =0.5) at both locations. The weak association with yield could mainly be because the yield was driven by grain number instead of grain weight.

These results reinforce the initial thought that the reduced height may have contributed the progress in yield. I also looked at a simple comparison between means of tall and short cultivars and found the shorter crops had the highest yield.

For the quality traits, starch content was positively related with yield (r=0.58), while protein content was inversely related to both yield and starch content. This phenomenon has been thoroughly described (Groos, Robert, Bervas, & Charmet, 2003; Rharrabti et al., 2001; Sayre et al., 1997).

The phenological data provided a positive relation between the grain filling period and yield at both locations. The regression test showed that it was significant at staur and not in at Ås. This result supports the assumption made earlier in the introduction that long grain filling period will result in high yield, but (Siddique et al., 1989) concluded with a different view that early maturity gave high yield. That study may not be relevant here due to differences in growing climate conditions.

Finally, there were positive correlations between NDVI and light interception. The MTCI also corelated with and Chlorophyll content. To all the variables light interception and chlorophyll content correlated to, they did similar but in a lesser extent. I would have been enthused to infer suggestions if the two traditional methods were themselves well correlated with yield. Thus, I think more data is needed to evaluate whether their correlations should be trusted. However, MTCI may be the best option to look at since its principle is similar to the Chlorophyll meter. Light interception and chlorophyll content were negatively correlated, did not significantly correlate to yield but and according to the PCA provided in the results, was accounted for a large amount of the variation in the cultivars.

5.3. Future studies

The inferences from this study should be tested for support or rejection.

Traits like leaf area index should be considered in the next phenotyping study since it is essential to give the best explanation to the rest of the data I collected. Radiation use efficiency will also give a better understanding of light relationship with yield than just the interception. If possible, destructive methods which are reliable, should be used to understand some of these concepts before abandoning them totally.

6. Conclusion

Inferences from this study are that grain yield of Norwegian spring wheat were associated with 1) number of grains per area, 2) grain weight and 3) and the period of grain filling. The rest of data taken were limited in predicting yield variations in the cultivars. Both grain number and grain weight have improved but grain number gives the best prediction of yield. Light Interception and chlorophyll content together account for a large variation in the cultivars but are not related to yield.

7. Appendices

7.1. All tables

Table 7.1 All variables measured at Staur and their probabilty value

Staur											
Cultivar	**Grain yield**	**Plant Height**	**Length of grain filling period**	**Protein content**	**StarchDM**	**TestWeight**	**GW**	**Li1707**	**Li 3107**	**CCI 1707**	**CCI 3107**
Bjarne	773.3	78.3	32	11.7	68.196	74.2	42	0.95	0.95	27.8	19.4
Zebra	731.7	98.9	37	11.9	67.9977	78.0	45	0.91	0.92	24.9	21.1
Demonstrant	787.3	89.7	39	10.9	68.7766	78.5	44	0.94	0.94	26.1	17.7
Krabat	773.3	86.6	37	11.4	68.0016	77.0	43	0.93	0.95	21.2	21.7
Mirakel	745.4	106.4	34	12.1	68.5634	76.8	44	0.95	0.94	14.9	17.7
Rabagast	757.3	81.2	33	11.6	70.2211	77.2	41	0.95	0.94	25.4	15.4
Seniorita	743.9	97.3	35	11.7	68.5908	78.6	40	0.96	0.96	14.5	15.5
Zombi	738.5	84.7	30	12.6	68.2214	80.7	41	0.95	0.95	17.3	22.9
GN11542	741.9	97.2	39	12.0	68.0628	78.2	39	0.94	0.96	31.1	17.0
GN13618	821.1	92.1	35	11.6	67.9961	77.7	46	0.94	0.94	21.4	21.0
Arabella	798.9	93.9	39	10.9	69.1261	77.6	44	0.95	0.95	15.2	17.0
Willy	786.2	93.0	36	10.7	68.8103	75.1	40	0.95	0.96	14.9	13.7
Caress	773.6	84.9	36	11.8	68.5988	77.9	43	0.95	0.96	23.9	19.7
GN10637	789.2	84.2	40	11.6	68.5966	79.8	43	0.95	0.94	26.5	20.5
SW11230	774.8	92.8	33	11.5	68.7302	76.9	48	0.92	0.93	20.7	20.0
PS-1	749.6	90.6	31	11.9	68.5394	77.7	43	0.94	0.93	16.5	19.3
SW11011	894.9	94.1	42	10.5	70.1086	80.2	50	0.92	0.94	33.2	20.4
SW21074	796.4	90.7	39	11.2	69.0186	79.2	42	0.94	0.93	25.8	17.0
Tjalve	735.9	84.8	33	12.3	67.3353	74.8	41	0.93	0.95	30.0	16.9
Avle	724.9	85.2	35	12.3	67.6689	76.6	38	0.94	0.95	24.9	17.3
Bastian	685.4	79.8	29	11.7	68.1864	76.5	38	0.93	0.95	19.0	12.5
Runar	668.7	103.6	27	12.6	67.9716	79.2	44	0.93	0.95	20.0	17.1
Reno	675.5	104.7	31	12.3	67.6024	79.0	42	0.93	0.92	20.1	15.5
Polkka	702.4	95.4	30	12.5	68.746	78.1	42	0.9363	0.93	21.6	20.4
	P<0.0001	**P<0.0001**	**P <.0001**	**P<0.0001**	**P= 0.0001**	**P <0.0001**	P **<0.0001**	**P= 0.0068**	**P= 0.2133**	**P= 0.0008**	**P =0.0135**

Table 7.2All variables measured at Ås and their probabilty value

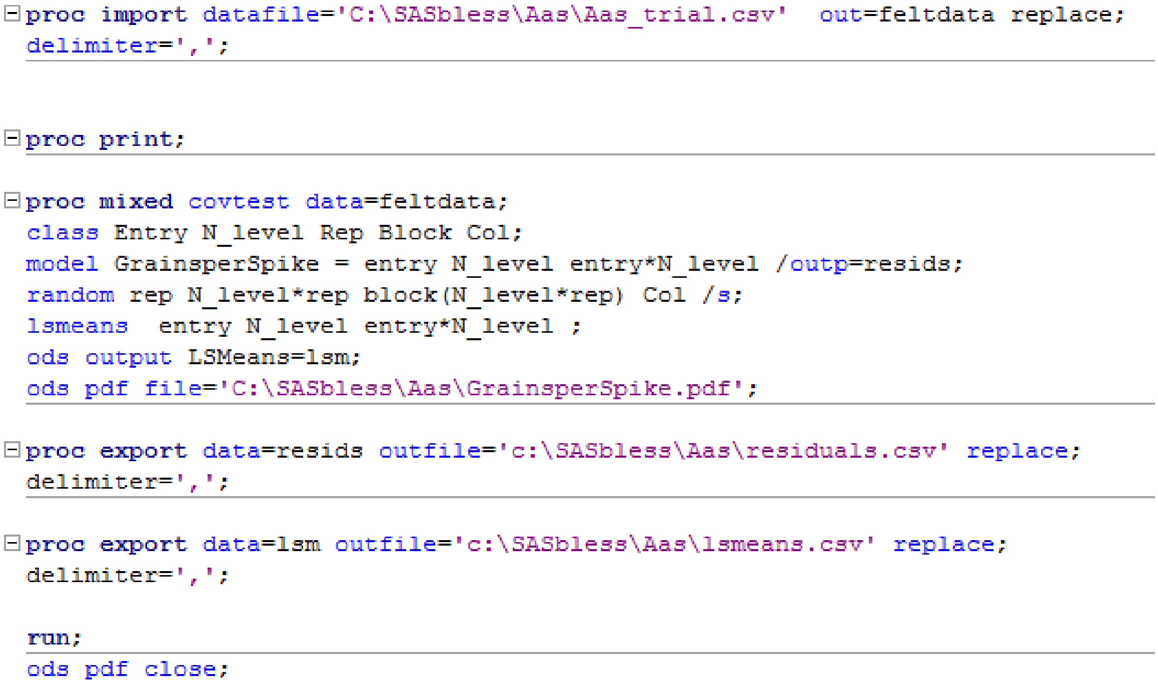
Ås																					
Cultivar	**Grain yield**	**Biomass**	**HI**	**GW (mg)**	**TestWeight**	**Grains/m^2**	**Grains/spike**	**spike/area**	**CCI7July**	**CCI14July**	**CCI25July**	**Days to H**	**H to P.m**	**Plant.H**	**Li19June**	**Li27June**	**Li5July**	**Li13July**	**ÅS PC**	**NDVI**	**MTCI**
Bjarne	565.3	1146.1	52.1	37	73.8	15402	27.8	552.3	20.3	18.4	17.6	51	60	72.8	0.53	0.78	0.85	0.89	11.3605	0.900	0.529
Zebra	548.2	1183.1	46.7	41	76.6	13211	27.9	465.3	22.0	23.6	26.7	49	61	86.8	0.51	0.76	0.82	0.84	12.7259	0.895	0.591
Demonstrant	636.7	1240.4	51.7	41	78.3	15265	28.9	538.4	20.1	21.5	24.2	51	60	81.1	0.57	0.76	0.86	0.88	10.6677	0.893	0.521
Krabat	592.7	1214.0	50.1	38	76.1	15250	30.6	513.5	18.7	22.0	25.1	51	59	82.4	0.54	0.77	0.85	0.88	12.5736	0.894	0.574
Mirakel	526.4	1247.1	47.0	40	75.7	13314	24.7	562.2	18.6	17.3	19.3	52	58	88.4	0.56	0.77	0.85	0.91	12.4069	0.900	0.530
Rabagast	571.2	1055.5	47.3	34	75.7	16586	26.0	652.8	17.9	20.1	23.6	50	60	74.7	0.55	0.72	0.81	0.87	12.2425	0.891	0.561
Seniorita	522.5	1207.9	48.8	35	77.8	14881	30.9	469.9	14.5	16.6	19.3	52	58	87.6	0.56	0.80	0.87	0.89	12.5312	0.911	0.515
Zombi	548.4	1111.7	50.2	38	79.8	14588	28.9	498.9	25.3	25.5	27.0	50	61	77.7	0.57	0.79	0.85	0.91	13.2661	0.899	0.544
GN11542	548.9	1223.2	47.3	35	76.8	16047	29.6	547.0	20.1	21.2	24.0	50	61	82.6	0.57	0.79	0.85	0.88	12.5485	0.896	0.502
GN13618	540.8	1185.4	45.9	40	75.8	13731	24.5	*568.9*	23.1	20.0	20.1	49	60	86.8	0.49	0.77	0.84	0.88	12.0613	0.893	0.539
Arabella	649.7	1333.0	53.6	40	75.6	16291	32.9	502.5	19.2	22.0	24.8	49	63	82.1	0.49	0.76	0.86	0.90	11.5505	0.891	0.499
Willy	575.6	1200.8	50.9	36	74.6	15747	30.7	513.7	15.2	15.2	15.1	50	61	81.5	0.56	0.81	0.90	0.91	11.7235	0.895	0.471
Caress	599.3	1134.9	52.2	38	76.8	15891	30.5	520.3	19.8	20.1	22.2	51	60	79.7	0.51	0.74	0.84	0.90	11.3345	0.900	0.506
GN10637	548.2	1157.7	49.8	38	78.0	14650	30.0	483.4	18.9	21.0	23.6	53	58	77.6	0.55	0.77	0.82	0.89	11.9334	0.889	0.557
SW11230	551.1	1123.3	50.7	43	74.8	12711	28.7	444.9	23.0	24.4	28.2	50	61	81.9	0.46	0.71	0.81	0.86	12.0318	0.891	0.540
PS-1	579.3	1247.5	52.7	39	76.9	14867	29.6	496.2	19.4	22.5	25.3	50	60	82.3	0.54	0.80	0.84	0.90	12.2079	0.892	0.523
SW11011	566.3	1125.5	50.3	45	77.2	12351	26.7	465.3	22.1	22.1	23.9	49	62	84.9	0.48	0.73	0.78	0.86	11.1093	0.877	0.514
SW21074	553.8	1246.3	50.7	37	77.1	15018	33.6	448.3	19.5	20.9	22.7	49	61	78.8	0.47	0.71	0.80	0.87	11.1724	0.890	0.539
Tjalve	542.9	1072.6	51.3	38	73.9	14328	28.0	517.0	20.9	22.9	25.7	51	59	77.1	0.54	0.72	0.83	0.87	12.6647	0.885	0.495
Avle	524.4	1124.4	50.7	33	73.9	15627	29.6	520.4	17.5	20.8	22.5	49	61	81.3	0.51	0.78	0.84	0.87	14.3156	0.893	0.544
Bastian	502.2	1148.5	47.0	34	75.6	14877	24.8	599.6	13.4	14.7	15.5	49	60	78.9	0.60	0.83	0.87	0.90	12.6915	0.897	0.507
Runar	522.2	1050.6	52.8	39	76.9	13265	25.9	514.2	17.2	18.8	19.0	49	62	90.4	0.64	0.82	0.89	0.90	11.8057	0.897	0.491
Reno	510.8	1174.4	45.9	39	77.5	12911	27.8	476.7	19.1	21.1	23.0	49	62	94.1	0.54	0.81	0.89	0.92	12.1061	0.888	0.452
Polkka	515.6	1239.8	47.7	37	76.0	14058	26.2	563.7	20.7	21.8	23.3	51	60	89.0	0.61	0.84	0.88	0.91	12.9438	0.892	0.486
P value	***< 0.001***	***0.0184***	***0.0153***	***<.0001***	***<0.05***	***<0.05***	***<0.05***	***<0.05***	***<.0001***	***0.0005***	***0.0081***	***<0.05***	***<0.05***	***<0.05***	***<.0001***	***<.0001***	***0.0002***	***0.0006***	***<0.05***	***0.0003***	***0.0019***
P value (N-Level)	**0.0531**	**0.0615**	**0.4236**	0.4094					0.2741						**0.2041**	**0.0879**	**0.1541**	**0.2177**			
P value (Cultivar*N-Level)	**0.0002**	**0.532**	**0.5924**	0.067					0.0288						**0.1457**	**0.3258**	**0.2856**	**0.1983**			

Table 7.3Correlation Matrix for Ås variables

	Grain yield	*Biomass*	*HI*	*GW (mg)*	*TestW*	*Grains/m2*	*Grains/spike*	*spike/area*	*CCI14July*	*Days to H*	*H to P.m*	*PH*	*Li13July*	*ÅS PC*	*NDVI*
Biomass	0.37983														
HI	0.589811	0.005118													
GW (mg)	0.337114	0.098403	0.195359												
TestW	0.065697	0.129122	-0.08931	0.195575											
Grains/m2	0.479219	0.198935	0.282846	-0.65779	-0.14287										
Grains/spike	0.51212	0.426654	0.534435	-0.10811	0.153641	0.483388									
spike/area	-0.05464	-0.16013	-0.32451	-0.46744	-0.29359	0.423203	-0.56773								
CCI14July	0.255227	-0.04971	0.162987	0.461992	0.268486	-0.22354	0.20133	-0.40048							
Days to H	-0.02253	0.056786	-0.06524	-0.21053	0.082172	0.173339	0.094243	0.066118	-0.15168						
H to P.m	0.184746	-0.04017	0.24683	0.229021	0.016451	-0.05654	0.151613	-0.20862	0.313702	-0.89385					
PH	-0.363	0.240464	-0.38096	0.314983	0.228136	-0.60535	-0.25779	-0.24759	-0.05379	-0.19828	0.138218				
Li13July	-0.14477	0.203711	0.019308	-0.27769	0.175192	0.15929	-0.05713	0.241798	-0.40504	0.090225	-0.10893	0.235539			
ÅS PC	-0.55796	-0.19515	-0.36084	-0.50315	-0.17555	0.018104	-0.18001	0.153345	0.113948	0.041251	-0.10362	0.09549	0.044012		
NDVI	-0.14586	0.123112	-0.06072	-0.47833	0.105252	0.300335	0.064342	0.15954	-0.45331	0.319944	-0.40086	0.039766	0.355905	0.204255	
MTCI	0.126818	-0.0915	-0.1035	0.032042	0.06949	0.049453	0.026031	-0.01064	0.332401	0.231651	-0.25469	-0.35559	-0.63132	0.199437	0.065708

7.2. SAS Code for Analysis of variance of cultivars from both Ås and Staur

Table 7.4 Code for alpha lattice design at Ås

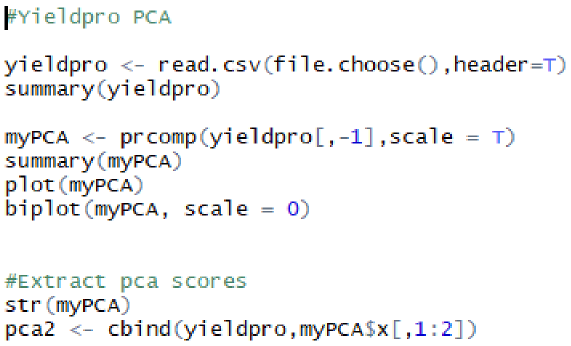


```
proc import datafile='C:\SASbless\Aas\Aas_trial.csv'  out=feltdata replace;
delimiter=',';


proc print;

proc mixed covtest data=feltdata;
class Entry N_level Rep Block Col;
model GrainsperSpike = entry N_level entry*N_level /outp=resids;
random rep N_level*rep block(N_level*rep) Col /s;
lsmeans  entry N_level entry*N_level ;
ods output LSMeans=lsm;
ods pdf file='C:\SASbless\Aas\GrainsperSpike.pdf';

proc export data=resids outfile='c:\SASbless\Aas\residuals.csv' replace;
delimiter=',';

proc export data=lsm outfile='c:\SASbless\Aas\lsmeans.csv' replace;
delimiter=',';

run;
ods pdf close;
```

Table 7.5 Code for column design at Staur

```
proc import datafile='C:\SASbless\Staur\Staur_trial.csv'  out=feltdata replace;
delimiter=',';


proc print;

proc mixed covtest data=feltdata;
class Entry Rep Block Col;
model Gperm2 = entry /outp=resids;
random rep block(rep) Col /s;
lsmeans entry;
ods output LSMeans=lsm;
ods pdf file='C:\SASbless\Staur\Gperm2.pdf';

proc export data=resids outfile='c:\SASbless\Staur\residuals.csv' replace;
delimiter=',';

proc export data=lsm outfile='c:\SASbless\Staur\lsmeans.csv' replace;
delimiter=',';

run;
ods pdf close;
```

7.3. Code for developing PCA in R



```
#Yieldpro PCA

yieldpro <- read.csv(file.choose(),header=T)
summary(yieldpro)

myPCA <- prcomp(yieldpro[,-1],scale = T)
summary(myPCA)
plot(myPCA)
biplot(myPCA, scale = 0)


#Extract pca scores
str(myPCA)
pca2 <- cbind(yieldpro,myPCA$x[,1:2])
```

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