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Jordbruk och extremt väder i Sverige, 2018: Att utveckla en bättre förståelse för effekten av värme- och torkstress på maltkorns proteinhalt

Agriculture and extreme weather in Sweden, 2018: developing a better understanding of heat and drought stress on malting barley protein levels

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1. Introduction

Barley (*Hordeum vulgare*) is a very important grain and it ranks fourth in both quantity produced and in area of cultivation of cereal crops in the world. Barley has many economic uses, being primarily produced as animal feed (around 75%), with nutritional values similar to maize (Zhou, 2010). Globally, malting (which underpins the malt-based beverage industry, as well as serve other food and beverage production) accounts for the second largest use of barley, supporting an economically and socio-culturally important industrial sector (Yawson, Adu, & Armah, 2020). Farmers also receive significantly higher prizes for malting barley than for barley as animal feed.

The acceptable protein content range for European malting barley is 9.5-11.5%. Too much protein lowers the extract yield, produces a beer that is not clear, and may slow down the start of germination; too little protein results in lower enzyme activity and slow growth of the yeast in the brewery (Pettersson, Söderström, & Frankow-Lindberg, 2005).

In Sweden, barley was cultivated on 271 thousand ha and yielded 1.4 million tons in 2019 (with an average yield of 5190 kg ha^{-1}) (Jordbruksverket, 2020), which was a year with relatively normal weather conditions. The crop season of 2018, in contrast, showed the susceptibility of the Swedish agricultural sector to weather conditions, when low precipitation combined with high temperatures not only significantly reduced yields - on average 3000 kg ha^{-1} (Jordbruksverket, 2020) - but also affected the quality of the production (Bergkvist, 2018), with protein levels much above of what is acceptable for malting barley. As result, in 2019 the Swedish brewing sector had to rely almost entirely on imported malting barley.

The complex interplay between agronomic management, temperature, water availability, yield and yield quality is not fully understood for malting barley (Fig. 1). Different studies approached crops such as rice (Ujiie et al., 2019), wheat (Panozzo et al., 2014), field peas and lentils (M. Bourgault et al., 2017; Maryse Bourgault, Brand, Tausz, & Fitzgerald, 2016) and others. Recently, Cammarano et al. (2019) analyzed the effects of precipitation and temperature on malting barley in UK, but under conditions that are more favorable than in Sweden, a longer growing season and twice as much annual precipitation, and without use of factorial experiments. In Sweden, previous research approached malting barley production and quality in the context of precision farming and spatial variability, but not targeting water aspects or management (Pettersson, 2008; Pettersson & Eckersten, 2007; Söderström, Börjesson, Pettersson, Nissen, & Hagner, 2010). In the literature, few experiments had a treatment in which they could reduce the amount of water available and all such studies found was conducted in pot experiments, which do not mimic field situations. The conditions of adequate water supply were achieved relying on precipitation and irrigation. No experiments have approached situations with excess of water.

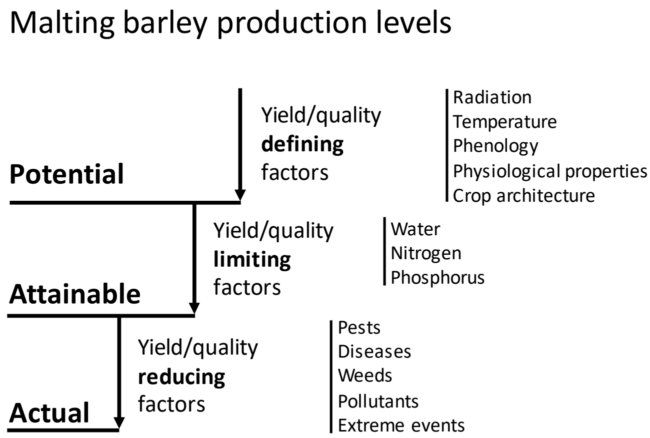

Figure 1. Production levels (adapted from (R. Rabbinge, 1993)*) and factors defining, limiting and reducing yields and quality (in this case, malting barley). While some factors are uncontrollable such as radiation, temperature, extreme events, farmers can manipulate other such as genotype (affecting phenology, crop architecture) and nutrients.*

Reaching adequate protein levels in barley is a challenge for Swedish farmers, because they need to cope with unpredictable weather and heterogeneous intra-field conditions that result in variable protein levels. Soil chemical and physical variables are also not strongly correlated with soil grain protein levels according Pettersson (2007).

The cultivation of malting barley particularly challenging in 2018, because low precipitation and high temperatures not only reduced yields, but also increased grain protein content (Bergkvist, 2018), reducing its industrial and market value. As already indicated by Savin & Nicolas (1996, 1999), reasons for high protein in malting barley are post-anthesis stresses that 1) reduce starch allocation to the grain and 2) reduced the length of the grain filling phase.

Farmers cannot react easily to events occurring after anthesis, since the crops are already fully developed and irrigation expensive. Therefore, it is of great interest to better understand processes and agronomic management strategies that can increase the likelihood of achieving adequate levels of yield and protein in malting barley. Three research questions were formulated to fill this knowledge gap:

- How susceptible is malting barley to droughts and heat stress?
- How do agronomic management (sowing date, irrigation, and cultivar choice) affect resilience in the production of malting barley?
- Can the grain protein level be predicted based on information collected in early development stages?

2. Methodology

Field experiments (source: NFTS) carried out between 2013 and 2018 (n=42) approaching different fertilizer strategies and regions were used to calibrate and validate DSSAT, a biophysical, process-based model (Jones et al., 2003).

Data regarding soil profiles were gathered from the Geological Survey of Sweden (SGU), Söderström et al. (2016), and ISRIC & Batjes (2015). Daily weather data (precipitation, solar radiation, maximal and minimal temperature) were obtained from LantMET (http://www.ffe.slu.se/lm/LMHome.cfm?LMSUB=1), SMHI (https://www.smhi.se/klimatdata) and NASAPower (https://power.larc.nasa.gov/).

The crop model was used to assess the influence of climatic and management factors on malting barley yield and quality. The development and growth of the crop is simulated on a daily basis from the sowing until the physiological maturity, and the model calculations are based on environmental and physiological processes that control the phenology and dry matter translocation and accumulation in the different organs of the plant. The DSSAT also has other embedded models that can simulate the flow of nutrients and water balance in the soil. The sowing date of barley was set mimic the experiment L3-2302-2017-004: Nitrogen strategy in malting barley (source: NFTS) (depending on the site, between early April until early May). The cultivar was Irina with 100 kg ha^{-1} N applied at sowing and 30 kg ha^{-1} N applied at BBCH 37. Since the model does not calculate the grain protein concentration, but determines the grain N concentration, a regression function (R^2 = 0.9987) was created using NFTS data (n= 502 entries) resulting in the following equation: [protein content = (6.2281 x (grain N content in %)) + 0.0464].

The model was parameterized for each one of the study sites (experiments) using past observations of weather and crop performance. Simulations were then run to test the ability of the models in mimic the field observations. In a second step, sensitivity tests with factorial, incremental changes (stressors) in precipitation and temperature were carried out to investigate the effects on protein levels in malting barley. This was done by selecting daily weather data from one year of the data series (in this case, 2017, since it was a typical year) and applying arbitrary changes in daily precipitation (-30% to +30%, at 10% steps) and daily temperature (increments of 0.5ºC, until +3ºC), following the procedure of Lana et al. (2017).

To investigate the possibility of predicting grain protein level from crop early development stages, results from 541 nitrogen fertilizations experiments carried out in Sweden between 2014 and 2018 were analyzed. Evaluation of crop development and data obtained by Yara N Sensor (available for 446 experiments) and Yara tester (available in 283 experiments) at BBCH 31 or 32 have been used to identify a correlation with malting barley protein content. Not all 541 experiments had both sensors available, therefore the difference in sum.

3. Results

Any agricultural production is dependent of a series of factors that define, limit and reduce yield and quality of the output (Lu, Ittersum, & Rabbinge, 2003; Rudy Rabbinge, 2009). In the case of malting barley, farmers have the challenge of reaching 1) high yield levels within a 2) narrow range of grain protein content. One challenge for malting barley producers is that the nitrogen fertilization can have a significant effect on protein and amino acid composition in grains (Marino, Tognetti, & Alvino, 2011; Taub, Miller, & Allen, 2008), mainly by stimulating the accumulation of gliadins and glutenins (Zhang et al., 2016). Water availability plays a crucial role because it modulates the amount of nitrogen that is absorbed by the crop, but cannot be correlated directly to protein accumulation in the grains, as indicated by Dai et al. (2016), since the crop phenology also affects protein formation in the grain. This is well exemplified by the 2018 cropping season in Sweden. During spring, the crops had sufficient supply of water, ensuring high and fast absorption of nitrogen from the soil, resulting in a high concentration of proteins. Later in the season, during the dry spell, the crops had not enough water to accumulate carbohydrates and counter balance the protein concentration, finishing the season with grains rich in proteins, as reported by Bergkvist (2018).

3.1. How susceptible is malting barley to droughts and heat stress?

Selected Swedish sites with previous field experiments with malting barley where selected to run simulations with incremental scenarios of temperature and precipitation (Fig 2 and 3). The year of 2017 was used as baseline, and incremental changes in temperature (0 to +3ºC) and precipitation (-30% to +30% in precipitation, at 10% steps) were applied on daily observations.

Regarding malting barley grain yields (Fig 2), it can be observed that the effect of the incremental scenarios shows a different arrangement, with the isoclines following a more vertical pattern. This indicates that the yield, under Swedish conditions, is much more affected by the availability of water during the cropping season than temperature. One of the reasons of such pattern is that crops can cope better with higher temperatures when they have an adequate supply of water. Assimilation and translocation of nutrients and carbohydrates are also facilitate under adequate water supply. Under certain circumstances, higher temperatures, especially at the beginning of the crop cycle, can be beneficial by promoting a faster establishment of the crop and also a shorter crop cycle, since it accelerates the crop phenology, helping the crop to escape higher temperatures during the grain filling season.

From Figures 2 and 3, it is possible to observe that under certain conditions, such as in Håbo, there is a negative relationship between protein and carbohydrates accumulation, while for other sites these processes seem unrelated. Another situation can be observed for Kristianstad´s conditions, in which the same combination of high temperatures and precipitation allow a higher accumulation of proteins and carbohydrates, while for Linköping a protein dilution effect can be seen. Since cultivar and fertilization are the same, the possible reasons for such discrepancy are underlying factors such as soil characteristics and local weather patterns that modulate the translocation and assimilation processes.

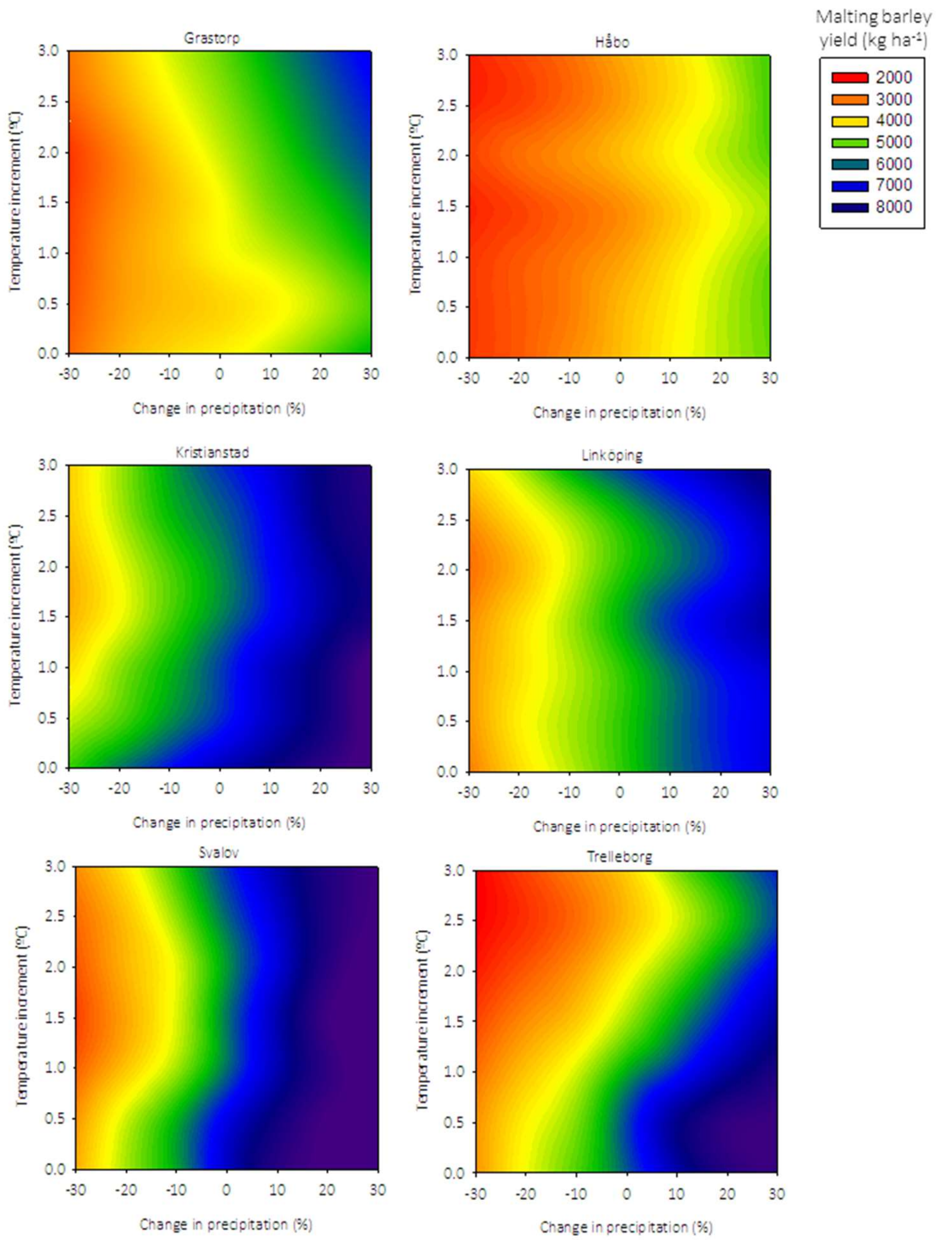

Figure 2. Impact surfaces depicting the interplay between changes in temperature and precipitation in affecting malting barley yield for selected locations in Sweden. The weather data baseline is daily weather from 2017. Temperatures (Y-axis) were then increased at 0.5ºC until 3ºC. Precipitation (X-axis) was changed from -30% up to +30%. A "0" in precipitation change means no changes. Warmer colors indicate lower yields.

The main target of the simulations is to understand the interplay between temperature and precipitation in the determination of malting barley protein content. From Fig 2 and 3 it is possible to observe that the sites react differently to the changes in temperature and precipitation. One of the reasons for that is that soils with high soil water holding capacity are able to reduce the probability and intensity of water stresses. Notably temperature (especially in Håbo conditions) is the factor with the stronger influence on grain protein content, as it can shorten significantly the grain-filling phase and reduce the storage and allocation of carbohydrates in the grains. Since the translocation of nitrogen occurs much faster and earlier than the carbohydrates translocation, a thermal+water stress during the grain filling season is likely to result in elevated protein levels, when compared with normal conditions. In the other hand, conditions like the ones found in Trelleborg or Linköping indicate that even under high temperatures malting barley protein levels will not be excessively high. One of the possible explanations is that the increase in temperature accelerates the development and the crop reaches maturity before entering a period of severe thermal or water stress. Another alternative is that a higher availability of water (as seen in the scenarios with a positive increment on precipitation) can counteract the effects of higher temperatures.

Overall, it is possible to observe that the response in terms of changes in grain protein concentration has a tendency to react to increments in temperature, but this effect is not linear and can behave significantly different depending on edaphoclimatic factors.

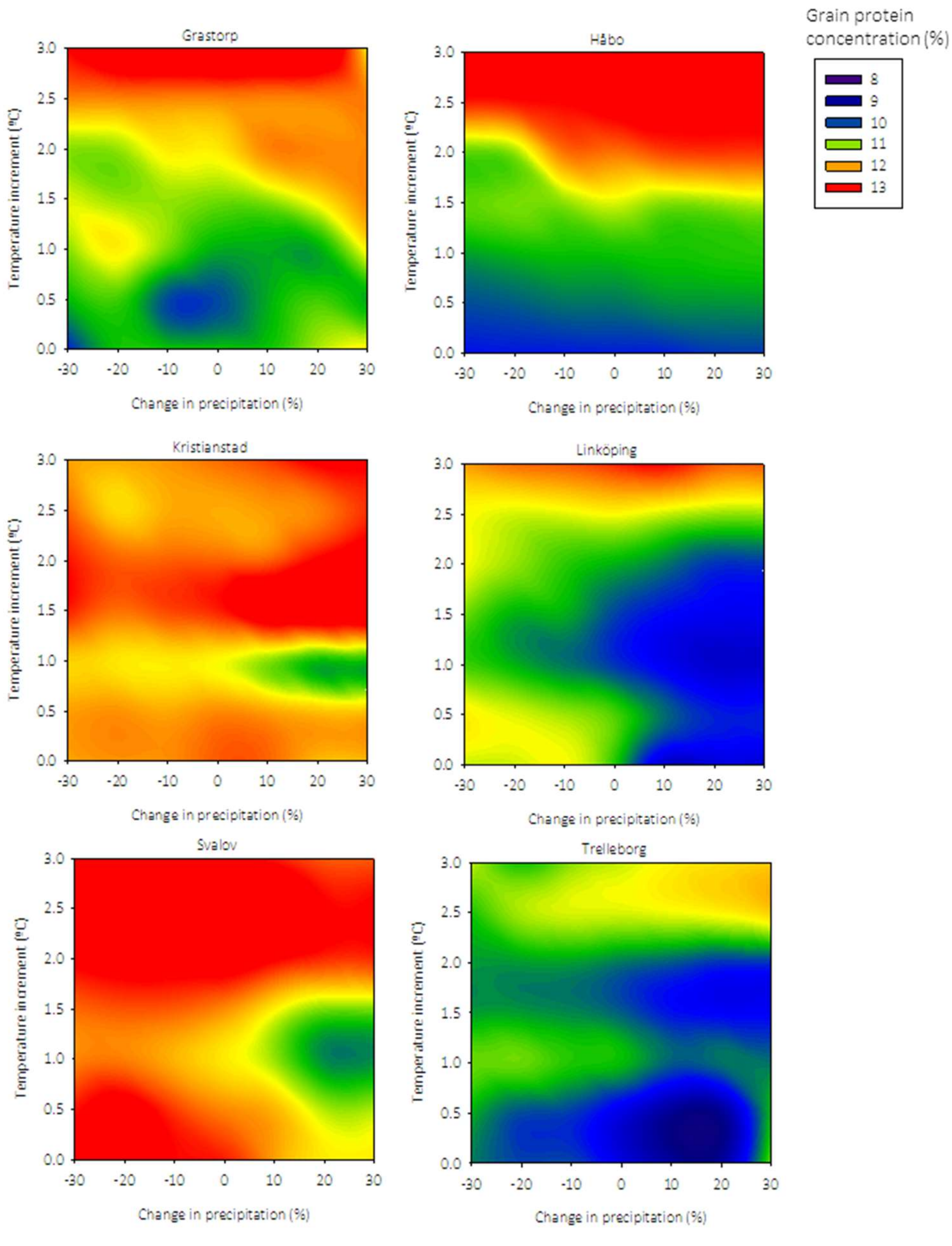

Figure 3. Impact surfaces depicting the interplay between changes in temperature and precipitation in affecting malting barley grain protein concentration for selected locations in Sweden. The weather data baseline is daily weather from 2017. Temperatures (Y-axis) were then increased at 0.5ºC until 3ºC. Precipitation (X-axis) was changed from -30% up to +30%. A "0" in precipitation change means no changes. Warmer colors indicate high protein levels in malting barley grains.

3.2. Can the grain protein level be predicted based on early development stages?

Previous attempts to forecast malting barley yield and quality have been done by different authors under Swedish conditions (Pettersson et al., 2005). While far-remote sensing applications, such as satellite images, yielded poor correlations (Söderström et al., 2010), the use of proximal sensors at BBCH 32 combined with management information (notably sowing date) could be were in some cases correlated with grain protein concentration at harvest (Pettersson & Eckersten, 2007). Despite the fact that during the BBCH 32 stage agronomic interventions, such as application of nitrogen, are still possible and might affect the final grain protein concentration, other variables of difficult predictability, such as air temperature and precipitation, will play a major role in defining the final crop protein concentration. This makes the use of proximal sensors a relatively ineffective tool for decision-making support for farmers aiming at specific grain protein levels. Field data from five years (2014-2018), containing 451 experiments using different nitrogen fertilizations schemes (amounts, forms and number of applications) in several Swedish locations showed no correlation when using two of the most commonly available proximal sensors for farmers, making explicitly that edaphoclimatic conditions strongly influence the crop quality (Figs 4 and 5).

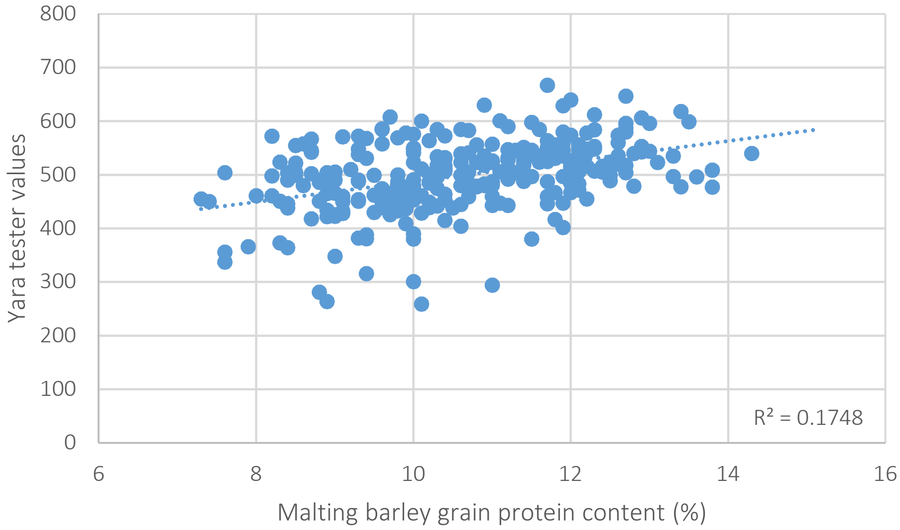

Figure 4. Scatter plot of malting barley grain protein content (at harvest) associated to readings from the Yara Tester equipment at BBCH 32. The results show no significant correlation between the equipment readings and final protein content. Data refers experiments (n= 283) carried out between 2014-2018 in different locations in Sweden. Source: NFTS.

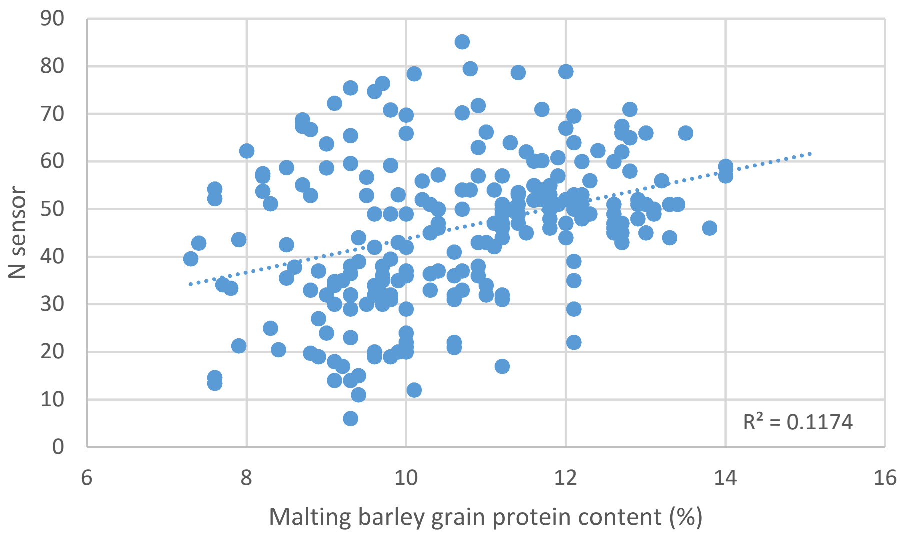

Figure 5. Scatter plot of malting barley grain protein content (at harvest) associated to readings from the Yara N sensor at BBCH 32. The results show no significant correlation between the sensor readings and barley final protein content. Data refers experiments (n= 446) carried out between 2014-2018 in different locations in Sweden. Source: NFTS.

3.3. How do agronomic management (sowing date, irrigation, and cultivar choice) affect resilience in the production of malting barley?

Considering that malting barley is a spring crop in Sweden and that the sowing in spring is done as early as conditions allow it, since late sowing penalizes the crop yield, changing sowing dates is usually not a factor from the malting barley cropping system that can be easily manipulated. Irrigation is frequently mentioned as a strategy to increase yields and reduce the susceptibility of crops to unfavorable weather, and as reported by 2019, with the potential to increase barley yields with relatively low protein content. While it is effective to prevent yield losses caused by droughts or other extreme events, the costs in financial and environmental terms are prohibitive for the majority of field crops, such as barley and other cereals. In a literature research, the most feasible aspects from the malting barley cropping system to ensure adequate yield and grain protein levels are:

1) a suitable crop rotation, with a pre-crop that has relatively low residual nitrogen levels (e.g. another cereal). As example, O'Donovan et al., (2017) states that that growing legume crops prior to malting barley is less likely to reduce malting barley quality than applying fertilizer N.

2) a cultivar that is appropriate for malting barley production for local situations. While there are several cultivars of barley available, some are breed for low protein content and other important characteristics that define malting quality, such as enzymatic activity, plumpness, uniformity of grain size, structure and stability of the grain, among others (Heisel, 2006).

3) a fertilization management system that considers the amount of nutrients already available for the crop at the beginning of the season (using soil analysis), and the splitting of nitrogen applications, so that the timing of nutrients release and accumulation by the crop can also be better controlled.

Combined, these three strategies can allow the farmer to better control the nitrogen supply within the cropping system, applying the adequate amounts of nitrogen to ensure acceptable yields but without exceeding the targeted grain protein levels. A proper crop rotation and soil management can also improve soil physical characteristics, notably the water holding capacity, which can buffer dry spells and prevent the crops from being negatively affected.

4. Final remarks

The results of this report show that malting barley quality is defined by a combination of different factors, with a higher influence of the precipitation x temperature interplay, notably temperature. More research efforts are in course to improve the knowledge about malting barley agronomic management. This SLF grant was important to generate and present this report, and it contributes to other recently started initiative, the “Stärkt resiliens i svensk matproduktion under ökad risk för extremt väder” FORMAS project, that will use the data here presented for further and in-depth analysis. Other cropping system parameters will be combined with long-term observations and weather scenarios to generate information that can support farmers and advisors decision-making processes. The 3-year effort will combine agro-climatic characterization and crop modelling, using crop trial data across Sweden, with new data on farmer behavioral responses under extreme weather. The expected results will fill a gap in scientific knowledge on current and future risks to agriculture and food security by extreme weather in Sweden. This new knowledge will contribute to design better risk mitigation and adaptation action for the agricultural sector, engaging science, policy and practitioners to build resilience into production systems under a ‘new normal’ of extreme weather events.

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