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An agroecological perspective for improving drought tolerance of wheat cultivars for Sweden

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An agroecological perspective for improving drought tolerance of wheat cultivars for Sweden

Ett agroekologiskt perspektiv för att förbättra torktoleransen för vetekulturer för Sverige

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Foreword

I am originally from Iraq. I was in the second year of my studies at an agricultural university when I left the university to become a military helicopter pilot. I was flying above the fields during operations around Iraq from south to north and from east to west and I noticed how these areas were severely affected by climate change. I began to think of possible solutions that could assist the farmers in cultivating their lands. In 2013, I decided to go back to studying at the university (by distance learning) to get a BSc degree in agricultural science from the University of Baghdad. In 2016, I moved to Sweden to follow my dream of finding a way to understand and prepare for the climate changes that are already affecting the Mediterranean regions where I was living. In Sweden, there are many master programs related to my background, but something attracted me to the master program in agroecology at the Swedish University of Agriculture (SLU). I believed that this program would help me find the right solution to deal with the effects of climate change. When I started the agroecology courses, it was a challenge, but at the same time, my experience and knowledge improved by learning from the teachers and the other students; there was a wide diversity in the nationalities of the students, which made me so lucky to be in this group. We discussed a broad range of issues related to our countries and what the farmers struggled with, as well as where the weak points were in the agriculture systems. The courses we took during the agroecology master program were from different disciplines relating to the social, economic and scientific sciences. We had a chance to gain real experience doing interviews with real farmers that increased our confidence in ourselves. Also, we discussed several case studies for different countries and evaluated the agroecological principles of the farm system for each case study by using different methods and tools that can assist the agroecologist in helping farmers when dealing with different farmrelated issues. Furthermore, we visited several companies around the Skåne region who were working hard to be more sustainable and eco-friendly. Finally, I now have the tools and methods that can assist me in applying agroecological principles to developing farm systems to be more sustainable and efficient in food production.

Acknowledgement

I am so grateful to have had the possibility to do my master thesis under the supervision of Dr. Aakash Chawade. I learned a lot from working with his group. I am also thankful for all the support I received from co-supervisor Dr. Sara Spendrup for her guidance. I want to extend my sincere gratitude to the plant breeding department for hosting and supporting me, especially to post-doctoral researcher Dr. Firuz Odilbekov, Dr. Dhananjay Kumar and PhD student Alexander Koc. Also, I want to mention the support from Tina Henriksson, the senior breeder in the winter wheat program in Lantmännen, who helped me to select candidate farmers and breeders for the interviews. Special thanks to interviewed breeders and famers. I appreciated their hospitality for the interviews and the tours they provided of their farms; without you, this study couldn't have been done. I am so grateful to Prof. Erik Steen Jensen for the unlimited support he provided, and for his guidance and advice throughout the period of the master program. I also want to acknowledge the recommendation from Dr. Suhad Alhedny at Al Qassim University College of Agriculture in Iraq that I should study the master at SLU. I am also grateful to my amazing friend Silver for proofreading my entire thesis. Finally, I would like to dedicate this work to the soul of my brother (Othman), and to my parents (Mohammed and Huda), my wife (Farah) and my two sons (Hussein and Yassin) for their support during the entire period of my studies.

Sincerely

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Abstract

Drought stress is one of the major abiotic stresses that cause losses in cereal production around the world. Drought stress causes several morphological, physiological, biochemical and molecular transformations in plants. All aspects of plant growth (leaf size, leaf index area and plant height) will be reduced when drought stress is imposed on a plant during all stages of growth. The plant's physiology under severe drought stress could reduce the transpiration rate and water consumption, which could lead to dried and dead plants, and also affect the quality of grain and cause losses in yield. The drought that happened in the south of Sweden in the 2018 season caused considerable losses in grain yield, primarily winter wheat. The aim of this study was to analyze the effects of drought stress on wheat production in the south of Sweden in the 2018 drought season and then to assess whether new technologies such as phenotyping can provide solutions for the agricultural sector in general and wheat production in particular. The study included two parts: the first part consisted of a five face-to-face interviews. Three interviews were with farmers from different locations in the south of Sweden. The aim of these interviews was to understand the farmers' perceptions of the drought that happened in 2018 and to explore if they have made plans to handle or prepare for future droughts. The other two interviews were made with plant breeders who work at Lantmännen. The aim of these interviews was to understand how breeders preparing their breeding programs related to climate changing in Sweden and if there are any trials or research relating to drought. The second part of the study consisted of a Biotron experiment to evaluate early vigour and drought stress responses of genotypes. Finally, the analyzed data from the Biotron experiment was compared to drought tolerance scoring obtained from the field trial performed in 2018 for another project. These field score data correlated well with the results of the Biotron experiment. In conclusion, there is a possibility to develop drought-tolerant varieties in wheat which can survive during the drought season. Also, the development in technology sector can provide more accurate tools for phenotyping crops in coming years.

Abbreviations

CSA Community Supported Agriculture

CSV Comma Separated Values

CPS Center Pivot Sprinkler

DSLR Digital Single Lens Reflex

ES Ecosystem services

FLI Food Loose Index

FWI Food Waste Index

GIS Geographic Information System

LCP Low-Cost Phenotyping

LRF the federation of Swedish farmers

PA Projected Leaf Area

RGR PA Relative Growth Rate Projected Leaf Area

SIS Surface Irrigate System

TA Thematic Analysis

TIFF Tagged Image File Formats

WWOOF WorldWide Opportunities on Organic Farms, Sweden

WUE Water Use Efficiency

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1. Introduction

1.1. Background: The history of wheat production

Wheat is one of the most important staple food crops in the world. As a widely consumed crop, it has been cultivated for over 10,000 years, since humans shifted toward the domestication of wild wheat (Kipel and Kriemhild, 2000; Katz, 2003). Although there is no widely accepted consensus on the point of wheat's origin, the Fertile Crescent, which extended from central Asia to northern Africa through the Mediterranean, is generally considered to be the region of wheat's birthplace. Emmer and einkorn are the oldest species of wheat, which were grown in south-eastern Turkey as early as 8700 B.C.E. (Huang et al., 2016). Throughout the prehistoric era, wheat cultivation quickly spread to Mesopotamia, Egypt, Rome and Greece, and extended to northern India by 4000 B.C.E., China by 3000 B.C.E., Europe by 2000 B.C.E. and North America by the early 17th century (Smith, 2004). The word "wheat" means “white” and is very close to the Welsh term "gwenith", the old German term "weizzi" and the term "whete" in old English. Wheat is defined as "that which is white" in almost all cultures due to its light-colored crop (Harper, 2001).

Wild einkorn wheat is the natural species that originated to the Karacadag Mountains, in what is now known as southeast Turkey (Heun et al., 1997), while wild emmer wheat has been discovered at several archaeological sites in Syria (Zohary and Hopf, 1993). Away from the Fertile Crescent, the northwest region extending from Armenia to the southeastern coastal areas in Iran also cultivated emmer wheat (Dvorak et al., 1998). The domestication of the progenitor wild wheats represents the key to the evolution of tetraploid and hexaploid wheat and provides breeders with the opportunity to improve wheat yields (Willcox, 1998). Modern wheat breeders pay more attention towards producing high-yielding, disease-resistant and drought-tolerant wheat. These demands were imposed on wild wheat in order to meet the soil and climate conditions of the Fertile Crescent. This means that the improvements in wheat breeding have contributed to the re-discovery of what was previously possible under stress environments. As a consequence, the interest in genetics and breeding tools is expected to successfully minimize losses and increase yields (Jaradat, 2011). Among the cereals, wheat provides over 20% of the required calories of the global population, as the global population is increasing, it increases the global demand of this daily consumed crop. Since the 1970s, the total area under wheat cultivation has increased in many countries, while the production has slightly increased or even decreased in other countries. So the yield it would be different in each country related to the conditions in these different areas, also because of most of these regions have rainfed irrigation which decreased yield in regions effected by abiotic stress. But, on the other hand, there was increased production in some regions and that increase reflects on the ability of wheat to grow under varied conditions along with the noticeable improvements in cultivation and crop management techniques which helped to increase the yield (FAO, 2008).

1.2. Wheat production in Sweden

Sweden adopted a set of agricultural reforms, starting in the 1300s, known as "Solskifte" or sun division. In theory, each farm had equal access to both good, and less productive, land. This farming policy was slowly phased out after 1600. In 1803, another reform, known as "Enskiftet", started. Under this farming policy, reorientation of land ownership from the village system to private farms was adopted. At the end of the 19th century, all of Sweden's farmlands transitioned to private ownership. Sweden adopted another set of reforms aimed towards eco-friendly production approaches after becoming a member of the EU, according to the framework of the EU's Common Agricultural Policy (CAP). Despite the natural limitations of the topography, Sweden still cultivates a large area of cereals and other crops. The southern province of Skåne has a growing season 100 days longer than in the northern province of Norrland. This high variation determines where the crops are cultivated. Wheat, rye and other cereals are mainly cultivated in the plains of the south and central Sweden, while potato production is uniformly spread across the country. Wheat - emmer, einkorn and spelt - were first introduced into Sweden during the Neolithic period, followed by other cereal crops (Engelmark and Viklund, 2008; Grabowski, 2011). According to Engelmark (1985), during the Iron Age, cereal production in southern Sweden changed and this shift was due to the adoption of a crop rotation of winter rye and barley.

Nowadays, most Swedish farmers cultivate winter wheat as their main crop (table 1). Winter wheat is one of the main crops that is used to produce ethanol; currently, in Sweden, ethanol production is based on 80% from winter wheat and 20% from barley (Lantz et al., 2018). The total area of cultivated grain cereals harvested in 2019 increased by 6% compared to the 2018 season. In 2018, more areas than usual were harvested as fodder for animals because of the dry weather during the early growth stages affecting the quality of the harvest by increasing the protein content which was classified as suboptimal quality.

Table 1: Winter wheat production in Sweden from (2014-2019), yield per hectare and total areas of winter wheat cultivation (Jordbruksverket, 2019)

Year	Hectare, yield kg/ha	Total Area	Total yield tons
2019	7 700	421 980	3 250 400
2018	4 790	292 530	1 399 900
2017	7 360	407 570	3 000 000
2016	6 680	374 380	2 502 100
2015	7 570	394 450	2 984 800
2014	7 250	379 450	2 750 800

When comparing different crops produced in Sweden (see table 2), wheat as crop produces the highest yield per hectare compared to other crops produced in Sweden. The yield in 2018 were lower than of all other years. The winter wheat harvested in 2019 consisted of an increase in the yield compared to the recent years which means the winter wheat is an important crop for the farmers in Sweden (see table 2)(Jordbruksverket and SCB, 2019).

Table 2: The total harvest of crops that grow in Sweden for 2019, five years harvest average including 2018 (Jordbruksverket, 2019).

Crops	Hectare, yield 2019 kg/ha	Hectare, yield 2018 kg/ha	Five years average kg/ha
Winter wheat	7 700	4 790	6 730
Spring wheat	4 740	2 760	4 290
Rye	6 980	4 510	6 020
Winter barley	6 600	3 770	5 720
Spring barley	5 160	3 000	4 580
Oat	4 660	2 570	4 060
Winter triticale	6 460	4 020	5 470
Mixed grain	3 320	2 280	3 240
Peas	3 310	-	3 260
Field beans	3 110	-	3 130
Winter rape	3 670	-	3 290
Spring rape	1 820	-	1 880

1.3. Drought stress in wheat production

To provide food security by 2050, the global wheat demand is expected to increase by up to 40% in order to feed the increasing population worldwide (Rosegrant and Agcaoili, 2010; Jahan et al., 2019). According to Hoegh-Guldberg et al. (2018), the losses of wheat yield under climate change are expected to increase by up to 30% by 2050. Drought, salinity and heat stress are the main climatic limitations for wheat yield and quality, causing alterations in the physiological activity of the plants (Yassin et al., 2019). In Sweden, the losses in winter wheat production 32% in 2018 in comparison with the production from 2014-2019 excluding 2018 (table 2). Under high-temperature conditions, the effects of heat may vary depending on the crop development stage, and result in a decrease in the yield per hectare or the quality of the produced crop. It has become urgent to understand the impact of climate change on the productivity of the crops in order to support food security for the future. Identifying the drivers of wheat yield and quality is a crucial step to mitigate the effects of of climate change (Vermeulen et al., 2012; Ricome et al., 2017). Drought-tolerant wheat may offer potentials towards minimising the confounding impacts of wheat production under drought-stress conditions. Mitigating drought effects through breeding requires the integration of knowledge in various methodologies and technologies in plant sciences from different perspectives (Stratonovitch et al. 2015).

1.4. The agroecological framework

Most of the land in Iraq are arid and semi-arid suggesting a challenge for the farmers. Most farmers approach this situation through diversifying their production and chose different solutions due to soil quality and the water source. As an example, most of the farmers have a dates palm *Phoenix dactylifera* orchards which they grow in the shadow of these palm trees, citrus trees and then in the rest of empty ground they have grown vegetables and salads plants as intercrops (Sanaa, 2020). So, the agroecological principles and approaches already used in Iraq before a thousand years ago. Nowadays most of those farmers within the agricultural sector in Iraq suffer from climate change effect (drought, salinity and desertification).

When I started in the agroecology master program all the courses that we took had a focus on finding the right balance of three aspects; scientific, social and economic and their effects on the life of farmers. From this point, I planned my thesis subject to understand how farmers deal with drought season in general and how they plan to meet future threat of drought here in Sweden. I am specifically interstested in exploring how to reduce the gap between researchers (including the breeders part of the researchers) and farmers. Are breeders and researchers aware of the drought and what the farmers need from them? Also, which of the new technologies can offer the right assistant for the breeders and farmers. I have tried to include a scientific, social and economic perspective, however due to time limits I have decided to limit my thesis to cover the social and scientific aspects.

The North European countries are considered less affected by drought compared to other European countries because most of the agriculture sector in the Nordic countries relies on rainfall. Most of the recent research has focused on the agricultural systems in the arid and semi-arid regions which are already affected by the drought and water scarcity (Kirby, et al. 2014). All the indications from the weather in recent years lead to an increase in the frequency of drought and high temperatures during summer seasons will be happening in the future which directly effects on the yield of crops produced in the future (Schleussner et al, 2017). That means we need to try to adopt new methods, tools and approaches that can be feasible to use by Swedish farmers.

1.5. Aim of the study

- Assist in the reduction of drought stress effects on wheat production in the south of Sweden
- Identify what the high-throughput phenotyping as new technique can provide for the agricultural sector in general, and wheat production in particular

1.6. Research questions

- How can drought affect wheat production in the south of Sweden?
- Can new techniques such as high-throughput phenotyping assist in developing better drought tolerant cultivars?
- What are farmers' attitudes towards the risk of drought within the next five years concerning? Are farmers planning to implement technical changes in order to mitigate the effect of drought stress?

2. Material and method

2.A.1. Interview design

Some events happened in the drought season that happened in 2018 in the south of Sweden which effects directly on the farmers' livelihood. For example, the less yield of crops decreased the income of the farm and some farmers who owned cattle struggled to feed their cattle. What and why that happened? We need to understand the situation beyond these events from the farmers and breeders. What was the social impact on the farmers' and breeders' communities during this drought season? The understanding of the social aspect from the interviews with farmers and breeders could assist researchers in developing new tools, methods and technics. The study is based on interviews with plant breeders and farmers. Interviews were regarded as a relevant tool since the aim was to extract the opinions and thoughts of the farmers and breeders interviewed (Kvale, 2007).

In order to find farmers and plant breeders to be included in the study, contact was made with Lantmännen which is Sweden's largest wheat farmers' association and conducts research on breeding of wheat and other crops in Nordic countries. In total, five interviews were conducted, two with breeders and three with farmers. The interviewees were recruited as experts with experience of the studied phenomena; this approach was expected to support the study with relevant data (both qualitative and quantitative). The interviews were conducted through the use of a semi-structured interview guide and the interviews were done face-to-face (Bernard, 2006). The interview guide (see appendix 1) was set up to initially cover more easily answered, open-ended questions and later on more direct questions.

2.A.2. Themes of the interviews

Two different interview guides were developed, one for the breeders and one for the farmers. This was necessary due to the differences in work tasks between farmers and breeders. The farmer interview guide was structured around four main topics. (1) Personal details of the farmer; (her/his) life on the farm, why they had become a farmer and their educational background. (2) Farm details; cultivation area, crops, irrigation system, the primary income of the farm and seed sources. Description of additional activities on the farm and crop rotation. (3) Drought stress, especially in relation to the 2018 summer season; plant diseases connected to drought and what assistance farmers received during the drought stress of 2018. (4) The future of the farm; planned investments, implemented preparations for drought in the next few years and thoughts about future additional investments in technologies.

The interview guide for the breeders was set up around five main topics. (1) Personal information; educational background, and why the interviewee became interested in plant breeding. (2) Drought resistance in crops; on-going trials, and ideas on how to mitigate drought in the future. (3) Regional climate change in the Skåne region. How breeders and the use of new technology can contribute to finding a new solution, increasing yields and resistance to drought. (4) Support offered to farmers (by Lantmännen); plans to increase crop diversity and ecosystem services. (5) The future vision for Lantmännen; individual plans for the future, thoughts on the most important traits that can increase yields.

Finally, the last question in the interview guide (for both farmers and breeders) was: What is your opinion about my experiment (the conducted study). The aim of this question was to get a deeper understanding of their opinions on combining a scientific and social science perspective of this project

2.A.3. Conducting the interviews

Contact information to the farmers and plant breeders were obtained through contact with a breeder at Lantmännen. Respondents were asked via emails to participate in the study. Once the respondents had accepted to participate, a date and time for the interview was agreed. Interviews were conducted during the end of June and the beginning of July. Each interview lasted 45 minutes. After each interview with a farmer, a short tour around their farm was conducted. This was done to increase the understanding of the current situation of the farm and how the farmer was planning to develop their farm in the future.

All interviews were recorded through the use of the mobile app Voice Recorder, version 21.1.06.11. Additional notes were made in writing during the interviews. In total, five interviews were conducted; two interviews were conducted with female plant breeders who both work with Lantmännen, one of them as the senior winter wheat breeder at Lantmännen and the other was a breeder responsible for spring wheat breeding. Their backgrounds include a Masters in agronomy plant breeding and a PhD in genetics. Furthermore, three interviews were conducted with farmers, one female and two male, all of whom have a Masters level education. Their farms were located in different parts of the Skåne region of Sweden. (see Table 3).

Table 3: Overview and details about the interviewees

Role	Overview	Group	Location
1st Breeder	Female, Spring wheat breeding program in Lantmännen	Breeder	Svalöv
2nd Breeder	Female, winter wheat breeding program in Lantmännen	Breeder	Svalöv
1st Farmer	Male, responsible for a large farm centeral Skåne region	Farmer	Svalöv
2nd Farmer	Male, responsible for a large farm in southern Sweden	Farmer	Kristianstad
3rd Farmer	Female, works with her parents in their medium farm	Farmer	Skivarp

2.A.4. Interview analysis

Prior to the analysis all the recorded interviews were transcribed into Text Raw Data. The analysis followed the method of Thematic Analysis (TA) (Braun & Clarke, 2006). Through the use of this method it is possible to analyse, identify and outline patterns as themes from the data. The method further enables the researcher to reduce, organise and characterise data sets rich in details (Boyatzis, 1998).

Thematic analysis is made up of six phases. It is important to conduct all six phases and do the analysis in a structured order, which means that it is not possible to proceed to the next step without completing the previous step. The first phase is to *be familiar with the interview text:* go through the text of the interview and take notes and outline the main topics. This process can lead to discovering new themes and ideas which may be related to the research question and the main topic. The second phase is *generate codes:* add highlights and labels to the text data by finding a word to use as a code for a sentence or paragraph. The coding process is not a tool to reduce data, but it can be used as an analytic process for each code by gathering the data that relates to a specific code. The third phase is *search for themes:* all the codes that have been noted down are gathered to create a pattern or theme that can be related to the research question. Discovering themes is an ongoing process of setting up the codes that are extracted from the interviews, and which must be related to themes. The fourth phase is *review the themes:* in this step, the researcher should go through each theme and see if there are any relations between the themes, then redesign the themes by merging two or more themes into a single theme, or by separating one theme into two or more themes. This could be done by creating a thematic map that explains the entire thematic analysis of the interviews (in this case, the two groups). The fifth phase is *define and name the themes:* continuing to find what is special about each theme. Additionally, this step should include a short description of each theme. The sixth phase is *write the final version*: in this final step, you have the opportunity to formulate the analysis into a story that will be understandable for readers (Braun & Clarke, 2006).

2.B.1. Plant material for the Biotron experiment

Twenty-one winter wheat *Triticum aestivum* genotypes from Nordgen genebank were selected from early vigour and drought evaluation experiments for 180 different genotypes that were conducted for another project (Kumar et al., 2020). The genotypes I selected from these experiments were 593106, 593143, 593007, 593149, 593161, 593138, 593126, 593056, 593185, 593010, 593013, 593123, 593077, 593108, 593127, 593011, 593105, 593174, 593008, 593072 and CYLON, of which ten were "most tolerant" plants, ten were "most sensitive" plants and one variety (Cylon) which would act as a control. Similar to as described earlier in Armoniene et al. (2018), all seeds were germinated for three days in Petri dishes on a moist filter paper at 4ºC under dark conditions. The germinated seeds were later sown in a square plastic pot (0.4L) filled with peat substrate soil named Blomjord Exclusive produced by Emmaljunga Torvmull AB, Sweden. Two seeds per pot for each genotype were sown in two replications for each time point. Plants were grown at 5ºC in the Biotron chamber for four weeks (see appendix 2) to simulate cold weather in winter with an 8h photoperiod and light intensity of 99 µ mol $m^{-2}s^{-1}$ and air humidity of 84% rH. Thereafter, the plants were moved from the cold chamber to a warm chamber and grown at 22ºC with 16h photoperiod and light intensity of 365 µ mol $m^{-2}s^{-1}$ and air humidity of 50% rH. All pots received the same quantity of water every three days (2000 ml for 21 pots in each block). Plant imaging was done after 10 and 18 days and thereafter, six days after the drought treatment. All plants were exposed to the drought treatment, during which there was no watering from day 18 to day 24, at a temperature of 22ºC with a 16h photoperiod, and with light intensity of 365 µ mol m−2 s−1 and air humidity of 50% rH. In the imaging process, plants were photographed from all four sides and the top for each plant and the control plants (figure 1). All the images taken included a ruler in order to enable any necessary adjustments for changes in camera distance between the time points. Also, the ruler was used as the measurement unit for converting from pixels to centimetres.

Figure 1: four side-view pictures and one top-view picture for the SE4 plant Replication one during ten days control photography

2.B.2. Setting up the phenotyping studio lab

The low-cost phenotyping lab (LCP) (Armonien´e et al, 2018) consists of two studio strobes (Visico ELFIN VL-200 Plus) with a direct effect of 200W each and a colour temperature of 5600K. These two strobes were fitted with softboxes of 50 × 70 cm each. These two light strobes were put on stands and placed on each side of the plant at an angle of 45º; at this angle, the strobes can light both the plant and background. The strobes include integrated wireless radio receivers; when the two cameras take images triggered by a wireless radio transmitter (V801TX, Visico, China), these are connected to the cameras. The white background (150 × 250 cm) hangs on a telescoping boom placed on two light stands, one on each side of the plant. The imaging process is performed with two Digital Single Lens Reflex (DSLR) Cameras (Canon 1300D, Canon, USA) using an 18-55 mm kit lens. The side-view camera was mounted on a tripod and the top-view camera was mounted on a space-arm (tristar). The same distance (150 cm) was used between the pot, side-view camera and top-view camera. The plant was placed on a white rotating disc. Also, for QR code reading, QR codes containing the details about each plant (genotype number, block number, replication number and plant number) were printed on the pots. A webcam (Logitech International S. A., USA) was placed 20 cm away from the pot. All these three cameras were connected to a computer (figure 2). The QR codes were generated by Bytescout Barcode Generator (http://www.bytescout.com), then the generated codes were printed on self-adhesive white labels by using a custom R script. When a pot was placed on the rotating disc (ComXim), the QR code would be read by the webcam which was placed in front of the pot and operated by the software program bcWebCam (http://www.bcwebcam.de). All the information read from the QR code was transferred automatically from bcWebCam to the linked software digiCamControl (http://www.digicamcontrol.com).

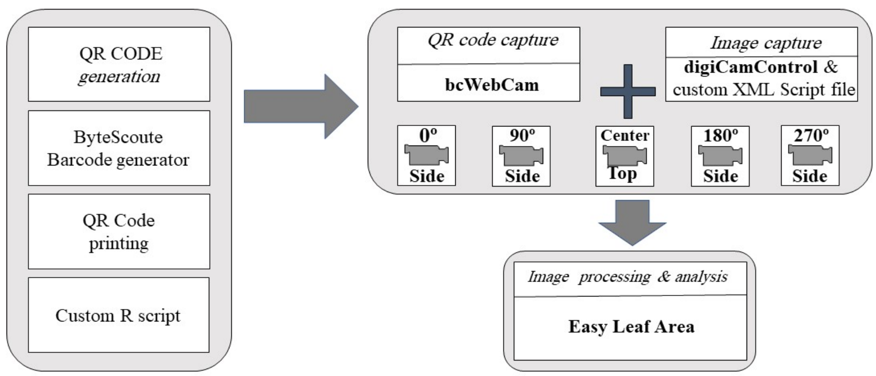

Figure 2: Pipeline for imaging and processing data. QR codes are generated with ByteScout Barcode Generator software and printed with a custom R script made for the time-lapse. The QR code is captured by bcWebCam linked to digiCamControl software which will capture five snapshots, four from the sides and one from the top. Image processing and analysis by Easy Leaf Area software (Armonien´e et al, 2018)

The two DSLR cameras were tethered to digiCamControl which took a series of five images using a custom XML script file. The script file sequence was as follows: first image taken by side-view camera followed by a five-second wait; second image taken by top-view camera, followed by a ten-second wait while the disc was rotated through 90º; third image taken by side-view camera, followed by a ten-second wait to rotate the pot to 180º; fourth image taken by side-view camera followed by a ten-second wait to rotate the pot to 270º; fifth image taken by side view camera. All the side-view images were taken with a custom setting (focal length of 43 mm, ISO 400, F-Stop f/10, and exposure time of 1/100 seconds) while the top-view camera images were taken using slightly different settings (focal length of 43 mm, ISO 400, F-Stop f/11, and exposure time of 1/60 seconds). Before starting to photograph, it was necessary to be aware of the light: the light can cause many issues in this process. It must provide lighting to the plant and the background without creating shadow. This can be done in different ways: manually by changing the direction of the light strobes, the camera distance or the camera settings and exposure, or by customising the white balance by imaging the white background. The LCP (Low-Cost Phenotyping) laboratory consolidates three cameras, one for reading the QR code and the other two for imaging from different positions: one from the sides and one from the top. These cameras took RGB images saved as JPG files. Pictures were later analysed by the Easy Leaf Area software program. This software appraises the projected leaf area from four different side- and top-view images.

2.B.4. Imaging process and analysis

All the images were taken by the two cameras and directly stored in the computer as a JPEG format file, resolution 72 dpi and size 1920 × 1280 pixels. All the files were named with the data read from the QR code. The pots were all black, and the black colour did not interfere with the image analysis software. All throughput images were checked manually to remove images in which the plant was out of frame or blurred. Then, ImageJ (www.imagej.net) was used to measure pixels per centimetre by randomly taking five images from different plants for the side-view and top-view from each replication. Lastly, just the plants with four side-view images and one top-view image went further to an analysis by a software program called Easy Leaf Area (Esalon & Bloom, 2014; Rita Armonien´e et al, 2018), installed on an HP laptop with dual-core i7 Intel processor and 16 GB of RAM. For Easy Leaf Area the parameters were: leaf minimum green RGB value: 25; Leaf Green Ratio (G/R): 1.00; Leaf Green Ratio (G/B): 1.34; scale minimum red RGB value: 109; scale red ratio (R/G & R/B): 1.46; processing speed: 3; minimum leaf size (pixel): 30.

2.B.5. Easy Leaf Area software

The Easy Leaf Area software parameters were adjusted to maximise the leaf area detection and minimise the detection of non-plant objects that appeared in the images. Then, the image files were selected for analysis by Easy Leaf Area, which led to the output of a CSV file with the measurements and the images appearing as just the leaf area saved as a TIFF file (figure 3).

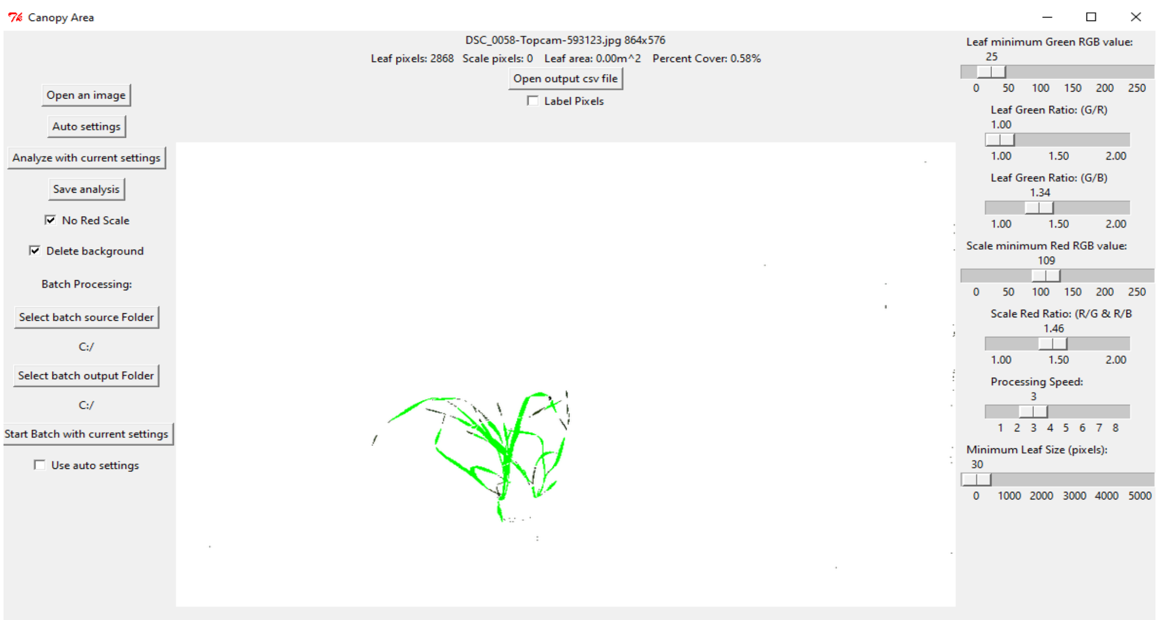

Figure 3: Easy Leaf Area software main window showing the best set of parameters to maximise total green pixel and minimise the non-plant areas that appear in the analysed image.

By using the ImageJ software, it was possible to know the number of pixels in each centimetre in the pictures, which was helpful as more straightforward calculations could be carried out using centimetres rather than pixels.

2.B.6. Early vigour and drought evaluation of the Biotron experiment

For each replication, five to six side-view pictures were analysed using ImageJ software, which measured one centimetre from the ruler in the picture and calculated how many pixels there were per centimetre. The same was done for the top-view pictures because the distance between the top camera and the plant was different from the distance between the side camera and the plant. From this, the number (N) of pixels per centimetre was taken from the previous step, then the total green pixels (TGP) number was taken from Easy Leaf Area and the analysed data was divided by N^2.

$$PA_{Side-view} = \frac{TGP_{Side-view}}{N^2}$$

$PA_{Side-view}$	*Projected Leaf Area for each plant (there are four side views)*
TGP	*Total Green Pixels*
N	*Number of pixels for each cm in the ruler*

$$PA_{Top-view} = \frac{TGP_{Top-view}}{N^2}$$

$PA_{Top-view}$	*Projected Leaf Area for each plant (there is one top view)*
TGP	*Total Green Pixels*
N	*Number of pixels for each cm in the ruler*

Using Excel, the average of summation for each PA view from five images for each genotype was taken for three time points: 10,18 and 24 DAS (days after sowing)

$$PA_{genotype} = \frac{(PA_{for\ 0°} + PA_{for\ 90°} + PA_{for\ Top-view} + PA_{for\ 180°} + PA_{for\ 270°})}{5}$$

$PA_{genotype}$ *Projected Leaf Area for each genotype (average of five views, sides and top)*

For the relative growth rate, the below equation was used; this shows what the major changes in the total green biomass for each genotype are between time point one and time point two

$$RGR_{PA} = \frac{\ln\left(\frac{PA_2}{PA_1}\right)}{(t_2 - t_1)}$$

RGR_{PA} *Relative Growth Rate for Projected Area* *ln* *Returns the natural logarithm of number*

PA *Projected Leaf Area for time point*

t *Timepoint for each photography process*

2.B.7. Scoring drought data from the field

There was a set of valuable scoring drought data for the summer of 2018 from Svalöv field that was generated from another project (Kumar et al., 2020) and obtained for the same genotypes that had been selected for the Biotron experiment. The scoring of drought tolerance data for the Nordgen materials in the field of Svalöv was assessed and evaluated by using the standard evaluation system (IRRI, SES, 2002; Herawati et al., 2017). The scoring classification from score 0 to score 9 is illustrated in Table 4.

Table 4: plant drought response classification based on SES, IRRI (2002) source (Herawati et al., 2017)

Score	Criteria	Description
0	Highly tolerant	No symptoms
2	Rather tolerant	Slight tip drying
4	Tolerant	Tip drying extends up to ¼
5	Moderately tolerant	¼ to ½ of all leaves dried
7	Moderately susceptible	More than 2/3 of all leaves thoroughly dried
9	Susceptible	All the plant is dead. Length in most leaves dried

3. Results

3.A. Interview results

The result is presented for plant breeders and farmers separately. The two interview groups highlighted different themes as factors affecting the farm and the breeding process. The results of the interviews cannot be generalised for all breeders and farmers in Sweden; they are the thoughts and opinions of the farmers and breeders interviewed. For breeders, the thematic analysis of the data resulted in six themes (figure 4): (1) crisis experience, (2) cooperating with SLU, (3) diversity and monoculture, (4) new technologies, (5) plant breeding, and (6) food waste. For farmers, the thematic analysis resulted in five themes (figure 5); (1) water management, (2) soil management, (3) drought, (4) organic and local food, and (5) role of community.

3.A.1. Plant-Breeders

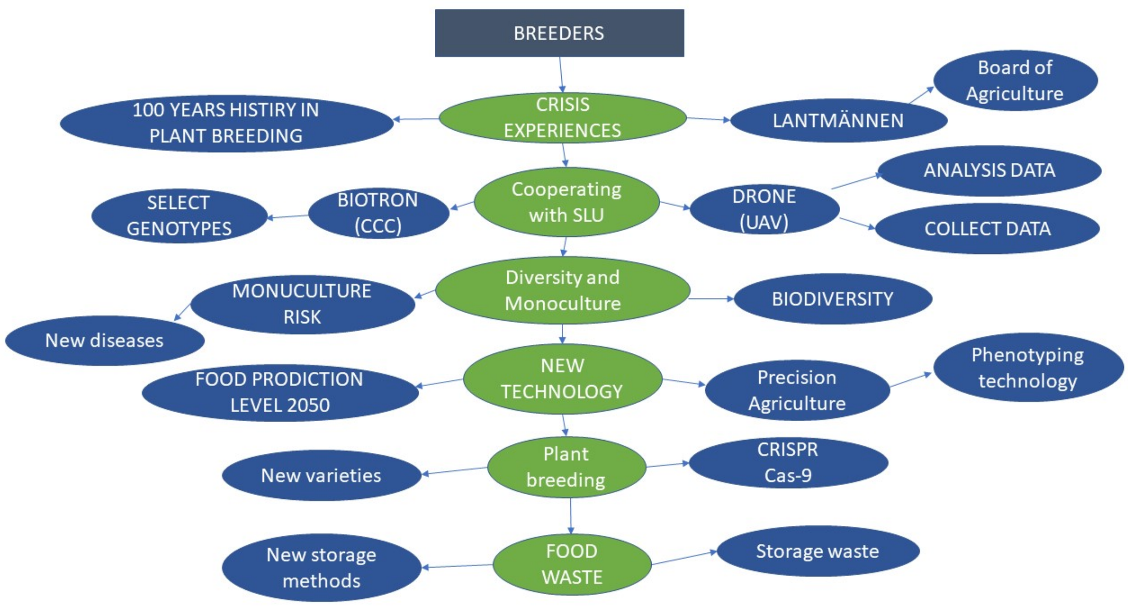

Figure 4: Overview of the thematic analysis of interviews with a group of wheat breeders, showing six themes in green oval figures and sub-themes in blue oval figures which belongs to the main themes.

Crisis experience: Lantmännen has been working on crop breeding for more than 100 years, especially winter and spring wheat. Through these years, the firm has acquired experience and knowledge in how to develop new varieties. After the drought in summer of 2018, employees at Lantmännen and the Board of Agriculture became more responsive, quick and prepared. For example, as one of the breeders who participated said in the interview:

"One thing that was extremely important was the seed for drilling because we had such dry conditions we could see early in the summer that we will not get enough harvest for the seed that we will use for drilling next season. Lantmännen and the Board of Agriculture decided to field inspect more fields that they could use for seed. So, the board of agriculture gave dispensation for reentering into the certification system more hectares of seeds than they normally would just to be able to secure seeds for the next season, and that was really really good" (Breeders group, breeder 1 Svalöv).

Also, Lantmännen offered help, advice and economic support to their members. By making this offer, they can mitigate the panic that farmers might feel if confronted with losing their crops or, in the worst-case scenario, not be able to prevent starvation among their cattle. Lantmännen produces a lot of feed in the northern parts of Sweden. Field trials are conducted with a special focus on the needs among farmers during the drought season who have cattle in the southern region of Sweden.

Cooperating with SLU: Lantmännen is one of the most well-known farmers' associations in Sweden that has cooperated with the Swedish University of Agriculture, SLU. The joint research is covering both laboratory experiments (SLU) and field experiments, Lantmännen in Svalöv. Lantmännen support farmers through selecting and developing new varieties that adapt to the cultivation conditions in Sweden. There is a difficulty in breeding for drought stress in the open field because it is unlikely that drought will occur in the field every year. This implies that experiments have to be conducted in climate control chambers that can be used for simulating drought stress and select the drought-resistant genes. In a research project, researchers at SLU are collecting and analysing the data from fields and laboratories to identify germplasm with drought tolerance and to develop genetic markers for breeding for drought tolerance.

Diversity and monoculture: Breeders observe that as the number of farmers decreases and the areas of the individual farms increases, the opportunities for new farmers to enter the market and buy land is reduced. This development additionally increases the area under monocultures. The development is believed to be driven by large farms controlled by large companies that cultivate one crop. If the farm depends on only one crop such a strategy can threaten the farm economy. Breeders could not create crops completely resistant against all diseases. Therefore, they must balance the resistance characteristics of the crops to adapt to balanced field conditions.

New technologies: most of the current research in the agriculture sector is focussed on increasing food production in order to meet the demand from an increased population. New technologies, such as precision agriculture can help the breeders to increase food production. This can be a suitable solution for more sustainable food production in some circumstances, by reducing the chemicals used for fertiliser and pest management. Using drones for phenotyping and collecting data means that less time is spent on this activity, and it is more objective to use drone images in scoring and observing the field instead of using human labour, which would take more time and be less accurate.

Plant breeding: the process of plant breeding and the development of new wheat varieties adapted to the new environmental conditions can take a long time. One of the plant breeders mentioned that plant breeding materials and climate change can follow each other because plant breeding cannot be done in just one year - it needs from seven to nine years. Therefore, the crops in conducted experiments will follow the increase in temperature through these years. Furthermore, there is the possibility of using the CRISPR-Cas 9 technology instead of GMO technologies; however this technique is not allowed to be used in EU countries; by using CRISPR-Cas 9 technology, the plant breeding period can be accelerated by selecting the appropriate gene for creating a new variety.

Food waste: As mentioned by one of the breeders, there was a lot of grain lost during the storage stage, and the interviewed breeders are presently conducting research to find a method to reduce this percentage of grain waste.

3.A.2. Farmers group

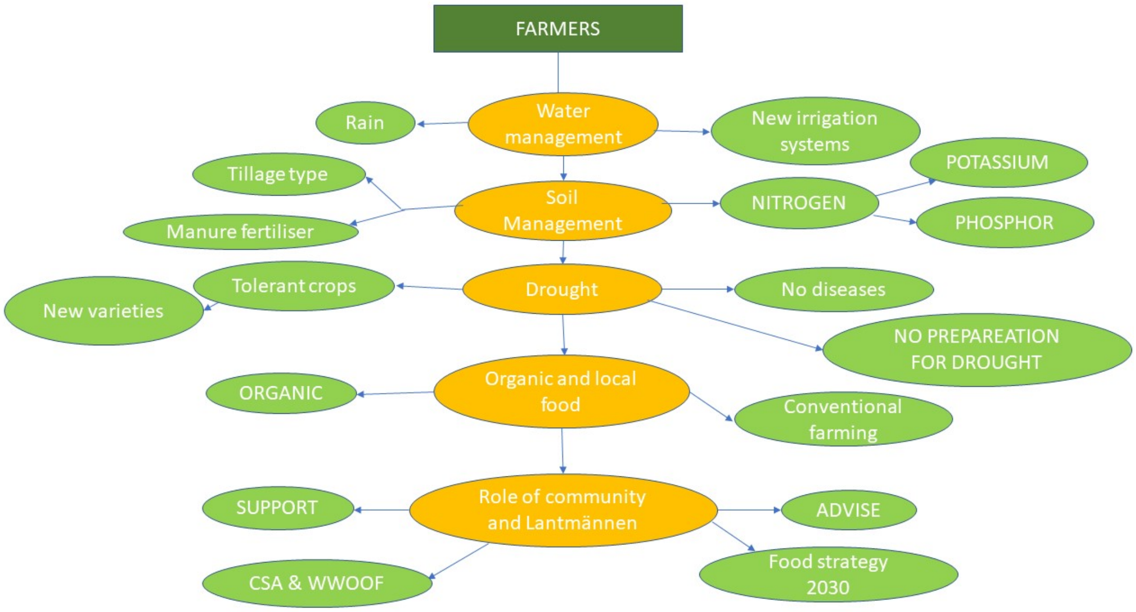

Figure 5: an overview of thematic analysis from the interviews with the group of farmers showing the five themes in orange oval figures with sub-themes in green oval figures which belongs to the main themes

Water management: Most of the farmers interviewed depend on the rain for their water, which can be a risk if they suffer from drought or hot weather. One of the farmers has a water gun used for irrigating the crops during summer. Additional solutions that can help the farmer are for example digging a well to use underground water or build a water pump if there is a river or lake close by. These solutions are often connected to big financial risk, since they can be a significant investment for the farmer. Also, one of the participating farmers mentioned that there are different irrigation systems with low pressure that can be efficient and less energy-intensive for more sustainable agriculture:

"The irrigation machine is now getting old so I need to buy a new one, but I still want some years to decide which irrigation system I will buy, but I was thinking about a liner or pivot irrigation system. My land looks like a square, so I think one of those systems will fit my field. Also, with this new system with low pressure that means less energy cost, more efficiency and more yield" (farmers group, farmer 2 Kristianstad)

Soil management: the first step, ploughing, has to be adjusted in regard to crop and soil type. Besides nitrogen (N) fertiliser, the two of farmers mentioned that there is a lack of other minerals like potassium (K) and phosphorus (P) that appeared in the last soil test report. These minerals could be found in cattle manure, but with a low percentage which is not enough for crops. In order to get the right amount of minerals fertilizers has to be added. Yet there can be a great diversity in different areas of the soil that make lacks of these minerals in the soil which need compensate these minerals. Also, for the N fertiliser, participating farmers express the use of new techniques that were used to spread different amounts of N according to soil needs by using satellite and drone images. That helps the farmers to know which are the areas that need more N fertiliser, depending on the information provided by the website, which uses satellite images and accurate locations by means of GIS.

Drought: The drought in the summer of 2018 increased the protein level in winter wheat, but decreased the yield. Nevertheless, there was one positive aspect to the drought: there were very little diseases, and as a result, there was a reduction in the amount of fungicides used. The sugar beet crop survived the drought, and the yield was better than other crops. This implies that some crops can adapt to dry and warm conditions. Also, the timing can play an essential role: if seed is sowed earlier in the season, that will prevent the drought effect. A conclusion from the interview analysis is that there is currently no preparation for drought. When such conditions arise again, they will affect the crops again, so farmers must prepare and find other sources of water instead of rain or use a drought-tolerant crop. In the future, climate change may bring new crops, plants and varieties that can be grown in warm and dry conditions.

Organic and local food: one of the farmers mentioned that consumers in Sweden prefer local food rather than organic food produced in South America or other distant locations around the world. Thus suggesting a trust between Swedish farmers and consumers that was expressed by the farmer. By comparing conventional farming from a global perspective and a Swedish perspective, there are differences. In Sweden, farmers are restricted by following domestic rules to reduce the use of chemicals like fertilisers and pesticides. There are thus great differences between Swedish and EU farmers, and South America in regard to what chemical fertilisers and pesticides that are allowed. Organic farming entails a lot of paperwork, and the yield can be reduced to half.

Role of community: all the farmers interviewed mentioned the support of the community when the drought of 2018 happened and how the community tried to help the farmers. Therefore, the role of community is vital, and can be promoted by encouraging people to buy local agricultural products, raising awareness in the community about local farms and what they offer to their community, and by direct support from the municipality and the local associations in the region. Besides the local farmers' associations, there are a number of movements who support small and local farms by helping them with stores and selling, sharing experiences and training farmers to produce sustainable agricultural products, for example, WorldWide Opportunities on Organic Farms WWOOF Sweden and Community Supported Agriculture CSA. For wheat production, there are a number of local farmers' groups like Lantmännen and the Federation of Swedish Farmers (LRF), the farmers' cooperative with the most wheat farmers in Sweden. Therefore, they conduct research to be more sustainable and efficient, and also to increase production in line with the food strategy in Sweden 2030, in which conventional and organic agricultural products should coincide with local consumer demand.

Farmers and breeders opinion on the study

The farmers and breeders opinion in regard to the conducted experiment varied. the summary of their answers were put together as an interviewees opinion about my study. The combination between the social aspect and scientific aspect will be offering great ideas for both farmers and breeders, by knowing the requirements for farmers in the field and how the drought can affect their crops and reduce the gap between researchers and farmers. For the breeders, they can find a way to breed the superior crop that can cultivate in the current and future weather conditions which could be increase the food productions. Then, the farmers and breeders appeared to have an overview of what the farmers struggled in the drought season and their memory stilled fresh and remembered all details that happened with them, and for the breeders they discovered which of their materials were survived in the drought season so that was a real experience to selected the most tolerant genotypes in the field for this drought season. The main purpose of the interviews in the study to see the issue from a different angle or to see it from the perspective of farmers and breeders.

3.B. Results of the experiment

The experiment of Biotron was twenty different winter wheat *Triticum aestivum* genotypes from Nordgen genebank selected after analysed images (using the same imaging technique as in this thesis) from early vigour and drought evaluation experiments for 180 different genotypes that were conducted for another project (Kumar et al., 2020). Drought tolerance analysis using change in biomass as a proxy measure was done from 180 different genotypes from Nordgen materials and four cultivars for control which were drought tolerant. All the twenty genotypes were selected from the experiment of 180 genotypes (figure6); the selection was made by identifying the most tolerant and most sensitive plants.

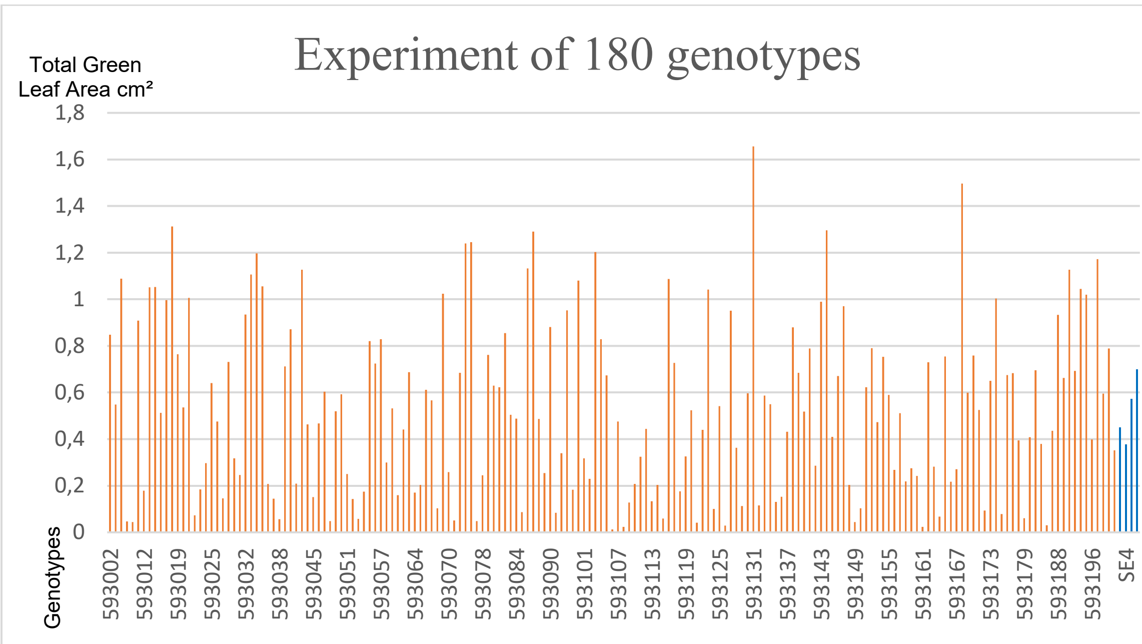

Figure 6: The total Green Leaf Area after drought for the first experiment, 180 genotypes were used in two replications in each replicate six blocks in each block there are 34 pots in each pot one different genotype. the colours in the figure the orange were the genotypes and the blue were the control

3.B.1. Results for early vigour and drought evaluation of Biotron experiment

The experimental results of the 20 genotypes from Nordgen materials and the Cylon cultivar as control (figure 7) confirmed there was phenotypic variation after six days of drought compared to time point two (18 days) control, and that there was a significant difference between genotype 593106 and Cylon. In this experiment, Cylon appeared to be the most sensitive genotype to drought, compared to 593106. However, the most sensitive genotype to the drought was 593072. Therefore, according to Armonien´e et al (2018), by using the equation of Relative Growth Rate, it can be shown which of the genotypes were more sensitive to drought and which were most resistant, as disclosed by the loss of green vegetation for the plant.

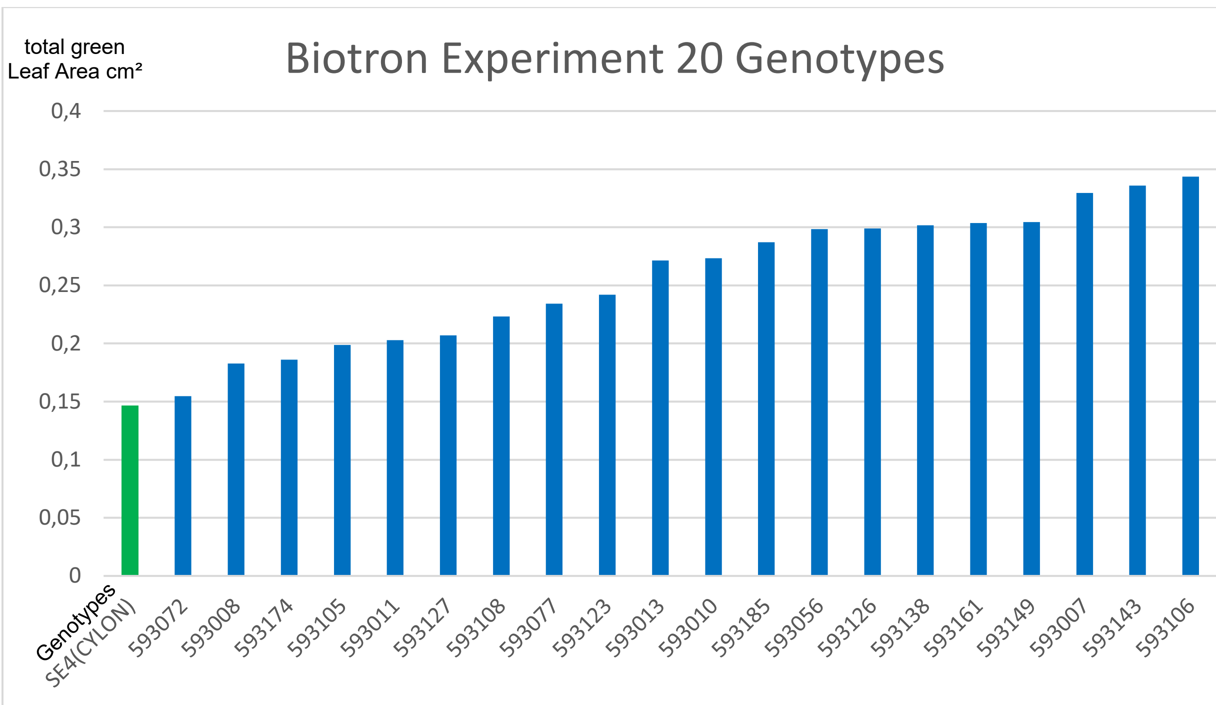

Figure 7: The total green Leaf Area estimated from analysis of images by Easy Leaf Area software for Biotron experiment for 20 genotypes and one control check for the third time point (six days of drought). Designed in two replications for each replication one block for each block 21 pots the colours in the figure the blue were the genotypes and the green was the control

The results of relative growth rate confirmed the results of the early vigour compared to the drought effect (figure 8). They also showed that Cylon and 593072 had the highest negative relative growth rate. That means these genotypes were the most sensitive plants because they showed the most significant loss of vegetation compared to the others. Conversely, 593106 and 593143 showed the lowest negative relative growth rate, meaning that these genotypes were the most tolerant plants to the drought effect. This information can assist the breeders to better select for drought-resistant plants. These genotypes were shown to have the ability to survive in drought conditions for six days when the plants were 18 days old.

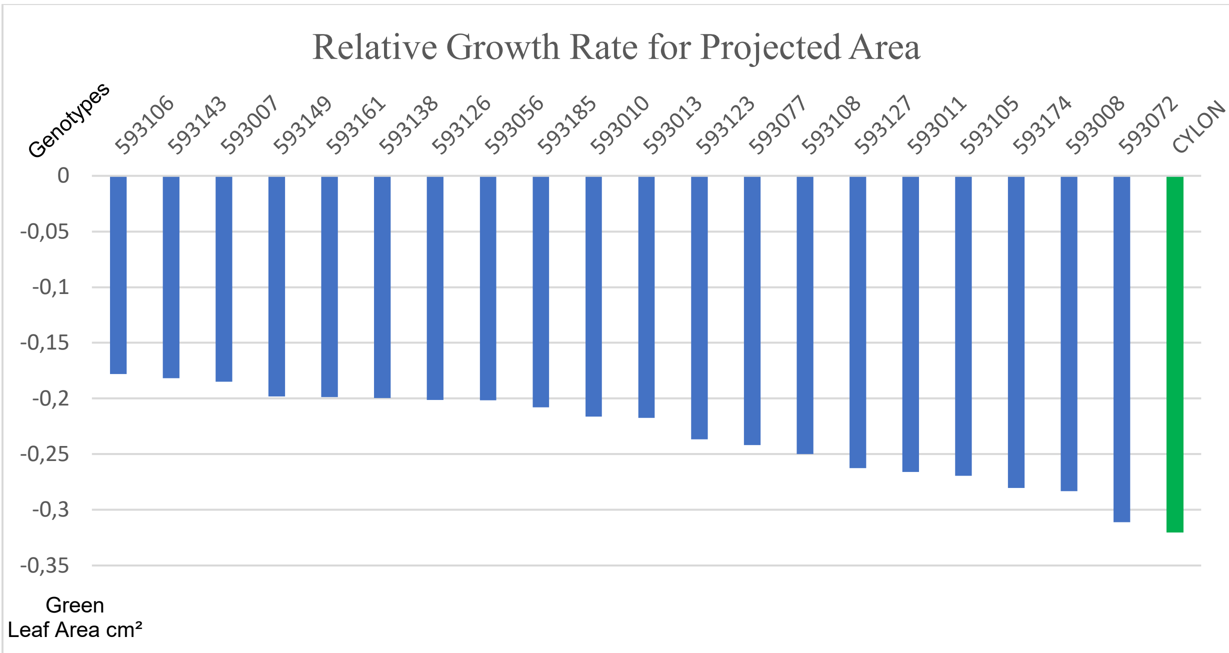

Figure 3: Relative growth Rate after the drought for each genotype based on the change in the projected leaf area between 18 and 24 days (i.e. during the drought treatment). The colours in the figure the blue were the genotypes and the green was the control.

3.B.2. Results of scoring drought data from the field

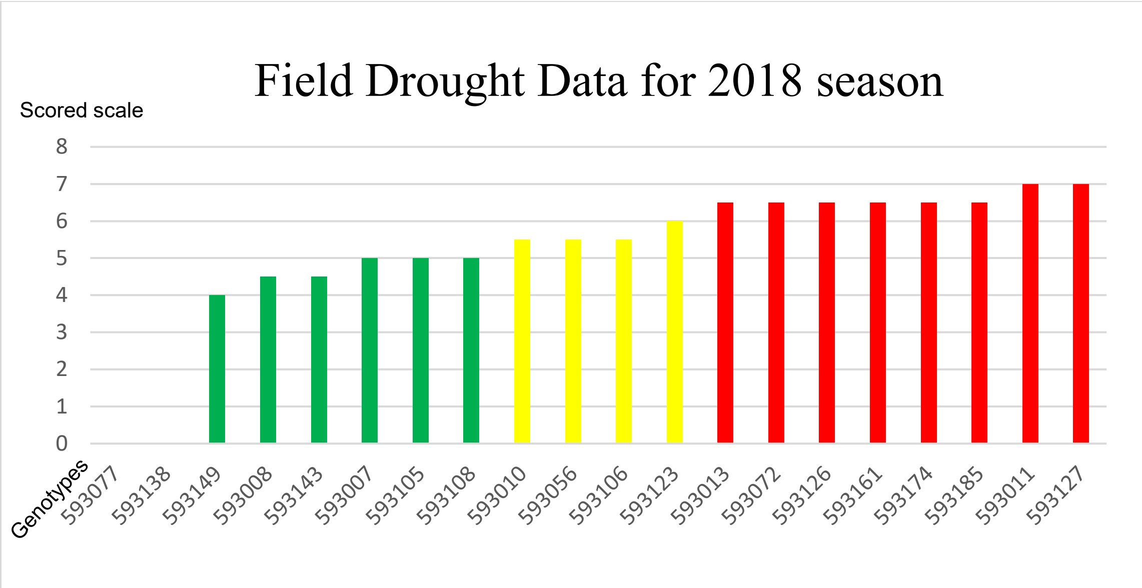

Figure 4: the scoring field drought data of 2018 season for 20 genotypes and the average of two-time point scored and evaluated based (SES, IRRI, 2002) the colours in the figure following the three main groups green were tolerant, yellow moderate tolerant and red moderate susceptible

These drought data observed and scored based on (table 4) were collected for two time points, the first time point during May of 2018 season and the second time point during July of 2018 season. The field data were classified for three main groups based on the scoring guide from (4 to 5) tolerant, from (5.5 to 6) moderate tolerant and from (6.5 to 7) moderate susceptible (figure 9).

Field data was missing for genotypes 593077 and 593138, so they were not considered as part of the results data. The tolerant genotypes in the field based on the scored data were (593149, 593008, 593143, 593007, 593105 and 593108) the symptoms of this group were ranged from slight drying tips of spikes to drying tips of spikes extend up to ¼ of spikes. The moderate tolerant genotypes in the field were (593010, 593056, 593106 and 593123) the symptoms of this group ranged from ¼ to ½ of the tips of spike and leaves dried. Then finally the sensitive group moderate susceptibles of the genotypes in the field were (593013, 593072, 593126, 593161, 593174, 593185, 593011 and 593127) the symptoms of this group was more than 2/3 of the leaves and spikes were dried and looking dead plants. This data approved these genotypes (593143, 593007 and 593149) more tolerant for the drought stress from Biotron experiment and the scoring of drought data from the field for 2018 season.

4. Discussion

The results from this study confirm that drought stress tolerance could be affected by the genotype of each plant, depending on each genotype's tolerance: some of these genotypes were sensitive to drought stress, whilst others appeared tolerant to it. Armoniené et al. (2018) obtained data from the greenhouse by using LCP lab or biomass and early vigour, these data were analysed using three different software programs - HTPheno, plantCV and Easy Leaf Area - and the results of R^2 relative growth rate were compared for each program. The most significant coefficient of determination was ($R^2 = 0.94$), which was obtained in the analysis by the HTPheno program. Therefore, these techniques can be considered a tool for early selection for the future plant breeding programs and for genetic traits which are related to drought and heat tolerance and the yield of the crop. These and other traits are now being developed by using low-cost High Throughput Phenotyping Platforms (HTPPs) (Araus et al, 2018).

According to the Swedish Board of Agriculture (Jordbruksverket), the effect of drought, high heat and little rain in the season of 2018 on the total cereal harvest for 2018 is estimated to have been about 3 254 400 tonnes (Jordbruksverket report, 2018). This amount is 45% less than the cereal harvest in the 2017 season. Furthermore, the total winter wheat harvest for 2018 is estimated to have been about 1 399 000 tonnes, which is approximately 43% of the total cereal harvest for 2018 season; in comparison, the total winter wheat harvest for 2017 is estimated to have been about 3 000 000 tonnes. This means that the 2018 winter wheat harvest was 46.66% less than in 2017. Another important reason that makes this yield appear less is because a much larger area was harvested as silage or fodder for animals. However, as both the farmers who were interviewed and the Board of Agriculture (report, 2018) mentioned, there were some quality problems linked to the drought. In southern Sweden, the protein content of the winter wheat became weak as the crops were not able to benefit from the nitrogen in the soil because of the dry and hot conditions. The malted grain, on the other hand, tended to have a higher protein content, which is considered as an unfavourable characteristic in the malt industry. The use of agricultural chemicals was lower than in other years, because of the effect of the dry and hot conditions on pests and fungus; all interviewed farmers and breeders mentioned that there were no diseases at all which meant that they did not have to use any pesticides and fungicides during the 2018 season.

Wheat as a crop requires adequate soil moisture during all plant growth stages for a regular rate of growth; that means an irrigation time plan is required in order to reduce the possibility of over-irrigation (Meena et al., 2018). Over-irrigation can cause waterlogging and leaching of nutrients from the root zone; therefore, farmers must use a proper irrigation method that can feasibly be used in wheat crop fields to provide scheduled irrigation water in accordance with Water Use Efficiency (WUE) and as a consequence of using such a scheduled irrigation plan, the productivity of the wheat field can be affected (Qiu et al., 2008). One of the most efficient methods that is used for irrigating wheat fields is the Centre Pivot Sprinkler (CPS) system; using this method can usually reduce water wastage. Furthermore, it can reduce the pressure of pumping water, which leads to increased energy-efficiency and reduced irrigation time, which in turn means increasing the productivity of the plant per unit of water demand. Thus, this more precise agriculture is also more sustainable. All of the aforementioned advantages of using a CPS system can increase the potential for improving WUE for the crops (Kahlown et al., 2007). However, several kinds of research have been carried out into the effect of using CPS systems on crop yields. Dechmi et al. (2003) mentioned in their research that the CPS system directly effects crop production. Also, Sezen and Yazar (2006) discovered as a result of their research that evapotranspiration, crop yield, WUE and crop harvest yield were all affected by water content through the CPS system used during the various growth stages.

Nevertheless, most of the farmers for whom cereals were their main crop, did not irrigate the grain areas during the drought season in 2018 (Board of Agriculture in Sweden report, 2018). Also, in the interviews most of the interviewees considered it to be necessary to invest for the future in an upgrade or a new irrigation system that could be used during future drought conditions. But, one of the farmers was thinking about upgrading his irrigation system from a water gun (which requires high pressure and thus consumes more energy and is also hard to control the water direction of, especially during windy days) to a CPS system with low-pressure pumping water that would reduce the energy consumed and wastewater produced, but would require a large capital investment.

Nowadays, plant breeding programs are expected to use advanced methods in phenotyping. There are new technologies that have improved the ability to measure plant traits. The competition in the technology sector catalyses the development of the best quality, lowest cost, lightest weight and highest resolution cameras. These can easily be attached to a drone or unmanned aerial vehicle (UAV), which can capture large numbers of high-quality images in a short time of the fields in different growth stages. The many parameters of the images can be used to assess the growth rate of the plant through different time points and to detect unusual colour that may be related to low nutrient uptake or disease infection in the plants. Also, by using long-wave infrared or thermal camera technologies the stress status of crops during the heat, drought or disease can be detected: when a plant is under drought stress, it looks more refreshed than other plants because of having longer roots that access deep water.

In addition to the red-green-blue (RGB) and infrared cameras, there are a range of hyperspectral cameras which can capture hundreds of images in a short time (Araus and Cairns, 2014; Falhgren et al., 2015). Precision phenotyping provides the ability to increase the selection of genetic and heritable traits. In several kinds of research, these new phenotyping techniques will allow breeders to use low-cost, high-throughput methods to screen larger populations than other, more complicated, high-cost or unreliable measurement methods (Serraj and Pingali, 2019).

The plant breeding cycle time can be defined as the period between each selection of genetics during a breeding program which produces new genetics, and that depends on the generation time, which is different from seed to seed or may be related to the selection methods used: single plant selection or large field plot selection. From the plant breeder interviews, it was clear that it is very important for them to reduce the breeding cycle time by using new methods or technologies. Most of the main cereal crops are annual plants, but now there is a possibility to grow more generations in a controlled climate chamber with the availability of light-emitting diode (LED) lights to promote the spectral requirements for plant growth. The efficiency of the accelerated cycle has improved for several crops including wheat, chickpea and field pea: breeders can now grow six generations in one year (Watson et al., 2017). As for the long generation species, the technologies can reduce the breeding cycle time for these crops too. For example, in apples, the general generation cycle time is from five to twelve years. The moment at which the plant passes through its juvenile stage to the flowering stage in this cycle can be accelerated by changing the expression of genes that control flowering period. This kind of approach was used in crossing the new fire blight resistance gene into apple cultivars; instead of the normal time framework of almost 20 years, the breeding cycle time was only three years (Le Roux et al., 2012).

One of the breeders interviewed mentioned that there was a new fascinating tool called Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) that can be more precise in editing genomes and can be used instead of Genetically Modified Organisms (GMO). When CRISPR-associated protein 9 (Cas 9) was discovered, this method proved to be easy to work with and more cost-effective when compared with other methods, yielding the potential to develop plant strategies radically (Kim et al., 2018). The CRISPR/Cas 9 system is an adaptable tool for genome editing based on the guidance of small RNAs that can target multiple genes in the same script of the plant (Doudna and Charpentier, 2014). This tool was initially discovered during the 1980s in a component of adaptive bacterial immunity in *Escherichia coli* (Ishino et al., 1987). According to Kim et al. (2018), improved in their research about the expression of many genes in wheat (*Triticum aestivum*) that selected for abiotic stress conditions such as drought stress, which can be considered as one of the main issues for wheat producers, causing tonnes of yield loss every year. Thus, this new technique could change the plant breeding programs for many crops.

All the farmers mentioned that they considered the diversification of their crops at the rotational level one of the most important approaches used by the newest software to plan their crop rotations. The diversity in the crops during the crop rotation can increase the resilience of food production system to the effects of climate change (Lin, 2011; Gaudin et al., 2015). Also, the crop rotation can increase the yield of grain crops were planted followed by forage crop rotation which can increase the soil organic matter considered as agroecological practices (Entz et al., 1995; Gliessman, 2007). On the other hand, there is only a small percentage of farmers who know that, if they use the right crop rotation, this will help to mitigate the effects of climate change (White et al., 2011; Degani et al., 2019). The crop rotation was approved, it was admissible for the crop yield and climate change effects respectively on Ecosystem Services (ES) provided by the vital communities in the soil which were sensitive to heat and drought conditions (De Vries et al., 2012). Still, up to now, there is not that much information about how sensitive these ES communities are under heat and drought stress and how this can impact crop yields. That information will be very important if the ecosystem services are to be resilient to the future effects of climate change (Degani et al., 2019). Biodiversity, ecosystem services and the biology of the soil are considered as measurements of soil quality processes, such as water and nutrient availability in the soil which is transferred to the crop and other organic matter as a content in the soil (Altieri, 1999). Degani et al. (2019) conducted research into the effect of using a short-term crop rotation on wheat production under stress caused by climate change. The three types of crop rotation were, (1) Diverse: the first year (winter wheat variety *Solstice* undersown with a legume mixture), the second year (a brassica winter cover crop followed by spring beans) and the third year (winter wheat variety *Solstice* undersown with a legume mixture), (2) Moderate: the first year (winter wheat variety *Solstice*), the second year (oilseed rape variety *Amalie*) and the third year (winter wheat variety *Solstice*), (3) Simple: the first year (winter wheat variety *Solstice*), the second year (winter wheat variety *Scout*) and the third year (winter wheat *Santiago*). The results of this research showed in the third year of the crop rotation that the Diverse crop rotation was better by reducing the effect of drought stress. The actual water availability in the plants was interrelated with several soil factors such as structure and organic content, and the biological activities of all these factors depended on the moisture content in the soil (Saxton and Rawls, 2006). Also, in the research carried out by Degani et al. (2019), it was shown that there were no differences in the wheat root system between the three rotations, but that there were differences between the soil moisture at depth; this was better in the Diverse crop rotation, thus indicating that using a diversity of crops in the same soil could improve the soil quality to withstand heat and drought stress better.

Of the various actors affected by drought stress (for example, governments and farming communities), the most vulnerable are the farmers. So, in this situation, if the national associations and government fail to offer a radical plan for the agriculture sector and food system, this will increase the vulnerability to drought stress (Wilhelmi and Wilhite, 2002). The losses from drought stress around the world have increased, and at the same time, the number of drought seasons has also increased. In recent years, the attention paid to drought vulnerability has increased because of the high economic cost and the social vulnerability caused by drought (Sonmez et al., 2005). Because of the losses from the drought stress which decrease the yield of crops around the world considered as a threat on farmers society, so there were a number of studies that focused on the societal vulnerability of drought stress. In one of these studies, Brooks et al. (2005) noticed there were differences in the level of vulnerability to drought between rural communities in developing countries and wealthy, technologically-advanced countries, and that this was because of the level of support that was offered by the government and national associations.

The economics of a farm can be affected by drought stress: it can decrease on-farm production, which increases the vulnerability of the farm's income. So, a decrease in income is one of the factors that can increase economic vulnerability. Hence, in areas in which drought stress is likely to occur frequently, farmers should try to find new coping strategies, primarily by diversifying their crops and using some drought-resistant and tolerant crops. If livestock is integrated into the farm, this can increase the income of the farm when drought happens, and that can provide an improvement of the socio-economic situation for farmers who have diversified their products with livestock and introduced agroecological practices for more sustainable food production (Gliessman, 2007).

The level of social interconnection between farmers could play a role in the effectiveness of decision-making processes by shortening the gap between the decision-maker and the farmer; that doesn't necessarily mean that the farmers can take action themselves, but it could make it easier for decision-makers to do so. In addition, the social network created between the farmers involved in local meetings will develop the diverse effects of social capital on different levels: farmers, local people and politicians (Zarafshani et al., 2012). One of the practical aspects of agroecology is the sharing of knowledge by farmers on different levels: locally, nationally and globally (Gliessman, 2007). Nowadays, with developments in technology, there is no real distance between countries. The experience of farmers who have struggled with different situations can be shared with other farmers around the world, helping everyone to find solutions. According to the FAO digital agriculture transformation seminar (2019), by using smartphones and cloud services, agriculture was transformed to be more accessible by sharing knowledge between farmers at any time and anywhere through apps. A farmer can take a picture of his crop, plant, pest or disease, which is then used to identify the issue by using the app. There are a number of apps that have been released by FAO and other developers. One of the apps, called NURU App, can identify the damage to a plant; this app uses a combination of machine learning and artificial intelligence. This app can work offline and is available on android mobile phones.

Long-term field studies in several European countries have discovered that there were lower yields in organic fields compared to conventional fields (Torstensson et al.,2006). According to Ivarsson and Gunnarsson (2001), in Sweden all the different crop yields studied were reduced by about 45% for a farm system that was without livestock, and 25% for farms that involved livestock in the farm system. However, providing a different perspective, more recent studies showed that the yield gap between organic and conventional was reduced to 19 to 25%, depending on the cropping system and other practices that were used in the field, and these percentage can be even less, depending on the management of the field (Jansen et al., 2015).

We as researchers need to find a way to expedite all the struggles that farmers could face when they decide to become organic production farms, by finding the approaches, methods, practices and tools that can assist them in adopting more sustainable agricultural practices in the field. In addition, if the yield in the organic field is lower, that will affect the farm's income, which means that a greater area of land is needed to reach the same amount of yield as a conventional field. Also, the price of organic agricultural products does not encourage farmers to transfer from conventional to organic because more of the profits go to retailers and markets, not to the farms. Finally, we need to raise awareness more about local organic food to reduce the profit chains: instead of the farm – storage – retails – market – consumer, the chain will be direct (farm – consumer) and that increases the profit for the farm and reduces the price for the consumer.

5. Conclusion

Drought can affect the entire agriculture sector and especially wheat production: in the south of Sweden, yields were reduced by half in the 2018 drought season. The greatest restrictions that affect the production of wheat during its different growth stages are drought stress and abiotic stress (Okuyama et al., 2014). Most of the farmers in the south of Sweden rely on the rain as their main source for watering, and that could affect their crop production during any drought seasons that may happen in the coming years. However, building a new irrigation system on the farm entails a big investment and is considered as a massive economic risk for the future of the farm. Abiotic stress reduces the yield for most major crop cereals by 50% around the world, and areas under drought stress are anticipated to expand further in the future (Yousuf et al., 2012). New technologies in plant breeding can play an important role in reducing yield gaps by creating new varieties which can be adapted for local conditions, making them more resilient to abiotic stresses (salinity, drought, heat, cold, frost and floods) and biotic stresses (insects, diseases, viruses and weeds). Abiotic stress is one of the main factors. The new phenotyping techniques, which come from different companies around the world, can be a solution to respond to climate change, and provide the appropriately selected genotypes which are tolerant to abiotic stress. Therefore, these kinds of innovations and new technologies can create agricultural systems which are more sustainable and more efficient. Awareness for the farmers about abiotic stress in general, and drought in particular, should help all the farmers and breeders prepare for drought conditions that are likely to happen more frequently in the next few years. Nowadays, breeders and farmers have experience of how to deal with drought and if it comes again, from my point of view I think they will manage to identify what are the relevant approaches that can be used to reduce the damage that could be caused to their crops because of drought, depending on the knowledge they acquired from the last drought season in 2018. The final point that should be mentioned is that there is a scarcity of literature and research concerning drought in the Nordic countries (in which drought and climate change in recent years have started to affect the agriculture sector) in comparison to countries which were already affected by drought. There is plenty of research and literature for these countries, but this is not valuable for the Nordic countries or countries in the north of Europe. One of the biggest differences between the farmers here and the farmers in the Middle East and north African countries is that most of the farmers here rely on rain as their main source for irrigating crops in the field, whereas on other side of the world, the scarcity of fresh water and the salinity of the water and soil are the major is.

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Appendix 1

The interviews guide that used to interview the farmers and breeders groups

Interview guide for breeders

Personal background

Name

Education background

Position in department

Future vision company

Questions

Personal

General questions about the personality of breeder

1. How you get your interest to be a plant breeder?
2. What is the most successful task accomplished in your career that you proud of?
3. What would be the most important skill you would suggest for students studying plant breeding and genetics nowadays?
4. What is your opinion about local and organic food movement in Sweden?

Drought

5. Is the drought stress one of the traits in your field studies in Läntmannen? (how much they focus on the drought on their plans)
6. What is the efficiency of different genetic approaches that can be developed crops with tolerant of abiotic stress as frost, heat and drought? (what kind of genetic approaches they use to find the solution)
7. What are the environmental consequences of drought resistance crops? (if they have any issues with drought resistance crops that used before)
8. What kind of help are you offering for your farmers any support according to drought stress in last summer? (What kind of support they offer to their farmers)
9. Are you notice what kind of diseases appears related to drought stress in the field? Are you score this disease? (are there any diseases increased if drought appear in summer)
10. According to the Swedish board of agriculture 2018, there is three drought summer in the raw of the last three years? Are you except that situation? And

what are your preparations? (what are the preparations they used to mitigate the drought)

Climate change

11. As a breeder what is your most significant impact of climate change that you notice in Skåne in the last few years? (the awareness of Läntmannen about climate change)
12. How will crops breeding, the new technologies, use of traditional crops and agronomic practices can be balanced to increase food production according to climate change impacts? (are the new technologies are able to increase the food production, for example, wheat production)

Läntmannen farmers

13. Are you have any advisory services to the farmers who cooperate with you? (are they close enough to support the farmers)
14. How many farmers are members of Läntmannen and what is the percentage of small-scale and organic farms? (how they can effect on the total number of all farmers in Skåne and the competition between small scale and organic farmers)
15. What are means these words for you (biodiversity and ecosystem services)? (what are their goals about biodiversity and ecosystems services)

Future and vision of Läntmannen

16. What are the benefits and risks of support the new technologies in different types of agriculture practices? (what are the cons and pros of using new technologies)
17. What are the improvements to crop varieties can be made by genetic researches? (the main purpose of genetic studies in wheat production)
18. How does the crop biodiversity help to reduce pests and diseases? Are you have any studies about it? (are they interesting to increase crop biodiversity)
19. Do you think the new technology in the agriculture sector can find new ways to increase food production by 2050? (how they involved the new technology)
20. What do you think about the new phenotyping technology can helps to find a different way of monitoring and observing that will be a benefit for farmers? (how they are using the phenotyping in their researches)
21. What are the main traits that you looking for in final grain yield of wheat plants in experiments field? (what are the most important traits they look for on the final yield)
22. What is your opinion about my experiment? (how she/he thinking about my experiment)

Interview guide for farmer

Personal history

Name of the farm

Name

Age

Education Background

Questions

Personal

General information about his/her life in the farm

1. When do you start farming?
2. What do you find interest to involved in the agriculture sector?
3. What is your main purpose to work as a farmer more as a business, lifestyle choice or some combination of both?
4. Are you a member of any community association that supports you with any kind of services?

Farm

5. What do you grow and what is the total cultivation area of your farm? What kind of crops do you grow? What is your main crop and why use that particular one to grow? (basic information about the farm)
6. Are you classified as conventional, organic? Are you certified as organic or ecological? (how is he/she thinking about the environment)
7. How much the harvest last year? And what is your estimate harvest for the last year? Is there a big difference between the estimate and the actual harvest? (the difference of yield according to drought last year)
8. Are you have access to water and drainage network in your field? (water management)
9. What kind of irrigation system do you have? Are you have any plans to invest to upgrade your irrigation system in the farm? (what is the preparations for drought)
10. What do you think about the negative impact of conventional practices in the agriculture sector? (farmer knowledge about climate change effects)
11. What is your crops rotation system do you use on your farm? (what the kinds of crops he/she used in crop rotation)
12. What are your main activities seasonally on the farm during the year? (Timeline activities in the farm during the year)
13. From where you can get your seeds? Are the seeds certified? (Seeds source)
14. Do you have any practices for soil management on your farm? What do you use for fertilizer and pesticides? (is he /she caring about the environment)

15. How do you monitoring or observe your field and your crops? Are you using any weather forecast stations or other new technology? (if they have time plan for disease appear or they using the new technology to take the right discussion)

Drought

(drought stress as the main threat to the farm all the questions to know how he/she dealing with it for the short and long term)

16. How did the quality of the harvest yield? If the quality was bad! Are the drought was the reason for that?
17. Are have you noticed any pest or disease pressure related to drought last summer? (any new diseases appear than not identified before)
18. Are you have any kind of contract with a large company who can support you! Are they support you related to the drought situation? (who is support farmers in these situations)
19. Are you planning to grow drought-tolerant crops in the next years? (any preparations for the next years)

Farm future

20. How do you see your farm in the future? (future vision of his/her farm)
21. What is your thought about climate change effect on Scania southern of Sweden? (what are the main changes they can recognize for the future climate change)
22. Is there a possibility to grow new varieties in the next few years according to climate change effects? Are you see it such as cons or bros? (are there any plans to adapt by using new crops which can here)
23. How you can see the new technology can be benefit for the agricultural sector in the future? (are he/she with using new technology)
24. What is your opinion about my experiment and how it will be benefit to wheat production? (his/her thought about my work)