VARIETY TESTING OF OAT (*Avena sativa* L.) FOR ORGANIC AGRICULTURE

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ABSTRACT

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Tiivistelmä – Referent - Abstract

Organic agriculture is growing steadily in Europe. Demand for organic products and pressure from policy changes in the EU have created a need for organic seed material. One of the limiting factors is the lack of organic variety testing. Currently no official organic Value of Cultivation and Use (VCU) trials or standards for organic variety testing excist in the EU. Plant breeding companies like Boreal Plant Breeding want to offer varieties for organic farmers but they lack information on the performance of their varieties in organic conditions.

The main objective of this experiment was to determine the most important variety traits in organic agriculture in Finland and which of the Boreal Plant Breeding oat varieties exhibit the most favourable traits for organic growing conditions. Relationships between observed traits were also examined.

A wide range of observations and measurements were performed from the trial throughout the growing season. Quality analysis of the yield were performed after harvest. The objects of examination during growing season included growth development, leaf area index (LAI), nutrient status with SPAD (Soil and Plant Analysis Development) measurements, plant height and yield components.

Plant height and LAI appeared to be the best indicators for evaluation of performance potential of oat in organic conditions. SPAD value wasn’t found to have a connection to oat yield nor was it an indicator for oat LAI. High LAI increased oat height, yield and yield component shoots/m^2 but effected negatively on the yield component panicles/m^2 during the end of stem elongation. Plant height was a good indicator of yield level. The number of weeds and LAI value didn’t have a connection in this experiment and neither did weed number and yield.

The early and late varieties varied in their reaction to the low-input growing conditions. Early varieties had generally lower yield but better yield quality than the late varieties. ‘Nella’ showed potential to be a variety with good yield quality and high yield in low-input conditions in Southern Finland. Area of cultivation and the end use of the oat are important factors in variety selection.

Avainsanat — Nyckelord — Keywords

Organic, low-input, plant breeding, oat, variety

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Tiivistelmä – Referent - Abstract

Luomutuotannon suosio on kasvussa luomutuotteiden kysynnän kasvaessa Suomessa ja Euroopassa. Luomutuotetulle siemenmateriaalille on tarvetta, mutta sen tuotantoa jarruttaa luomulajikkeiden testauksen puuttuminen. Virallisia luomulajikekokeita ei tehdä tällä hetkellä EU alueella, eikä niiden suorittamiseen ole luotu yhteisiä standardeja. Kasvinjalostusyritykset, kuten Boreal Kasvinjalostus haluavat tarjota lajikkeita myös luomuviljelijöille, mutta lajikkeiden suoriutumista luomuoloissa ei ole testattu kokeissa.

Tämän tutkimuksen tavoitteena oli tunnistaa kauralajikkeiden tärkeimmät ominaisuudet luomutuotannossa Suomen oloissa ja mitkä Boreal Kasvinjalostuksen jalostamista kauralajikkeista pärjäävät parhaiten luomuoloissa. Mitattujen ominaisuuksien suhteita tarkasteltiin muun muassa korrelaatioiden avulla.

Koekentältä tehtiin paljon havaintoja ja mittauksia kasvukauden aikana ja sadosta tehtiin laatuanalyysit sadonkorjuun jälkeen. Kasvukauden havaintoihin kuului muun muassa kasvurytmin seuranta, lehtialaindeksi (LAI), kasvien typpitason tarkastelu SPAD mittarilla, korkeus mittaus ja satokomponenttien laskenta.

Kokeen perusteella LAI ja kasvien pituus olivat parhaita mittareita kauran sopivuudesta luomuoloihin. SPAD arvoilla ei havaittu olevan yhteyttä kauran satotasoon, eikä se vaikuttanut kasvien LAIn kehitykseen. Korkea LAI lisäsi kauran pituutta, satoa ja satokomponenttia versot/m^2, mutta sillä oli negatiivinen vaikutus satokomponenttiin röyhyt/m^2 korrenkasvun loppupuolella. Kauran pituus toimi mittarina satotasolle. Yhteyttä rikkakasvien määrän ja LAI:n, eikä rikkojen ja sadon välillä ollut tässä tutkimuksessa.

Aikaiset ja myöhäiset lajikkeet reagoivat eri tavalla luomutuotannon kasvuoloihin. Aikaisilla lajikkeilla oli pääasiassa matalampi satotaso, mutta korkeampi laatu kuin myöhäisillä lajikkeilla. ’Nella’ oli lajikkeista potentiaalisin luomuviljelyyn eteläisessä Suomessa, sillä sen laatu ja satotaso yhdistelmä olivat lajikkeiden parhaimmistoa tässä kokeessa. Viljelyalue ja sadon käyttötarkoitus ovat tärkeimpiä tekijöitä lajikevalinnassa.

Avainsanat — Nyckelord — Keywords

Luomu, kasvinjalostus, kaura, lajike

Säilytyspaikka — Förvaringsställe — Where deposited

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1 INTRODUCTION

Organic agriculture has grown steadily in popularity in recent decades. Between 2010 and 2019 organic farmland in Europe has increased by 6.49 million hectares and the organic share of all farmland in Europe was 3% in 2019 (FiBL 2021a). In Finland over the same time period organic farmland nearly doubled from 169 000 hectares to over 306 000 hectares, covering 13% of all agricultural land in 2019 (FiBL 2021b). The rising trend is likely going to continue in the future as people grow more conscious of climate change and look for naturally produced food with a potentially lower impact on climate. The sketch of the new Finnish National Organic Strategy for 2030 (VN 2021) concluded that European Commission has recognised the demand for organic products and the new Green Deal and Farm to Fork strategies have identified organic food production as means to further develop climate conscious agriculture and food production. The goal is to increase the share of organic farmland in the EU to 25% by 2030. The Finnish National Strategy has also identified nine goals for development of organic production by 2030. One of the goals is to increase organic agriculture by promoting production of organic seed material and establishing organic variety trials. This will also challenge plant breeders and the organic seed market as the aim in Europe is that all seed material used in organic agriculture will be certified organic in near future.

Organic agriculture poses different demands for varieties than high input conventional agriculture does. With no use of synthetic fertilizers or crop protection measures, varieties in organic agriculture need to have traits that aid them in yield formation and competition against weeds while also being able to tolerate unstable growing conditions and diseases. Varieties bred for conventional agriculture are adapted to high input systems in which they experience less biotic and abiotic stresses that risk their ability to produce high quality yields. Since there is a limited number of tools to aid crops thrive in organic production systems, farmers have to pay attention to every choice they make in the management of their crop. In order to produce high yielding, high quality crops the most basic but also important decision is the choice of crop variety (Hoad et al. 2008; Wolfe et al. 2008).

In order to put new varieties to the market in Europe, variety candidates of all field crops need to go through at least two years in trials of Value for Cultivation and Use (VCU). The VCU trial networks are extensive, encompassing nearly all growing conditions in the target country. Currently there is no official organic VCU testing in Europe, which makes it challenging to get varieties bred for organic agriculture to the market. Most of the organic seed on the market for farmers in Finland is from varieties that were bred for conventional agriculture. This is the case for over 95% of the varieties used in organic agriculture worldwide (Lammerts van Bueren et al. 2011). It has also been shown that varieties bred under conventional conditions are not necessarily sufficient in traits that are important in organic agriculture, like nutrient use efficiency or disease resistance (Murphy et al. 2007; Lammerts van Bueren et al. 2011; Wolfe et al. 2008).

Because of the small market share that organic crops have compared to conventional crops, most plant breeding companies don’t find it worthwhile to dedicate time and resources to organic variety breeding (Pedersen 2012; Kovács & Pedersen 2019). With little availability for organic variety testing, breeding companies have to market their seed to organic farmers without knowing how well their varieties are adapted to organic conditions. In order for organic farmers to find the best varieties for their purposes they should be able to base their variety choice on research information rather than speculation. This thesis aims to solve which oat varieties bred by Boreal Plant Breeding display traits considered important in organic farming conditions.

2 LITERATURE REVIEW

2.1 Oat

Oat (*Avena sativa* L.) is a cereal crop that is well adjusted to temperate climate conditions. It’s used for human consumption and animal feed. In 2019 over 23 million tonnes of oats was produced world-wide on almost 10 million hectares of land. Oat is generally grown in cooler climate conditions compared to other cereal crops (Uusitalo & Leino 2019) but also in places like Australia and New-Zealand. Some of the biggest oat producers in the world include Russia, Canada, Poland and Finland, all countries located in areas of cool climate (FAO 2020).

For many years, oat has been the most cultivated cereal in organic agriculture in Finland. In 2020 it was grown on over 40500 hectares (Finnish Food Authority 2020) with a total yield of 83.4 million tonnes (Luke 2021). Oat-based products also dominate the organic export market with most of the products being exported to Germany (ProLuomu 2021). The interest in oat cultivation can also be partly credited to its cholesterol-lowering health benefits due to its β-glucan fiber content (Othman et al. 2011), importance in human diets and suitability for gluten sensitive diets (Kaukinen et al. 2013; Rasane et al. 2015). The change in food consumption towards non-animal products has also added to the popularity of oat as it has been used to develop new non-dairy (Rasane et al. 2015) and vegan products.

Traits that make oat suitable for organic production include its ability to compete with weeds due to its broad leaves, tillering ability, well-developed rootsystem (Feledyn-Szewczky & Jonczyk 2016; Klima et al. 2020) and its higher tolerance towards varying environmental and soil conditions, especially drought (Labanowska et al. 2016; Puzynska et al. 2021) and acidic soils (Mukula & Rantanen 1989). It is also a suitable crop for mixtures and its nutrient levels generally increase in mixtures with legumes (Carr et al. 2004; Tarui et al. 2013). According to Tarui et al. (2013) oat-legume mixtures also improve the nutrient uptake and growth of the following crop which makes them a great addition to crop rotations. Oat has performed well in organic trials in Estonia in the past (Ingver et. al 2008) and has been found to be a suitable species in organic production (Spasova & Menkovska 2009; Zinta et al. 2004).

2.2 Organic agriculture

The European Union Council Regulation no 2018/848 on organic production and labelling of organic products (European Parliament 2018) defines organic production as follows:

> ”Organic production is an overall system of farm management and food production that combines best environmental and climate action practices, a high level of biodiversity, the preservation of natural resources and the application of high animal welfare standards and high production standards in line with the demand of a growing number of consumers for products produced using natural substances and processes.”

Organic agriculture aims for balance at ecosystem level with regenerative measures and minimal synthetic inputs (Mäder et al. 2002). Great focus is given to natural function of soil microbes that improve soil structure as well as water and nutrient availability to plants (Østergård et al. 2009). Using manure as organic fertilizer improves soil microbe function and nutrient availability to plants.

Mäder et al. (2002) found that although the nutrient inputs in organic cropping systems can be up to 50% lower than in conventional systems, the organic yields were only 20% lower compared to conventional systems over the study period of 21 years. Organic production system can benefit the whole ecosystem and make it work in harmony. On the contrary to the positive things organic agriculture offers, it has been criticized for being inefficient at producing enough yield to feed the world (Pinstrup-Anderson & Pandya-Larch, 1998; Kirchmann & Ryan 2004; Murphy et al. 2007). However, Murphy et al. (2007) have shown that lower yields in organic agriculture are often result from using varieties not suitable for organic production. Murphy et al. (2007) also concluded that plant breeding can help develop suitable crop varieties that have been directly selected for in organic rather than in conventional conditions.

2.3 Important traits for organic crops

In organic agriculture, crop varieties need to have tolerance to heterogenous, less controllable growing conditions that are not buffered by things like seed treatment or mineral fertilizers common in conventional agriculture (Baresel & Reents 2006). Organic crop varieties need to have superior adaptation to low soil fertility, pests, diseases and weeds as well as the ability to still produce high quality and volume yields (Pilksere et al. 2013). This means that the traits required of organic crop varieties are different than the traits required of conventional varieties (Lammerts van Bueren, 2002). Seed health is also important in organic agriculture to prevent seed borne diseases and provide a vigorous crop stand (Osman et al. 2008). A vigorous and rapidly growing crop can compete with weeds, decreasing the yield losses they can cause. A complete lack of weeds is however not desirable since research (van Elsen 2000; Fuller 1997) shows that a small weed population can benefit small organisms that use weeds as feed and cover this way adding to biodiversity of the farm.

2.3.1 Height

It has been generally believed that higher straw length indicates also longer root length (Mac Key 1988) for more efficient nutrient uptake leading to higher yields, but this is not always the case. Instead, the connection between straw length and root length has been proven to be a more complex interaction, depending highly on plant genetics and the environment (Holbrook & Welsh 1980; Siddique et al. 1990; Gorny 1993; Chloupek et al. 2006; Jia et al. 2019). Growing conditions and stresses such as drought, can have a substantial effect on plant above and below ground growth (Hoad et al. 2001). Long straw can lodge in unfavourable conditions affecting negatively yield and yield quality, whereas short straw exposes plants to competition with weeds in organic agriculture. Short varieties with dwarfing genes are commonly used in conventional agriculture and these dwarf and semi-dwarf varieties have improved lodging resistance and yield potential especially in wheat

(*Triticum aestivum* L.) while raising the harvest index (Hedden 2003; Lammerts van Bueren 2011). Lopes et al. (2012) and Butler et al. (2005) showed that many variety-specific traits and conditions during the growing season affect yield potential so higher yields can't be credited solely to shorter straw length. Some of the dwarf lines also exhibit weaknesses in other important traits like disease resistance and susceptibility to unfavourable growing conditions (Wojciechowski et al. 2009). Gooding et al. (2012) found that in organic conditions the nitrogen use efficiency (NUE) was highest in taller crops than in conventional conditions. The peak height of the crop for optimized NUE was 15 cm higher in organic conditions compared to conventional (Gooding et al. 2012), indicating that taller crop may have generally better chances at thriving in organic growing conditions.

2.3.2 Weed competition

Weed competition has been proven to be a significant reason for decreased yield in organic crops (Beveridge & Naylor 1999; Bond & Grundy 2001) as the competition for water, nutrients and light is intense (Zimdahl 2004). Weed suppression ability is viewed as one of the most important traits in the breeding of organic crop varieties (Piliksere et al. 2013). Weed control is challenging without chemical intervention and it is essential that farmers aim to reduce the seed bank in the soil as well as preventing the germinated weeds from adding to the seed bank. Many farmers find that the available weed control methods are not effective enough (Beveridge & Naylor 1999). Therefore, integrated weed management is recommended to all organic farmers as it combines many cultural practices that together can aid in weed management on the farms while optimising the whole cropping system in a long time frame (Barberi 2002).

The ability of crops to compete with weeds is an interdependence of many traits (Kruepl et al. 2006; Wolfe et al. 2008). It is also important to note both weed-suppressive ability and weed tolerance of the crop as both are important in slightly different ways in competition against weeds (Watson et al. 2006). Piliksere et al. (2013) investigated the traits that are useful for crops in suppressing weeds and found that extensive crop ground cover, growth habit in different points of growing season, canopy height and development rate impacted the crops ability to compete with weeds. Crop height, tillering tendency, LAI and early establishment of the crop stand were found by Fradgley et al. (2017) to be important traits for the crop in weed competition and tolerance. A less considered factor in weed suppression ability is the root system development of a crop. Bertholdsson & Jönsson (1994) found that over 50% of the weed biomass variance in barley (*Hordeum vulgare* L.) and oat stands was explained by the root and shoot growth rate.

2.3.3 Leaf area index

Leaf area index (LAI) represents the leaf area of a plant to soil ratio while also giving indication of the leaf angle and density of the canopy. Organic crops benefit from fast growth in the beginning of growing season as well as good tillering ability compared to crop density (Kruepl et al. 2006): the lower the crop density, the more tillers are needed. Rapidly increasing leaf area represses weed growth and increases photosynthesis and nutrient uptake that further accelerate crop growth. Piliksere et al. (2013) noticed that a crop covering ground well resulted in reduced weed dry weight. Leistrumaite et al. (2009) discovered that crop ground cover has a stronger correlation with yield at stem elongation than with the productive tiller number and could be considered as a trait for selection in breeding programs. Crop stand's shading ability can be evaluated based on the LAI value, which is one of the most important variety traits for weed suppression (Kruepl et al. 2006; Hoad et al. 2006) and therefore vital in organic agriculture.

2.3.4 Nitrogen use efficiency

Nitrogen (N) availability is often the most important limiting factor for crop yield and growth (Andrews & Lea 2013) and its importance is emphasized in organic crop production. The N status of the crop can be easily observed on the field by using portable SPAD (Soil and Plant Analysis Development) meters or N-testers. SPAD value represents the chlorophyll concentration in plant leaves and coverts it to a reference number that can be used to determine the need for additional N fertilization. This measurement has been gaining popularity among farmers since it is fast and non-destructive (Lin et al. 2010). SPAD-measurements provide a mean for farmers to decide on the timing and amount of fertilizer application improving the crop nutrient management (Monostori et al. 2016). Significant positive correlation has been found between SPAD values and leaf chlorophyll and N content which suggests that the SPAD values are a good indication of the plant N content (Koning et al. 2015). Monosori et al. (2016) found that SPAD-yield relationship is highly cultivar specific so calibration is necessary for precise prediction. SPAD values can also provide a mean for organic farmers to keep up with crop health and make management decisions accordingly throughout the growing season.

Crop's ability to tolerate low nutrient conditions and still produce high yield is variety dependent (Ericson 2006). Muurinen et al. (2006) and Rajala et al. (2007) have shown that plant breeding has improved crop N use efficiency over the years. Muurinen et al. (2006) also stated that the better NUE was caused by the improvement in N utilization efficiency rather than in N uptake efficiency. Variety differences have been detected in the timing of N uptake in the growing season (Barsel et al. 2005). Early N intake and high translocation ability are favourable traits in varieties intended for organic agriculture (Ericson 2006). Varietal differences in NUE make it important to test varieties in the conditions they are intended for in practice.

2.4 Breeding for organic varieties

Organic plant breeding aims to develop varieties that are well suited for organic farming practices using sustainable methods that depend on the natural reproductive ability of plants (IFOAM 2019). Breeding for organic varieties utilizes mostly the same practices and selection methods as conventional breeding. As organic production uses sustainable and natural means of production, some breeding methods are not allowed in organic breeding. All methods that alter the genome or cells of the plant are forbidden, for example genome editing and the use of radiation (Lammerts van Bueren et al. 2011; IFOAM 2019). The methods used during the breeding of organic varieties need to be made known to the public before the seeds go on the market (IFOAM 2019).

Wolfe et al. (2008) summarized three sources for varieties used in organic agriculture at the moment: 1) breeding programs for conventional farming, 2) breeding programs for organic farming and 3) breeding programs within organic farming. Breeding programs for conventional farming offer organic farmers varieties that are bred specifically for conventional farming. This is the most common source for organic seed at the moment. Breeding programs for organic farming offer varieties for which the breeding process usually starts with initial crosses for organic agriculture but is mostly performed under conventional conditions. Then at the end of breeding the most promising candidates are tested in organic conditions. Breeding programs within organic farming perform the whole breeding process under organic conditions and only use techniques that comply with principles of organic production (Wolfe et al. 2008).

Breeding programs for organic varieties are mostly performed under organic conditions, but there are exceptions. Some companies perform early breeding activities in conventional conditions and change to organic conditions later on in the process (Löschenberger et al. 2008; Wolfe et al. 2008). Murphy et al. (2007) found that increasing yield in organic farming requires selection to be performed under organic conditions instead of indirect selection under conventional conditions. They (Murphy et al.

2007) also encourage establishing separate breeding programs for organic and conventional varieties, since most potential varieties for organic production have a high risk of being dropped from the conventional breeding program early on due to selection for yield.

The breeding goals of organic and conventional varieties are similar but not all important traits for organic agriculture are shown under conventional farming conditions. Therefore, material in organic breeding programs should be tested under organic conditions in order to see which traits are displayed in those conditions (Lammerts van Bueren et al. 2011). It is also possible that traits that are helpful under conventional conditions (e.g. semi-dwarf genes) can have negative effects in organic agriculture (e.g. reduced resistance to abiotic stresses). Selection for traits like ground cover and leaf mass for organic agriculture can be easier in organic trials, since varietal differences are larger than in conventional trials (Osman et al. 2008).

Varieties grown under organic conditions are much more responsive to the genotype × environment interactions than varieties under conventional conditions (Konvalina & Moudry 2007; Murphy et al. 2007). According to Murphy et al. (2007) organic breeding programs should focus on improving variety adaptability to stresses like low nutrient availability and tolerance to weeds, pests and diseases that are controlled chemically in conventional agriculture. Combining these traits to high yielding cultivars with good yield quality, organic agriculture would have better chances for expansion. In order to create breeding lines with good adaptation ability in organic agriculture, adding genetic diversity to the breeding material is important (Østergård et al. 2009; IFOAM 2019).

2.5 Organic variety testing

Variety testing is a necessary way to evaluate the suitability of a variety to its target environment in different productions systems. This is important since varieties react differently based on their genetics and growing conditions (Kovács & Pedersen 2019). Testing new varieties from breeding programs and for example potential new additions to the variety selection from another geographic area is necessary for reliable evaluation of their functionality to the intended area. Extensive trial networks and multi-year trials ensure a thorough testing of the varieties to verify their suitability to the tested environments. Setting up these networks often requires co-operation between different operators in the agriculture industry including breeders, seed companies, farmers and the food sector.

2.5.1 Value of Cultivation and Use (VCU) testing

VCU testing is a mandatory variety trial system in European Union (EU) that is coordinated by the Natural Resources Institute (Luke) in Finland. Variety candidates are tested in their target environments in trials that simulate on farm cultivation to get reliable information of the variety candidates cultivation value, yield and quality characteristics (Ministry of Agriculture and Forestry 2004). The new varieties need to have some superior traits compared to previous varieties so that they provide improvement in the variety market. They also need to pass the inspection of Distinctness, Uniformity and Stability (DUS) which ensures that the new variety is distinct from the previous ones. After completing the two-year testing, varieties can be applied into the National List of Plant Varieties. In Finland, the Plant Variety Board appointed by the Ministry of Agriculture and Forestry decides on the listing of the varieties. The EU Commission compiles a Common European Catalogue of the national lists of the member states after which the varieties on the list can be marketed in the EU.

VCU testing is carried out in conventional farming conditions but EU member states can decide for themselves if they want to perform VCU testing in organic conditions. Varieties that are suitable for organic agriculture can rarely compete with conventionally bred varieties in the current VCU setting. This is a serious shortage for the organic sector. Currently there are no uniform standards or guidelines for performing organic variety trials in Europe. In order to change this, the European Parliament (2018) according to the EU regulation 2018/848 have ordered for a seven-year temporary experiment to be established to provide further insight on organic varieties and their special characteristics. The experiment will be conducted by The Commission's Directorate-General for Health and Food Safety (DG SANTE) and it is set to start late 2021. It is expected that during this experiment an outline for practical organic VCU and DUS testing will be determined (Pedersen et al. 2021).

One of the biggest problems in the way of expanding organic VCU testing networks is financing (Osman et al. 2008). Breeders and representatives of varieties have to pay most of the cost to get varieties tested in organic networks. As the market for organic varieties is relatively small, breeders will likely not get financial benefit from investing into organic testing (Osman et al. 2008). This has also led to having only a few established organic testing networks in Europe with programs for only the most important crop species (Kovács & Pedersen 2019).

2.5.2 Organic variety trials in Europe

Organic variety testing principles and practises vary among countries. According to Kovács & Pedersen (2019), the set-up of organic trials is quite similar in the studied European countries with wheat, barley, oat and triticale (*Triticale rimpaui* Wittm.) being the most commonly tested varieties in organic conditions. Almost all field trial organizers conducted organic variety trials in conventional conditions but most of them also observed specific traits for organic farming. Organic VCU and registration trials were set up only in Austria, Denmark, Germany, France and Latvia, of which only Latvia and France offered conventional VCU trials supplemented with organic trials. The low demand for organic testing is due to the small organic market share and often high cost of trial fees. The traits observed from the field differs among countries but they often include disease resistance, weed competition, crop physical qualities and nutrient use efficiency. After harvest analysis also differ with assessment of baking quality and milling characteristics (Kovács & Pedersen 2019).

2.5.3 Organic variety trials in Finland

Some organic variety trials have been performed around Finland by Luke since 1980s but there haven’t been systematic trials. Organic testing has become more active in the 2010s as the interest in organic products and changing legislation have raised the demand of more adapted varieties for organic crop production (Nykänen et al. 2014). Trials have been mostly performed as projects and co-operations between different players in the agricultural industry. Some of the latest are the EkoNu project in co-operation with Nylands Svenska Lantbrukssällskap (NSL) that have performed organic trials in Loviisa since 2012, trials in Mustiala performed by Häme University of Applied Sciences (HAMK), some trials around Finland by Pro Agria and technical trials by Luke in Siikajoki. These trials have mostly focused on grain yield and yield quality results (Ström 2019; Erlund et al. 2019; Raiskio & Hinkkanen 2020).

A few trials in Finland have focused on questions such as the response of crop species and varieties to the conditions during growing season or the most important qualities other than yield and yield quality to evaluate the degree of varietal adaptation to organic farming conditions. In recent years observations have been performed during the growing season in EkoNu (Ström 2019) and ProAgria (Nykänen et al. 2014) trials. Since 2017, three oat varieties form Boreal Plant Breeding have been included in the EkoNu trials: ’Meeri’, ‘Niklas’ and ‘Donna’. Oat varieties ‘Meeri’, ‘Perttu’ and ‘Donna’ were included in the Mustiala organic trials in 2020.

3 RESEARCH OBJECTIVES

The main objectives of this research were to identify the most important traits in oat under organic conditions in Finland and which oat varieties bred by Boreal Plant Breeding exhibit most favourable traits for organic production. This was done by observing several different crop traits in the field throughout the growing season and analysing their interdependence.

There were also other research questions to consider:

1) Does plant height, LAI or SPAD value predict yield or yield components?
2) Does the number of weeds limit yield potential?
3) Does high LAI promote plant hight development and decrease the number of weeds?

4 MATERIALS AND METHODS

4.1 Experimental site and field management

The experiment was performed at Boreal Plant Breeding (60°48'N 23°29'E, 122 m above sea level), Jokioinen, Finland. The experimental site was divided into seven segments that together represented a seven-year crop rotation (Figure 1). Soil type was clay loam with organic content of 6-12 %. Soil samples from the experimental area for a soil fertility test were taken in May 2020 and the analysis was performed in October 2020 at Eurofins Agro Oy, Mikkeli, Finland (Appendix 1). According to the soil analysis, nutritional status of the experimental area was at a satisfactory level at the least and there were no nutrient sufficiencies (Table 1). Prior to this experiment, the field was used for meadow fescue (*Festuca pratensis* Huds.) seed production from 2017 to 2019. The field was not certified organic but it was the best available option to start organic variety testing at Boreal. The conditions on the field were similar to fields that are under transition to organic farming. In September 2019, 30 t/ha of cattle manure was applied, followed by ploughing. On May 14th 2020, couch grass (*Elymus repens* L.) was eradicated from the site by spraying 2,5 l/ha of Roundup Flex (potassium salt of glyphosate, 480 g/l, Monsanto, Belgium).

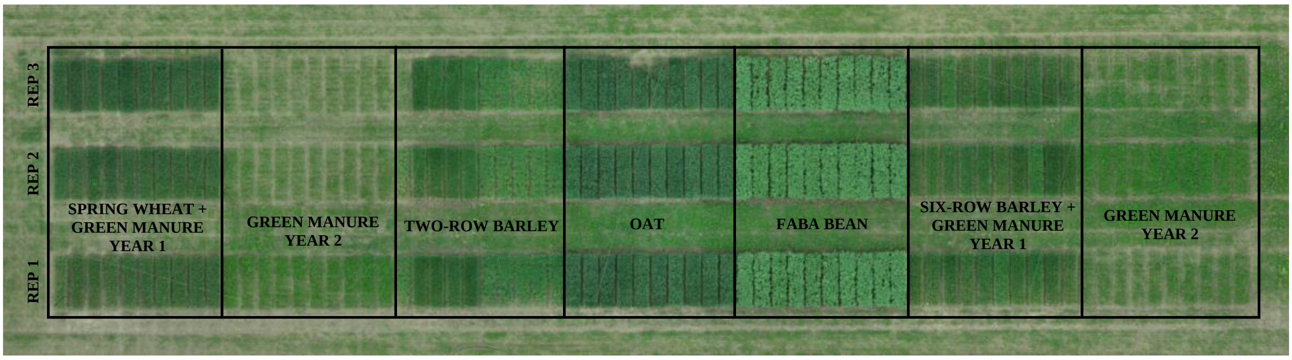

Figure 1. Layout of the experimental site with seven crop segments and three replications.

Experimental site was harrowed on May 30th and 31st 2020 followed by fertilization with 380 kg/ha of Ecolan Agra N-P-K: 13-0-0 (Ecolan Oy, Nokia, Finland) on June 1st 2020. The crops were sown into 6 m^2 plots on June 2nd 2020 and green manure plots for soil improvement on June 8th 2020. The green manure plots had to be sown again on July 3rd 2020, because they had not established well by that point because of dry weather in the beginning of the growing season. The early varieties 'Meeri', 'Niklas', 'Nella' and 'Perttu' were harvested on September 2nd 2020 and the late varieties 'Oiva', 'Taika' and 'Donna' on September 10th 2020.

Table 1. Soil nutrient analysis results for pH, macro- and micronutrients from each crop segment (1-7).

		Macronutrient content mg/l					**Micronutrient content mg/l**		
	pH	**Ca**	**P**	**K**	**Mg**	**S**	**Cu**	**Mn**	**Zn**
1 - Spring wheat	6,4	3500	26	320	590	23	14	110	17
2 - Green manure	6,7	3900	22	320	700	10	14	84	13
3 - Two-row barley	6,9	4600	26	320	620	10	15	67	14
4 - Oat	7,1	5800	36	290	550	15	15	48	19
5 - Faba bean	6,9	4700	32	320	550	12	14	63	14
6 - Six-row barley	6,9	4600	26	330	610	12	14	60	14
7 - Green manure	7,2	6600	37	300	630	14	14	43	18

4.2 Plant material and experimental design

The experiment was arranged in a randomized block design with three replications. The crop rotation included spring wheat, two-row and six-row barley, oat and faba bean (*Vicia faba* L.) in addition to two green manure segments (Figure 1). The varieties used in the experiment (Table 2) were chosen by the responsible breeders of these species at Boreal Plant Breeding. All oat plots were sown at 550 viable seeds/m^2 to the depth of 25 mm. To start the experiment, the plain green manure segments were sown at 25 kg/ha and the mix included 60% Italian ryegrass (*Lolium perenne* L.), 20% red clover

(*Trifolium pratense* L.) and 20% Westerwold ryegrass (*Lolium westereoldicum* L.). For the following years, the green manure was established in a nurse crop in the spring wheat and six-row barley segments at a rate of 20 kg/ha as a mix of 50% Italian ryegrass, 35% red-clover and 15% white clover (*Trifolium repens* L.).

Table 2. Oat varieties used in the experiment and their characteristics. The variety order is based on the length of season.

Variety	Year of listing	Length of season	Purpose of use	Cropping zone
Meeri^{BOR}	2012	Early	Milling, feed, export	I-IV
Niklas^{BOR}	2014	Early	Milling, feed, export	I-IV
Nella^{BOR}	2018	Early	Milling, feed, export	I-IV
Perttu^{BOR}	2018	Early	Milling, feed, export	I-IV
Oiva^{BOR}	2017	Medium late	Milling, export	I-III
Taika^{BOR}	2019	Late	Milling, feed, export	I-III
Donna^{BOR}	2016	Late	Milling, export	I-III

4.3 Weather conditions

May and June were very dry and warm, followed by rainy and cool weather at the beginning of July (Figure 2). The weather became warmer with some rainfall at the end of July. Temperatures decreased again at the end of August and in the beginning of September with occasional rain.

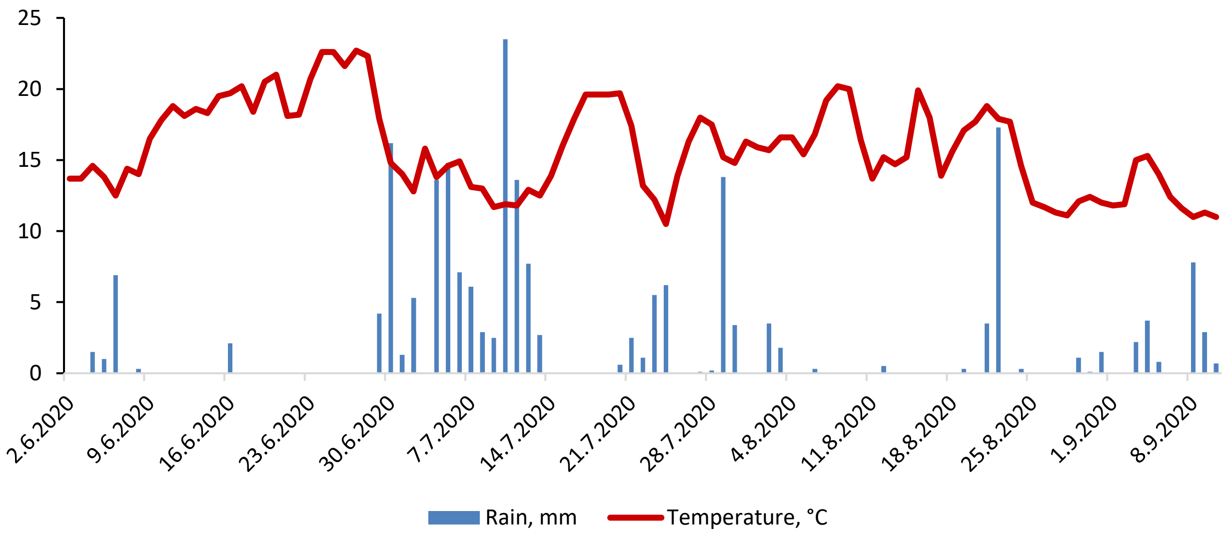

Figure 2. Daily precipitation and temperatures during the 2020 growing season in Jokioinen, Finland (FMI 2021). Data shown are daily averages.

4.4 Observations and analyses

4.4.1 Field observations

A wide range of observations were performed at the site throughout the growing season (Table 3). Growth stage was recorded according to the BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical industry) scale (Lancashire et al. 1991) and a photograph was taken of each plot weekly until harvest. Dates for the main developmental stages were recorded as well as the date crop growth of the plot reached full ground coverage and was shadowing the undergrowth. Crop height average was recorded once a week from sprouting (BBCH 10) until the end of seed filling (BBCH 70). Weed number was counted from a 0.5 m^2 square from tillering (BBCH 30) until seed development (BBCH 70). Lodging percentage was determined one week before harvest.

Table 3. Plan for field observations and measurements starting 14 days after sowing (DAS).

Measurement	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Growth stage (BBCH)	x	x	x	x	x	x	x	x	x	x	x	x	x
Height (cm)		x	x	x	x	x	x	x	x				
LAI		x		x	x	x	x		x				
Pictures	x	x	x	x	x	x	x	x	x	x	x	x	x
SPAD		x	x	x	x	x	x	x					
Weeds (pcs/0,5m^2)			x	x	x	x	x						
Yield components	x	x									x	x	

LAI was measured with a SunScan SS1 (Delta-T Devices Ltd, Cambridge, UK) canopy analysis system at 3, 5-8 and 10 WAS. The measurement was taken from the front and back of a plot by putting the measurement beam inside the plot about 5 cm off the ground and the mean value for the plot was calculated from the two measurements. SPAD measurements were taken with a Yara N-Tester (YARA GmbH & Co. KG, 30002337, Dülmen, Germany) starting at sprouting (BBCH 10) until seed development (BBCH 70) as 30 random measurements from the youngest fully open leaves to get a representative mean value for the plot. Nitrogen assimilation was calculated after harvest (1).

$$\text{Yield (kg/ha)} \times \text{protein\%} \div 100 \div 6.25 = \text{N assimilation (kg N/ha)} \qquad (1)$$

All yield components were counted from a 80 cm row that was randomly chosen by throwing a tape measure into the plot. Results from the 80 cm row were multiplied by 10 to get the result for one square meter. Yield components for sprouts/m^2 were observed at sprouting (BBCH 10) and shoots/m^2 at tillering (BBCH 20). Panicles/m^2, seeds/panicle and seeds/m^2 were observed at seed ripening (BBCH 80). For yield components seeds/panicle and seeds/m^2 10 randomly chosen plants from the 80 cm row were used for analysis. Only the number of filled seeds were counted.

4.4.2 Quality analyses

Plots were harvested with a Wintersteiger plot combine (Classic, Wintersteiger AG, Pied im Innkreis, Austria), dried on a table dryer and plot yields were sorted and weighted. Hectolitre weight (HLW) and moisture content were measured (GAC 2100, DICKEY-john, Auburn, IL, USA). Thousand seed weight (TSW) was calculated by counting 200 seeds then weighting them multiplied by five. Protein, starch and oil content of the seeds were measured with near infrared spectroscopy (NIRS DS2500, FOSS Analytical AB, Höganäs, Sweden).

A 50g sample from each plot was sieved (SORTIMAT K3, Pfeuffer GmbH, Kitzingen, Germany) into three fractions (Frakt1= <2 mm, Frakt 2 = 2-2.5 mm and Frakt3 = >2.5 mm). The fractions were weighted after which the smallest fraction was discarded. Husk content of the sieved seeds was determined with an industrial hulling method by separating the husks and kernels using a laboratory huller (LPS 1, Streckel & Schrader K.G, Hamburg, Germany). The huller was run for one minute after which the husks were taken out and weighted. The leftover kernels were then inspected by hand and different components were separated and weighted.

4.4.3 Statistical analyses

Statistical analyses were performed with SPSS (IBM SPSS Statistics, 27.0.1.0, New York, USA). The analyses were done as a randomized complete block design following a syntax script that is used at Boreal for statistical analysis based on the experimental model of trials, in this case alpha model. The first analyses were done to identify outliers in the data so that the deviant values could be excluded from the analyses if detected. After that, the least significant difference (LSD) at 0.05 level and the coefficient of variation (CV) were calculated for each yield and quality variable. Correlations were calculated to identify connections between different yield, yield quality and field measurements. The two-tailed Pearson correlation coefficient was used for these analyses. Significant differences between varieties were determined using ANOVA and Tukey post hoc test at p=0.05.

5 RESULTS

5.1 Ground coverage

Canopy height didn't differ significantly between the studied oat varieties at the beginning of the growing season. Varietal differences in height became visible starting from the beginning of seed development at 56 DAS and by the last measurement at 70 DAS the latest varieties 'Taika' and 'Donna' were the tallest at 115 cm and 113 cm, respectively (Figure 3). Height differences between varieties were statistically significant only at 70 DAS.

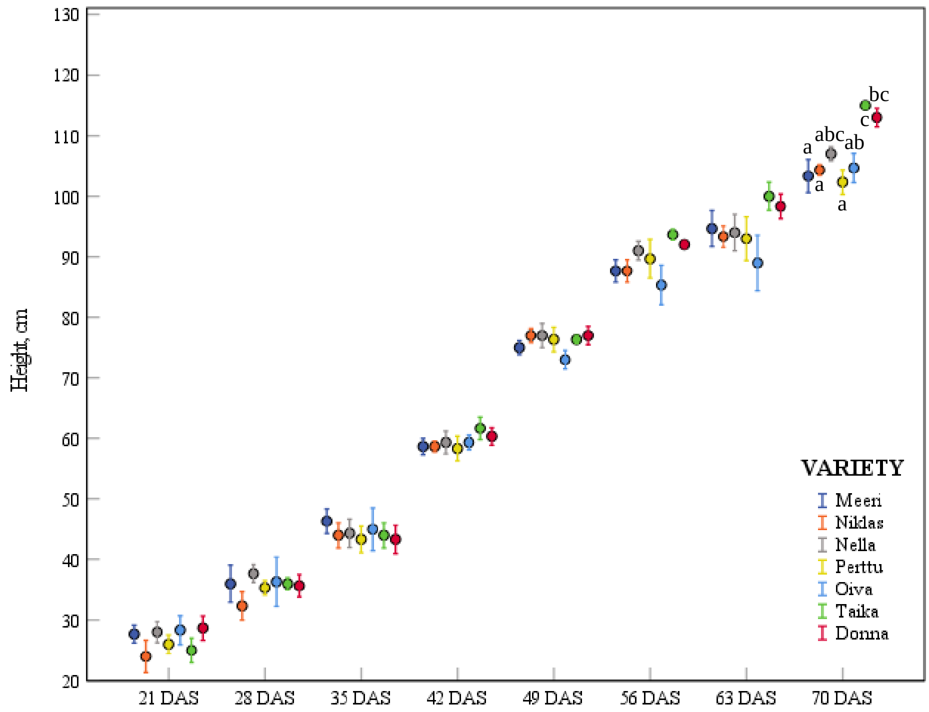

Figure 3. Height of oat varieties measured weekly. Data shown are means, *n*=3. Significant differences were only seen for measurements at 70 DAS. Error bars represent standard errors. Bars with different letters are significantly different (Tuckey-test, *p*=0.05).

On the first week of measurements, at 21 DAS during tillering, 'Donna' had the biggest LAI followed by 'Meeri' (Figure 4). Differences in LAI between varieties started to show from 35 DAS on, during the end of stem elongation. 'Taika' and 'Donna' had the biggest LAI at this point. All varieties reached full ground coverage at 35 DAS. At 42 DAS in the end of booting and beginning of heading, 'Taika' and 'Donna' had the biggest LAI followed by 'Perttu'. The last week of LAI measurements was at 70 DAS by which, 'Oiva' had developed the biggest LAI followed by 'Taika' and 'Donna', respectively. The LAI results increased every week except for 49 DAS and 70 DAS when there was a slight decrease.

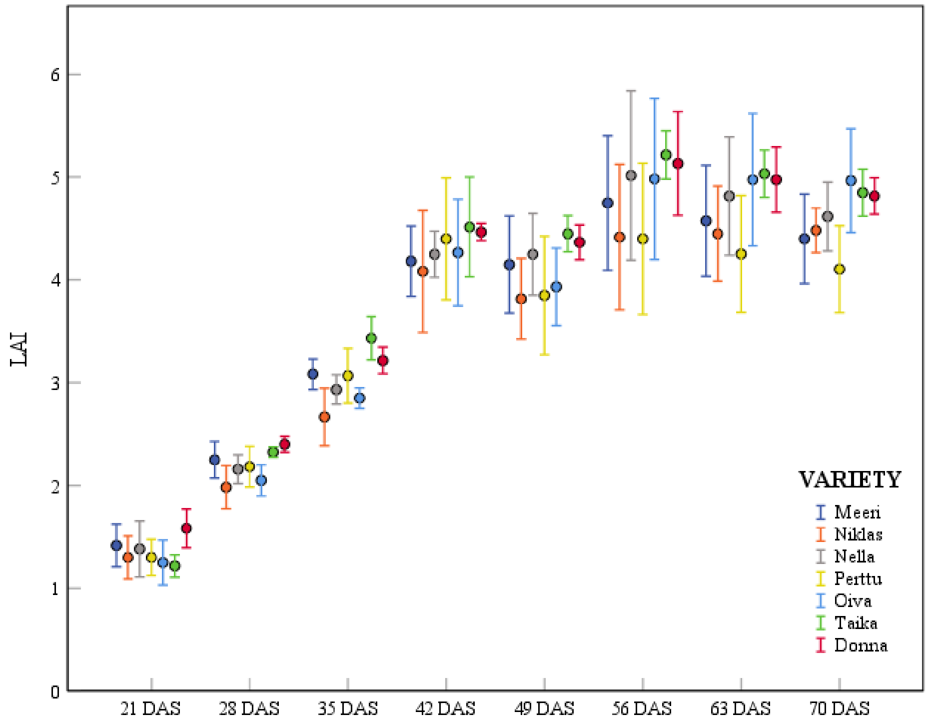

Figure 4. LAI of oat varieties measured weekly. LAI wasn't measured at 28 DAS and 63 DAS so these values are averages from measurements of the previous and following week. Data shown are means, *n*=3. Error bars represent standard errors.

The number of weeds in each plot varied weekly but the differences weren't statistically significant. During the first week of weed observations at 28 DAS, 'Oiva' had the smallest number of weeds at 92 weeds/plot and 'Nella' had the most at 212 weeds/plot (Figure 5). The number of weeds increased for all plots at 35 DAS with 'Donna' having the least weeds at 256 and 'Perttu' had the most at 432. At 42 DAS the number dropped with 'Donna' still having the least weeds at 132/plot and 'Meeri' having the most at 224 weeds/plot. At 49 DAS and 56 DAS the weed count increased steadily with all the varieties. 'Donna' had the least weeds/plot on most weeks followed by 'Niklas'. 'Nella' and 'Meeri' were the varieties with most weeds during the observation period.

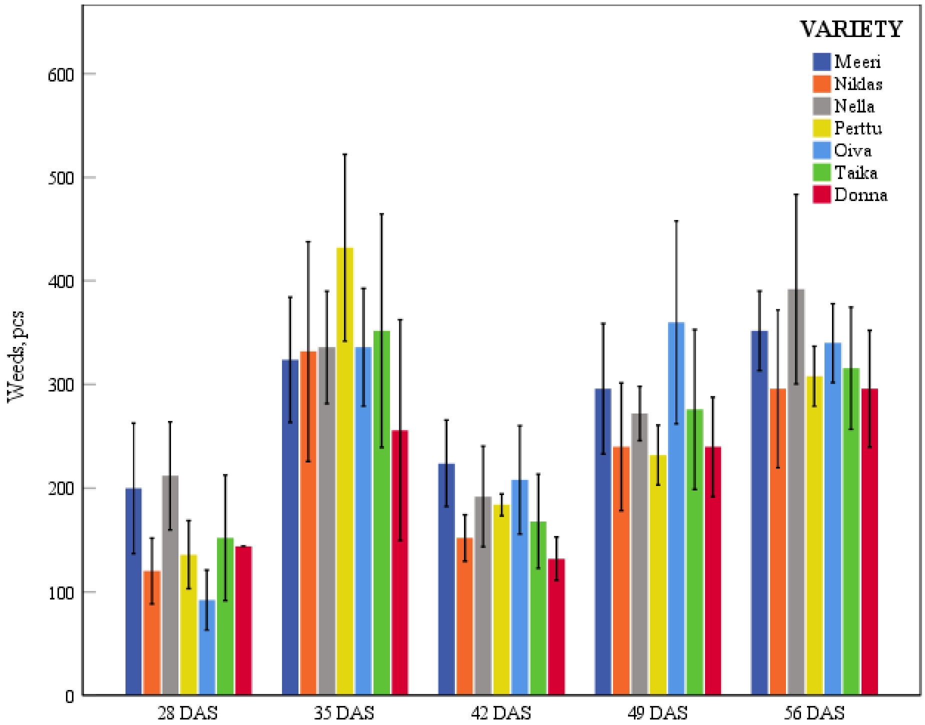

Figure 5. Number of weeds in each oat plot counted weekly. Data shown are means, *n*=3. Error bars represent standard errors.

‘Meeri’, ‘Perttu’, ‘Taika’ and ‘Donna’ had the lowest lodging percentages at 8%, 17%, 10% and 18%, respectively. Varieties with the most extensive lodging were ‘Niklas’ at 35% and ‘Nella’ and ‘Oiva’ both at 28%.

5.2 Nutrient use

The SPAD values increased until 42 DAS, after which they started to decline with a slight increase at 63 DAS (Table 4). The variety with the highest SPAD value varied each week but ‘Meeri’s value being among the lowest was consistent. The most variation in the SPAD values were observed at 28 DAS at the beginning of stem elongation, when the values ranged from 432 to 521, ‘Niklas’ having the highest value and ‘Meeri’ the lowest. The only significant differences between varieties were seen at this time. At 35 DAS and 42 DAS, ‘Oiva’ had the highest SPAD value, 725 and 808, respectively. ‘Meeri’ had the lowest value at 35 DAS at 677 and at 42 DAS ‘Niklas’s value was the lowest at 762 with ‘Meeri’ very close with a value of 764. From 49 DAS to 56 DAS, the varieties among the highest SPAD values were ‘Perttu’, ‘Taika’, ‘Oiva’ and ‘Donna’ with ‘Meeri’ having the lowest values on both weeks. The last measurement at 63 DAS showed that ‘Nella’ had the highest value at 719 and ‘Taika’, ‘Meeri’ and ‘Niklas’ the lowest at around 680.

Table 4. SPAD values of oat varieties measured weekly. Data shown are means, *n*=3. Significant differences were only seen for measurements at 28 DAS.

	Meeri[BOR]	**Niklas[BOR]**	**Nella[BOR]**	**Perttu[BOR]**	**Oiva[BOR]**	**Taika[BOR]**	**Donna[BOR]**
21 DAS	459	493	481	478	477	480	496
28 DAS	432[a]	521[b]	475[ab]	463[ab]	466[ab]	449[a]	494[ab]
35 DAS	677	691	691	679	725	685	684
42 DAS	764	762	784	768	808	770	778
49 DAS	748	773	779	783	781	782	763
56 DAS	659	684	699	715	701	696	713
63 DAS	682	682	719	705	706	680	703

Means within a row with different letters are significantly different (Tuckey-test, p=0.05)

From the late varieties ‘Taika’ had the biggest nitrogen (N) assimilation at 120 N kg/ha and ‘Oiva’ the smallest at 107 N kg/ha. ‘Nella’ had the biggest N assimilation from the early varieties at 116 N kg/ha and ‘Meeri’ the smallest at 110 N kg/ha. The N assimilation of the other varieties ranged from 114 N kg/ha to 115 N kg/ha.

5.3 Yield and yield components

From all the varieties the late variety ‘Donna’ had the biggest yield and ‘Meeri’ had the smallest yield (Figure 6). From the early varieties ‘Nella’ had the biggest yield and from the later varieties ‘Oiva’ had the smallest yield. The later varieties had generally a higher yield than the early varieties. The coefficient of variation (CV) for yield was 5.20 and the least significant difference (LSD) was 564.75. Yields between varieties were not statistically significant.

The early varieties produced generally more sprouts/m^2, panicles/m^2 and seeds/m^2 than the late varieties, which were more efficient in forming shoots/m^2 and seeds/panicle (Figure 6). ‘Nella’ was the only variety that was efficient at forming all yield components, although its seeds/panicle count fell slightly short of the mean of all varieties. ‘Meeri’ was the least efficient in forming yield components and all of its values were below the mean of all varieties. ‘Donna’ had the biggest yield but its values were below the mean in all of the yield component categories except for seeds/panicle.

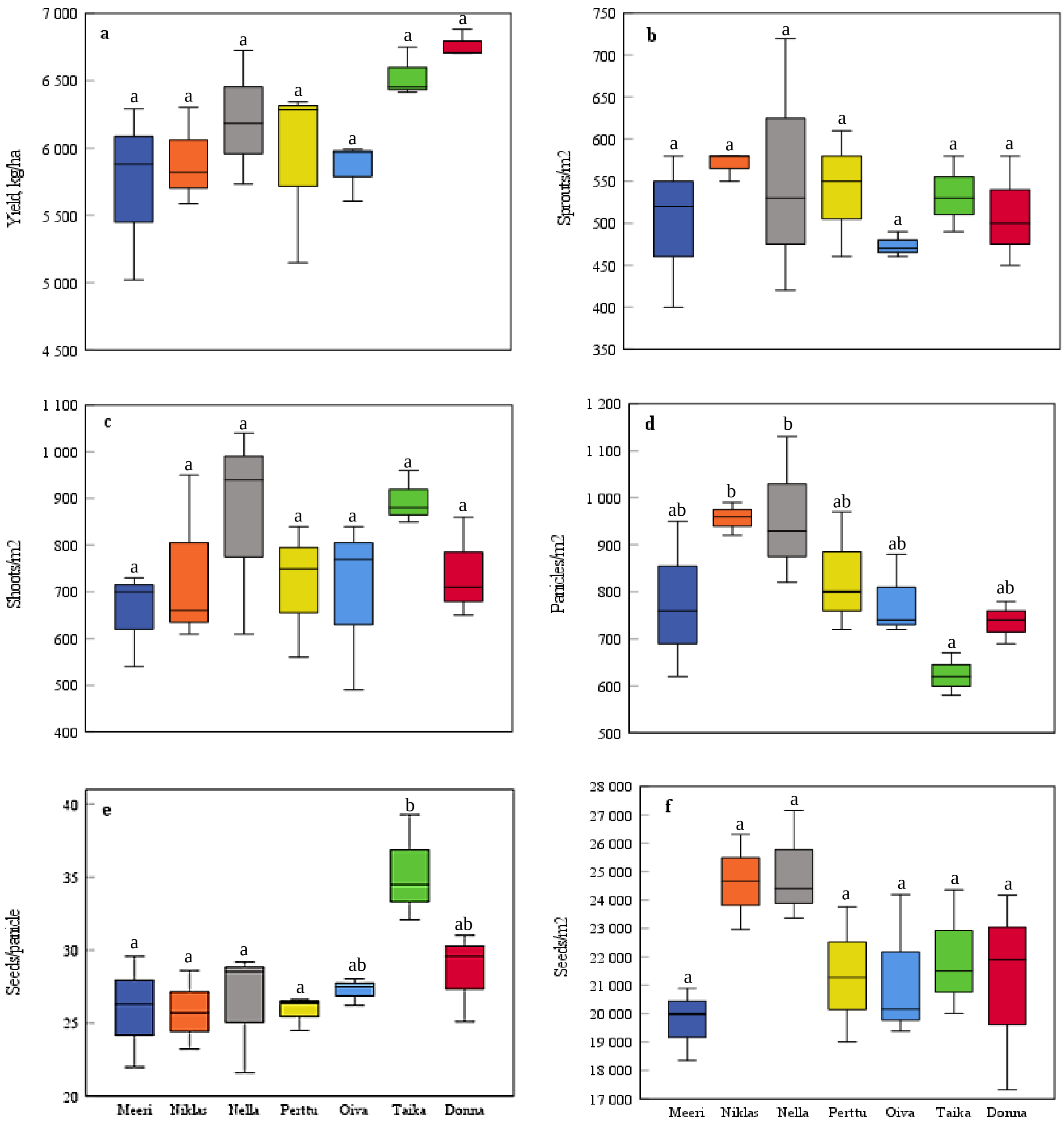

Figure 6. The (**a**) yield kg/ha, yield components (**b**) sprouts/m^2, (**c**) shoots/m^2, (**d**) panicles/m^2, (**e**) seeds/panicle and (**f**) seeds/m^2 of seven oat varieties counted from three replications. The number of seeds was counted from filled seeds only. Within graphs, bars with different letters are statistically different (Tuckey-test, p=0.05).

5.4 Yield quality

The early varieties had generally higher hectolitre weight (HLW) and thousand seed weight (TSW) than the late varieties, with an exception of 'Oiva' having a high HLW (Table 5). 'Meeri' had the highest HLW and 'Niklas' the highest TSW. 'Donna' had the lowest HLW and TSW. The number of seeds bigger than 2.5 mm was the highest in 'Nella' and lowest in 'Perttu'. 'Nella' also had the least seeds smaller than 2 mm and ‘Niklas’ the most. The CV value was high for the groups <2 mm and >2.5 mm. The husk content was the lowest in ‘Nella’ and the highest in ‘Taika’. The rest of the varieties didn’t vary much in the husk content. ‘Perttu’ had the highest protein content and ‘Donna’ the lowest. The early varieties had higher protein contents than the late varieties. ‘Perttu’ had the highest oil content and ‘Oiva’ the lowest. Starch content was the highest in ‘Nella’ and the lowest in ‘Taika’. The early varieties had a generally higher starch content than the late varieties. Overall, the early varieties had higher yield quality than the late varieties.

Table 5. Yield quality and their coefficient of variation (CV) and least significant difference (LSD) for the seven oat varieties. Data shown are means, *n*=3.

Variety	HLW, kg	TSW, g	< 2 mm, %	2 – 2.5 mm, %	> 2.5 mm, %	Husk content, %	Protein, %	Oil, %	Starch, %
$Meeri^{BOR}$	56.57^{b}	36.65^{c}	2.20^{b}	34.60^{cd}	13.13^{ab}	24.80^{b}	12.10^{a}	6.50^{d}	48.40^{cd}
$Niklas^{BOR}$	56.40^{b}	37.40^{c}	3.23^{c}	31.67^{bc}	15.00^{abc}	24.40^{a}	12.10^{a}	6.20^{c}	48.80^{cd}
$Nella^{BOR}$	55.63^{b}	35.12^{bc}	1.13^{a}	23.80^{a}	25.10^{e}	21.90^{b}	11.70^{a}	5.60^{ab}	50.30^{d}
$Perttu^{BOR}$	54.20^{a}	34.52^{abc}	2.50^{b}	35.40^{d}	12.07^{a}	24.50^{ab}	12.20^{a}	7.20^{e}	47.00^{bc}
$Oiva^{BOR}$	55.80^{b}	33.08^{ab}	1.70^{ab}	28.43^{b}	19.90^{d}	23.50^{b}	11.50^{a}	5.40^{a}	47.00^{bc}
$Taika^{BOR}$	53.77^{a}	33.60^{ab}	2.10^{b}	30.70^{b}	17.10^{bcd}	28.20^{c}	11.50^{a}	5.80^{b}	42.10^{a}
$Donna^{BOR}$	53.43^{a}	31.92^{a}	2.20^{b}	30.17^{b}	17.63^{cd}	25.00^{b}	10.70^{a}	5.60^{ab}	44.60^{ab}
CV	1.47	2.70	15.50	4.20	8.30		3.00	1.80	2.20
LSD	1.43	1.63	0.58	2.27	2.49		0.62	0.19	1.79

Means within a row with different letters are significantly different (Tuckey-test, *p*=0.05)

5.5 Correlation coefficients

There was a significant positive correlation between yield and yield components shoots/m^2 (r=0.564, $p \leq 0.01$) and seeds/panicle (r=0.473, $p \leq 0.05$). The rest of the yield components didn’t have a significant relationship with yield.

The correlation between yield and SPAD value varied from negative to positive on different weeks but there were no significant relationships (Table 6). The correlation between yield and plant height was positive on all weeks and the relationships were significant on all weeks except on 21 DAS and 35 DAS. There were no significant relationships in the correlation between yield and the number of weeds in a plot.

LAI and yield had a moderate to strong positive correlation each week on a significant level (Table 6). The correlation between LAI and shoots/m^2 was positive and significant at 21-28 DAS and 42-70 DAS but no significance was detected at 35 DAS. The only significant relationship between LAI and panicles/m^2 was the negative correlation at 35 DAS. Correlations between LAI and seeds/panicle as well as LAI and seeds/m^2 were not significant.

The only significant relationship between LAI and SPAD values was detected at 21 DAS while the relationship was negative (Table 6). LAI and plant height correlated positively on a significant level except for 35 DAS. LAI and the number of weeds didn't have a significant correlation.

Nitrogen assimilation and plant height had a positive correlation of a significant level on all observed weeks (Table 6). N assimilation and LAI also had a positive and significant correlation on all weeks but at 35 DAS.

Table 6. Correlations of the most important yield, yield component and field observation relationships between all seven oat varieties, *n*=21. LAI wasn't measured at 28 DAS and 63 DAS so the values used for the correlations are averages from measurements of the previous and following week.

	21 DAS	**28 DAS**	**35 DAS**	**42 DAS**	**49 DAS**	**56 DAS**	**63 DAS**	**70 DAS**
				Yield				
SPAD	-0.119	0.174	-0.149	-0.059	0.293	0.26	0.143	
Height	0.407	0.452*	0.191	0.655***	0.594**	0.729***	0.659***	0.754***
Number of weeds		0.387	-0.015	-0.285	-0.028	-0.235		
				LAI				
Yield	0.576**	0.726***	0.543*	0.570**	0.768***	0.656**	0.659**	0.612**
Shoots/m^2	0.561**	0.625**	0.41	0.552**	0.741***	0.758***	0.723***	0.607**
Panicles/m^2	0.08	-0.289	-0.483*	-0.07	-0.112	-0.05	-0.079	-0.124
Seeds/panicle	0.061	0.339	0.432	0.24	0.335	0.285	0.291	0.278
Seeds/m^2	0.203	0.003	-0.171	0.136	0.205	0.239	0.208	0.138
SPAD	-0.602**	-0.134	-0.135	0.196	0.29	0.159	0.236	
Height	0.761***	0.703***	-0.101	0.540*	0.709***	0.712***	0.635**	0.607**
Number of weeds		0.418	-0.367	0.083	0.14	-0.251		
				N assimilation				
Height	0.451*	0.627**	0.591**	0.696***	0.772***	0.796***	0.704***	0.503*
LAI	0.727***	0.707***	0.385	0.802***	0.885***	0.801***	0.783***	0.691***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

6 DISCUSSION

6.1 Ground covering ability of the crop didn’t affect weed suppression

High LAI value seemed to increase plant height throughout the growing season according to the correlation of these two traits. Based on this result, LAI and plant height are favourable traits in low-input conditions and should be observed also in the future. Fradgley et al. (2017) observed that height and LAI of winter oat are linked and suggested that the selection for LAI in organic conditions could be done based on plant height in conventional conditions. Although, the study of Fradgley et al. (2017) was performed in England using winter oat phenotypes adapted to the local conditions the positive correlations between LAI and plant height in Boreal Plant Breeding oat cultivars indicate that height could be used to select for LAI also in Finnish spring oat varieties. Despite these results, measuring both LAI and plant height during the growing season is possibly more reliable to evaluate the suitability of varieties to organic agriculture during a longer time period.

The growth rate in LAI and plant height varied among weeks and varieties. Until full ground cover of all varieties at 35 DAS, ‘Meeri’, ‘Taika’ and ‘Donna’ had the fastest growing LAI values. As fast development of LAI early in the growing season has been found to be a good indicatior of the varieties ability to compete against weeds (Lemerle et al. 1996; Huel & Hucl 1996; Fradgley et al. 2017) these varieties display potential for competitive ability against weeds. The LAI values dropped when measured at 49 DAS and 70 DAS. The decreased measurements at 49 DAS are most likely due to technical issues caused by the weather and timing of the measurement during the day as it wasn’t possible to conduct the measurements at the same time and same conditions each week as recommended in the user’s guide of the LAI meter. At 70 DAS the decrease in LAI values could have been caused by maturation of the plants.

Height development was quite steady between varieties until the beginning of seed development at 56 DAS when ‘Taika’ and ‘Donna’ gained clearly more height compared to other varieties. At this point the biggest advantage from fast growth speed in connection to weed competition had passed. In this experiment, ‘Meeri’ was one of the shortest varieties and ‘Donna’ was among the tallest, which is in line with the results from the organic trials in Mustiala (Erlund et al. 2019; Raiskio & Hinkkanen 2020). As plant height can also indicate competitive ability against weeds early in the growing season (Kruepl et al. 2006), none of the varieties showed more potential than others in this trait.

No significant relationship was found in the correlations between the number of weeds and plant height or LAI, which is in contrast with previous research on multiple cereal crops (Fradgley et al. 2017; Piliksere et al. 2013; Kruepl et al. 2006) that showed LAI and plant height to have a weed suppressive effect. This is a result of slow weed growth due to dry weather at the beginning of the growing season so that the minor weed competition didn't disturb the growth of the oats. Another possibility is that calculating the number of weeds instead of measuring weed dry weight (Piliksere et al. 2013) might have affected the results. The significance of weeds requires further examination in the following years, since many studies have confirmed the important weed suppressive effect of LAI and plant height.

The lodging rates differed between varieties but showed similar differences as in conventional trials during the same year. Only 'Oiva' had more lodging than usual. Based on SPAD values, no deficiency was detected in N after booting so lodging could partly be result from high N availability from soil. Ample supply of N has led to lodging also in other studies (Reich et al. 2014). Oat is normally treated with growth regulators in conventional agriculture to prevent lodging. As the lodging observations were done only once before harvest it is hard to draw conclusions on its reasons and effects on yield quality. The timing of lodging has to be observed more closely in order to make better conclusions.

6.2 Nutrient uptake is promoted by plant height and leaf area index

As correlations between LAI and SPAD value were statistically significant only during tillering at 21 DAS, no clear relationship between these two traits was found in this experiment. The significant negative correlation during tillering could be caused by the competition for resources towards building yield potential and growing the leaf area at the same time (Peltonen-Sainio et al. 2005). Heat stress is also one possible cause, since oat has been shown to have low heat tolerance (Hakala et al. 2020) and the weather during spring was dry, and the average temperature during 21 DAS was around 22℃.

All oat varieties showed deficiency in N levels during tillering and at the beginning of stem elongation based on SPAD value guidelines by Yara (Yara n.d.). During this time period, about three weeks before heading, plants go through many simultaneous growth events inside two weeks. Their yield potential is determined through flower formation, which is also dependent of successful pollination and favourable growing conditions (Peltonen-Sainio et al. 2005). Nutrient demand is high during this development stage and so is competition for nutrients. The plants are still relatively small, and their root system is not optimized to get nutrients from deep in the soil. Unfavourable weather conditions can also slow down growth. In this experiment the weather was dry and hot during tillering and cool and wet during stem elongation. These factors can impact the SPAD value during these times.

Correlations between LAI, plant height and N assimilation were positive on significant level throughout the growing season, which indicates that N assimilation, plant height and big LAI have a possitive effect on each other among these varieties. The correlation has also been detected by Gooding et al. (2012) which suggests that high plants have better N assimilation ability.

6.3 High leaf area index and plant height increase crop yield in low-input conditions

Crop yield and growth time correlate on a positive level (Sokoto et al. 2012; Li et al. 2019) which means that late varieties are higher yielders than early varieties. Based on the correlations, LAI has a significant positive effect on yield throughout the growing season and this has also been observed on rice (*Oryza sativa* L.) by Hirooka et al. (2017) and on spring crop mixtures by Klima et al. (2020). During tillering and the beginning of stem elongation LAI had a positive effect on the yield component shoots/m^2 which is likely due to the high demand of resources for fast growth and formation of yield potential. It has been found that high LAI increases potential for photosynthesis and further plant growth (Weraduwage et al. 2015). Towards the end of the growing season 'Nella', 'Oiva', 'Taika' and 'Donna' had the biggest LAI values which suggests that they would have the best potential for photosythesis and N assimilation during this time and therefore efficient seed filling. By this point, the number of flowers has been determined and based on yield 'Nella', 'Taika' and 'Donna' were able to fill their yield potential better than 'Oiva' which had much lower yield.

Plant height and yield correlated on a significant and positive level except for 21 DAS and 35 DAS. Yield components shoots/m2 and seeds/panicle were the components that best determined yield in this experiment based on their correlation with yield. This contrasts researches by Peltonen-Sainio et al. (2007) and Sadras & Slafer (2012) who found seeds/m^2 to be the most important yield component for oat, especially under favourable growing conditions. The late varieties were able to produce more shoots/m^2 and seeds/panicle, which likely explains their higher yields in this experiment. The early varieties likely suffered from the timing of dry weather, continued by strong rain during the development of their yield potential which could have decreased their yield potential.

A significant negative correlation between LAI and panicles/m^2 during stem elongation at 35 DAS could be a result of the competition for resources during this time of many simultaneous growth events as the plant is producing panicles and flowers while also growing its biomass (Peltonen-Sainio et al. 2005). It is also possible that the production of new adventitious shoots starting around this time due to high precipitation caused additional competition for resources.

LAI and plant height proved to be good indicators of the crops yield production ability in low-input conditions based on their correlations with each other, yield and N assimilation. This has also been remarked in research by Gooding et al. (2012) on wheat. Hoad et al. (2006) also detected these to be favourable traits for crops in organic farming in addition to good establishment and tillering ability. Leistrumaite et al. (2009) considered early ground cover on oat to be a good indication of yield potential. If this is the case, the necessary LAI measurements could be performed from start of tillering to the end of stem elongation and reliable conclusions about yield potential could be made based on only those results. The reduced number of measurements would make the process of testing variety suitability to organic conditions much easier.

The highest yielders in this experiment ‘Nella’, ‘Taika’ and ‘Donna were also among the highest varieties throughout the growing season and their LAI values were among the highest towards the end of the season at 49 DAS to 70 DAS. This result suggests that varieties with increased LAI and height are better yielding in low-input conditions.

‘Meeri’ and ‘Donna’ performed in the same yield level in the EkoNu and Mustiala organic trials as they did in this experiment. ‘Niklas’ in the EkoNu trial and ‘Perttu’ in the Mustiala trial also performed in the same level as in this experiment. This gives indication that despite the defects in this experiment, the results are similar than in trials performed in organic conditions in Southern Finland.

6.4 Growth rate and weather conditions effect yield quality

Early oat varieties had higher thousand seed weight than the late varieties. This is likely caused by conditions with higher moisture during seed filling compared to the late varieties which had seed filling stage in dryer conditions. The dry period in the beginning of the growing season and then almost daily rain starting at 28 DAS caused development of late tillers and thus uneven plant stand maturity. Due to the development of late tillers, the late seeds of these plants didn’t have time to fill properly in the later varieties which can also be seen in their higher husk content. Compared to this expriment, the thousand seed weight was higher among varieties in the EkoNu trials (Ström 2020).

The early varieties had a higher protein content than the late varieties. High yield causes lower protein content and this general negative correlation between the two has been noted previously by Kibite & Evans (1984), Simmonds (1995) and Bogard et al. (2010). The difference in growth time among varieties and the weather before seed filling explains the difference in protein content: early varieties used the nutrients made available by rain towards increasing protein content as they had already started seed filling and late varieties still used nutrients towards yield formation (Pleijel et al. 1999). Therefore, late varieties require more nitrogen. Based on the SPAD measurements in this experiment, the nutrient content in plants wasn't insufficient according to SPAD value guidelines by Yara (Yara n.d.). The protein contents of 'Meeri', 'Niklas', 'Perttu' and 'Donna' were at similar levels in EkoNu and Mustiala trials (Ström 2020; Erlund et al. 2019; Raiskio & Hinkkanen 2020) as in this experiment.

This experiment and the EkoNu trial show that 'Donna' and 'Niklas' are good choices for organic agriculture. This is dependent on the intended end use, since variety selection depends on the cultivation area and end use of the yield. The varieties from this experiment offer alternatives for a wide range on end uses. 'Meeri' however seems to be a little bit more sensitive to organic and low-input conditions and therefore, is not the best available choice for organic production in Southern Finland. As the growing season is shorter in Northern Finland the use of early varieties becomes more important. In this experiment, 'Nella' was the variety with the best combination of yield and quality as it had the highest yield out of the early varieties and also high yield quality overall. From the early varieties also 'Perttu' and 'Niklas' were good in quality but lower in yield. Out of the late varieties 'Oiva' had the best quality but unexpectedly low yield, which could have been caused by poor establishment and lodging rate compared to the other varieties possibly during seed filling. 'Donna' and 'Taika' were both high in yield but relatively low in quality.

6.5 Weaknesses of the experiment

Oat varieties with good resistance and tolerance towards diseases like leaf blotch (*Pyrenophora chaetomioides* Speg.) and rust (*Puccinia coronata* Corda) are important in organic agriculture but they weren't observed regularly during this experiment. Plant diseases will definitely be under closer scrutiny in the coming years. The observations and measurements conducted during the growing season were time consuming and many different people were helping with them. This creates a certain unreliability in the results caused by human error. For example, in growth stage observations the differences were not as clear between early and late varieties as expected.

The limiting factor in this study was the lack of trial field that is certified organic. The used field resembles a field that is in transition to organic production. As the nutrient levels in the field naturally decrease, the differences between varieties will likely become more obvious. Crop rotation is essential in organic agriculture and the way it's carried out varies between farms. In this experiment it was not possible to create an extensive crop rotation or add mixed cropping because of limited space and technical limitations. This is a defect that could be fixed by taking this experiment to a field of an organic farm. The experimental field was located in a slight hill and differences between replications were detectable in the measurements.

7 CONCLUSIONS

LAI and plant height were found to be good indicators in evaluation of the performance potential of oat in organic conditions. SPAD value wasn't found to have a connection to oat yield nor was it an indicator for oat LAI. High LAI increased oat height, yield and yield component shoots/m^2 but effected negatively on the yield component panicles/m^2 during the end of stem elongation. Plant height seemed to be a good indicator of yield level. The number of weeds and LAI value didn't have a connection in this experiment and neither did weed number and yield.

The early and late varieties varied in their reaction to the low-input growing conditions. Early varieties had generally lower yield but better yield quality than the late varieties. The late varieties are good choices if the goal is high yield. 'Nella' showed potential to be a variety with good yield quality and relatively high yield in low-input conditions in Southern Finland. The area of cultivation is an important factor in variety selection.

Organic testing is needed in order to see how conventionally bred varieties perform in organic conditions. Results from organic trials help organic farmers make better variety selections for their farm. The most beneficial traits for organic varieties were discovered during this experiment. Improvements can be made by growing the testing network and performing this experiment on a certified organic field that has longer history in organic production.

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9 REFERENCES

Andrews, M. & Lea, P. J. 2013. Our nitrogen 'footprint': the need for increased crop nitrogen use efficiency. Annals of Applied Biology 163: 165-169.

Barberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Research 42: 177-193.

Baresel, J. P. & Reents, H-J. 2006. Observations on long-term wheat variety trials under organic and conventional conditions in Germany. In: Østergård, H & Fontaine, L. (eds.). Cereal crop diversity: Implications for production and products (Proceedings of the COST SUSVAR workshop, June 13-14 2006, La Besse, France). Paris, France: ITAB. pp. 83-87.

Baresel, J. P., Reents, H. J. & Zimmermann, G. 2005. Field evaluation criteria for nitrogen uptake and nitrogen use efficiency. In: Lammerts van Bueren, E. T., Goldringer, I. & Østergård, H. (eds.). Proceedings of the COST SUSVAR/ECO-PB workshop on organic plant breeding strategies and the use of molecular markers (January 17-19 2005). Diebergen, the Netherlands: Louis Bolk Institute. pp. 49-54.

Bertholdsson, N-O. & Jönsson, R. 1994. Weed competition in barley and oats. In: Borin, M. (eds.). Proceedings of 3rd Congress of the European Society of Agronomy, September 18-22 1994, Padova, Italy). pp. 656-657.

Beveridge, L. E. & Naylor, R. E. L. 1999. Options for organic weed control – what growers do. In: British Crop Protection Council. Proceedings in the Brighton Crop Protection Conference – Weeds (November 15-18 1999, Brighton, UK). British Crop Protection Council 3: 939-944.

Bogard, M., Allard, V., Brancourt-Hulmel, M., Heumez, E., Machet, J-M., Jeuffroy, M-H., Gate, P., Martre, P. & Le Gouis, J. 2010. Deviation from the grain protein concentration-grain yield negative relationship in highly correlated to post-anthesis N uptake in winter wheat. Journal of Experimental Botany 61(15): 4303-4312.

Bond, W. & Grundy, A. C. 2001. Non-chemical weed management in organic farming systems. Weed Research 41: 383-405.

Butler, J. D., Byrne, P. F., Mohammadi, V., Chapman, P. L. & Haley, S. D. 2005. Agronomic performance of *Rht* alleles in a spring wheat population across a range of moisture levels. Crop Science 45: 939-947.

Carr, P. M., Horsley, R. D. & Poland, W. W. 2004. Barley, oat and cereal-pea mixtures as dryland forages in the Northern Great Plains. Agronomy Journal 96: 677-684.

Chloupek, O., Foster, B. P. & Thomas, W. T. B. 2006 The effect of semi-dwarf genes on root system size in field-grown barley. Theoretical and Applied Genetics 112: 779-786.

Dawson, J. C., Huggins, D. R. & Jones, S. S. 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. Field Crops Research 107: 89-101.

European Parliament 2018. Regulation of the European Parliament and of the Council on organic production and labelling of organic products and repealing Council regulation no 834/2007. Regulation no 2018/848. Enacted 30.5.2018. Official Journal of the European Union L150. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0848&from=fi. Published 14.6.2018. Visited 20.4.2021.

Ericson, L. 2006. Nutrient use efficiency. In: Donner, D & Osman, A. (eds.). Handbook: Cereal variety testing for organic and low-input agriculture (COST 860 – SUSVAR). Wageningen, The Netherlands: GSC van Gils. pp. N1-N8.

Erlund, P., Fröberg, M. & Lindholm A-S. 2019. Försöksrapport 2019. https://www.nsl.fi/download/Rapporter/forsoksrapporter/Forsoksrapport2019.pdf/?lang=fi. Nylands Svenska Landbrukssällskap. Visited 12.4.2021.

FAO. 2020. Crops. http://www.fao.org/faostat/en/#data/QC/visualize. Rome, Italy: Food and Agriculture Organization of the United Nations. Visited 17.4.2021.

Feledyn-Szewczky, B. & Jonczyk, K. 2016. Assessment of the suitability of oat varieties (*Avena sativa* L.) for cultivation in organic system. Journal of Research and Application in Agricultural Engineering 61(3): 82-87.

FiBL. 2021a. Area data on organic agriculture in Europe 2010-2019. https://statistics.fibl.org/world/area-world.html?tx_statisticdata_pi1%5Bcontroller%5D=Element2Item&cHash=f367262839ab9ca2e7ac1f333fbb1ca2. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL). Visited 17.4.2021.

FiBL. 2021b. Area data on organic agriculture in Finland 2010-2019. https://statistics.fibl.org/world/area-world.html?tx_statisticdata_pi1%5Bcontroller%5D=Element2Item&cHash=f367262839ab9ca2e7ac1f333fbb1ca2. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL). Visited 17.4.2021.

Finnish Food Authority. 2020. Luomuhyväksytty tuotantoala. https://www.ruokavirasto.fi/globalassets/viljelijat/luomutilat/tilastot/lkasva2020.pdf. Seinäjoki, Finland: Finnish Food Authority. Visited 17.4.2021.

FMI. 2021. Finnish Meteorological Institute observatory database. Accessed at Boreal Plant Breeding database. Visited 12.2.2021.

Fradgley, N. S., Creissen, H. E., Pearce, H., Howlett, S. A., Pearce, B. D., Döring, T. F. & Girling, R. D. 2017. Weed suppression and tolerance in winter oats. Weed Technology 31: 740-751.

Fuller, R. J. 1997. Response of birds to organic arable farming: Machanisms and evidence. In: Brighton, UK: Proceedings Brighton Crop Protection Conference – Weeds 3: 355-360.

Gooding, M. J., Addisu, M., Uppal, R. K., Snape, J. W. & Jones, H. E. 2012. Effect of wheat dwarfing genes on nitrogen-use efficiency. The Journal of Agricultural Science 150(1): 3-22.

Gorny, A. G. 1993. Differences in root and shoot response to limited N-supply in oat and spring barley. Journal of Agronomy and Crop Science 171(3): 161-167.

Hedden, P. 2003. The genes of the Green Revolution. Trends in Genetics 19(1): 5-9.

Hirooka, Y., Homma, K., Maki, M., Sekiguchi, K., Shiraiwa, T. & Yoshida, K. 2017. Evaluation of the dynamics of the leaf area index (LAI) of rice in farmer's fields in Vientiane Province, Lao PDR. Journal of Agricultural Meteorology 73(1): 16-21.

Hoad, S. P., Davies, D. H. K. & Topp, C. F. E. 2006. How to select varieties for organic farming: science and practice. Aspects of Applied Biology 79: 117-120.

Hoad, S., Russell, G., Lucas, M. E. & Bingham, I. 2001. The management of wheat, barley and oat root systems. Advances in Agronomy 74: 193-246.

Hoad, S., Topp, C. & Davies, K. 2008. Selection of cereals for weed suppression in organic agriculture: a method baseed on cultivar sensitivity to weed growth. Euphytica 163: 355-366.

Holbrook, F. S. & Welsh, J. R. 1980. Soil-water use by semi-dwarf and tall winter wheat cultivars under dryland field conditions. Crop Science 20(2): 244-246.

Huel, D. G. & Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breeding 115(5): 325-329.

IFOAM. 2019. The IFOAM norms for organic production and processing. https://www.ifoam.bio/sites/default/files/2020-04/ifoam_norms_version_july_2014.pdf. IFOAM International. Published October 2019. Visited 5.6.2021.

Ingver, A., Tamm, I. & Tamm, Ü. 2008. Effect of organic and conventional production on yield and the quality of spring cereals. Latvian Journal of Agronomy 11: 61-67.

Jia, Z., Gruber, B. D., Neumann, K., Kilian, B., Graner, A. & von Wiren, N. 2019. Genetic dissection of root system architectural traits in spring barley. Frontiers In Plant Science 10: 400.

Kaukinen, K., Collin, P., Huhtala, H. & Mäki, M. 2013. Long-term consumption of oats in adult celiac disease patients. Nutrients 5: 4380-4389.

Kibite, S & Evans, L. E. 1984. Causes of negative correlations between grain yield and grain protein concentration in common wheat. Euphytica 33: 801-810.

Kirchmann, H. & Ryan, M. H. 2004. Nutrients in organic farming – Are there advantages form the exlusive use of organic manures and untreated minerals? In: Fischer, T., Turener, N., Angus, J., McIntyre, L., Robertson, M., Borrell, A. & Lloyd, D. (eds.). New directions for a diverse planet (Proceedings for the 4th International Crop Science Congress, September 26-October 1 2004, Brisbane, Australia).

Klima, K., Synowiec, A., Pula, J., Chowaniak, M., Puzynska, K., Gala-Czekaj, D., Kliszcz, A., Galbas, P., Jop, B., Dabkowska, T. & Lepiarczyk, A. 2020. Long-term productive, competitive and economic aspects of spring cereal mixtures in integrated and organic crop rotations. Agriculture 10(6): 231-245.

Koning, L. A., Veste, M., Freese, D. & Lebzien, S. 2015. Effects of nitrogen and phosphate fertilization on leaf nutrient content, photosynthesis and growth of the novel bioenergy crop *Fallopia sachalinensis* cv. 'Igniscum Candy'. Journal of Applied Botany and Food Quality 88: 22-28.

Konvalina, P. & Moudry, J. 2007. Choice of species and varieties of wheat for organic farming. In: Gaile, Z., Spogacuteis, K., Ciprovica, I., Kakitis, A. & Dumbrauskas, A. (eds.). Research for rural development 2007 (Proceedings of the 13th International Scientific Conference "Research for Rural Development 2007", May 16-18 2007, Jelgava, Latvia). Latvia University of Life Sciences and Technologies. pp. 22-29.

Kovács, T. & Pedersen, T. 2019. Overview of the current organizational models for cultivar testing for organic agriculture over some EU countries. https://www.liveseed.eu/wp-content/uploads/2019/07/LIVESEED_D2.1_Overview-of-the-organisational-models-of-cultivar-trials-for-organic-agriculture.pdf. Liveseed. Published 27.5.2019. Visited 2.5.2021.

Kruepl, C., Hoad, S., Davies, K., Bertholdsson, N-O. & Paolini, R. 2006. Weed competitiveness. In: Donner, D & Osman, A. (eds.). Handbook: Cereal variety testing for organic and low-input agriculture (COST 860 – SUSVAR). Wageningen, Netherlands: GSC van Gils. pp. W1-W16.

Labanowska, M., Kurdziel, M., Filek, M. & Weselucha-Birczynska, A. 2016. The impact of biochemical composition and nature of paramagnetic species in grains on stress tolerance of oat cultivars. Journal of Plant Physiology 199: 52-66.

Lammerts van Bueren, E. T. 2002. Organic plant breeding and propagation: Concepts and strategies. PhD Thesis. The Netherlands: Waningen University. pp. 195.

Lammerts van Bueren, E. T., Jones, S. S., Tamm, L., Murphy, K. M., Myers, J. R., Leifert, C. & Messmer, M. M. 2011. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. Wageningen Journal of Life Sciences 58: 193-205.

Lancashire, P. D., Bleiholder, H., van den Boom, T., Langeluddeke, P., Stauss, R., Weber, E. & Witzenberger, A. 1991. A uniform decimal code for growth stages of crops and weeds. Annals of Applied Biology 119(3): 561-601.

Leistrumaite, A., Liatukas, Z. & Razbadauskiene, K. 2009. The spring cereals traits of soil cover, disease resistance and yielding essential for organic growing. Agronomy Research 7(1): 374-380.

Lemerle, D., Verbeek, B., Cousens, R. D. & Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Research 36(6): 505-513.

Li, R., Li, M., Ashraf, U., Liu, S. & Zhang, J. 2019. Exploring the relationship between yield and yield-related traits for rice varieties released in China from 1978 to 2017. Frontiers in Plant Science 10: 543.

Lin, F. F., Qiu, L. F., Deng, J. S., Shi, Y. Y., Chen, L. S. & Wang, K. 2010. Investigation of SPAD meter-based indices for estimating rice nitrogen status. Computers and Electronics in Agriculture 71S: S60-S65.

Lopes, M. S., Reynolds, M. P., Manes, Y., Singh, R. P., Crossa, J. & Braun, H. J. 2012. Genetic yield gains and changes in associated traits of CIMMYT spring bread wheat in a "historic" set representing 30 years of breeding. Crop Science 52: 1123-1131.

Luke. 2021. Satotilasto. https://stat.luke.fi/satotilasto. Helsinki, Finland: Natural Resources Institute Finland. Visited 17.4.2021.

Löschenberger, F., Fleck, A., Grausgruber, H., Hetzendorfer, H., Hof, G., Lafferty, J., Marn, M., Neumayer, A., Pfaffinger, G. & Birschitzky J. 2008. Breeding for organic agriculture: the example of winter wheat in Austria. Euphytica 163: 469-480.

Mac Key, J. 1988. Shoot:root interrelations in oats. In: Mattson, B. & Lyhagen, R. (eds.). 3rd International Oat Conference (Lund, Sweden). Svalöf AB. pp. 340-344.

Ministry of Agriculture and Forestry 2004. Maa- ja metsätalousministeriön asetus kasvilajikkeiden lajikeluettelosta. Regulation no 51/2004. Enacted 23.6.2004. Finlex® electronic statute data bank: https://finlex.fi/fi/viranomaiset/normi/400001/19536. Visited 2.5.2021.

Monostori, I., Arendas, T., Hoffman, B., Galiba, G., Gierczik, K., Szira, F. & Vagujfalvi, A. 2016. Relationship between SPAD value and grain yield can be affected by cultivar, environment and soil nitrogen content in wheat. Euphytica 211: 103-112.

Mukula, J. & Rantanen, O. 1989. Climatic risks to the yield and quality of field crops in Finland. VII. Oats 1969-1986. Annales Agriculturae Fenniae 28: 37-43.

Murphy, K. M., Cambell, K. G., Lyon, A. R. & Jones, S. S. 2007. Evidence of varietal adaptation to organic farming systems. Filed Crops Research 102: 172-177.

Muurinen, S., Slafer, G. A. & Peltonen-SAinio, P. 2006. Breeding effects on nitrogen use efficiency of spring cereals under Northern conditions. Crop Science 46: 561-568.

Mäder, P., Fliebach, A., Dubois, D., Gunst, L., Fried, P. & Niggli, U. 2002. Soil fertility and biodiversity in organic farming. Science 296: 1694-1697.

Nykänen, A., Ajosenpää, H., Erlund, P., Järnefelt, S., Kuosmanen, V., Luokkakallio, J., Matilainen, K., Nurkka, J., Partanen, E., Suutarla, M., Terhemaa, P. & Vihonen, E. 2014. Mikä viljalajike luomuun? – Tuloksia kesän 2014 ruutu- ja havaintokokeista. https://www.ekonu.fi/wp-content/uploads/Luomuviljojen-lajikekokeet-2014-loppuraportti.pdf. Pro Agria. Published 2014.

Osman, A., van den Brink, L. & Lammerts van Bueren, E. 2008. Comparing organic and conventional VCU testing for spring wheat in the Netherlands. In: Rey F, Fontaine L, Osman A, van Waes J (eds.). Proceedings of the COST ACTION 860 – SUSVAR and ECO-PB Workshop on Value for Cultivation and Use testing of organic cereal varieties. What are the key issues? (February 28-29 2008, Brussels, Belgium). Paris, France: SUSVAR, COST, ECO-PB, ITAB. pp. 37-41.

Østergård, H., Finckh, M. R., Fontaine, L., Goldringer, I., Hoad, S. P., Kristensen, K., Lammerts van Bueren, E. T., Mascher, F., Munk, L. & Wolfe, M. S. 2009. Time for a shift in crop production: embracing complexity through diversity at all levels. Journal of the Science of Food and Agriculture 89: 1439-1445.

Othman, R. A., Moghadasian, M. H. & Jones, P. Jh. 2011. Cholesterol-lowering effects of oat β-glucan. Nutrition Reviews 69(6): 299-309.

Pedersen, T. M. 2012. Organic VCU testing – Current status in 16 European countries. Knowledge Centre for Agriculture. Denmark. 48 pp.

Pedersen, T. M., de Buck, A., Flamm, C. & Rey, F. 2021. Guidelines for adapted DUS and VCU testing of organic varieties. https://www.liveseed.eu/wp-content/uploads/2021/02/D2.4-LIVESEED-Guidelines-for-adapted-DUS-and-VCU-testing-of-organic-varietie.pdf. Liveseed. Publihed 11.2.2021. Visited 5.10.2021.

Peltonen-Sainio, P., Kangas, A., Salo, Y. & Jauhiainen., L. 2007. Grain number dominates grain weight in temperate cereal yield determination: Evidence based on 30 years of multi-location trials. Field Crops Research 100: 179-188.

Peltonen-Sainio, P., Rajala, A. & Seppälä, R. T. 2005. ABC of cereal development and growth. Maa- ja elintarviketalous 67. Jokioinen, Finland: Agrifood Research Finland, Plant Production Research. 72 pp.

Piliksere, D., Strazdina, V., Vïcupe, Z., Jansone, Z., Legzdina, L., Beinarovica, I. & Kronberga, A. 2013. Cereal breeding for organic farming: Crop traits related with competitiveness against weeds. Proceedings of the Latvian Academy of Sciences. Section B, Natural Sciences 67(3): 272-276.

Pinstrup-Andersen, P. & Pandya-Lorch, R. 1998. Major uncertainties and risks affecting long-term food supply and demand. In: The future food – long-term prospects for the agro-food sector. OECD. Paris, France. pp. 53-70.

Pleijel, H., Mortensen, L., Fuhrer, J., Ojanperä, K. & Danielsson, H. 1999. Grain protein accumulation in relation to grain yield of spring wheat (*Triticum aestivum* L.) growing in open-top chambers with different concentrations of ozone, carbon dioxide and water availability. Agriculture, Ecosystems and Environment 72: 265-270.

ProAgria 2016. Kauralajikkeiden testausta luomutuotannossa Pohjois-Pohjanmaalla. Kauralajikkeiden testausta luomutuotannossa Pohjois-Pohjanmaalla | ProAgria Koko Suomi. Published 16.12.2016. Visited 10.5.2021.

ProLuomu. 2021. Luomuelintarvikkeiden vientiselvitys. https://proluomu.fi/wp-content/uploads/2018/04/luomuelintarvikkeiden-vientiselvitys-2020.pdf. Ministry of Agriculture and Forestry of Finland. Visited 10.4.2021.

Puzynska, K., Puzynski, S., Synowiec, A., Bocianowski, J. & Lepiarczyk, A. 2021. Grain and total protein content of organically grown oats-vetch mixtures depending on soil type and oats' cultivar. Agriculture 11(1): 79-100.

Raiskio, S. & Hinkkanen, K. 2020. Lajike- ja lajikeseoskoe 2020 Mustiala. https://sites.google.com/a/luovapaja.com/luomussa-vara-parempi/tuotokset. Häme University of Appled Sciences. Published 8.12.2020.

Rasane, P., Jha, A., Sabikhi, L., Kumar, A. & Unnikrishnan, V. S. 2015. Nutritional advantages of oats and opportunities for its processing as value added foods – a review. Journal of Food Science and Technology 52(2): 662-675.

Reich, M., Aghajanzadeh, T. & De Kok, L. J. 2014. Physiological basis of plant nutrient use efficiency – Concepts, opportunities and challenges for its improvement. In: Hawkesford, M. J., Kopriva, S. & De Kok, L. J. (ed.). Nutrient Use Efficiency in Plants: Concepts and approaches. Switzerland: Springer. pp. 1-28.

Sadras, V. O. & Slafer, G. A. 2012. Environmental modulation of yield components in cereals: Heritabilities reveal a hierarchy of phenotypic plasticities. Field Crops Researh 127: 215-224.

Siddique, K. H. M., Belford, R. K. & Tennant, D. 1990. Root:shoot ratios of old and modern, tall and semi-dwarf wheats in a Mediterranean environment. Plant and Soil 121(1): 89-98.

Simmonds, N.W. 1995. The relation between yield and protein in cereal grain. Journal of the Science of Food and Agriculture 67(3): 309-315.

Sokoto, M. B., Abubakar, I. U. & Dikko, A. U. 2012. Correlation analysis of some growth, yield, yield components and grain quality of wheat (*Triticum aestivum* L.). Nigerian Journal of Basic and Applied Science 20(4): 349-356.

Spasova D. & Menkovska, M. 2009. Comparative analysis of oat quality grown in organic and convetional conditions. Biotechnology in Animal Husbandry 25(5-6): 1163-1170.

Ström, M. 2019. Loviisan vuoden 2019 luomukokeiden esittely. https://www.ekonu.fi/wp-content/uploads/EkoNu-luomukokeet-tulokset-2019-korrigerad-version.pdf. EkoNu 3.0. Published 21.11.2019. Visited 14.4.2021.

Ström, M. 2020. Presentation av ekoförsök i Lovisa 2020. https://www.ekonu.fi/wp-content/uploads/Presentation-av-ekosortf%C3%B6rs%C3%B6ken-i-Lovisa-2020_sortval.pdf. EkoNu 3.0. Published January 2021. Visited 15.4.2021.

Tarui, A., Matsumura, A., Asakura, S., Yamawaki, K., Hattori, R. & Daimon, H. 2013. Evaluation of mixed cropping of oat and hairy vetch as green manure for succeeding corn production. Plant Production Science 16(4): 383-392.

Uusitalo, V. & Leino, M. 2019. Neutralizing global warming impacts of crop production using biochar from side flows and buffer zones: A case study of oat production in the boreal climate zone. Journal of Cleaner Production 277: 48-57.

VN 2021. Luomu 2.0 – Suomen kansallinen luomustrategia vuoteen 2030. VN/10305/2021. https://mmm.fi/documents/1410837/2046626/LIITE+Luonnos+Luomu+2.0+%E2%80%93+Suomen+luomuohjelma.pdf/a3a1ae4f-ff9f-a985-9d14-4f6835969f5b/LIITE+Luonnos+Luomu+2.0+%E2%80%93+Suomen+luomuohjelma.pdf?t=1619726171221. Published 23.4.2021. Visited 10.5.2021.

Watson, P. R., Derksen, D. A. & Van Acker, R. C. 2006. The ability of 29 barley cultivars to compete and withstand competition. Weed Science 54: 783-792.

Weraduwage, S. M., Chen, J., Anozie, F. C., Morales, A., Weise, S. E. & Sharkey, T. D. 2015. The relationship between leaf area growth and biomass accumulation in *Arabidopsis thaliana*. Frontiers in Plant Science 6: 167.

Wojciechowski, T., Gooding, M. J., Ramsay, L. & Gregory, P. J. 2009. The effects of dwarfing genes on seedling root growth of wheat. Journal of Experimental Botany 60(9): 2565-2573.

Wolfe, M. S., Baresel, J. P., Desclaux, D., Goldringer, L., Hoad, S., Kovács, G., Löschenberger, F., Miedaner, T., Østergård, H. & Lammerts van Bueren, E. T. 2008. Developments in breeding cereals for organic agriculture. Euphytica 163: 323-346.

Yara 2013. N-tester instruction manual. https://www.yara.my/contentassets/6d5ba39b1a364a33be1e4e6b6b2a2be1/n-tester-instruction-manual.pdf/. Yara GmbH & Co. Published March 2013.

Yara. n.d. N-tester – to measure leaf nitrogen. https://www.yara.co.uk/crop-nutrition/farmers-toolbox/n-tester/. Yara GmbH & Co. Visited 15.5.2021.

Zimdahl, R. L. 2004. Weed-crop competition: A review. 2nd ed. Oxford, UK: Blackwell Publishing Ltd. 220 pp.

Zinta, G. Bleidere, M., Skrabule, I. & Vigovskis, J. 2004. The first steps in variety testing for organic agriculture in Latvia: oats and potatoes. In: Martinez, A., Scialabba, N., Geier, B. & Le Buanec, B. (eds.). Challenges and opportunities for organic agriculture and the seed industry (Proceedings of the First World Conference on Organic Seed, July 5-7 2004, Rome, Italy). pp. 173.

APPENDIX 1: Soil analysis

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Tutkimustodistus AR-20-FV-017048-01-fi **Sivu 1/2**
Päivämäärä 29/10/2020
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Tutkimuksen yhteyshenkilö : Venla Jokela
Näyte otettu 22.5.2020
Saapunut 6.10.2020
Tila 169078676
Kunta Jokioinen

Analyysi		Yksikkö	20-00096193	20-00096194	20-00096195	20-00096196	20-00096197	20-00096198	20-00096199
Numero			1	2	3	4	5	6	7
Peruslohkotunnus			1690376358	1690376358	1690376358	1690376358	1690376358	1690376358	1690376358
Nimi			J9/1	J9/2	J9/3	J9/4	J9/5	J9/6	J9/7
Maalaji	FV(a)		HeS	HeS	HeS	HeS	HeS	HeS	HeS
Multavuus	FV(a)		rm	rm	rm	rm	rm	rm	rm
Johtoluku	FV(a)	10 mS/cm	1,8	1,7	2,4	3,0	2,5	2,6	2,7
pH	FV(a)		6,4	6,7	6,9	7,1	6,9	6,9	7,2
Kalsium (Ca)	FV(a)	mg/l	3500	3900	4600	5800	4700	4600	6600
Fosfori (P)	FV(a)	mg/l	26	22	26	36	32	26	37
Kalium (K)	FV(a)	mg/l	320	320	320	290	320	330	300
Magnesium (Mg)	FV(a)	mg/l	590	700	620	550	550	610	630
Rikki (S)	FV(a)	mg/l	23	10	10	15	12	12	14
Kupari (Cu)	FV(a)	mg/l	14	14	15	15	14	14	14
Mangaani (Mn)	FV(a)		110	84	67	48	63	60	43
Sinkki (Zn)	FV(a)	mg/l	17	13	14	19	14	14	18
Fosfori (P), varastorav.	FV	mg/l	410	340	310	380	380	320	400
Magnesium (Mg), varastorav.	FV	mg/l	5300	5100	5100	5000	5000	4800	5300
Kalium (K), varastorav.	FV	mg/l	2800	2500	2500	2600	2600	2500	2700
Kalsium (Ca), varastorav.	FV	mg/l	4000	3900	5200	6300	5000	4800	6600
Kationin vaihtokapasiteetti	FV	cmol/kg	27	29	31	36	31	31	40
Ca/ KVK	FV	%	65	67	74	81	76	74	83
K/ KVK	FV	%	3	3	3	2	3	3	2
Mg/ KVK	FV	%	18	20	17	13	15	16	13
Na/ KVK	FV	%	1	1	1	1	1	1	1
Kalkitustarve	FV	tonni/ha	0	0	0	0	0	0	0
Suositeltava kalkkilaji	FV		Kalkkikivi-jauhe	Kalkkikivi-jauhe	Kalkkikivi-jauhe	Vapaa-valintainen	Vapaa-valintainen	Kalkkikivi-jauhe	Vapaa-valintainen

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T096 (EN ISO/IEC 17025)

Tutkimustodistus AR-20-FV-017048-01-fi Sivu 2/2
Päivämäärä 29/10/2020
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Saapunut 6.10.2020

Tila 169078676
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MENETELMÄKUVAUKSET

FVM01	**Pintamaan maalaji:** Aistinvarainen määritys	FVM02	**Multavuus:** Aistinvarainen määritys
FVM03	**Johtoluku:** ISO 11265 : 1994, mod.	FVM04	**pH:** ISO 10390 : 2005, mod.
FVM05	**Kalsium (Ca), vaihtuva:** Vuorinen, J. & Mäkitie O. 1955	FVM06	**Fosfori (P), liukoinen:** Vuorinen, J. & Mäkitie O. 1955
FVM07	**Kalium (K), vaihtuva:** Vuorinen, J. & Mäkitie O. 1955	FVM08	**Magnesium (Mg), vaihtuva:** Vuorinen, J. & Mäkitie O. 1955
FVM10	**Rikki (S), liukoinen:** Vuorinen, J. & Mäkitie O. 1955	FVM12	**Kupari (Cu), liukoinen:** Acta Agr. Fenn. 122:223-232
FVM13	**Mangaani (Mn), liukoinen:** Acta Agr. Fenn. 122:223-232	FVM14	**Sinkki (Zn), liukoinen:** Acta Agr. Fenn. 122:223-232
FVM15	**Kationinvaihtokapasiteetti, laskenn.:** CC Attribution-ShareAlike 4.0	FVM17	**Ravinnereservit (Ca, K, P, Mg):** Sis. men.
FVM34	**Kalkitustarve:**		

Huomautukset
Asiakirjojen osittainen kopioiminen on kielletty. Testaustulos koskee vain tutkittua näytettä. Lausunto ei kuulu akkreditoinnin piiriin. Akkreditoidut menetelmät on arvioitu tutkimuksen suorittaneen laboratorion oman maan akkreditointielimen toimesta. Tämä tutkimustodistus on luotu sähköisesti ja se on tarkastettu ja hyväksytty. Mittausepävarmuuksien osalta lisätietoja saatavilla pyydettäessä, eikä mittausepävarmuuksia huomioida raja-arvotarkasteluissa.
= Tulos poikkeaa raja-arvosta.
[ ] = Mahdolliset raja-arvot ovat tuloksen perässä hakasuluissa.

FV = Analysoiva laboratorio on Eurofins Viljavuuspalvelu (Mikkeli).
(a) = Analyysit on tehty akkreditoidulla menetelmällä (SFS EN ISO/IEC 17025:2005 FINAS T096).
Ali = Analyysin suorittanut laboratorio ei kuulu Eurofins-konserniin.

Viljavuusluokat	Lähde: Viljavuustutkimuksen tulkinta peltoviljelyssä 2000 (raja-arvot kuuluvat ylempään viljavuusluokkaan)
Huono, Huononlainen, Välttävä, Tyydyttävä, Hyvä, Korkea, Arveluttavan korkea	