CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENGINEERING

DEPARTMENT OF AGRICULTURAL MACHINES

DIPLOMA THESIS

VARIABLE AND MODIFIED PLANT ESTABLISHMENT WITH RESPECT TO AGRO-ENVIRONMENTAL MEASURES

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Engineering

DIPLOMA THESIS ASSIGNMENT

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Technology and Environmental Engineering

Thesis title

Variable and modified plant establishment with respect to agro-environmental measures

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Objectives of thesis

The aim of the diploma thesis is to evaluate the variable and modified tillage and sowing impact on the development of the plants and the yield of corn, cereals and sugar beet.

Methodology

The diploma thesis will focus on the evaluation of variable and modified tillage and sowing of corn, cereals and sugar beet. Procedures for establishment of plants with limited intensity of tillage will be evaluated. Prescription maps for establishing stands will be designed based on knowledge of land variability and land yield potential. The physical properties of the soil, the infiltration properties of the soil, the biometric indicators of the stands and the crop yield will be evaluated during the growing season.

As part of the biodiversity support, wheel rows will sow with flowering plants in the corn fields. The impact on the edge effect of the plants will be assessed.

Methodology

1. Compilation of a literature review with a focus on tillage, traffic intensity, variable seeding and water infiltration.

2. Preparation of map materials, proposal for the organization of a field experiment and establishment of field experiments with variable and modified tillage and sowing.

3. Sampling and evaluation of biometric indicators of plants, evaluation of physical properties of the soil at selected points.

4. Evaluation of infiltration ratios at different intensities of tillage.

5. Evaluation of crop yield and evaluation of economic impacts.

6. Discussion of results and conclusion.

The topic fits into the concept of the Common Agricultural Policy and the upcoming legislative measure Green Deal for Europe and Farm to Fork. Specifically, it is a reduction in the intensity of land cultivation, associated with a reduction in greenhouse gas emissions, the promotion of biodiversity and a reduction in pesticide load and fertilization.

The proposed extent of the thesis

50 p.

Keywords

Soil tillage; variable seeding; soil compaction; root development; biodiversity;

Recommended information sources

HEEGE, Hermann J. *Precision in crop farming : site specific concepts and sensing methods: applications and results.* Dordrecht: Springer, 2013. ISBN 978-94-007-6759-1.

TITI, Adel El. *Soil tillage in agroecosystems.* Boca Raton: CRC, 2003. ISBN 978-0849312281.

ZHANG, Qin. *Precision agriculture technology for crop farming.* Boca Raton: CRC Press, 2016. ISBN 9781482251081.

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Prague on 31. 03. 2024

DECLARATION

I hereby declare that this Master's Thesis '**Variable and Modified Plant Establishment with Respect To Agro-Environmental Measures**' is the result of my work and that it has not been submitted to this University or any institution for a degree. All references, however, used in the development of the work have been duly acknowledged in the text and provided in the list of references.

In Prague Date: 31st March 2024

Nurul Dinda Latifah

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I express my heartfelt appreciation to my parents for their unwavering support and encouragement, which have empowered me to pursue my path and navigate life's decisions. Their guidance and belief in me have been instrumental in shaping my journey, and I am deeply grateful for their constant presence and encouragement. This transformative journey of self-discovery would not have been possible without their steadfast support.

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ABSTRACT

Global food security relies on food production, yet persistent difficulties such as soil desertification, chemical pollution, and biodiversity loss persist. The problems may increase with the predicted world population surpassing nine billion by 2050. This study aims to evaluate the effects of different tillage and sowing procedures, both variable and modified, on the yields of corn, barley, and sugar beet. The research was carried out in collaboration with Statek Chyše s.r.o. and Zemědělská akciová společnost Mžany a.s. They are employing prescription maps to maximize resource utilization and improve profitability per unit of land. The study's results demonstrate a multifaceted correlation between soil conductivity, seeding density, and grain production, wherein elevated conductivity levels tend to be linked to enhanced productivity. The utilization of NDVI as a measure of vegetation vitality is crucial, as there is a positive correlation between higher seeding ratios and healthier vegetation. The efficacy of greening spraying rows in enhancing agricultural functions is underscored by operational testing conducted in 2023. However, it is essential to acknowledge that there may be trade-offs in primary crop yield, which the advantages of biomass production and ecological variety can counterbalance. Implementing modified tillage practices in sugar beet farming has enhanced water infiltration and soil health, improving precipitation usage and accessibility to water resources. In summary, the implementation of variable seeding and modified tillage techniques shows the potential to enhance agricultural productivity and promote sustainability.

KEYWORDS: Biodiversity; NDVI Index; soil tillage; variable seeding; yield potential

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1 INTRODUCTION

Agriculture was a point of focus for the economic sciences for a long time. Yet, since the second half of the 20th century, it has increasingly been under the focus of environmental sciences. As food production is a fundamental component of the food security system due to its production capacities, the extensive production measures brought to the attention the diminishing of these capacities due to soil desertification due to monocropping, the impact of chemicals on biodiversity, and environmental pollution. In 2009, the Food and Agriculture Organization of the United Nations (FAO) issued a report, "How to Feed the World in 2050", predicting the global population to reach over nine billion in the year 2050. The report raises awareness of the increasing constraints on agricultural production factors such as "soil nutrient, depletion, erosion, desertification" (FAO, 2009, p. 8).

There are different ideas on how to improve the agricultural production system and its health, starting from overarching institutional arrangements on an international level, such as other EU's Common Agricultural Policy (CAP) programs beginning with the Agenda 2000 and the 2030 SDG (Sustainable Development Goals) (Bernini & Galli, 2024), going through Health Check, and ending with the European Green Deal, for now, to mention a few. All of these increase the focus on the environmental part of agriculture, aligning with the so-called II Pillar. In contrast, the I Pillar focuses on the production and economic part of agriculture (Bernini & Galli, 2024). The goal of II Pillar measures is to, first and foremost, improve the non-production features of agriculture (the so-called multi-functionalism, i.e., the view that agriculture grants not only economic benefits but multiple others, such as reducing environmental impact (Jeremias, 2015; Saman, 2021)).

Moreover, direct measures implement new techniques and environmentally beneficial (or at least neutral) technologies on-field. Precision farming maximizes the utilization of inputs like water, fertilizer, and pesticides by utilizing cutting-edge technologies like drones and GPS (Monteiro et al., 2021). The application of conservation tillage techniques is an additional direct measure. Conservation tillage techniques lessen soil disturbance, strengthen soil structure, lessen erosion, increase water retention, and sequester carbon, all of which help to mitigate the effects of climate change (Bufebo et al., 2023; Hunt et al., 2020; Spence et al., 2011). As a sustainable farming method, intercropping entails growing several crop species concurrently in one field. While having a more negligible negative environmental impact, it increases agricultural productivity, resource efficiency, soil health, biodiversity, nutrient cycling, insect control, grain quality, greenhouse gas emissions, and weed control (Brooker et al., 2015; L. Li et al., 2014; Maitra et al., 2021).

Throughout this research project, a multifaceted approach was undertaken to investigate the effects of tillage, traffic intensity, variable seeding, and water infiltration. This included compiling a thorough literature review focusing on these factors and preparing map materials and proposals for field experiments. Subsequently, field experiments were established, incorporating diverse tillage and seeding methods. Biometric indicators of plants were sampled and evaluated, alongside the assessment of soil physical properties at specific points. Infiltration ratios were then examined across different tillage intensities to understand water movement in the soil. Finally, crop yield was assessed, and the economic impacts of the various agricultural practices were rigorously analyzed, culminating in a comprehensive evaluation of the study's findings. The diploma thesis aims to evaluate the effects of variable and modified tillage and sowing on plant development and corn, barley, and sugar beet yield.

2 LITERATURE REVIEW

2.1 Factors Influencing Plant Establishment

The establishment of plants in the field is impacted by a variety of complex elements, both environmental and biological. Seed lifetime is a crucial determinant that influences the rates at which seeds emerge in the field, form seedlings, and contribute to the overall growth of plants. This, in turn, significantly impacts the yield and quality of crops in agroecosystems (Zhou et al., 2020). The spread and establishment of plants can be substantially influenced by the allocation of resources inside the plant, which is, in turn, affected by plant diversity (Gaiero et al., 2013).

The interactions between seeds, shoots, and soil microorganisms in the field significantly impact plant physiology and establishment throughout the early stages of growth. This emphasizes the necessity of comprehending the dynamics of seed-borne endophytes (Hardoim et al., 2012). In addition, external variables such as highly low-frequency magnetic fields can affect plants' growth and development, affecting their reactions to other environmental elements (Grinberg et al., 2022).

2.1.1 Environmental Factor

A. Soil characteristics

The soil properties are critical in determining the success of plant growth and establishment. Soil fertility, texture, pH, and nutrient content are key factors that directly influence plant growth and development. Studies have shown that soil nutrients and biomass plays a crucial part in comprehending the distinctions within soil microbial communities during ecological succession. This highlights the complex connection between plant biomass, soil nutrients, and microbial diversity (Le Gall et al., 2015). Furthermore, invasive plant species can alter the amounts of carbon and phosphorus in the soil, especially in the uppermost layer, which may aid in the growth of future generations of plants (Muhammad et al., 2021).

Soil salinity and solidity are essential elements that significantly impact soil-water relations and plant growth in dryland settings. Excessive soil salinity can impede plants' capacity to absorb water, resulting in decreased agricultural output, soil erosion, and diminished economic profits (Fusi et al., 2016). This study examines the correlation between soil electrical conductivity and soil salinity is well-established, rendering it a significant parameter for evaluating salt levels in agricultural settings (Casterad et al., 2018; Garcia & Hernandez, 1996; Malicki & Walczak, 1999).

Research has indicated that an elevation in soil electrical conductivity, frequently caused by salty solutions, can adversely affect soil biological and biochemical fertility. This, in turn, can harm microbiological activity and, ultimately the overall health of crops (Garcia & Hernandez, 1996). Table 1 lists the Electrical conductivity (EC) properties of some important soils and clays, but interconnected clay layers can also contribute to low soil resistivity or high conductivity (Katsube et al., 2003).

Table 1 Electrical conductivity (EC) properties of several prominent soils and clays.

Material	**Soils and Clays**	**Electrical Conductivity (mS/m)**
Soil Types	Clay (general term)	10 - 1000
	Loam	25 - 250
	Top Soil	5 - 25
	Clay-rich Soil	2.5 - 10
	Sandy Soil	0.25 - 2.5
	Loose Sands	0.01 – 1
Clay Type	Kaolinite	0.2 - 20
	Montmorillonite	67 - 250

(Source: Katsube et al. (2003)

The physical, chemical, and biological characteristics and mechanisms of the soil can be significantly impacted by soil salinity. The majority of soils are classified as mildly saline when the electrical conductivity (EC) of a saturated paste extract (EC) surpasses 2 dS/m (mhos/cm). This value corresponds to an EC for a 1:1 soil-to-water mixture (EC1:1) ranging from 1.0 to 1.4 dS/m for soils with coarse and delicate textures. Table 2 demonstrates the significant variation in salt tolerance among crops. Salt-sensitive species have soil EC values ranging from 1.0 to 3.2 (with an EC1:1 ratio of 0.6 to 2.0) dS/m, whereas salt-tolerant species have EC1:1 values ranging from 2.7 to 8.0 (with an EC1:1 ratio of 1.7 to 5.1) dS/m (Smith & Doran, 1996).

Table 2 Crops' threshold EC ratio (25°C) for salt tolerance is reached at the beginning of yield loss and decreases further in yield per unit EC.

Crop Vegetation	**EC (dS/m)***	**Yield decrease per unit EC (%)**
Alfalfa	1.1 – 1.4	7.3
Barley	4.5 – 5.7	5.0

Crop Vegetation	EC (dS/m)*	Yield decrease per unit EC (%)
Cotton	4.3 – 5.5	5.2
Sugar Beet	3.9 – 5.0	5.9
Potato	1.0 – 1.2	12
Rice	1.7 – 2.1	12
Soybean	2.8 – 3.6	20
Tomato	1.4 – 1.8	9.9
Wheat	3.9 – 5.0	7.1

**Electrical conductivity of soil to water in a 1:1 ratio compared to that of a saturated paste extract. (Source:* Katsube et al. (2003))

B. Climate conditions

Climate conditions have a substantial impact on the process of plant establishment in different environments. Climate variations, including temperature, precipitation, and humidity, can significantly impact plants' growth and spread. Research has shown that climate change has an impact on the process of cold acclimation and freezing tolerance in plants, affecting their capacity to adjust to shifting environmental conditions (Y. Liu et al., 2019). Furthermore, changes in humidity and elevated temperatures might impact the occurrence of fungal diseases, which in turn affect the well-being and development of plants by modifying water availability and other non-living stress factors (Romero et al., 2022).

The impact of climate change-induced temperature increase on plant populations can differ depending on their geographical origin and ability to adapt to different temperature ranges. Research has shown that rising temperatures can harm the growth of plants, particularly those originating from colder regions in the north, as opposed to plants from warmer areas in the south (DeMarche et al., 2017). Moreover, temperature variations can cause modifications in plant phenology, physiology, and reproductive fitness, which can impact plant communities and the dynamics of ecosystems (Lemoine et al., 2017; Meyer et al., 2017).

Precipitation and temperature are vital climatic elements significantly influencing plant species' geographic distribution and flourishing. Research has stressed the significance of climatic conditions in affecting the distribution and growth of fleshy-fruited plant species. Specifically, precipitation and temperature play a crucial role in structuring plant communities, as highlighted by Zhao et al. (2018). In addition, the continuous increase in global temperatures might alleviate limitations on vegetation activity in specific areas. Still, at the same time, it can have detrimental effects due to drought and heat stress in other locations. This can significantly affect plant development and the distribution of different ecosystems (F. Li & Zhang, 2017).

C. Water availability

Water availability is a critical component that affects the establishment of plants in different habitats, as water in the soil is crucial for their growth and development. Studies have demonstrated that soil temperature impacts soil's ability to retain, transmit, and make water available to plants. This highlights the importance of soil temperature in controlling water availability for plants to absorb (Onwuka & Mang, 2018). Moreover, silicon in soil might impact the accessibility and buildup of mineral nutrients in different plant species, potentially offsetting alterations in tissue nutrient concentrations (Greger et al., 2018).

The infiltration of water is a fundamental phenomenon in the field of soil hydrology, which has significant implications for the movement of water within the soil profile. Numerous research has been conducted to investigate the various elements that impact the rates and patterns of water infiltration. For instance, Blanco-Canqui et al. (2017) provided evidence about the influence of tillage techniques on soil hydraulic properties, indicating that moldboard plowing may increase water infiltration rates compared to no-till practices. Similarly, Chen et al. (2020) demonstrated that surface water repellency can substantially impact infiltration rates, emphasizing the significance of comprehending soil water repellency in effective infiltration management.

Furthermore, Nyman et al. (2010) examined the collective impact of water repellency and macropore flow on soil hydraulic conductivity, finding that soils with water-repellent properties may display distinct infiltration characteristics. Previous research has also examined the impact of soil texture and water content on infiltration rates. Roy et al. (2020) found that infiltration rates varied depending on the water content of the soil, while Guo & Liu (2019) investigated the influence of the initial soil water content and bulk density are factors to consider on infiltration and desalination processes in salty soils, highlighting their importance in water movement.

Additionally, Haruna et al. (2022) examined vegetation's significance in water infiltration, highlighting the potential of cover crops to boost sorptivity characteristics. This observation underscores the potential of land management strategies, such as the implementation of cover crops, to benefit infiltration rates. Understanding water availability is crucial for the survival and establishment of young plants, as demonstrated by research examining the competition between various plant species and their water absorption patterns (Hamati et al., 2023). Furthermore, the influence of water stress on plant growth has been examined within the framework of drought stress, wherein a deficiency of accessible water in the soil can result in less water absorption by plants, hence impacting their inherent growth mechanisms (Khalaf et al., 2023).

2.1.2 Biological factors

A. Seed quality and viability

The quality and viability of seeds play a critical role in ensuring the effective establishment of plants. Research findings indicate that the quality of seeds significantly influences crop productivity and seedling establishment. The size of seeds plays a crucial role in determining their quality, influencing multiple factors like germination, growth, and yield (Muhsin et al., 2021). Numerous studies have consistently demonstrated a clear correlation between seed size and crop productivity (Lv et al., 2019). According to Poeta et al. (2016), the impact of seed size variation on crop growth and development can vary since varied seed sizes might influence plant performance.

The quality and viability of seeds play a pivotal role in the development of crops, exerting a direct impact on crop yield and the overall sustainability of agriculture. The germination vigor, viability, and longevity of seeds are among the factors that influence their quality. The decline in seed quality is associated with impaired cellular structures and macromolecules such as lipids, proteins, and nucleic acids (Waterworth et al., 2019). The deterioration of seed quality during storage can lead to decreased seed strength and survival ability, ultimately impacting crop productivity (Schausberger et al., 2019). Moreover, the duration of seed growth is a crucial characteristic that affects the seed germination process and the overall productivity of crops, thereby determining the level of food security (Zhou et al., 2020).

The viability of reproductive organs can be significantly diminished by environmental stressors, such as heat stress, resulting in reduced seed sets and decreased agricultural output (Y. Wang et al., 2021). Furthermore, using herbicides, such as glyphosate, during crucial phases, such as the initial reproductive stages, can potentially hinder seeds' formation and viability, affecting the overall crop yield (Piasecki et al., 2019). Seed viability in crops such as maize is influenced by various factors, including salinity stress, insufficient boron levels, and water availability. These factors significantly impact the overall quality of seeds and the production of crops (Hitti et al., 2023; Khalid et al., 2021).

The importance of seed quality extends beyond present crop productivity, encompassing the preservation of genetic resources for future utilization. According to Al-Turki et al. (2019), seeds of superior quality and favorable viability can endure over extended periods within gene banks, guaranteeing the conservation of vital genetic material.

B. Pest and disease pressure

Pests and diseases in agricultural production present substantial obstacles for farmers worldwide, affecting crop yields and food security. Multiple studies offer valuable insights into the impacts of pests and diseases on diverse crops and successful techniques for managing these challenges. A survey conducted by Labrie et al. (2020) revealed that insect pressure in corn fields was predominantly minimal since most study sites exhibited pest numbers below a specific threshold. This suggests that pest pressure in maize crops may not consistently approach detrimental thresholds, yet it remains imperative to observe and control these populations diligently.

Wondifraw et al. (2021) conducted a study within the domain of barley crops to evaluate the extent of crop damage caused by rodent pests in barley fields. The study successfully identified rodent species responsible for inflicting harm on barley crops, emphasizing the necessity of using focused pest management strategies in barley cultivation. In their research, Agatz et al. (2020) estimated crop production reductions due to animal pests. Notably, barley exhibited yield losses of up to 7%. This highlights the economic ramifications of pests on agricultural output and emphasizes the significance of employing efficient pest management strategies.

The significance of timing and pesticide application in cover-crop-to-corn systems was emphasized by Carmona et al. (2022). Unforeseen pest pressure can result in heightened utilization of insecticides, underscoring the imperative for proactive approaches to pest management. Furthermore, the significance of disease resistance research in the context of pest control alternatives was examined by Mooney et al. (2022). Gaining insight into the extent of disease infestation and adopting efficient pest management strategies are essential for maintaining agricultural output and reducing yield losses.

The study conducted by Lundin (2021) investigated the effects of prohibiting neonicotinoid seed treatments on the output of oilseed rape. The study revealed patterns of heightened pest and disease prevalence after the prohibition, underscoring the significance of pesticide interventions in controlling pest populations and mitigating crop failures. In addition, Wayua et al. (2020) examined the difficulties encountered by small-scale farmers engaged in greenhouse crop cultivation in Kenya, highlighting the notable issues of pests and illnesses. This observation underscores the heterogeneity in insect and disease pressures across diverse agricultural contexts and the necessity for customized pest management approaches. Furthermore, Chen et al. (2023) underscored the enduring influence of crop pests and diseases on agricultural productivity, highlighting the ongoing peril these elements present to crop yields and farmers' livelihoods. Using sophisticated technology to identify pests and diseases can contribute to the timely discovery and effective management of these concerns.

C. Competition with weeds

Weed competition can substantially impact agricultural productivity, reducing crop yield and quality. The efficacy of intercropping systems in combating weeds has been substantiated by research, which has shown that these systems can maintain asymmetric competition irrespective of the specific weed species, crop biomass, or soil nitrogen availability (Corre-Hellou et al., 2011). Weed competition can decrease crop production by up to 40% and affect seed quality, emphasizing the importance of high-quality seeds for optimal plant growth Bachri et al. (2023).

Additionally, the ability of seeds to compete with weeds is influenced by factors such as seedbed preparation and cultivar selection, which can determine their competitiveness in the field (Gazoulis et al., 2021). Despite prevalent weed control methods, weeds can endure and generate significant quantities of viable seeds, hence contributing to the formation of seed banks and subsequent occurrences of weed infestations (Walsh & Powles, 2014). Krohmann P’s (2002) study on weed seedling distribution in maize, sugar beet, winter wheat, winter barley, and continuous maize found that maps in Figure 1 were effective for site-specific weed control (Heege, 2013).

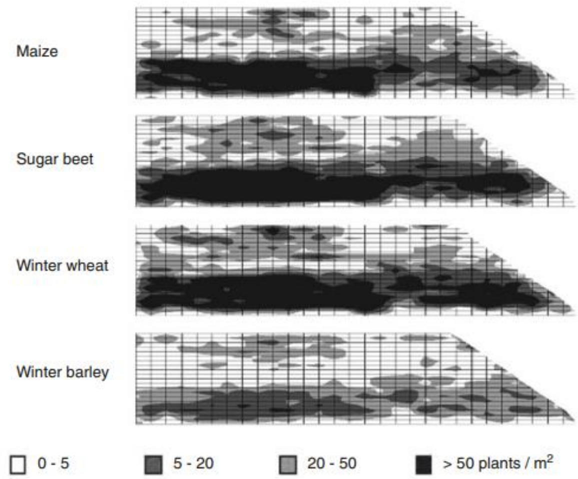


Figure 1 Field violet (Viola arvensis) distribution in maize, winter wheat, winter barley, and sugar beet in a 5-hectare arable field at the Dikopshof Research Station near Bonn, Germany (Revised following Krohmann et al., 2002) (Source: (Heege, 2013).

The significance of crop density, planting patterns, and crop spatial layout in shaping weed competition has been emphasized in many studies (Olsen et al., 2012; Swanton et al., 2015). The management of weed species is significantly influenced by crop competition, which substantially impacts the distribution of weed biomass and the production of seeds (Berquer et al., 2021; Walsh & Powles, 2014). The occurrence of weed emergence in conjunction with crop emergence substantially impacts the direct competition between crops and weeds (Borger et al., 2020). Moreover, it is worth noting that crop seedlings, namely those of cereals, frequently possess a competitive advantage over weed seedlings due to their more excellent dimensions, a phenomenon referred to as size-asymmetric competition (Wu et al., 2021).

Furthermore, there is a correlation between the length of weed competition and increased crop growth and production reductions, highlighting the importance of using efficient weed management tactics (Qasem, 2021). According to Al-Hajaj (2021), implementing crop rotation, primary tillage operations, and zero tillage procedures has been suggested to improve crop competitiveness against weeds and mitigate yield losses. In addition, Ramesh et al. (2017) indicate that crop competitiveness against weeds can be enhanced by adjusting many factors, such as cultivar selection, crop density, planting rate, and intercropping.

The presence of weeds not only reduces the development and productivity of crops but also affects the arrangement and density of crops, affecting the ability to suppress weeds (Olsen et al., 2012). According to Weiner (2023), it is crucial for weed management strategies to prioritize the enhancement of crop competitiveness against weeds. This can be achieved by using management measures and cultivating traits that effectively suppress weeds in specific environmental situations. Understanding the intricacies of crop-weed competition is paramount in pursuing sustainable agricultural methodologies that promote maximum crop yield while reducing the adverse effects of weeds.

2.1.3 Management Practices

A. Tillage methods

Using tillage technologies is crucial in shaping the growth and productivity of plants within agricultural systems. According to Vyn & Raimbault (1993), empirical evidence suggests that no-till systems may decelerate plant development compared to alternative tillage methods. The selection of a tillage system can influence various aspects of soil, including its physical, chemical, and biological properties, which can impact plant growth and yield (Aikins & Afuakwa, 2012). According to O'Brien & Hatfield (2020), the impact of tillage practices on the variability of biomass and grain yield across plants can differ based on meteorological conditions and other agronomic management practices.

Research has shown that implementing conservation and no-tillage systems leads to increased soil compaction, which has a detrimental impact on the early establishment of plants and reduces plant densities (Adamič & Leskovšek, 2021). However, it should be noted that traditional tillage methods may need a greater allocation of resources, time, labor, and energy, all of which are becoming progressively limited and costly (Tripathi, 2013). Furthermore, the implementation of conservation tillage practices has the potential to improve the stability of the rhizosphere bacterial community, which is known to have a significant effect on the regulation of plant growth (Z. Wang et al., 2017).

The selection of tillage techniques substantially impacts crop yield as they modify the physical characteristics of the soil, the distribution of roots, and the growth of plants (Kahlon & Dhingra, 2019). Zamir et al. (2016) have reported that research findings have demonstrated the influence of tillage practices on various aspects of crop growth, yield, yield characteristics, and soil physical attributes. In addition, examining sorghum's reaction to tillage methods and nitrogen fertilization underscores the significance of carefully choosing suitable tillage techniques and fertilizer dosages to ensure the long-term viability of crop cultivation (Ramadhan & Muhsin, 2021). Ultimately, tillage techniques significantly influence the development of plants, productivity, soil properties, and the general sustainability of agriculture. Understanding the impacts of various tillage methods on plant productivity is crucial for maximizing crop yield and soil well-being in agricultural systems.

B. Fertilization strategies

Effective fertilization tactics play a vital role in crop production, exerting a substantial influence on plant development, output, and the long-term viability of agriculture. Choosing and using suitable fertilization methods are crucial for optimizing crop yield and resource utilization. Multiple studies have highlighted the significance of fertilization tactics in improving crop productivity and tackling environmental issues. The study conducted by Zhang et al. (2022) in southeast China emphasized the importance of implementing sustainable fertilization and tillage techniques to enhance agricultural production capacity and ensure steady agrarian output. Furthermore, it has been acknowledged that implementing liming as a method for nitrogen fertilization optimization has proven advantageous in enhancing crop productivity in tropical agriculture and nitrogen utilization efficiency and soil characteristics (Crusciol et al., 2021).

Climate change poses challenges to crop production. While it has been suggested that increasing fertilizer inputs to reduce nitrogen stress can improve overall yields, this strategy may also increase the vulnerability of crops to climate stresses, potentially exacerbating the negative effects of climate change on crop production (Sultan et al., 2014). According to Leng et al. (2016), research has demonstrated that proper fertilization and irrigation strategies can substantially impact crop production simulations, especially in places where crops are cultivated extensively.

Microbial nutrient acquisition in soils can be influenced by several agricultural management methods, such as cropping systems, tillage, and fertilization, which can impact the eco-enzymatic stoichiometry. The abovementioned techniques significantly influence soil conditions, nutrient availability, microbial biomass, and metabolic demand, highlighting the interdependence between fertilization strategies and soil health and crop yield (X. Chen et al., 2021).

In addition, incorporating agronomic methods and herbicides in crop rotations underscores the need to optimize fertilizer utilization for sustainable weed control and crop yield. According to a study conducted by Blackshaw et al. (2005), applying fertilizers during the spring season can enhance the efficiency of fertilizer use in crops grown in the spring. This highlights the importance of timing in fertilizer application to achieve optimal crop production. The function of fertilization tactics in crop production is of utmost significance as they significantly impact plant nutrition, development, and ability to withstand environmental stressors. Farmers have the potential to enhance crop yields, improve soil health, and contribute to long-term agricultural sustainability by employing sustainable and optimum fertilization strategies that are specifically adapted to each crop and soil condition.

2.2 Advanced Techniques for Variable and Modified Plant Establishment

2.2.1 Precision Agriculture Technologies

Precision agriculture, often called precision farming, is a contemporary methodology that employs technological advancements to enhance agricultural operations by considering farming systems' inherent variability and uncertainty (Gebbers & Adamchuk, 2010). According to Yin et al. (2021), this approach encompasses diverse technologies, including sensors, information systems, advanced machinery, and informed management, to effectively monitor and regulate variables such as soil conditions, crop health, and resource utilization. According to Yin et al. (2021), using soil sensors and plant wearables enables real-time data collection of various parameters such as temperature, moisture, pH, and pollutants. This data (Figure 2) may be employed to optimize crop growth conditions, mitigate stressors, and enhance overall yields.

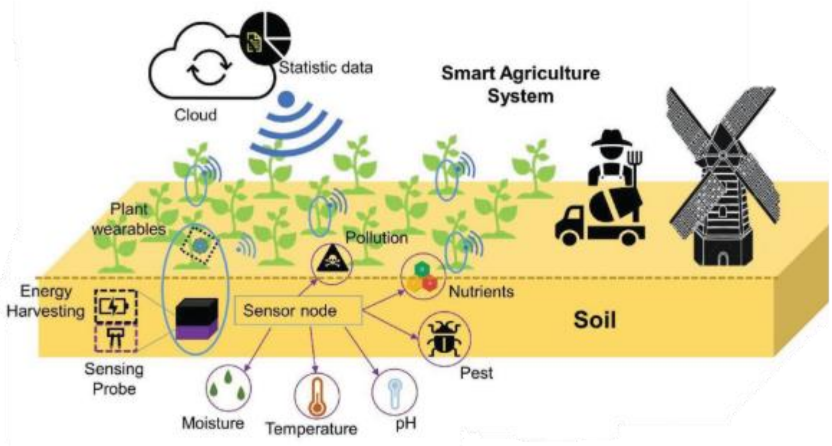


Figure 2 In intelligent agriculture, the primary sensors detect soil health issues. This category's sensory components include soil moisture sensors, soil temperature sensors, soil pH sensors, soil nutrient sensors, soil pest/insect sensors, soil pollution sensors, and plant wearables (Source: Yin et al., 2021).

The perceived advantages of precision agriculture technologies, like heightened crop yields, diminished production expenses, and improved convenience, influence farmers' choices to adopt these tools in their agricultural operations (Figure 3) (Thompson et al., 2019). In addition, Gallardo et al. (2019) have highlighted the accessibility of research project outcomes and involvement in extension programs as significant factors influencing growers' adoption of precision agriculture technologies.

Precision agriculture provides advantages in crop and livestock farming, as it facilitates the implementation of data-driven management strategies to enhance production efficiency (Monteiro et al., 2021). Farmers can achieve sustainable agronomy by effectively utilizing resources through accurate variable rate applications using precision agriculture technologies (Bhakta et al., 2019). Furthermore, the utilization of precision agricultural technologies has demonstrated its ability to facilitate the sustainable advancement of crop production in diverse geographical areas, resulting in increased financial gains through the exploitation of spatial disparities in soil characteristics (Abuova et al., 2019).

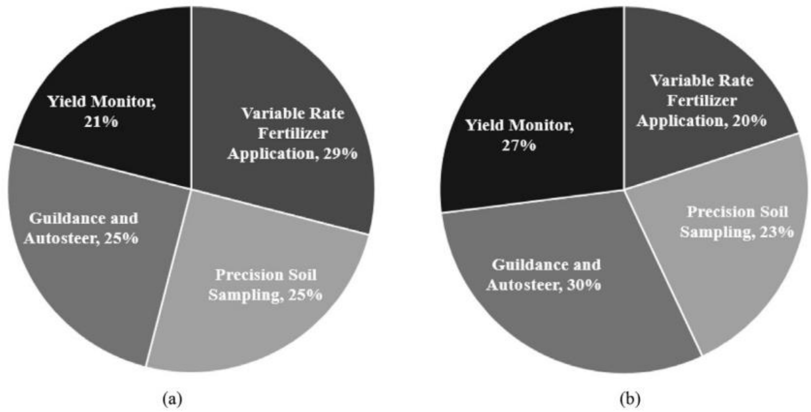


Figure 3 Preference Shares for Precision Agriculture Technology with the (a) Highest Probability of Yield Increase and Production Cost Reduction, Pooled (n = 574), and (b) Highest Probability of Convenience Increase (n = 263) (Source: Thompson et al., 2019).

Advancements in technology, example an artificial intelligence, machine learning, robots, and the Internet of Things (IoT), have shown good prospects for the future of precision agriculture (Machii et al., 2023; Yousaf et al., 2023). According to Dutta et al. (2021), using these technologies facilitates the development of advanced decision support systems, empowering farmers to make well-informed decisions about various agricultural activities such as planting, fertilizing, pest management, and harvesting. Incorporating big data analytics and deep learning in precision agriculture enables the identification of plant diseases, pests, and nutritional deficiencies in the agricultural setting, thereby enhancing crop management strategies (Machii et al., 2023).

Precision agriculture is an innovative farming method that uses technology to improve agricultural techniques, increase efficiency, and foster environmental sustainability. Precision agriculture allows farmers to make well-informed decisions, enhance efficiency, and attain improved crop and livestock production outcomes by integrating technology and data-driven solutions.

A. Variable Rate Seeding

Variable-rate seeding (VRS) is an agricultural technique that empowers farmers to finely tune the amount of seeds sown in different field areas based on certain management zones. This approach holds the promise of maximizing crop establishment and ultimately enhancing production. Seeding for crops with high seed densities requires targeted methods (Figure 4), such as bulk drilling, which is essential for low-density crops like small grains, grasses, clover, and alfalfa due to cost constraints (Heege, 2013).

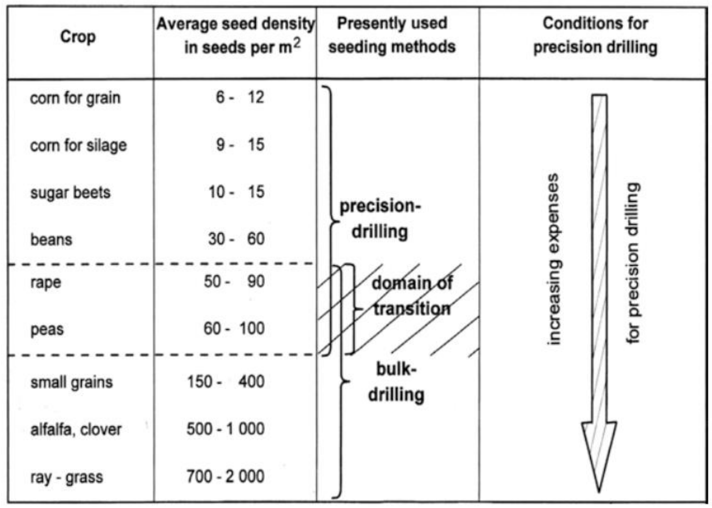


Figure 4 Requirements for seeding techniques (Source: Heege 2013)

Research has shown that using variable rate seeding (VRS) in soybean production has gained significant popularity among farmers. This approach allows them to customize the seeding rates according to their fields' unique characteristics (Figure 5), as Hamman et al. (2021) highlighted.

Precision seeding has been found to produce outcomes comparable to drilling regarding seed production and nutritional composition (Sobko et al., 2020). Within the realm of alternative crops, such as peanuts, employing the double-seeded precision sowing technique has gained considerable traction. Extensive research has been conducted to investigate the impact of spacing between seeds within a row on the development of pods and subsequent production (C. Zhao et al., 2017).

An investigation has been conducted into advancing variable-rate seeding management systems tailored to specific crops, such as corn. This inquiry has shed light on the promising prospects of enhancing field performance and crop establishment (He et al., 2019). Furthermore, researchers have delved into the exploration of precision seeding technology, which encompasses the examination and refinement of seed metering devices, to augment the accuracy and efficacy of variable seeding methodologies (B. Li et al., 2021; Tang et al., 2022; Xiong et al., 2021). As an illustration, scholarly investigations have prioritized the development and empirical examination of seed-metering mechanisms for diverse agricultural produce, including maize and Brassica chinensis, to attain superior seeding outcomes and reduce instances of omitted or excessive seed allocation (B. Li et al., 2021; Tang et al., 2022; Xiong et al., 2021).

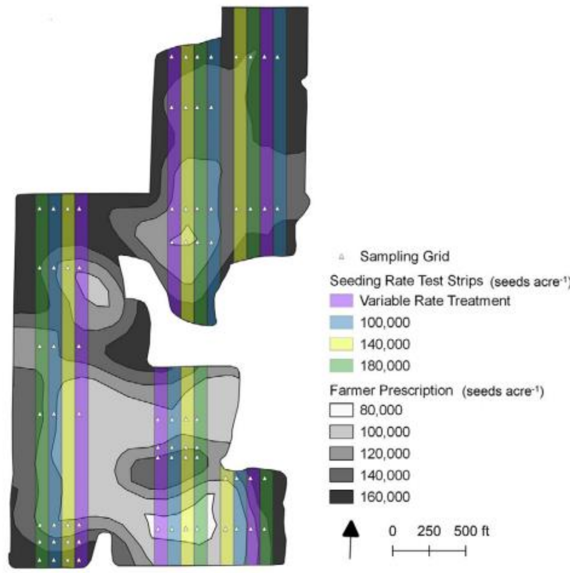


Figure 5 An illustrative seeding rate prescription map (grayscale) depicting four distinct seeding rate treatments (represented by colored strips) and five replications (represented by blocks) originating from the OH-N1-2017 site. Test strips for the seeding rate were arranged to ensure all seeding rate treatments intersect with all management zones in grayscale. The triangles represent a sampling grid to collect stand count and yield data (Source: Hamman et al., 2021).

In addition, scholars have suggested using cutting-edge technologies, such as deep neural networks and performance monitoring systems, to augment the accuracy and dependability of variable seeding methods (B. Li & Li, 2022; Z. Liu et al., 2021). These technologies aim to enhance the precision of seed metering systems, guaranteeing optimal seeding results under diverse field circumstances and operational velocities. Using variable seeding can enhance crop establishment and production by customizing seeding rates to suit individual field circumstances. The continuous progress in precision seeding technologies and control systems, along with the developments in seed metering devices, is a testament to the persistent endeavors to enhance the accuracy and effectiveness of variable seeding methods in diverse crop types.

B. Remote Sensing and GIS Application

Precision agriculture relies on remote sensing and Geographic Information Systems (GIS) as crucial tools, offering vital data and insights to optimize crop management. According to Sharma et al. (2023), these technologies possess diverse applications within the field of precision agriculture, facilitating farmers in making well-informed decisions by utilizing spatially explicit information. According to Adhikary et al. (2023), remote sensing enables the collecting of data in a non-destructive manner, providing repetitive information on crops that can be utilized for several agricultural purposes.

The utilization of remote sensing and geographic information systems (GIS) in the field of precision agriculture facilitates several activities, including the control of nutrient and water stress, monitoring of crops, detection of diseases, and estimation of crop production (Gebeyehu, 2019; Shofiyati, 2022; Sun et al., 2022). The effective monitoring of crop health, identification of stress causes, and optimization of resource allocation can be achieved by farmers through the utilization of spectral indices derived from remote sensing data (Kumawat et al., 2023). Uncrewed aerial vehicles (UAVs) and satellite imaging sensors are examples of remote sensing technologies that offer detailed data for accurate crop monitoring and management (Cuaran & Leon, 2021; Yang, 2018).

These techniques, namely artificial intelligence and deep learning, have been integrated into remote sensing technologies to improve data analysis and decision-making in precision agriculture (Sun et al., 2022). Precision farming involves utilizing information from the present crop yield for site-specific operations for subsequent crops (Figure 6). This information can be derived from previous crops, such as fertilizing or nutrient removals. For holistic control, information transfer should occur within and between precision agriculture cycles, extending over multiple crop rotations. However, it's essential to consider the value of information transfer and minimize unused data. The process should be gradual, averaging signals and sorting out useless data to improve control (Heege, 2013).

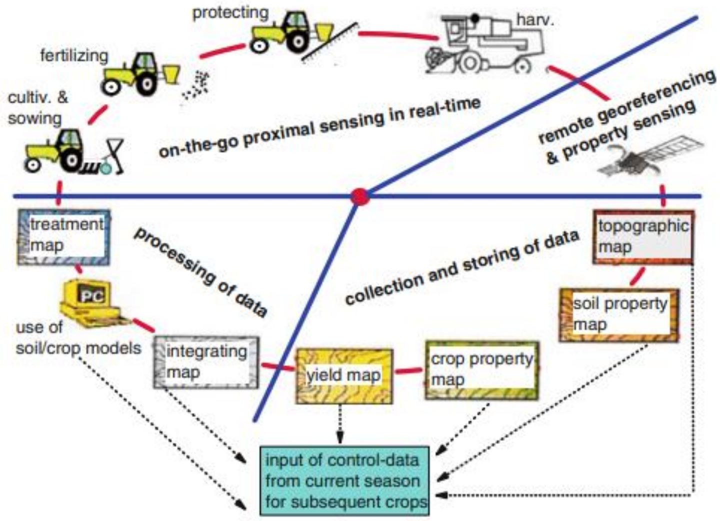


Figure 6 The process of transferring information within a precision agriculture cycle and between following crops have been summarized and supplemented with relevant data from Stafford (2006) (Heege, 2013)

According to Sathiyamoorthi et al. (2022), these technologies facilitate the creation of predictive models for calculating crop yield, identifying diseases, and other crucial elements of agricultural management. Furthermore, integrating data from many platforms, including satellites and uncrewed aerial vehicles (UAVs), enhances the quality and dependability of the information collected for precision agriculture (Xie et al., 2013). Utilizing remote sensing capabilities enables farmers to conduct spatial analysis of diagnostic results, hence facilitating the implementation of more precise and sustainable crop protection measures. In addition, utilizing remote sensing techniques facilitates the categorization, surveillance, and evaluation of crop yields, enhancing the effectiveness and productivity of agricultural practices (Shofiyati, 2022).

In summary, exploiting remote sensing and geographic information systems (GIS) in precision agriculture presents farmers with prospects to augment crop management methodologies, optimize resource allocation, and promote agricultural operations' overall sustainability. Farmers can make knowledgeable decisions based on data through these technologies, leading to heightened production, diminished environmental consequences, and improved profitability within agricultural activities.

2.2.2 Modified Planting Strategies

A. Conservation Agriculture Practices

The potential of conservation agriculture strategies to increase sustainability in agricultural systems has garnered considerable attention. Conservation agriculture is a farming system characterized by various measures, including minimal soil disturbance (no-till), permanent soil cover, crop variety, and the utilization of legumes. According to Page et al. (2020), these activities aim to preserve soil organic carbon, enhance soil physical, chemical, and biological characteristics, and ultimately augment crop productivity. Smallholder farmers have experienced advantages in soil health, moisture retention, and crop yields by incorporating conservation agriculture techniques into climate-smart practices (Figure 7) (Molua et al., 2023).

According to Feyisa (2022), research findings suggest that implementing conservation agricultural techniques, such as conservation tillage, crop residues, manure application, and crop rotation, can effectively enhance water penetration and mitigate the likelihood of crop failure. Moreover, the economic and agronomic appeal of conservation agriculture practices, such as crop rotation, minimal tillage, and the preservation of soil cover through cover crops and residue, has been demonstrated (Rabach et al., 2022). According to Adhikari et al. (2023), implementing these strategies enhances soil health and mitigates the adverse environmental consequences of conventional agricultural production techniques.

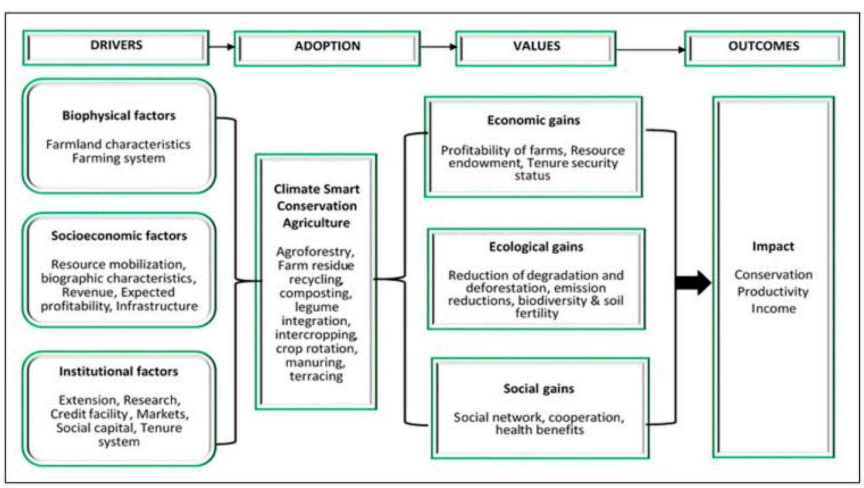


Figure 7 The factors and benefits of climate-smart sustainable agriculture (Source: Molua et al., 2023).

To address issues such as low profitability and soil degradation in smallholder farms, particularly in sub-Saharan Africa, it is imperative to use conservation agricultural practices

Tsegaye et al. (2017). Conservation agriculture provides a sustainable agricultural method for the future by adhering to fundamental principles such as minimal soil disturbance, maintenance of permanent soil coverings, and crop diversity (Hobbs et al., 2008).).

To facilitate the extensive adoption of conservation agriculture, it is imperative to effectively tackle obstacles and capitalize on potential advantages by utilizing stakeholder engagement procedures (Reimer et al., 2023). According to Mcconnell (2019), precision agriculture has been recognized as a crucial approach for enhancing conservation practices and achieving profitability, fostering the development of environmentally resilient agricultural landscapes. To improve soil health, enhance crop yields, and encourage sustainable farming systems on a global scale, it is imperative to prioritize promoting and implementing conservation agriculture methods.

B. Soil Tillage and Water Infiltration

Water penetration in agricultural soils is strongly influenced by soil tillage techniques. The soil structure, porosity, and organic matter content, which in turn affect water penetration rates, are influenced by different tillage practices such as conventional tillage, no-tillage, and reduced tillage (Blanco-Canqui et al., 2017). According to Cunha et al. (2015), the implementation of conservation tillage strategies, such as no-tillage, has been shown to boost water penetration through the improvement of soil structure, an increase in organic matter content, and a reduction in soil compaction. This can be attributed to the better soil structure, increased organic matter content, and greater soil water storage capacity.

Furthermore, the influence of tillage strategies on soil water penetration is contingent upon other factors, such as soil porosity, soil compaction, and the formation of voids within the soil profile that promote water movement (Amami et al., 2021). According to Khorami et al. (2018), empirical evidence suggests that the implementation of no-tillage methods can yield greater rates of water infiltration in comparison to tilled soils, particularly in arid environments. This, in turn, can enhance the availability of water within the root zone. Nevertheless, it is crucial to acknowledge that the implementation of extended no-tillage practices may entail certain disadvantages, including the degradation of soil structure. This degradation can lead to a decrease in water penetration rates and an increase in runoff and erosion processes (Bombino et al., 2019).

In addition, tillage practices have the potential to influence soil physical characteristics, such as the distribution of pore sizes, which subsequently alter the rates at which water infiltrates the soil. Alterations in soil physical characteristics, such as total porosity and microporosity, have a substantial impact on the process of water infiltration into the soil (Wolschick et al., 2021). Additionally, the presence of plant roots, residue cover, and soil compaction brought on by tillage techniques can all have a significant impact on the effects of soil water infiltration (Meek et al., 1992; Mukhtar et al., 1985).

a. Strip-till System

Strip tillage, or zone tillage, is a conservation technique characterized by the deliberate disturbance of soil inside sowing rows while allowing the areas between rows to remain undisturbed until harvesting. The proposed approach integrates the advantages of traditional tillage and no-tillage practices by establishing cultivated environments close to the plant and providing residue management between crop rows (Licht & Al-Kaisi, 2005; Overstreet & Hoyt, 2008). Strip tillage has become increasingly popular among producers due to its ability to preserve surface residues, reduce soil evaporation, and improve root growth and function by providing subsurface tillage to counteract the impact of restrictive soil layers (Aulakh et al., 2015).

Studies have demonstrated that strip tillage can substantially influence soil physical characteristics, such as soil temperature, and potentially optimize crop yield and profitability while mitigating soil erosion (Monfort et al., 2007; Wenninger et al., 2019). Strip tillage provides a distinctive method for improving crop productivity and sustainability by establishing a soil matrix with moderate disturbance compared to traditional tillage and no-till methods.

The practice of strip tillage has been investigated in several agricultural systems, encompassing peanuts, maize, sugar beets, and brassica crops. The findings of these studies suggest that strip tillage holds promise in enhancing soil health, increasing crop productivity, and effectively managing weed growth (Al-Kaisi & Licht, 2004; Clark et al., 2021; Rathore et al., 2021; Spivey et al., 2019). Previous research has also brought attention to the impact of strip tillage on nitrogen absorption, grain production, and the formation of residual nitrates in the soil. However, the findings of these studies have been inconclusive when compared to alternative tillage methods (Edwards et al., 1988).

In addition, incorporating strip tillage into cropping systems necessitates the deliberation of variables such as the timing of planting, the application of herbicides, and the rotation of crops to maximize yields and efficiently control pests (R. G. Evans et al., 2010). To make well-informed decisions on equipment choices, cultivation practices, and overall cropping system management, it is crucial to comprehend the interactions between strip tillage and other agricultural practices.

Strip tillage presents a favorable method for achieving sustainable agriculture by effectively managing soil disturbance and residue, resulting in enhanced crop yield, soil health, and environmental sustainability. Farmers can effectively utilize its advantages to optimize agricultural methodologies and address the complexities associated with contemporary farming practices by comprehensively examining the possibilities of strip tillage across various cropping systems and geographical areas.

b. No-till System

Adopting no-till systems has become a prominent agricultural approach that offers notable advantages regarding soil health, crop yield, and environmental preservation. Numerous studies have demonstrated that using no-till techniques, in contrast to conventional tillage methods, can result in heightened production of rainfed crops in arid climates. Consequently, these practices emerge as a valuable approach for adapting to climate change in arid regions (Pittelkow et al., 2015). Furthermore, it has been observed that no-till systems exhibit effective carbon sequestration, particularly in the case of cover crop-based no-till systems, which demonstrate higher rates of carbon sequestration in comparison to no-till systems lacking cover crops (Mirsky et al., 2012).

According to Grandy et al. (2006), implementing no-till methods has been linked to enhancements in soil physical characteristics, including soil aggregation and organic matter content. These changes have positively impacted erosion rates and overall soil health. According to de Faccio Carvalho et al. (2010), no-till systems have demonstrated the ability to improve soil microbial communities, boost carbon sequestration, and decrease energy consumption and carbon dioxide emissions. On the other hand, Yuan et al. (2022), the implementation of conservation tillage techniques, including low tillage, no-tillage, and straw mulching, has demonstrated the ability to mitigate soil erosion, enhance soil nutrient retention, and reduce greenhouse gas emissions, including nitrous oxide (N_2O). These findings underscore the promise of no-till systems in mitigating environmental impacts.

Research has shown that no-till systems can result in yields similar to or even more significant than conventional tillage systems. Additionally, these systems offer the advantages of less soil erosion and enhanced soil structure (Pittelkow et al., 2015). In addition, previous research has demonstrated that incorporating no-till techniques into crop-livestock systems (Figure 8) can effectively augment nutrient cycling, soil enhancement, and the overall sustainability of the system (Muniz et al., 2021).

Draghi et al. (2018) and (Noel et al., 2022) have underscored the efficacy of no-till systems in bolstering biodiversity, preserving soil meso- and macrofauna, and fostering the resilience of microbial communities within agricultural environments. Kühling et al. (2018) have acknowledged the significance of no-till practices in promoting sustainable intensification within dryland cropping systems. These techniques present prospects for adaptation and enhanced resource use efficiency in demanding conditions.

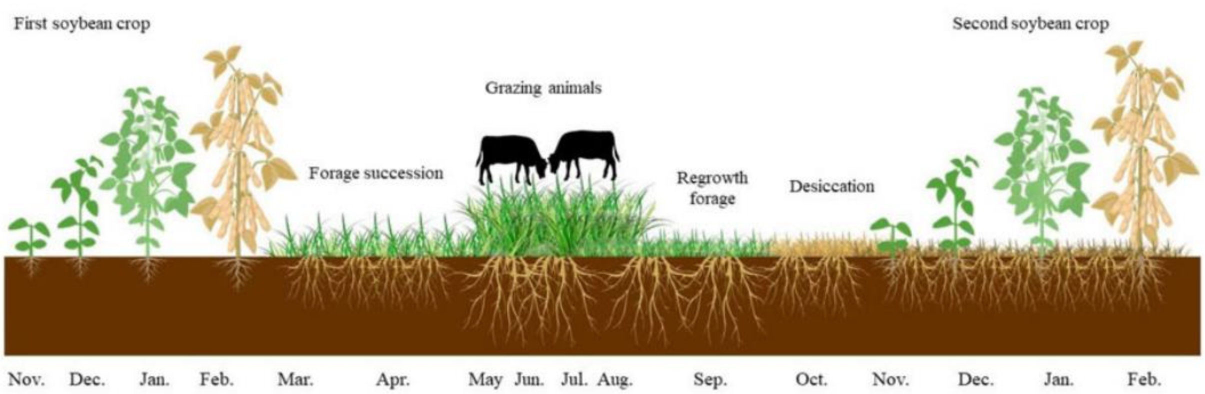


Figure 8 An integrated crop-livestock system diagram showing the cropping schemes that include Tamani guinea grass and Paiaguas palisade grass forage species (Source: Muniz et al., 2021).

In summary, the extensive implementation of no-till systems offers a hopeful avenue for achieving sustainable agriculture through the augmentation of soil health, amplification of carbon sequestration, enhancement of crop output, and mitigation of environmental consequences. The ongoing investigation and application of no-till methodologies are crucial in fostering agricultural systems that are both resilient and environmentally sustainable.

C. Cover Cropping and Intercropping

a. Cover Cropping

In the agricultural practice known as "cover cropping," crops are planted mainly for soil cover instead of harvesting (Figure 9). Additionally, it provides many advantages regarding soil health, crop yield, and environmental preservation. The utilization of cover crops has demonstrated positive effects on soil structure, erosion reduction, weed suppression, nutrient cycling enhancement, and organic matter content augmentation (Fernando & Shrestha, 2023; Kruse & Nair, 2016). According to Holman et al. (2021), they significantly impact the augmentation of biodiversity, facilitation of advantageous microbial processes, and provision of supplementary nutrients to future cash crops, thus diminishing the need for synthetic fertilizers.

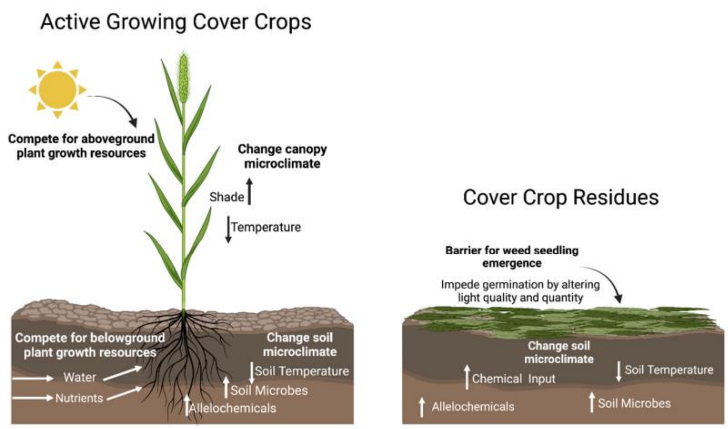


Figure 9 The provided diagram presents a conceptual representation of potential interactions that may occur during the active growth phase of the cover crop (on the left) and after the termination of the cover crop, resulting in its presence as a surface residue on the soil (on the right) (Source: Fernando & Shrestha, 2023).

Incorporating cover crops into agricultural systems can yield positive outcomes such as higher soil health, heightened carbon sequestration, and improved ecological services. According to Bergtold et al. (2012), cover crops help manage weeds due to their weed-suppressive properties, which may be included in annual and perennial cropping systems. According to P. Sharma et al. (2018), the careful choice of cover crops plays a crucial role in achieving effective integration into vegetable cropping systems.

The economic implications of cover cropping have been examined in several studies, which have demonstrated that incorporating cover crops into cropping systems yields both direct and indirect advantages and disadvantages (Carmona, Robinson, Tonon Rosa, et al., 2022).

Furthermore, cover crops play a significant role in promoting sustainable soil health and agricultural practices through their ability to enhance the accumulation of soil organic matter, mitigate soil disturbance, and perhaps augment crop output (Uchino et al., 2009).

In addition, it has been observed that cover crops have the potential to impact arthropod activity in future crops. Research findings suggest that cover crops are frequently seen as a sustainable practice within cropping systems as long as they do not diminish the productivity of cash crops. The optimization of cover crop management strategies, including the selection of suitable cover crop kinds and the control of cover crop growth period, can effectively maximize the advantages associated with cover crops.

In summary, cover cropping is a beneficial mechanism for augmenting soil fitness, raising crop yield, and fostering ecological sustainability within agricultural frameworks. Farmers can attain several advantages, such as enhanced soil structure, less erosion, improved nutrient cycling, and suppression of weeds through meticulous selection and effective management of cover crops. These benefits ultimately contribute to developing more resilient and sustainable farming techniques.

b. Intercropping

Intercropping is an environmentally conscious agricultural technique that simultaneously cultivates two or more crops nearby (Figure 10). This method provides many advantages for the well-being of soil, the productivity of crops, and the sustainability of the environment. According to Maitra et al. (2021), intercropping systems, which are alternatively referred to as mixed cropping or polyculture, employ relatively minimal inputs while enhancing the overall quality of the agroecosystem. According to Brooker et al. (2015), implementing intercropping in crop production can increase aggregate yields per unit input, mitigate the risk of crop failure and market volatility, cater to food preferences, safeguard and enhance soil quality, and augment revenue.

Studies have demonstrated that intercropping can enhance resource utilization efficiency, improve the cycling of nutrients, and foster biodiversity in agricultural systems (Raza et al., 2020). Legume-cereal intercropping is extensively utilized in agrarian systems to enhance sustainability by optimizing cropping intensity and enhancing land usage rates (Ton, 2021). According to Gura (2023) and Manevski et al. (2015), intercropping has the potential to mitigate nitrogen leaching, promote soil fertility, and improve soil microbial community features, hence promoting the adoption of more sustainable farming practices.

Figure 10 Intercropping maize with red fescue was conducted at Foulum. Subsequently, red fescue was planted following the maize harvest at Foulum.

Furthermore, previous studies have demonstrated that intercropping positively impacts the distribution of nitrogen, soil microbial communities, and nitrogen uptake across diverse crop systems (Lai et al., 2022; Yong et al., 2015). Intercropping systems can enhance crop output, land utilization rates, and resilience to continuous cropping hurdles and diseases by harnessing resources such as sunshine, water, and nutrients (Lai et al., 2022). In addition, intercropping has the potential to decrease insect infestation, promote soil fertility, and improve the effectiveness of phytoremediation in fields that have been poisoned (J. Liu et al., 2022).

Intercropping is advantageous for promoting sustainable agriculture, providing advantages such as enhanced soil fertility, heightened crop yield, and diminished ecological footprints. Farmers may boost resource use efficiency, encourage biodiversity, and develop more resilient agricultural methods for the future by establishing various intercropping systems and optimizing crop combinations.

2.3 Yield Potential

The yield potential in agriculture is a critical determinant of the highest attainable output of a crop under ideal circumstances. The study conducted by Lobell et al. (2009) has demonstrated that in large-scale irrigated wheat, rice, and maize systems, the average yields generally approach approximately 80% of their maximum potential, with just a few cases exceeding this limit. A significant disparity in crop production can be resolved to enhance agricultural productivity.

According to Reynolds et al. (2009), the potential for yield enhancement in plants could be significantly increased by up to 50% or more through advancements in plant genetics. These advancements may involve enhancing photosynthesis through natural variability or adopting more efficient metabolic pathways. Nevertheless, there is contradictory information about the augmentation of maize production capacity in the North-Central United States (Duvick & Cassman, 1999), underscoring the intricacy of improving yield potential and the want for additional investigation in this domain.

To attain maximum yields, it is essential to address yield gaps by implementing sustainable practices and optimizing fertilizers (Pradhan et al., 2015). Research conducted by Zhang et al. (2024) shows that in 2022, the Beers and Fabrieke fields exhibited wheat yields that fell within the anticipated range, and the application of MSB-VRMA treatments did not have a detrimental impact on the overall output. Nevertheless, there were noted fluctuations in yield, with most regions exhibiting yields falling between 11.9-14.1 t/ha and 11.6-13.3 t/ha. The blue areas exhibiting low yields align with established subsoil compaction locations, highlighting the necessity for more analysis (Figure 11).

Evans & Fisher (1999) have underscored the significance of genetics and environmental factors in determining agricultural productivity. Measuring yield gaps in rice production systems is paramount to optimize farm productivity and enhance resource efficiency (Y. Guo et al., 2019). The present growth rate in produce capacity is inadequate to satisfy the increasing need for food (K. G. Cassman, 1999). A comprehensive comprehension and effective resolution of yield gaps are necessary to optimize agricultural productivity and enhance resource utilization.

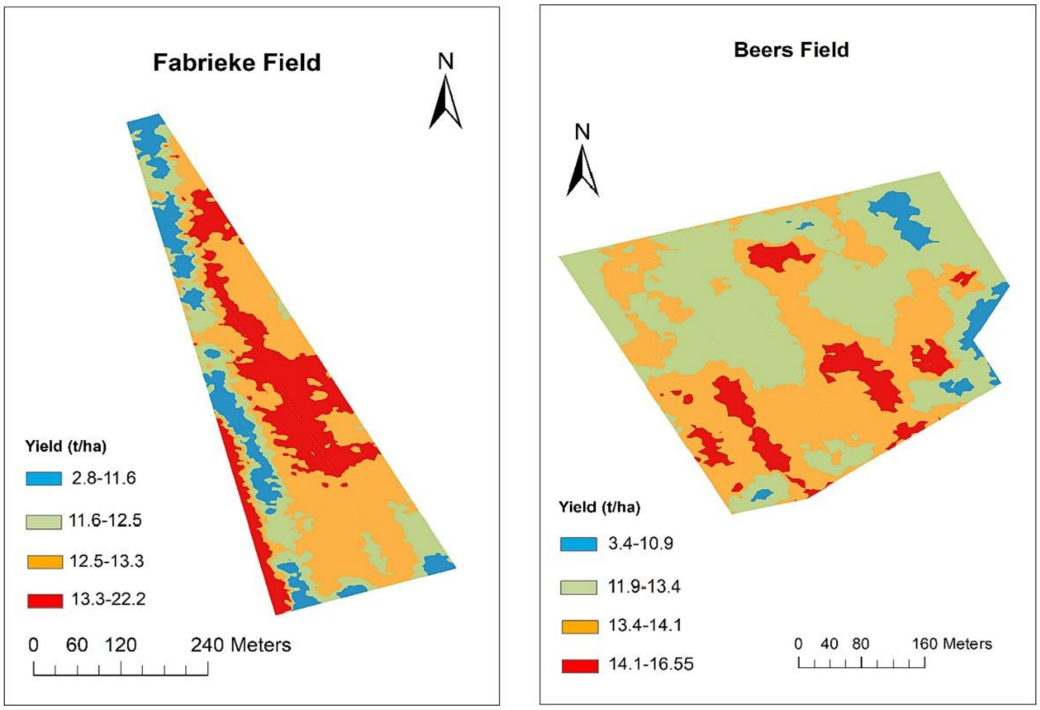


Figure 11 Wheat yield map depicting the quantification of wheat production in the Fabrieke (left) and Beers (right) farms (Source: Zhang et al., 2024).

2.3.1 Impact of Plant Establishment Techniques on Yield Potential

Assessing plant establishment procedures is pivotal in evaluating the potential yield of diverse crops. Research conducted by Liu et al. (2004) has shown the importance of plant emergence variability in determining prospective yield, even when there is a generally consistent spacing of plants within a row. In addition, Copeland et al. (2023) have highlighted that enhancements in stand establishment can have a favorable impact on yield potential by improving the uniformity between plants and increasing the coverage of the canopy. This, in turn, enhances the interception and efficiency of radiation usage.

The successful cultivation of crops such as switchgrass is crucial to attaining optimal production potential. According to a research conducted by Hong et al. (2014), it was found that switchgrass can achieve a substantial amount of its yield potential within the first year of establishment, provided that appropriate establishment procedures, effective weed management, high seed quality, and suitable precipitation conditions are implemented. Similarly, Keyser et al. (2016) emphasized the significant influence of inadequate weed management on the productivity of switchgrass, hence emphasizing the criticality of implementing efficient establishment techniques.

The timing of planting is a crucial factor that significantly influences the potential yield. The study conducted by Assefa et al. (2014) revealed a strong positive association between the timing of planting and the yield of winter canola. This finding suggests that the timing of planting can substantially impact the overall yield results. Furthermore, Butler et al. (2020) proposed that the impact of plant population on yield potential may vary depending on the abundance of the plants. However, they found that lower densities of plants can result in reduced production, underscoring the significance of achieving optimal plant density to maximize yield potential.

Various factors can influence yield, including planting date, population, plant density, and tillering potential. Bastos et al. (2020) study involved a synthesis analysis to identify the optimal plant density for agronomic purposes in various yield scenarios. The researchers highlighted the importance of using customized plant density techniques to maximize yield potential under specific conditions.

To fully realize the potential production of crops, it is imperative to establish them by implementing proper planting procedures, which encompass optimal spacing, timing, and density. Farmers can enhance crop stand establishment and improve yield potential and overall productivity by implementing uniform emergence, efficient weed management, and timely planting strategies.

2.3.2 Influence of agro-environmental measures on crop yield potential

Implementing agro-environmental measures is crucial for determining the possible crop production. The study conducted by Raza et al. (2019) emphasizes the role of abiotic pressures, which are affected by climate change, on the productivity of crops. The degree of harm resulting from these stressors can exhibit variability and directly impact agricultural productivity. Their study by Maitra et al. (2021) highlights the significance of implementing appropriate cropping systems to optimize yield potential in various agro-climatic situations. This underscores the importance of environmental measures in improving crop productivity.

In addition, Parihar et al. (2022) illustrate the correlation between environmental circumstances and crop phenological dynamics, which in turn affects crop output in various agroecological locations. Gaining insight into these dynamics is essential for maximizing the potential of crop productivity. According to (Bene et al., 2022), soil-crop models can be employed to evaluate the enduring impacts of agroecological practices on crop yield. This underscores the importance of adopting sustainable agricultural methods to augment productivity.

In addition, Lepse et al. (2021) examine the impact of distinct agro-environmental factors, such as climate and soil characteristics, on the productivity and characteristics of fava bean harvests. This research emphasizes the significance of considering environmental conditions while implementing crop-growing strategies to optimize yield potential. In addition, Diacono et al. (2016) emphasize the importance of adopting integrated agroecological approaches to adjust organic horticultural systems to climate change, underscoring the necessity of robust production systems to guarantee food security.

In summary, agro-environmental measures exert a significant influence on the potential yield of crops. Farmers may tackle climate change problems, create appropriate cropping systems, comprehend environmental dynamics, and adopt sustainable practices to enhance crop output and assure food security in changing climatic conditions.

2.3.3 NDVI Index

The NDVI (Normalized Difference Vegetation Index) is widely recognized as agriculture's predominant vegetation index (VI). It is attributed to (Rouse et al. 1973), but the concept was initially introduced by Kriegler et al. (1969). The calculation of the NDVI is as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The values of reflectance in the near-infrared (NIR) and red (RED) bands are equal. The index has a range of values from -1 to 1 (Ortega-Blu & Molina-Roco, 2016).

Studies have exhibited a distinct correlation between the Normalized Difference Vegetation Index (NDVI) and agricultural attributes, including leaf area index (LAI) and photosynthetic activity (Al-Gaadi et al., 2016). Furthermore, previous research has provided evidence of the affiliation between the Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and crop output as a means of forecasting the effects of drought on agricultural productivity (Kourouma et al., 2021).

Moreover, the Normalized Difference Vegetation Index (NDVI) has demonstrated its utility in evaluating the agricultural productivity of crops across distinct growth phases and under diverse management strategies. For instance, previous studies have demonstrated the importance of the NDVI in evaluating microbial inoculants' effects on crops' biomass and yield (Klimek-Kopyra et al., 2018). The utilization of NDVI is prevalent in agricultural growth mapping and vegetation dynamics monitoring (Kazemi & Parmehr, 2023).

NDVI can be used to evaluate soil agrochemical indices and identify their correlation with crops. The relevance of the NDVI in defining soil-crop interactions and its significance in assessing agricultural interventions has been highlighted in several studies (Herbei et al., 2022). Moreover, NDVI has played a crucial role in the visual representation of agricultural and meteorological droughts, demonstrating its effectiveness in evaluating drought conditions (Senamaw et al., 2021).

To summarize, NDVI is essential for monitoring crops, evaluating vegetation health, and forecasting agricultural results. The uses of this technology encompass a wide range of tasks, including the assessment of crop phenology metrics and yield potential, as well as the mapping of spatial and temporal fluctuations in vegetation cover. As a result, it has become an essential tool in contemporary agricultural practices.

2.4 Agro-Environmental Measures and Sustainable Agriculture

Agro-environmental practices are essential to the shift to sustainable agriculture. Agricultural resources must be managed sustainably to meet human needs, protect the environment, and improve biological resources (Kumar Ghosh et al., 2020). Adopting agroecological systems and putting specific agro-environmental measures in place are necessary for this transition (Mićić et al., 2022). These actions are intended to encourage sustainable production methods and lessen the detrimental impacts of agriculture on watersheds (Riccioli et al., 2019). To maintain soil health and productivity, sustainable agriculture also strongly emphasizes crop rotation, soil cover management, and minimizing soil disturbance (Dev et al., 2023). To evaluate the viability of sustainable production methods and implement suitable agro-environmental policy measures, policymakers require accounting and assessment tools (C. Pacini et al., 2009; G. C. Pacini et al., 2011). Furthermore, extension programs have a critical role in supporting the implementation of sustainable agriculture techniques, which are necessary for preserving agricultural sustainability (Muhaimin et al., 2023).

Agricultural cooperatives can also encourage farmers to use innovative and ecologically friendly farming methods, hence improving the environmental sustainability of farms (Candemir et al., 2021). Optimizing agricultural structure and resource usage efficiency is crucial for achieving sustainability (Duan, 2022; Fu et al., 2022). According to Sarcinelli et al. (2022), this optimization entails using lands with high agricultural production potential for agriculture and food production and allocating lands with low agricultural production potential for the production of wood, agroforestry, ecotourism, and the preservation of natural ecosystems.

3 BIBLIOMETRIC ANALYSIS

Bibliometric analysis was performed with the data obtained from Scopus and Web of Science (WoS) databases. To broaden the scope of bibliometric analysis, the word “variable seeding” was enlarged to “seed rate” and “seeding”, and added words regarding intercropping instead of biodiversity, soil tillage, and soil compaction Thus for Scopus, the code was constructed as presented below:

Scopus: *(TITLE-ABS-KEY ("variable seeding" OR "seed rate" OR "seeding" OR "soil tillage" OR "soil compaction" OR "intercrop*") AND TITLE-ABS-KEY ("precision farming" OR "precision agriculture"))*

while the code for WoS was constructed accordingly:

WoS: *(((Topic) AND (Topic)) AND TS=("variable seeding" OR "seed rate" OR "seeding" OR "soil tillage" OR "soil compaction" OR "intercrop*")) AND TS=("precision farming" OR "precision agriculture")*

Scopus found 448 documents, while WoS found 290 documents. Thus, these databases comprised 738 documents, making it sufficient to analyze using the bibliometric method. Both databases were merged and deduplicated using the RStudio bibliometrix library (Aria & Cuccurullo, 2017). Of 738 documents, 215 were removed by the software due to deduplication, thus leaving the merged database with 519 documents. The data was saved in the .csv format and analyzed with the software VOSviewer.

Out of 3571 total keywords among all the documents occurring in the database, 220 met the threshold of 8, i.e. 101 words appeared five or more times in all the 519 documents. The whole, unanalyzed network map is presented in Figure 12 and the keywords cluster is shown in Table 3.

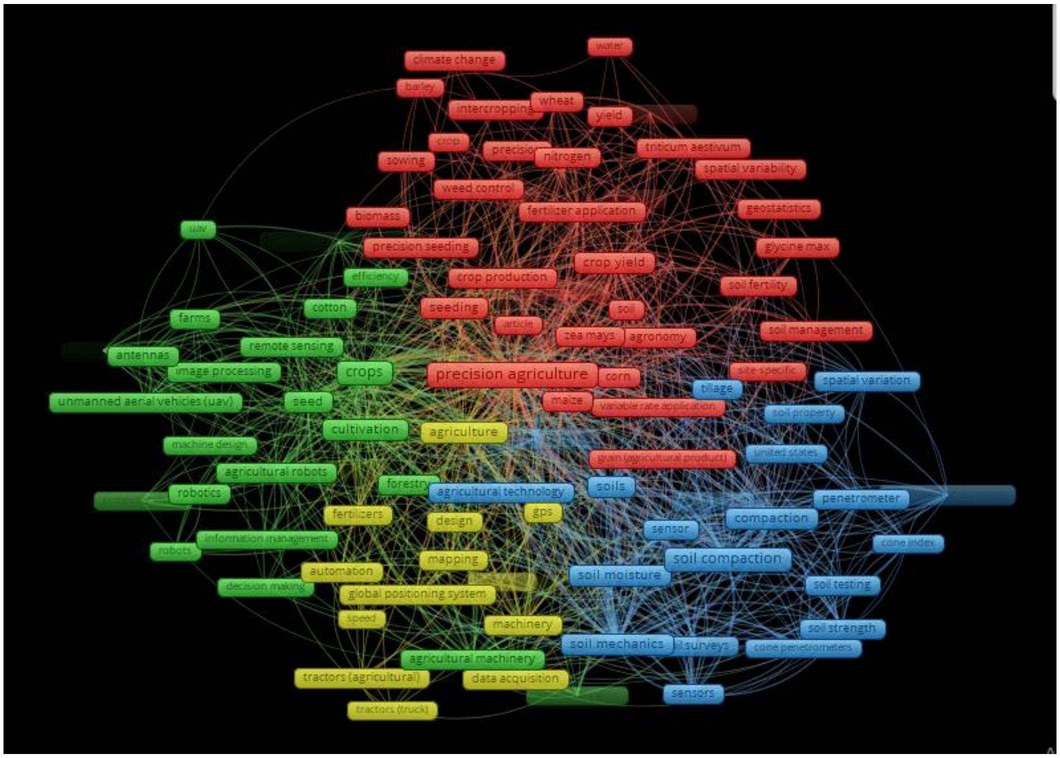


Figure 12 Network map of the selected terms (Source: own study, generated by the software VOSviewer)

Table 3 Keyword cluster

Cluster	**1**	**2**	**3**	**4**
Keywords	agricultural management, agronomy, article, barley, biomass, climate change, corn, crop, crop production, crop yield, fertilizer application, geostatistics, glycine max, grain (agricultural production), growing season, herbicide, intercropping, maize, management zones, ndvi, nitrogen,	agricultural machinery, agricultural robots, antennas, computer vision, cotton, crops, cultivation, decision making, deep learning, efficiency, farms, forestry, image processing, information management, machine design, remote sensing, robotics, robots, seed, soil conservation, sustainable	agricultural technology, compaction, cone index, cone penetrometers, electrical conductivity, penetrometer, precision farming, sensor, sensors, soil analysis, soil compaction, soil mechanics, soil moisture, soil property, soil strength, soil surveys, testing, soils, spatial variation, tillage	agriculture, automation, data acquisition, design, experimental study, fertilizers, global positioning system, gps, harvesting, machinery, mapping, neural networks, plant (botany), simulation, speed, tractor (agricultural), tractors (truck)

Cluster	1	2	3	4
	optimization, precision agriculture, precision seeding, seeding, site-specific, soil, soil fertility, soil management, sowing, spatial variability, triticum aestivum, variable rate application, water, weed control, wheat, yield, yield response, zea mays	development, uav, unmanned aerial vehicle		
Common theme	Crop production and management practices.	Precision farming technologies and methods.	Soil analysis and precision farming.	Agricultural automation and technology.

Density visualization

Density visualization means the most occurring themes among analyzed keywords (Figure 13). According to findings, the most occurring of these were:

1. Precision agriculture	5. Seed
2. Agriculture	6. Crops
3. Precision farming	7. Compaction
4. Soil compaction	8. Soil mechanics

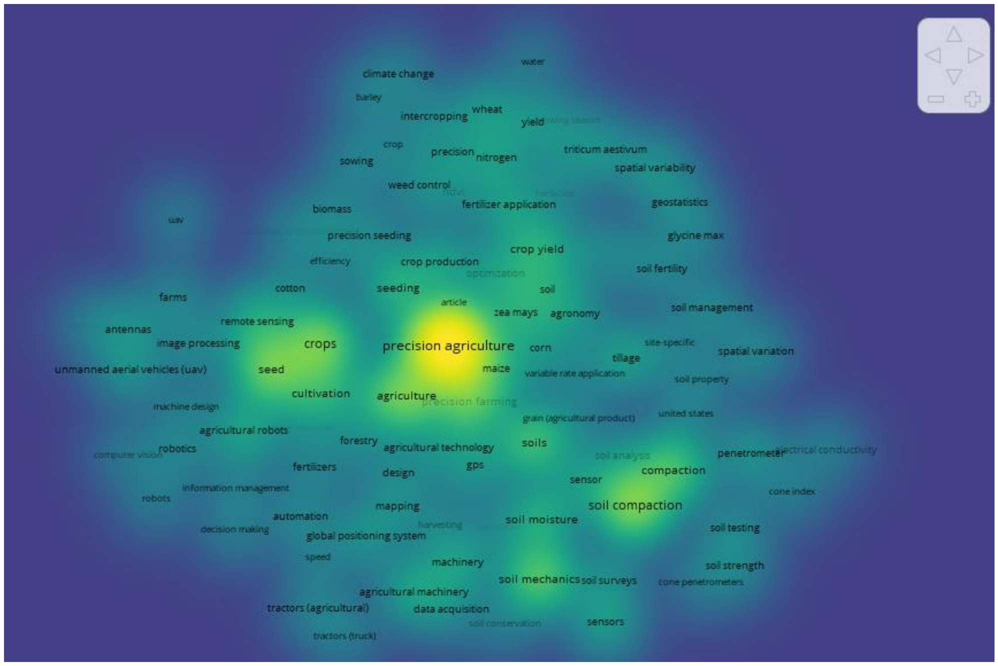


Figure 13 *Bibliometric analysis of the density visualization (*Source: own study, generated by the software VOSviewer)

In discriminatory search for Variable seeding

As the threshold of a minimum of 8 co-occurring keywords did not find "variable seeding", "soil tillage", and "intercropping" an in-discriminatory search was performed (no minimum co-occurrence threshold). There was only one relevant term for variable seeding: "seeding rate". The first one (Figure 14) was connected to such words as:

1. Seed
2. Precision agriculture

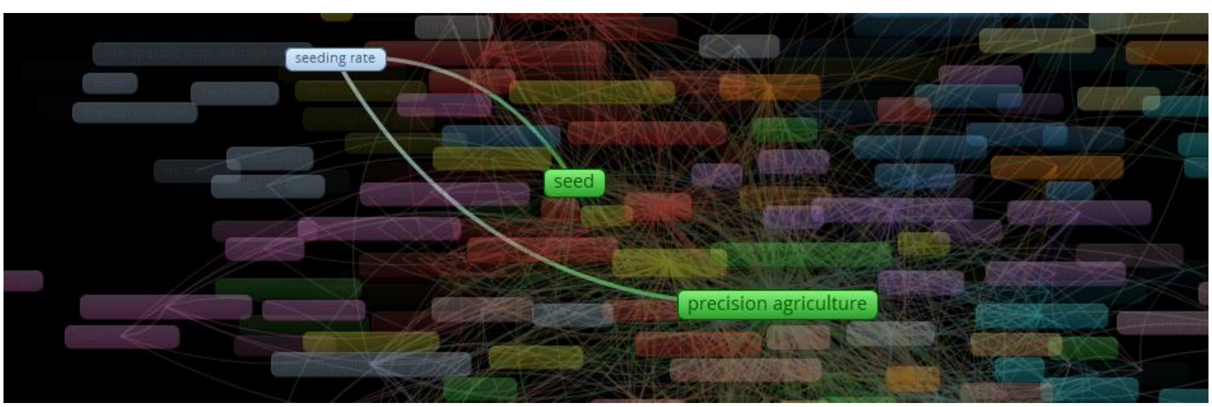


Figure 14 Bibliometric network for the term "seeding rate" *(*Source: own study, generated by the software VOSviewer)

“Soil tillage” was not connected to any words, as presented in the picture below (Figure 15). While Intercropping (Figure 16) connected to words such as:

1. Climate change
2. Agriculture
3. Precision agriculture

Figure 15 Bibliometric network for the term “soil tillage” (Source: own study, generated by the software VOSviewer)

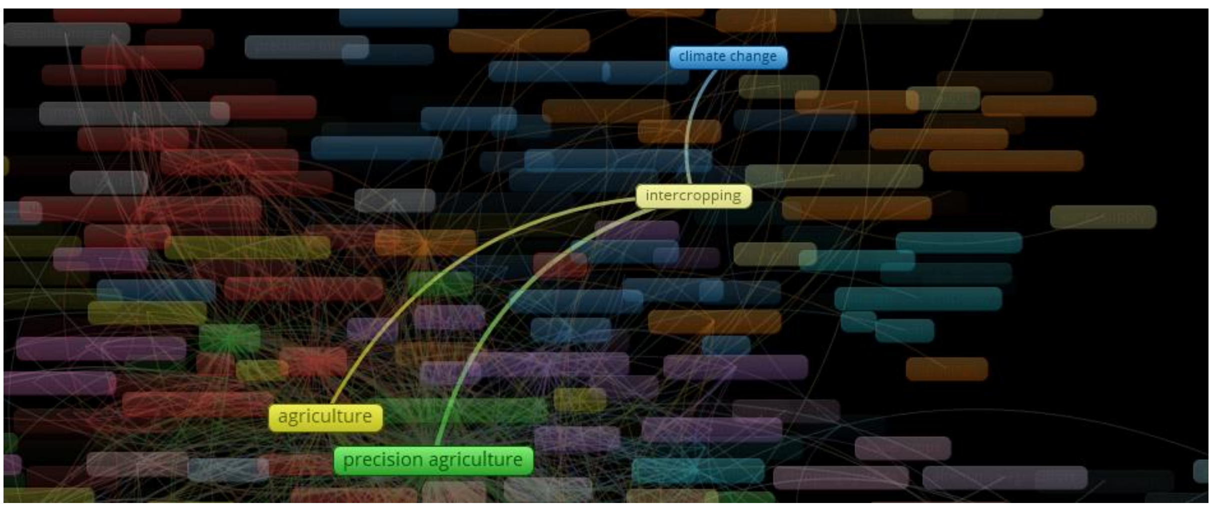


Figure 16 Bibliometric network for the term “intercropping” (Source: own study, generated by the software VOSviewer)

4 MATERIALS AND METHODS

A literature review pertinent to the work assignment will be prepared, with an emphasis on sowing technology, variable seeding, field variability, and water infiltration.

Experimental areas were established in the companies Statek Chyše s.r.o. and Zemědělská akciová společnost Mžany a.s. The situation plan is in Figure 17.

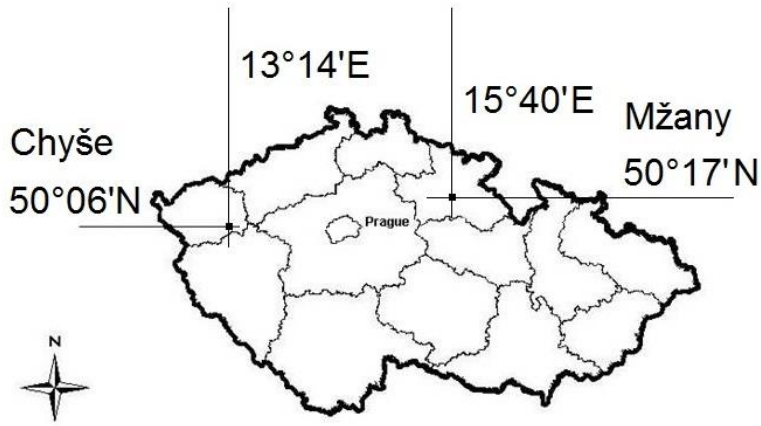


Figure 17 Location of experimental areas.

4.1 Experimetal fields Chyše

The land of Statek Chyše s.r.o. was utilized to conduct experiments with variable sowing. The plots were chosen based on the need for soil conditions to vary. The experiment involved the selection of three plots. The Bojos spring barley variety was planted in plot 7701 (41.11 hectares) in 2022. Plots 1011 (31.8 hectares) and 2002/13 (19.23 hectares) were cultivated in the year 2023. The Bojos variety was also sown. The pre-crops were winter wheat.

The electrical conductivity of the soil was assessed prior to seeding using an EM38 MK2 equipment manufactured by Geonics Limited in Canada (see Figure 18). The recorded values were accompanied by the corresponding position at regular intervals of one second, with a measurement interval of 36 meters. The values were used to construct soil conductivity maps. The plots were partitioned into five management zones based on the soil's conductivity. These zones were then utilized to determine the appropriate sowing of different varieties and to collect plant samples for the evaluation of biometric markers.

Figure 18 Measurement of electrical conductivity of the soil with the EM38MK2 probe.

To assess the influence of different seeding methods, we selected sowing rates of 2 million, 3 million, 4 million, and 5 million germinating seeds per hectare (MGS/ha). The seeding machine's individual test strips, which had a working width of 9 m, were picked in a manner that ensured they intersected all the designated management zones based on soil conductivity. For each seeding rate, two strips were planted. A Horsch Pronto seeding machine was used to establish the stands. Following that, all variants were addressed in a similar manner. The plot was designated for the collection of points for each kind. There were four trials, five measurements of conductivity, and five repetitions. A comprehensive set of 100 samples was gathered, specifically selected using a GPS receiver. Samples were consistently obtained subsequent to the appearance of the stand in order to ascertain the quantity of plants and the mass of aboveground biomass, as well as prior to the harvest to evaluate characteristics that contribute to yield generation. Following that, the stand was harvested using a harvester, and the resulting yield was documented. The strip for the specified seeding was consistently collected individually.

The laboratory of the Department of Agricultural Machinery conducted the analysis of plant samples. During spring sampling, the quantity of plants was ascertained, followed by the separation of the root portion and the subsequent drying and weighing of the above-ground portion of the plants. The values of stand height, number of ears, number of grains in an ear, weight of straw, weight of grain, and weight of one thousand grains were determined based on the samples collected prior to harvest.

Images were captured periodically using the DJI Mavic3M unmanned aerial vehicle, which is equipped with a multispectral camera. The camera has specific features and operates in the following bands: NIR 860 nm ± 26 nm, RE 730 nm ± 16 nm, R 650 nm ± 16 nm, and G 560 nm ± 16 nm. Subsequently, the NDVI index was calculated for the respective areas of the sampling points.

4.2 Experimetal fields Mžany

The experimental areas of corn and sugar beet were established on the land of Zemědělská aktiové společností Mžany a.s. The plots were planted with a Väderstad Tempo seed drill. The control electronics of the sowing machine enable individual setting of each sowing unit. In 2023, corn plot 3901/2 (39.55 ha) (Figure 19) and sugar beet plot 9502/4 (13.87 ha) were sown.

The technologies for establishing corn are sown track row preparation is front-mounted cultivator and the sowing of the spaying row with a seeder mounted on a front-mounted cultivator. The width of the spraying rows was 3 m. In the marginal rows, the sowing rate was 95,000 seed/hectare. The second rows from the belt were sown with 90,000 seed/hectare. The seeding of maize sown in the other rows was 85, seed/hectare by standard (Figure 20), the inter-row distance between the rows of plants was 0.75 m. The variety Hybrid LG 31.305 was sown.

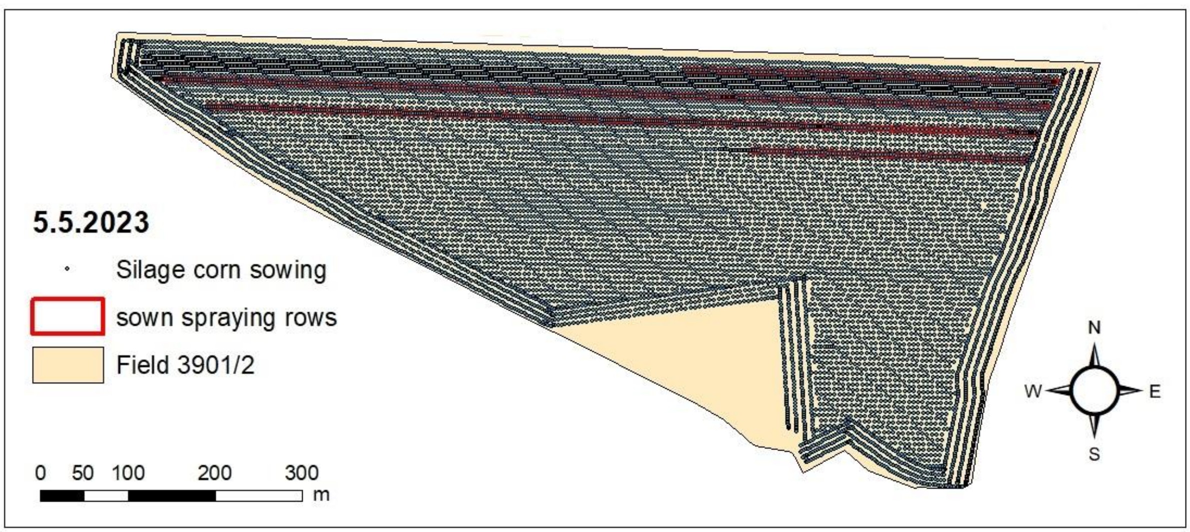


Figure 19 Record of corn sowing with marked sown track rows.

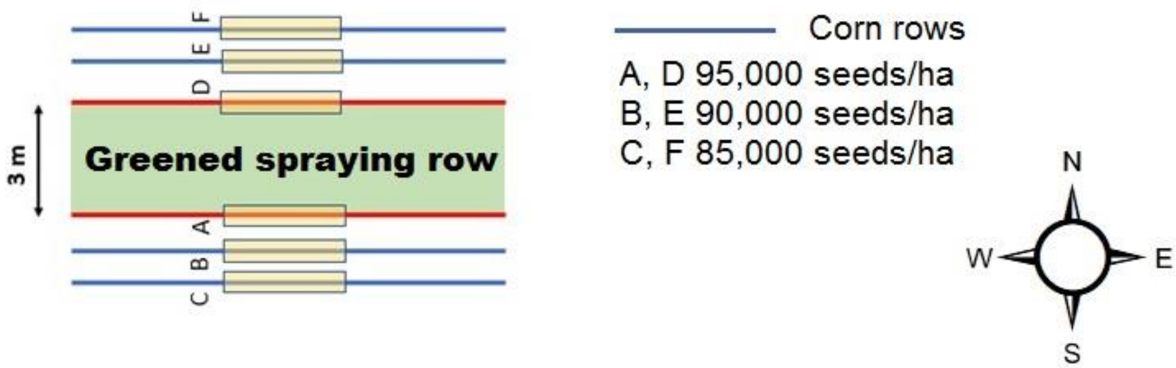


Figure 20 Detail of seeding organization.

The character of water infiltration into the soil will observe in the sugar beet stand. Blue food dye E133 was used to visualize the flow of water in the soil profile. After 24 hours, the soil profile was uncovered and individual sections in three replicates for each variant were imaged. The BMPTool program was used for the analysis.

4.3 Statistical Analysis

4.3.1 Pearson Correlation Coefficient

The statistical technique, Pearson correlation analysis, is employed to assess the magnitude and direction of the linear association between two continuous variables. One validation technique that can be applied to linked or linear variables is based on Haryanto et al. (2021). Using Excel, a pair-wise Pearson Correlation Coefficient (PCC) was initially calculated to quantify the linear link among the variables to provide a more comprehensive view of the correlation and geographic patterns between biometric markers, variable seeding, and soil physical parameters. The Pearson correlation equation is as follows:

$$r = \frac{n \sum XY - \sum X \sum Y}{\sqrt{\{n \sum X^2 - (n \sum X^2)\}\{n \sum Y^2 - (n \sum Y^2)\}}}$$

Information:

r = Correlation value;
n = Number of data pairs X and Y;
ΣX = Total number of variables X;
ΣY = Total number of variables Yf;
ΣX^2 = Square of the total number of variables X;
ΣX^2 = Square of the total number of variables Y;
ΣXY = The product of the total number of variables X and Y.

4.3.2 Analysis of Variance

ANOVA, or one-way analysis of variance, is a statistical technique used to compare means based on one or more variables from distinct groups, according to Walpole et al. (2016). Response variables, or measurements of variables seen in multiple independent groups, are handled using this method. The one-way ANOVA technique tests (0.05 significance level) were run to determine the importance of the variable differences. The null hypothesis states that the population means of the groups under comparison do not differ significantly.

5 RESULTS AND DISCUSSION

5.1 Prescription Map for Plant Establishment in the Spring Barley Field

The prescription map for field codes 7701, 2002, and 1001 in Figures 21, 22, and 23 reveals a nuanced spatial distribution of soil conductivity classes, spanning classes 1 through 9, 0 through 4, and 1-5, respectively. This variation highlights the diverse salinity levels within the field, likely influenced by factors such as irrigation practice and soil composition (Pulido-Bosch et al., 2018). Higher conductivity levels, indicative of increased soil salinity (Marković et al., 2013), may pose challenges to crop growth and yield due to hindered nutrient uptake and water balance.

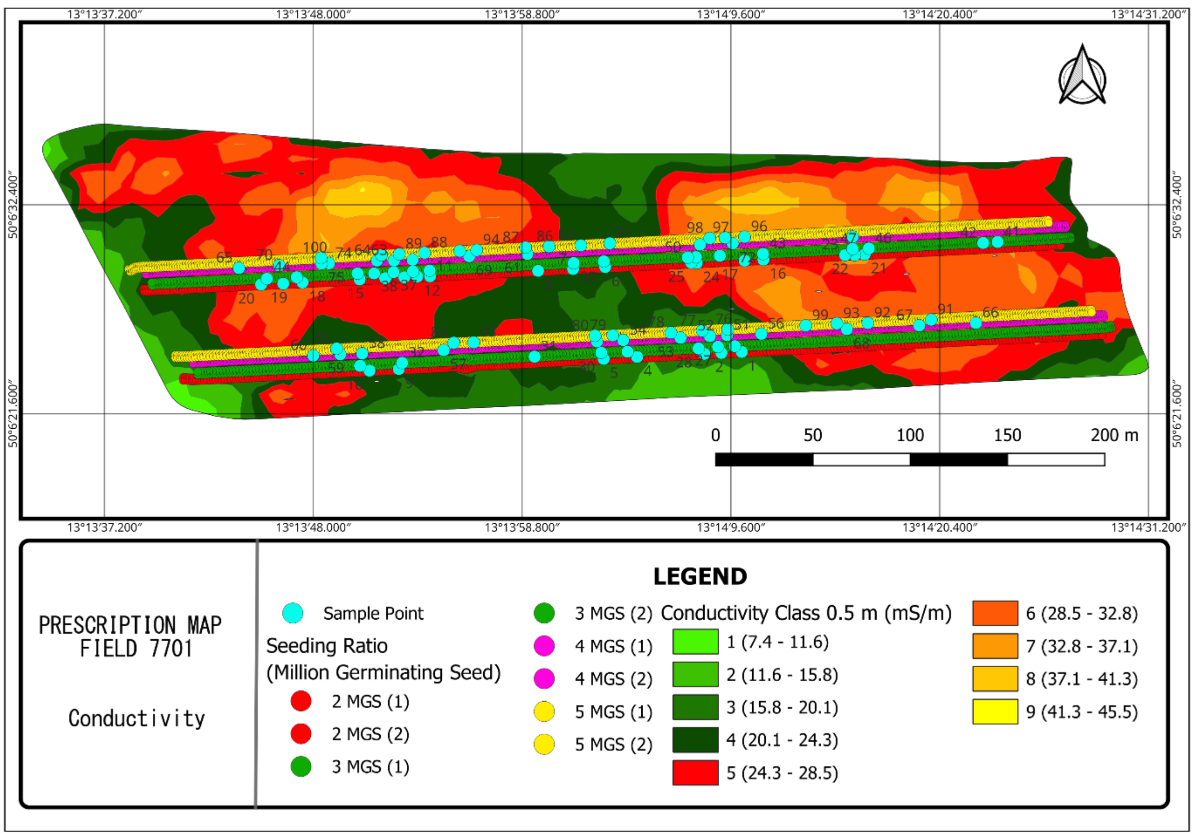


Figure 21 The Prescription map shows the conductivity class, seeding ratio, and sampling point on field 7701.

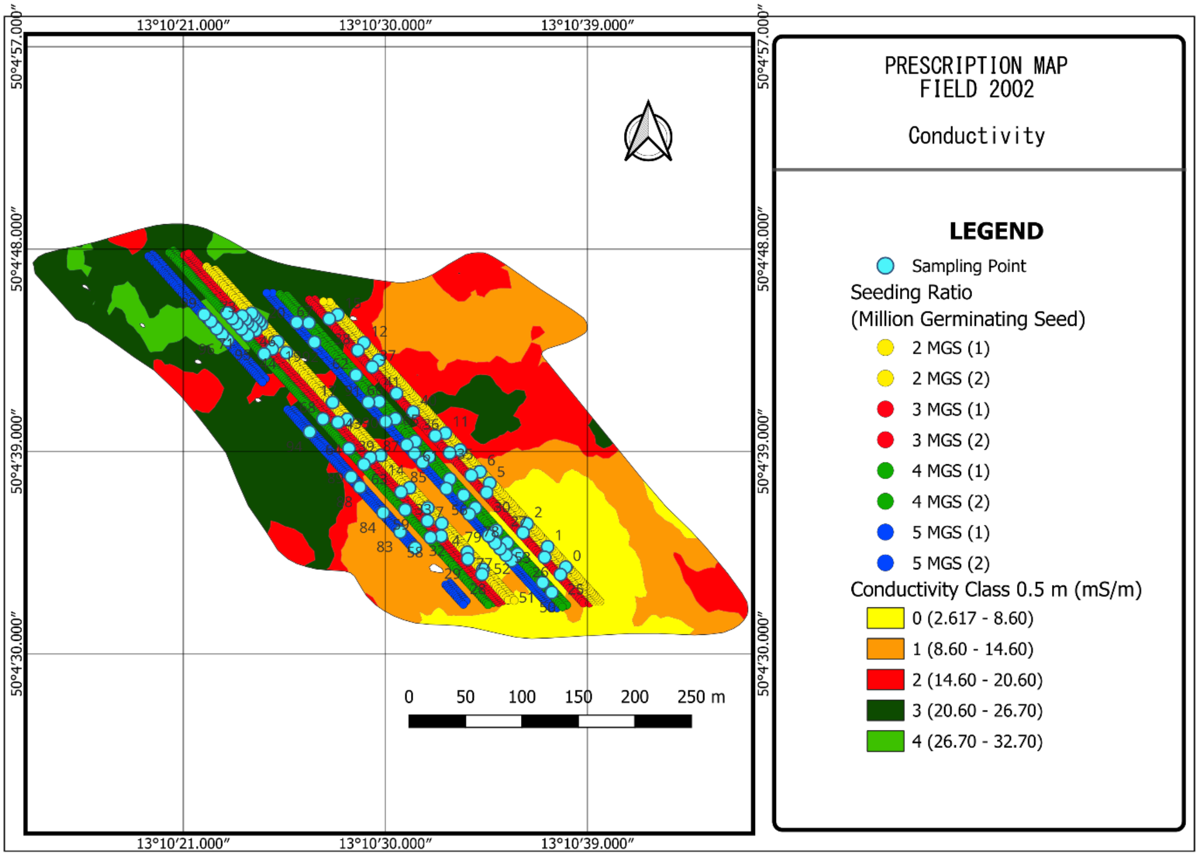


Figure 22 The prescription map shows the field's conductivity class, seeding ratio, and sampling point in 2002.

Furthermore, an examination of seeding density in diverse soil conditions is demonstrated by the application of four distinct seeding ratios (2, 3, 4, and 5 MGS/ha) across fields 7701 and 2002. The relationship between conductivity classes and seeding ratios offers significant insights into the capacity of crops to adjust and react to different intensities of planting. This information is vital for adopting site-specific management methods. Possible approaches to enhance resource utilization and minimize output reductions encompass precision irrigation, soil amendments, and crop selection based on salinity tolerance levels to achieve optimal plant population densities to maximize production potential.

Based on Table 1, we can identify the soil types in the field by analyzing their respective conductivity values. Field 7701 in Figure 21 has nine conductivity levels, but only levels 3 through 7 were selected for the sampling point. These classes range from 3 to 7, with

18.80 and 41.30 mS/m conductivity values. The soil type for conductivity classes 3 and 4 is topsoil, while classes 5 through 7 are loam.

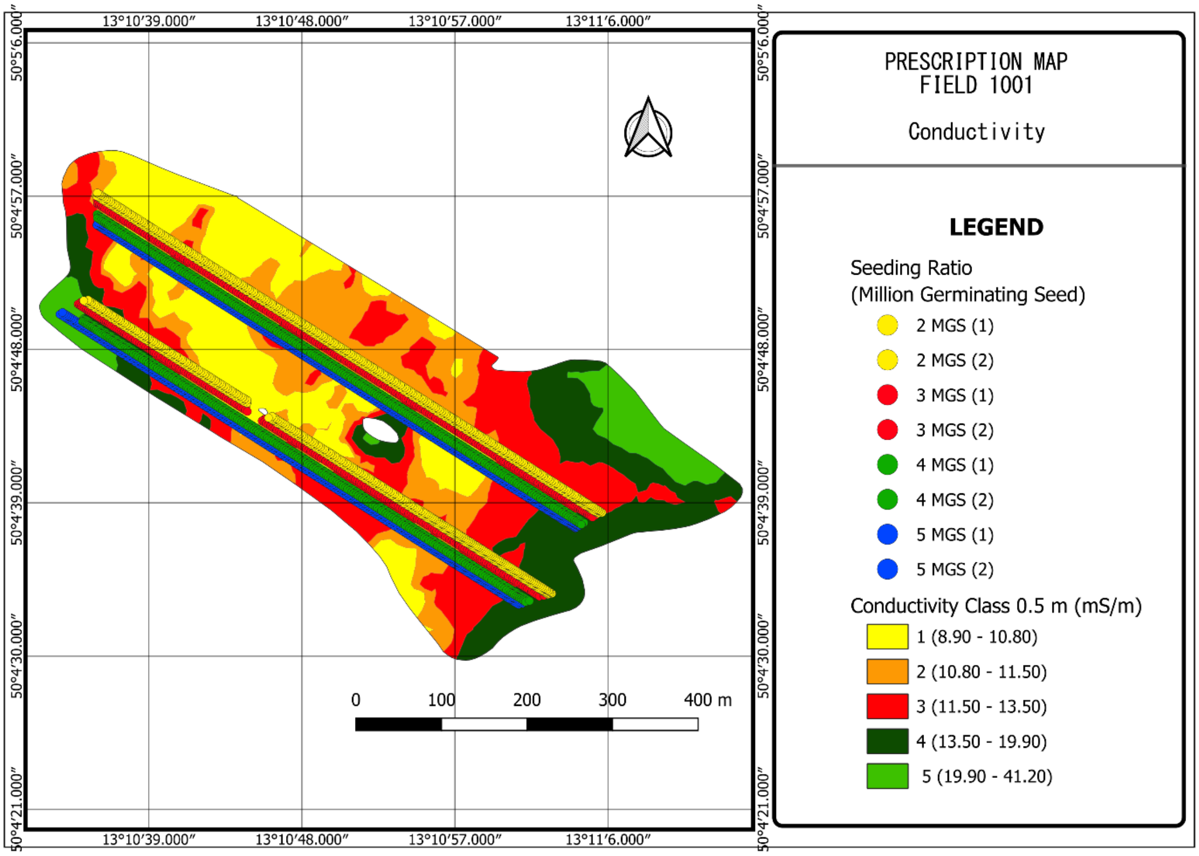


Figure 23 The prescription map shows the conductivity class and seeding ratio on the field 1001.

Field 2002 in Figure 22 has conductivity levels ranging from 0 to 4 with values between 2.617 and 32.70 mS/m. For conductivity class 0, the soil type is clay-rich soil, while classes 1 through 3 are topsoil, and class 4 is classified as loam. Field 1001 in Figure 23 includes conductivity levels ranging from 1 to 5, with conductivity values between 8.90 and 41.20 mS/m. The soil type for conductivity levels 1 through 4 is topsoil and level 5 is loam.

Some studies have shown that barley can be grown in soils with electrical conductivity (EC) levels of 8 dS/m or less. Soil with EC values below 8 dS/m is considered suitable for barley cultivation, allowing for optimal crop growth and yield (Casterad et al., 2018). This is supported by the research by Katsube et al. (2003), which indicates that barley has a salt tolerance threshold between 4.5 and 5.7 dS/m (Table 2). Furthermore, studies have shown that barley can be successfully grown in soils with moderate salinity levels, with EC values ranging from 3 to 5 mS/m. These moderate salinity levels do not significantly hinder barley growth and can support good crop yields (Saini, 1972).

5.2 Biometric Indicator of Plant and Soil Evaluation in the Barley Field

5.2.1 Field 7701

Figure 24 presents the relationship between soil conductivity and grain yield across various seeding ratios (2, 3, 4, and 5 MGS/ha) in Field 7701. The average grain yield data from 100 sampling points in various seeding ratios and conductivity levels, as depicted in Figure 21, was used for this analysis. A significant enhancement in grain yield is observed at conductivity class 4 (20.1-24.3 mS/m) when varying seeding ratios are employed. The observed seeding ratio of 5 MGS/ha indicates a positive correlation between conductivity and grain production.

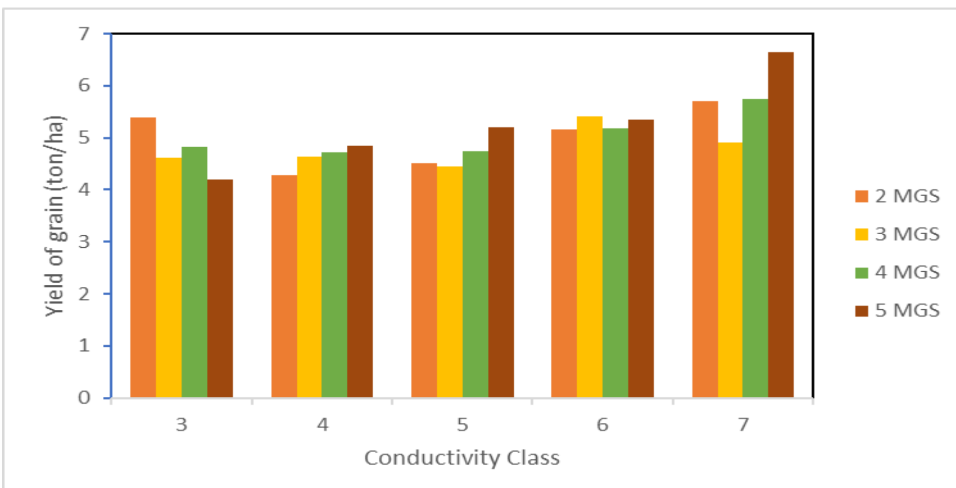


Figure 24 Field 7701 graph of grain yield in different seeding ratios and classes of conductivity from the sampling point.

An ANOVA was conducted to assess the effect of conductivity on yield potential (Tables 4 and 7). The very low p-value of 4.1e-06, which indicates a highly significant effect of the conductivity class on grain yield, supports the ANOVA test's conclusion that conductivity has a substantial and positive impact on yield potential in Table 4. This indicates that variations in conductivity levels rather than random variation are more likely to cause yield disparities across the different conductivity levels (3, 4, 5, 6, and 7).

Table 4 ANOVA result field 7701 in R from the sampling point.

Variable	Df	Sum_Sq	Mean_Sq	F_value	Pr (>F)	Significance
Conductivity_Class	1	12.98	12.985	23.59	0.00000452	***
Residuals	98	53.95	0.551			

Source: own study

Tables 5 and 8 show the correlations between factors and outcomes examined using Pearson correlation coefficients. These correlation coefficients provide insightful information on the relationships between various variables, making it easier to understand how multiple factors affect the growth and productivity of barley. A perfect positive linear relationship is denoted by a value of 1, a significant negative linear relationship by a value of -1, and no linear relationship between the variables is indicated by a value of 0 (Akoglu, 2018). According to Altman, correlations with values near 0.2 are considered bad, whereas those over 0.8 are considered outstanding (Akoglu, 2018).

Table 5 Pearson correlation analysis field 7701 from the sampling point.

Variable	Seeding Ratio	Conductivity Class	Number of Plant	Leaf Dry Matter	Height	Number of Grain/ear	1000 Grain Weight	Number of ear/m2	Number of ear/plant	Yield of Straw	Yield of Grain
Seeding Ratio			**0.8240**	**0.8335**	0.0118	**-0.1149**	**-0.2446**	**0.4415**	**-0.7092**	0.2183	0.1308
Conductivity Class			0.0069	-0.0586	0.3037	0.0344	**0.7133**	0.0087	**-0.1436**	0.2132	**0.4408**
Number of Plant				**0.8004**	0.0533	**-0.0445**	-0.1989	**0.4408**	**-0.8271**	0.2600	0.1818
Leaf Dry Matter					**-0.0455**	**-0.2273**	-0.2899	0.4095	**-0.7006**	0.1658	0.0722
Height						0.3631	0.3800	0.3860	0.1171	0.6336	**0.6544**
Number of Grain/ear							0.2399	0.1079	0.0763	0.3430	0.3006
1000 Grain Weight								0.0638	0.1629	0.3688	**0.6016**
Number of ear/m2									**-0.1261**	**0.7338**	**0.6638**
Number of ear/plant										-0.0213	0.0193
Yield of Straw											0.4011
Yield of Grain											

A strong positive association (r = 0.8240) has been found in Table 4 between the seeding ratio, the number of plants, and the leaf dry matter (r = 0.8335). This suggests a more excellent seeding ratio is linked to more plants and leaf dry matter. The number of ears per plant (-0.7092) and the grain weight average (-0.2446) have a strong negative and moderate negative correlation, respectively, with an increasing seeding ratio. This means that while the number of ears per plant decreases significantly, the grain weight average tends to decrease (Figure 25). At the traditional significance threshold of 0.05, the correlation between grain yield and seeding ratio has a p-value of 0.1308, which suggests that there is no statistically significant correlation between these two variables. Therefore, the seeding ratio has little effect on grain yield (Figure 25).

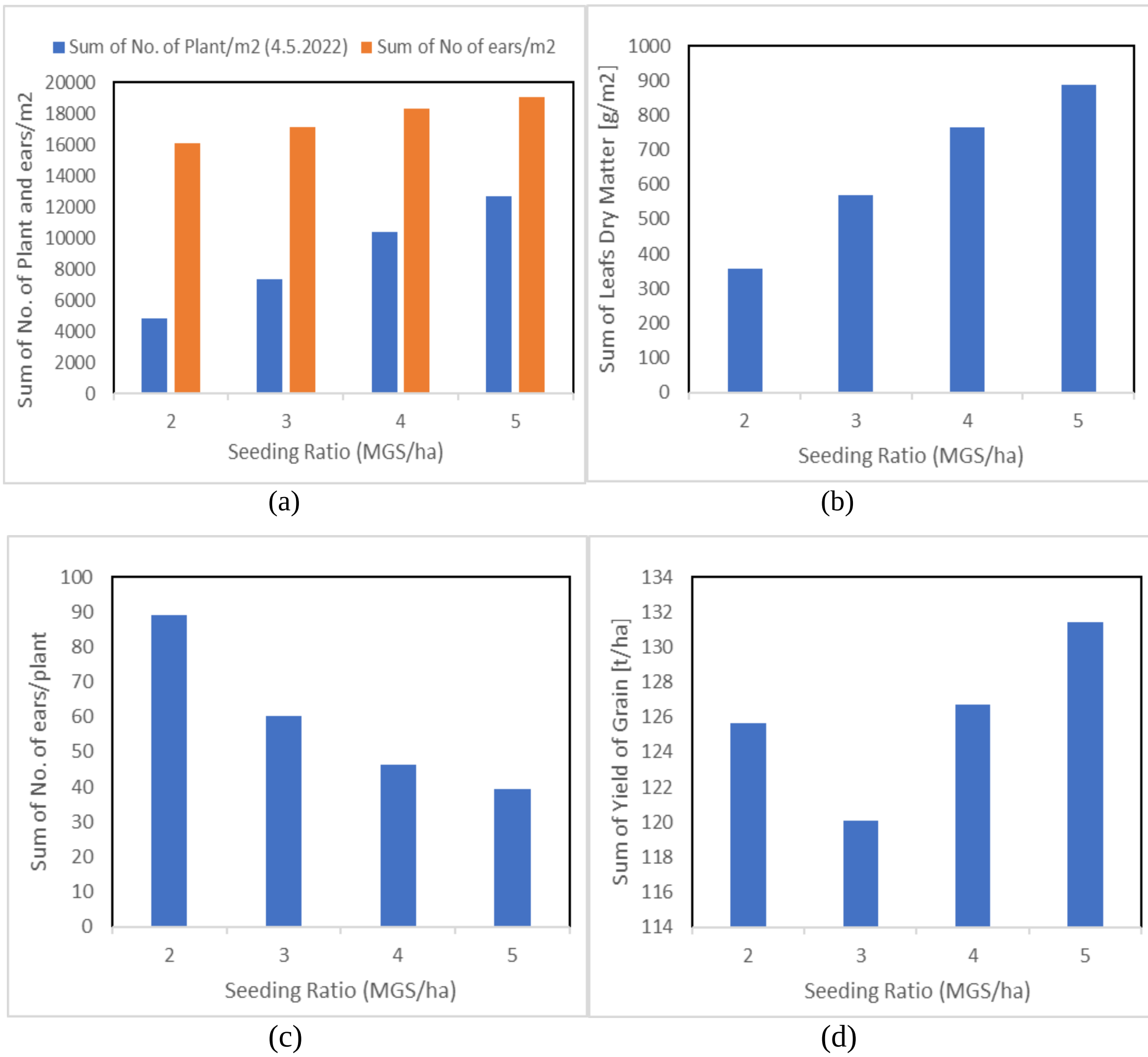
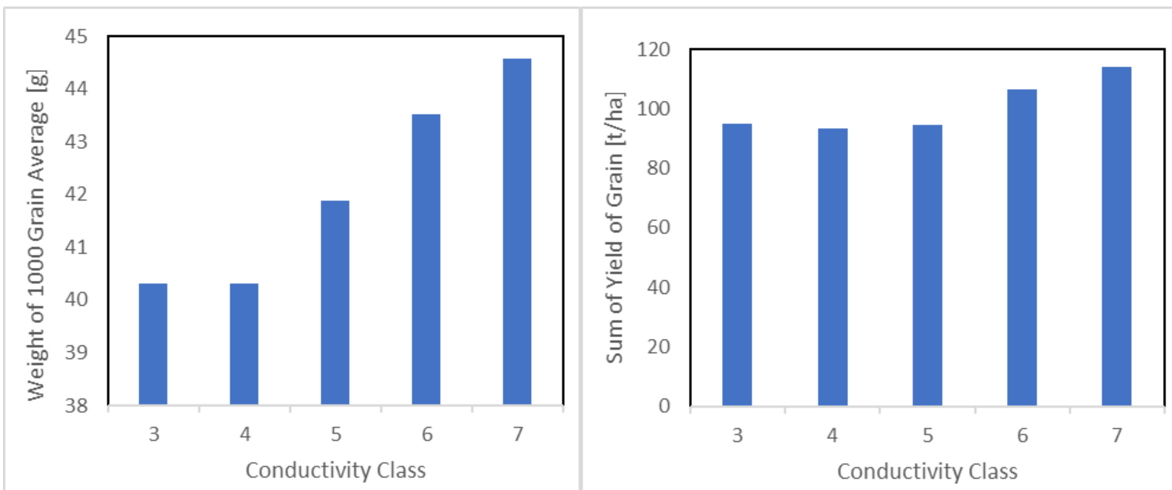


Figure 25 Field 7701 graph of seeding ratio correlation with (a) the number of plant/m^2 and number of ear/m^2 (b) leaf dry matter (c) the number of ears/plant (d) grain yield.

Figure 26 shows a weak positive correlation with the number of plants (0.0069) and a moderate positive correlation with the grain weight average (0.7338), suggesting that higher conductivity classes are associated with heavier average grain weights due to these correlations. The correlation coefficient of 0.4408 indicates a moderate tendency for higher conductivity levels to be associated with higher grain yields, highlighting the relationship between conductivity levels and grain yields. It can be inferred from this positive link that grain yields tend to rise in tandem with increasing conductivity levels (Figure 26). There is a relationship between conductivity and grain yield. However, this correlation does not necessarily imply causality, as other factors may also be responsible for differences in grain output.

Different research shows the positive impact of the seeding ratio on multiple features of plant growth, such as yields or leaf area (Isidro-Sánchez et al., 2017). The conductivity level is reported to be beneficial for the harvest of bioproducts not only in the production of grains (Cassman, 1999) but also in vegetables (Silva et al., 2019) and even fisheries (Mustapha, 2008). It confirms the outcome of this research, which confirms a strong correlation (0.7133) between the 1000-grain weight and conductivity class, as presented in Table 5.



(a) (b)

Figure 26 Field 7701 graph of conductivity class correlation with (a) weight of 1000 grain average and (b) grain yield.

Figure 27 presents the relationship between soil conductivity and grain yield across various seeding ratios (2, 3, 4, and 5 MGS) in Field 7701. The average grain yield data is from the combined harvester. Grain yield increases noticeably in each conductivity class at various planting ratios, showing a discernible percentage growth. The moisture content of the grain at varying soil conductivity levels is displayed in Figure 28. As soil conductivity increases within each sowing variety, a visible trend of decreasing moisture content is seen across the conductivity classes, with a substantial drop in moisture levels. According to this tendency, harvested grain may become less wet due to rising soil conductivity levels, which could affect grain quality or call for particular storage circumstances.

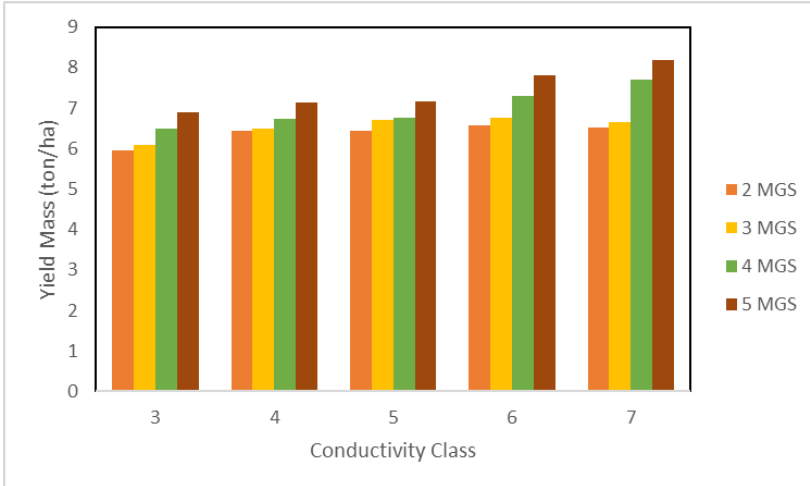


Figure 27 Field 7701 graph of grain yield in different seeding ratios and classes of conductivity from the combined harvester.

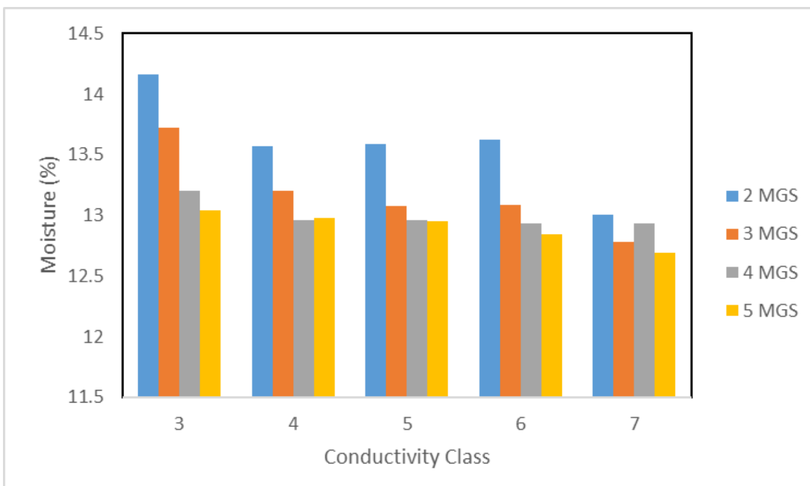


Figure 28 Field 7701 graph of the grain moisture content in different seeding ratios and classes of conductivity from the combined harvester.

Tables 6 and 9 provide the result from an ANOVA that determines if there are statistically significant variations in the means of grain yield across various categorical predictor variables, such as Moisture, Seeding Ratio, and Conductivity Class.

Table 6 ANOVA result field 7701 in R from the harvester.

Factor	**Df**	**Sum_Sq**	**Mean_Sq**	**F_value**	**Pr (>F)**
Moisture	1	50	49.6	50.32	1.5e-12 ***
Seeding_Ratio	7	732	104.5	105.95	< 2e-16 ***
Conductivity_Class	1	1197	1197	1213.2	< 2e-16 ***
Residuals	4841	4841	1.0		

The F-statistic p-values show that the mean grain yield varies considerably according to the amounts of moisture, seeding ratio, and conductivity class.

5.2.2 Field 2002

Figure 29 presents the relationship between soil conductivity and grain yield across various seeding ratios (2, 3, 4, and 5 MGS) in Field 2002. The average grain yield data from 100 sampling points at different seeding ratios and conductivity levels—as shown in Figure 22—were employed for this field. The 4 and 5 MGS/ha seeding ratios show higher conductivity levels are typically associated with more significant grain yield amounts. For all planting ratios, grain yield decreases noticeably for conductivity class 1 (8.60–14.60 mS/m). Among all seeding variations, conductivity levels 3 and 4 typically provide the maximum yields.

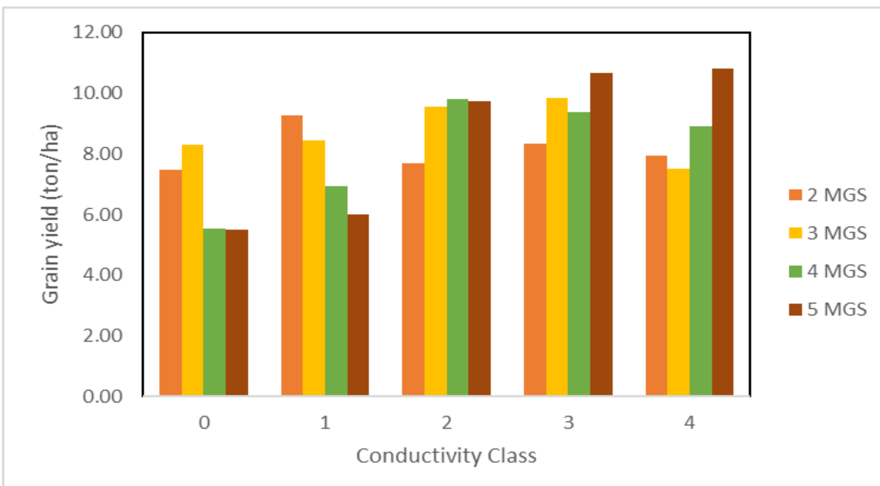


Figure 29 Field 2002 graph of grain yield in different seeding ratios and classes of conductivity from the sampling point

The ANOVA test has indicated that conductivity has a significant and positive impact on yield potential in Table 7, supported by the extremely low p-value of 9.92e-09, indicating a highly significant effect of the conductivity class on grain yield. These findings suggest that variations in grain yield among different conductivity classes are improbable to be attributed to random events.

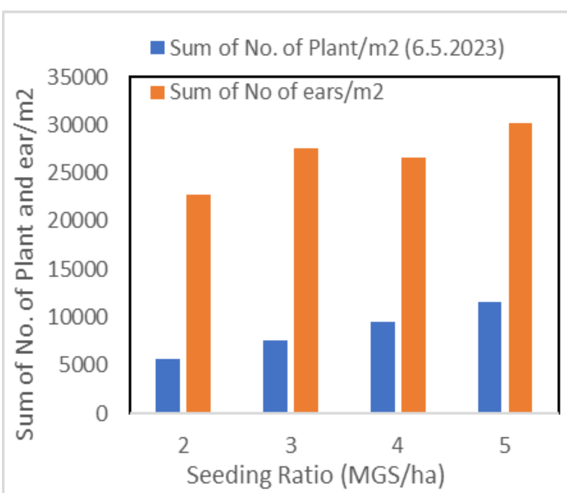
Table 7 ANOVA result field 2002 in R from the sampling point.

Variable	Df	Sum_Sq	Mean_Sq	F_value	Pr (>F)
Conductivity_Class	1	137.1	137.07	39.57	9.92e-09 ***
Residuals	94	325.6	3.46		

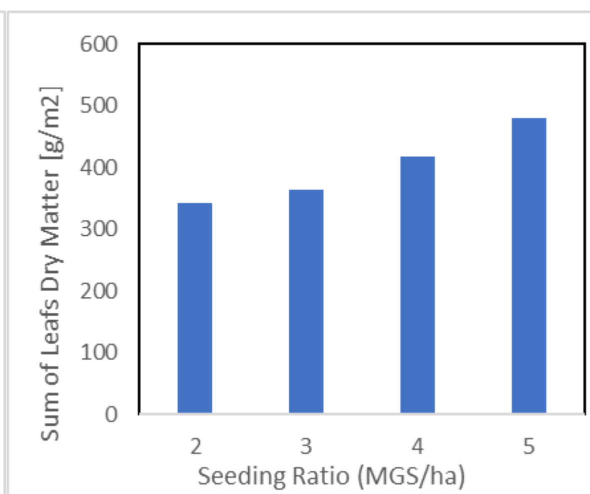
Table 8 Pearson correlation analysis field 2002 from the sampling point.

Variable	Seeding Ratio	Conductivity Class	Number of Plant	Leaf Dry Matter	Height	Number of Grain/ear	1000 Grain Weight	Number of ear/m2	Number of ear/plant	Yield of Straw	Yield of Grain
Seeding Ratio			**0.8526**	**0.6431**	**-0.0976**	**-0.3892**	**-0.2274**	**0.5313**	**-0.6442**	0.1420	**0.1752**
Conductivity Class			**-0.1450**	**-0.3365**	**0.4926**	0.4102	**0.5390**	0.2462	0.2548	**0.5199**	**0.5443**
Number of Plant				**0.7745**	**-0.1511**	**-0.3941**	**-0.2494**	**0.4577**	**-0.8073**	0.0624	0.0638
Leaf Dry Matter					**-0.2268**	**-0.3635**	**-0.3482**	0.2394	**-0.6892**	**-0.0639**	**-0.1033**
Height						**0.5660**	**0.5329**	0.2963	0.3150	**0.6358**	**0.5870**
Number of Grain/ear							**0.5406**	**-0.0190**	0.3923	0.4263	0.3216
1000 Grain Weight								0.2098	0.3801	**0.5528**	**0.5660**
Number of ear/m2									0.0757	**0.7725**	**0.8271**
Number of ear/plant										0.3657	0.3891
Yield of Straw											**0.4639**
Yield of Grain											

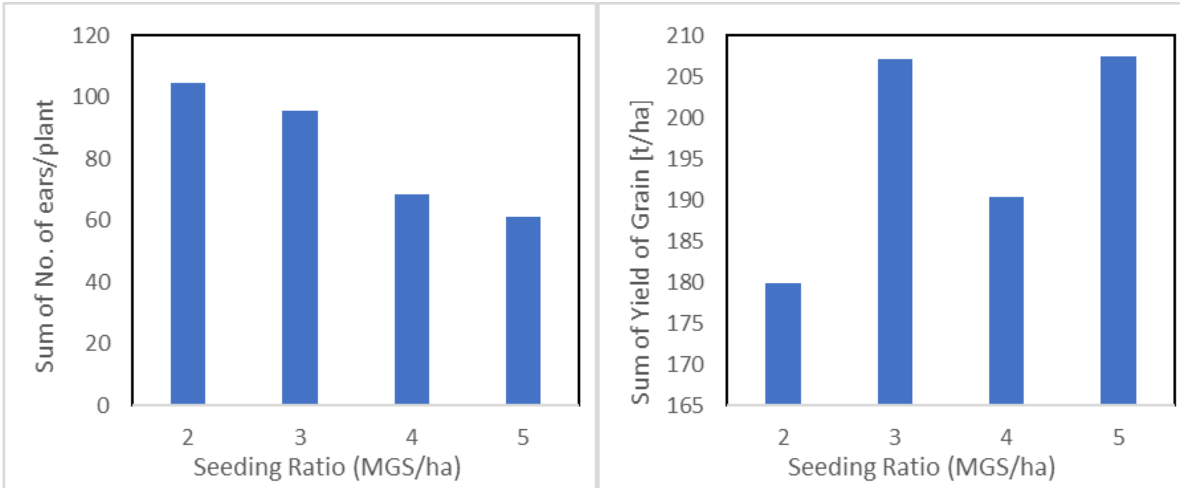
Table 8 shows a specific positive correlation between the number of plants (0.8526) and the dry matter content (0.6431) of the leaves. This suggests a higher seeding ratio is linked to more plants and dry matter-containing leaves. The number of ears/m2 and the seeding ratio have somewhat positive correlations (0.5313), suggesting that a larger seeding ratio may result in more ears/m2. The number of ears per plant has a strong negative connection (-0.6442) with an increase in the seeding ratio, resulting in a considerable decrease in the number of ears per plant (Figure 30). At the traditional significance level of 0.05, the correlation between grain yield and seeding ratio has a p-value of 0.7522, suggesting no statistically significant link between these two variables. Therefore, the seeding ratio has little effect on grain yield (Figure 30).



(a)



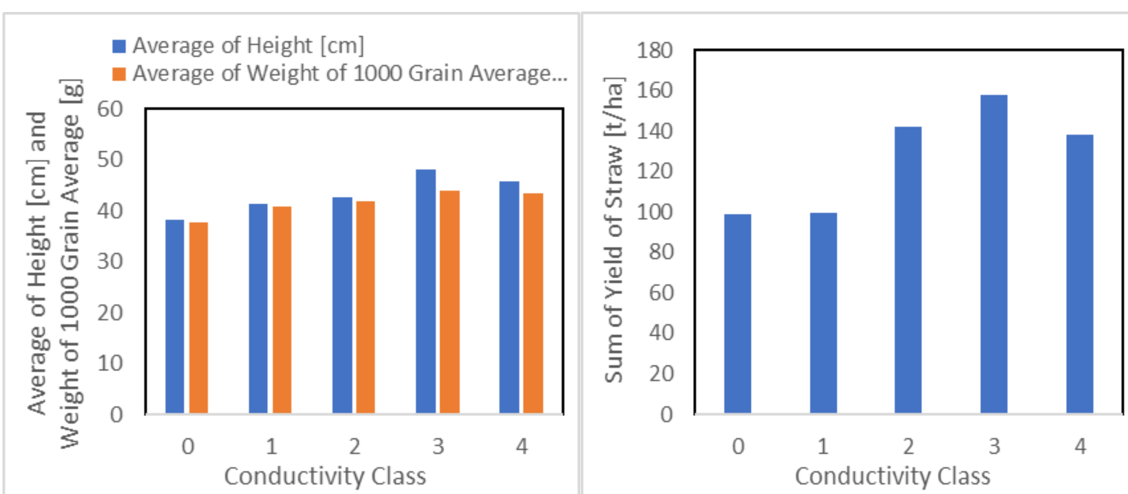
(b)



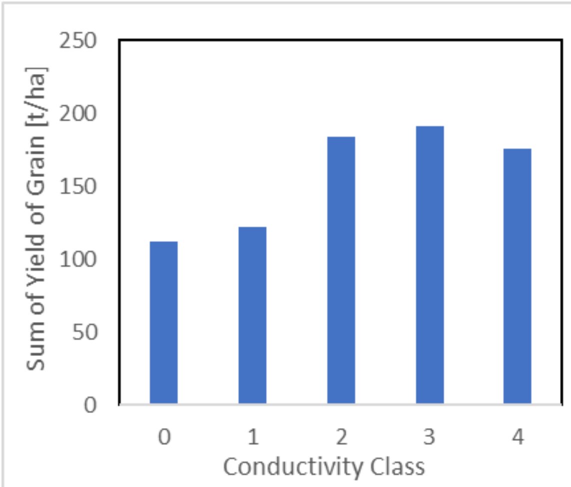
(c) (d)

Figure 30 Field 2002 graph of seeding ratio correlation with (a) the number of plant/m^2 and the number of ear/m^2 (b) leaf dry matter (c) the number of ears/plant (d) grain yield.

Figure 31 shows a moderate positive correlation with height (0.4926), the grain weight average (0.5390), yield of straw (0.5199), and yield of grain (0.5443), suggesting that higher conductivity classes are associated with taller height, heavier grain weights, higher yield straw, and grain yield. However, correlation does not imply causation, so while there is an association between conductivity and grain yield, other factors may also contribute to variations in grain yield. As shown in Table 8, the gain yield also positively correlates with height, 1000 grain weight average, and the number of ears/plant.



(a) (b)



(c)

Figure 31 Field 2002 graph of conductivity class correlation with (a) weight of 1000 grain average and height (b) yield of straw, and (c) grain yield.

The data on grain yield from the combined harvester at various seeding ratios and conductivity levels is presented in Figure 32. Class 4, which has the highest conductivity, exhibits the highest yield. Higher seeding ratios, like 4 MGS/ha, typically produce larger yields, especially in a higher conductivity class. Figure 33 shows a consistent trend of rising grain moisture content with increasing soil conductivity across all conductivity classes. This trend is particularly pronounced for the 3 MGS/ha and 4 MGS/ha seeding variants. However, this trend is not consistent across all seeding variants.

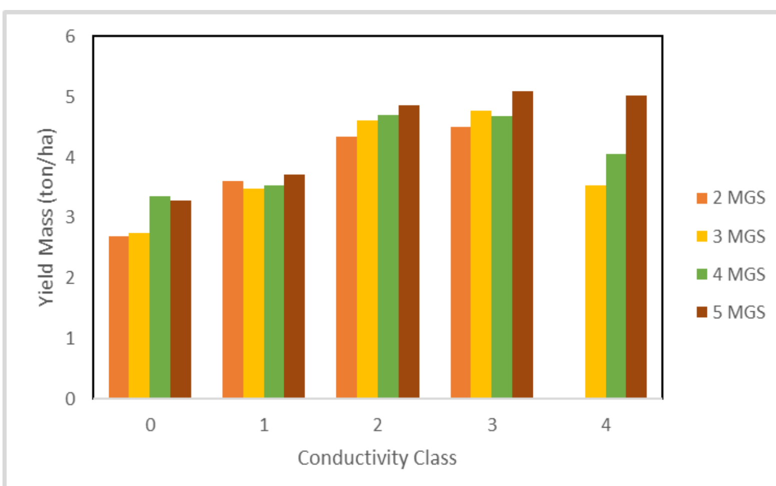


Figure 32 Field 2002 graph of grain yield in different seeding ratios and classes of conductivity from the combined harvester.

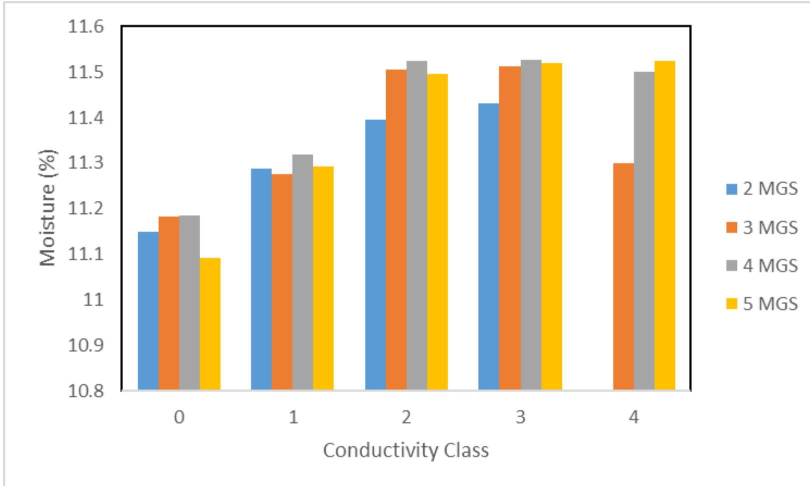


Figure 33 Field 2002 graph of the grain moisture content in different seeding ratios and classes of conductivity from the combined harvester.

According to the ANOVA result, moisture content, seeding ratio, and conductivity class significantly impact the response variable (likely grain moisture content). An exceptionally low p-value suggests that moisture content substantially affects the response variable, indicating statistically solid evidence that moisture level variations are unlikely to occur at random. Extremely low p-values demonstrate great statistical significance and show that the conductivity class and seeding ratio considerably impact the response variable.

Table 9 ANOVA result field 2002 in R from the harvester.

Factor	Df	Sum_Sq	Mean_Sq	F_value	Pr (>F)
Moisture	1	132.68	132.68	282.31	<2e-16 ***
Seeding_Ratio	7	34.28	4.90	10.42	3.712e-12 ***
Conductivity_Class	1	62.12	62.12	132.17	< 2e-16 ***
Residuals	455	213.84	0.47		

5.2.3 Field 1001

Grain yield measurements for various seeding ratios (2, 3, 4, and 5 MGS/ha) and conductivity classes (1 through 5) are shown in Figure 34. Seeding ratios 2, 3, and 4 MGS/ha show a range of yield values from 2.8 to 5.3 tons/ha, whereas seeding ratio 5 MGS/ha of the seeding combination shows a range of yield values from 2.9 to 5.3 tons/ha. Overall, it is evident that higher conductivity classes (4 and 5) are positively correlated with better grain yields, while lower conductivity classes (1 and 2) are connected with lower yields. Sowing variety 5 MGS/ha seemed to have the maximum yields in most conductivity classes.

Compared to other conductivity classes, conductivity class 5 consistently demonstrates considerably higher yield values across all seeding ratios. This observation implies that soil exhibiting elevated conductivity levels, which are commonly associated with enhanced soil fertility and moisture retention ability, or other environmental conditions specific to each conductivity level may potentially promote increased grain yields. These results indicate that this particular seeding type may be the most suitable option for soils exhibiting varying conductivity levels.

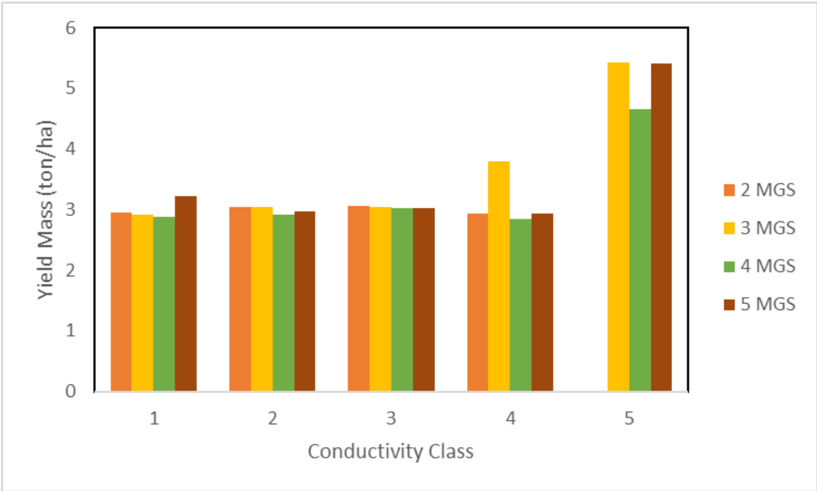


Figure 34 Field 1001 graph of grain yield in different seeding ratios and classes of conductivity from the combined harvester.

Each seeding variant in different conductivity classes shows different grain moisture content values in Figure 35. The grain moisture content levels of seeding variations 2 and 3 MGS/ha are often higher compared to variants 4 and 5 MGS/ha. The seeding variant 3 MGS/ha consistently demonstrates greater moisture content values across all conductivity classes, suggesting that it is suitable for effectively regulating grain moisture levels.

For all seeding options, conductivity class 5 has slightly higher grain moisture content values than its neighboring classes. More investigation might be needed to understand this anomaly's underlying causes fully. The absence of a consistent trend in the relationship between conductivity and moisture content suggests that additional factors could impact grain moisture content and conductivity.

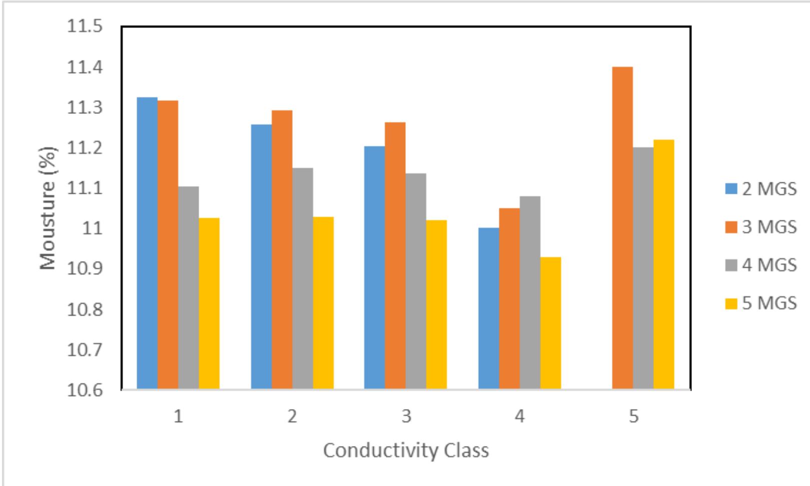


Figure 35 Field 1001 graph of the grain moisture content in different seeding ratios and classes of conductivity from the combined harvester.

Table 10 ANOVA result field 1001 in R from the harvester.

Factor	Df	Sum_Sq	Mean_Sq	F_value	Pr (>F)
Moisture	1	12.3	12.31	26.26	3.83-e-07 ***
Seeding_Ratio	7	71.6	10.22	21.81	<2e-12 ***
Conductivity_Class	1	61.5	61.51	131.23	< 2e-16 ***
Residuals	718	336.6	0.47		

As described before, the ANOVA result in Table 10 demonstrates the substantial effects of moisture, seeding ratio, and conductivity class on grain production. According to research, the moisture content of barley hulls is roughly 6.43%, but the moisture content of whole-grain barley is approximately 11.5% (Ali et al., 2014). Baktash (2017) emphasized the significance of harvesting moisture content for later grain output. In the subsequent generations, seeds harvested at specific moisture levels (19–22%) produced improved agronomic characteristics. To avoid severe shattering and husk damage during processing in a roller mill, barley should have a moisture level of at least 16% (Preston et al., 1965). For the best grain output and quality, barley must have the correct moisture content during the harvesting and processing. To avoid any possible problems during production, it's critical to keep an eye on and keep the moisture levels within the advised range. To maximize grain output, ideal moisture levels must be maintained during all growth stages, including seeding and harvesting. Controlling the soil's moisture significantly impacts crop productivity and sustainable agriculture.

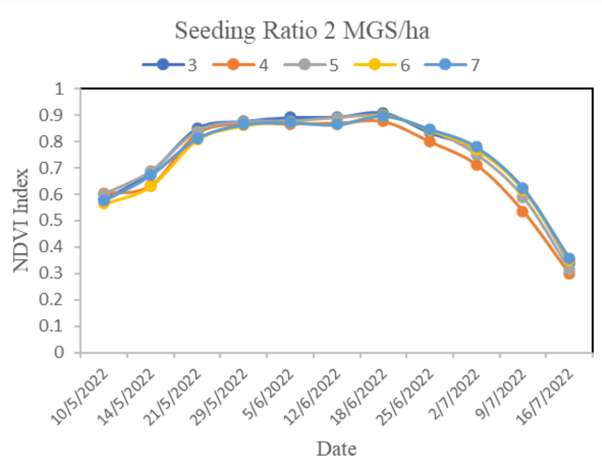
5.2.4 NDVI Index Trend in the Barley Field

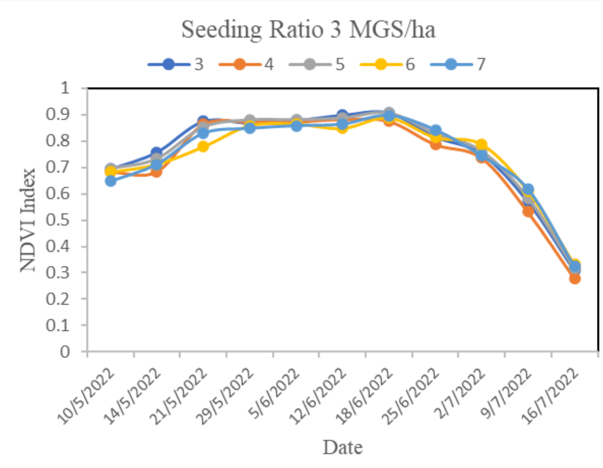
Depending on density, NDVI values usually fall between 0.1-0.75, and they are one of the most widely used indices for describing vegetation in connection to soil and growth conditions (Herbei et al., 2022). Figure 36 presents the seasonal pattern of crop NDVI variance across all conductivity classes in field 7701. The NDVI results in a 2 MGS/ha seeding ratio, indicating different vegetation dynamics. The NDVI readings in Classes 3 and 4 gradually decrease with time, which may indicate a decline in the density or general health of the vegetation. On the other hand, the NDVI values in Classes 5, 6, and 7 fluctuate but remain primarily constant, which may indicate that the vegetation density is more significant in the higher conductivity classes.

Similar trends are seen by the NDVI trends at a seeding ratio of 3 MGS/ha. All conductivity classes have variations in their NDVI values; some, like Class 5, have growing tendencies, while others, like Class 3, have modest declines. These patterns correspond with observations made at a 2 MGS/ha seeding ratio, where conductivity classes with greater values typically maintain higher NDVI values.

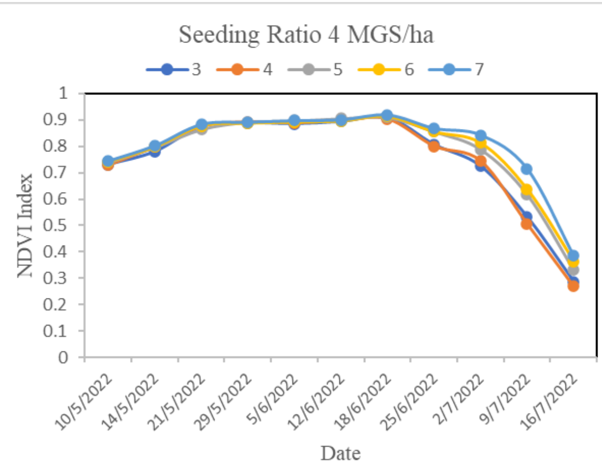
The NDVI patterns demonstrate the precise relationship between vegetative health and the seeding ratio as they transition to a 4 MGS/ha. Higher seeding ratios result in higher initial NDVI values across all conductivity classes. However, there are still variations, suggesting that they might have a beneficial impact on vegetation density. Finally, the NDVI trends show changes at a 5 MGS/ha seeding ratio. Some classes (like Class 5) retain constant NDVI values, while others (like Class 7) show more fluctuating patterns.

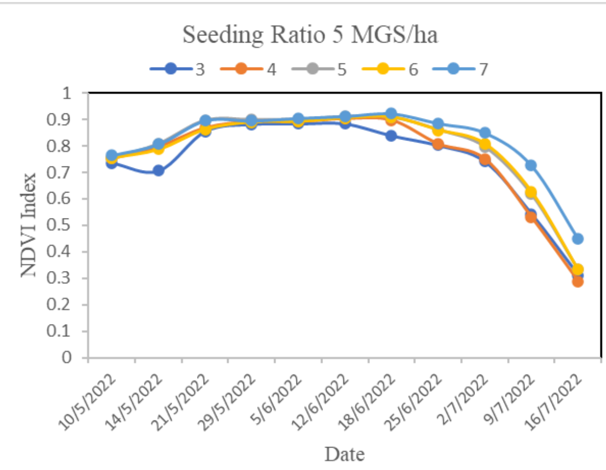
Overall, it is evident from Figure 36 that an upward trend was observed in the initial week across all seeding ratios. Verbyla (2008) and (Slayback et al., 2003) have demonstrated a correlation between NDVI and plant health. The rising NDVI values frequently indicate a "greening trend," indicating improved plant health and population density. Significantly, the NDVI values for weeks three through seven are elevated and constant in the 0.8-0.9 index range, signifying a period of extremely high levels of vegetation density and health. In their analysis of rice growth, Kazemi & Parmehr (2023) also discovered that young, healthy rice products in the vegetative stage exhibit good reflection in the NIR sensor and absorb the red reflection due to active photosynthesis. Hence, the NDVI values range from 0.6 to 1 during the rice-growing season.





(a) (b)





(c) (d)

Figure 36 Weekly NDVI Index trends in different classes of conductivity for seeding ratio (a) 2 MGS/ha (b) 3 MGS/ha (c) 4 MGS/ha and (d) 5 MGS/ha

Moreover, Figure 36 shows the tendency to begin to drop in the seventh week (18/6/2022). By reaching NDVI amounts below 0.5, the NDVI after week 7 shows a deterioration in plant condition, which may be brought on by variables such as interplant competition, fertilizer depletion, and moisture stress (Kourouma et al., 2021), the crop color turns yellow and matures for harvest (Parida & Ranjan, 2019). In addition, because the field's surface is in the harvest stage, which is characterized by no active photosynthesis, the NDVI index values drop from 0.6 to -0.6 (Kazemi & Parmehr, 2023).

The observed NDVI changes provide significant insights into vegetation dynamics and their consequences for yield potential. As shown by the lower NDVI values in seeding ratios 4 and 5 MGS/ha (Figure 36 c and d) in conductivity classes 3 and 4, increased seeding density does not translate into higher yield potential in locations with lower conductivity. Mazur et al. (2022) found a correlation between NDVI, soil nutrients, and electrical conductivity (EC). A high NDVI index and EC levels indicate high soil nutrient levels. Figures 36 c and d show this trend. They show that when conductivity is low, and the seeding ratio is high, there is more competition for nutrients in the soil, which makes the NDVI index lower. Higher conductivity levels are associated with higher NDVI readings, suggesting better access to nutrients and moisture for increased plant growth.

5.3 Yield Potential Prescription Map in the Barley Field

Prescription maps using the Normalized Difference Vegetation Index (NDVI) are very effective instruments in precision agriculture. The NDVI is a commonly employed metric for assessing vegetation health and vitality. It is calculated using satellite or drone images and depends on the reflectance of near-infrared and visible light (Bostan et al., 2022; Hamel et al., 2009). Figures 37 through 39 show the prescription map with NDVI index from the different fields.

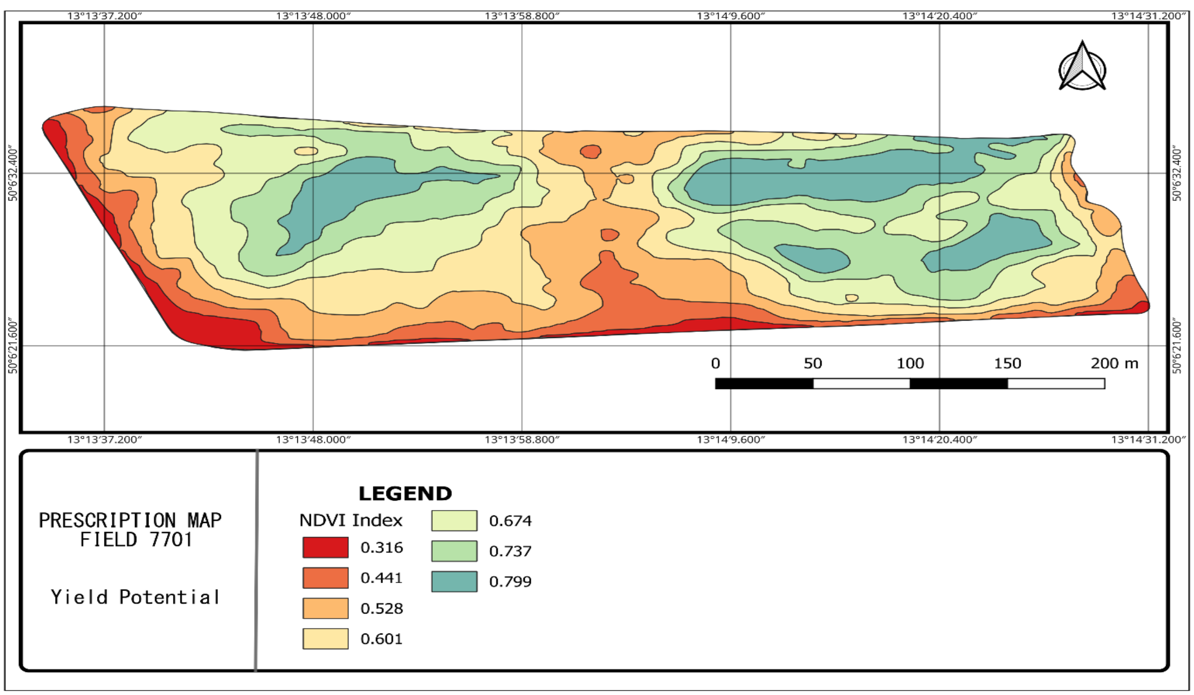


Figure 37 NDVI index map field 7701.

The NDVI Index maps for fields 7701, 2002, and 1001 show values ranging from 0.316 to 0.799, 0.7206 to 0.8053, and 0.6088 to 0.7289, respectively. These values are closely related to crop health status and growth condition. According to Bolaños et al. (2020), areas with higher NDVI values are considered healthier vegetation, whereas those with lower values may be experiencing problems like water stress.

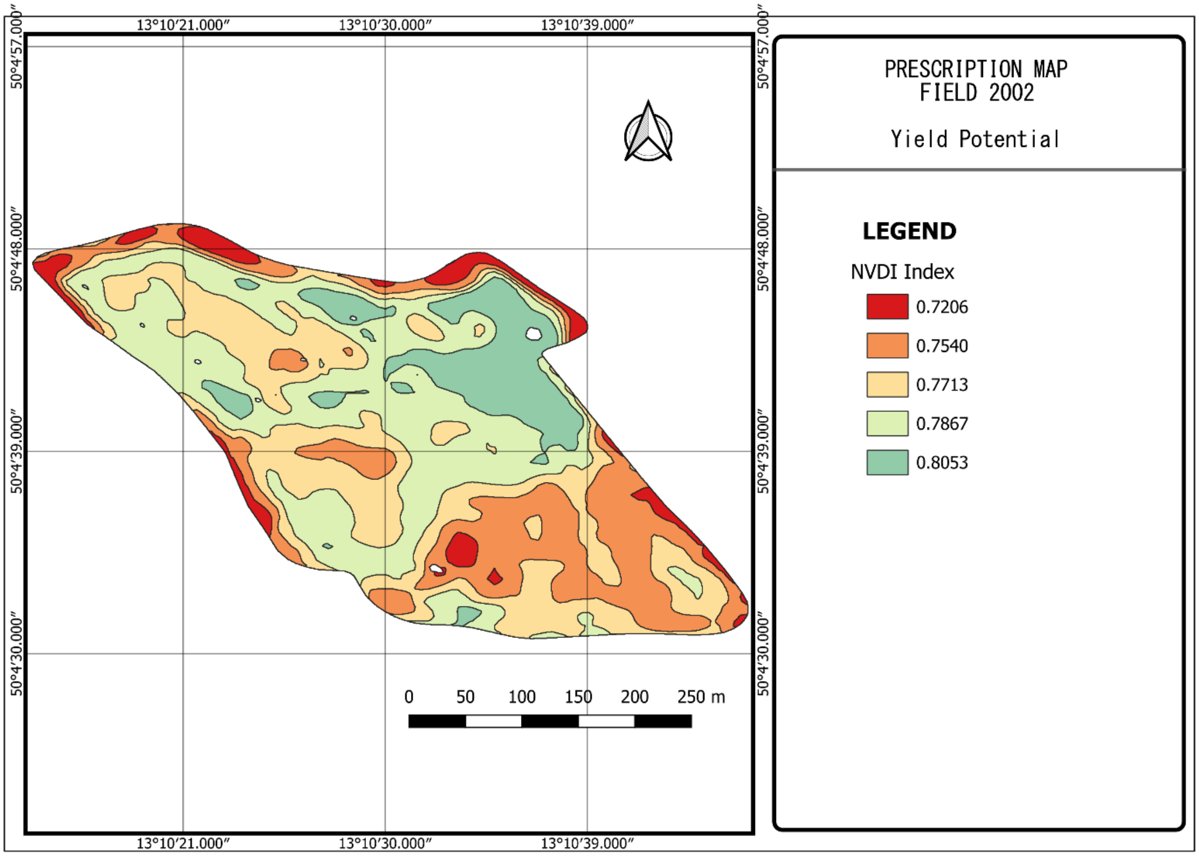


Figure 38 NDVI index map field 2002.

Field 2002 in Figure 39 showed NDVI index values, which are comparatively higher than the ranges seen in fields 7701 and 1001. Field 2002 shows greater vegetation health and density than the other fields. The NDVI index range seen in field 2002 indicates that the vegetation in this particular field is currently benefiting from ideal growing environments. This could be attributed to factors such as enhanced soil fertility, increased moisture availability, or improved management practices.

NDVI cannot only estimate agricultural yield but also evaluate the nutritional condition of crops. The green color of crops can be used to indicate their nutritional condition, making it a valuable tool for managing nitrogen fertilization in crops (Barbosa et al., 2020). Mazur et al.

study from 2022 says that electrical conductivity and NDVI are related and can be used together to make management zones for soil samples that are all the same within the field.

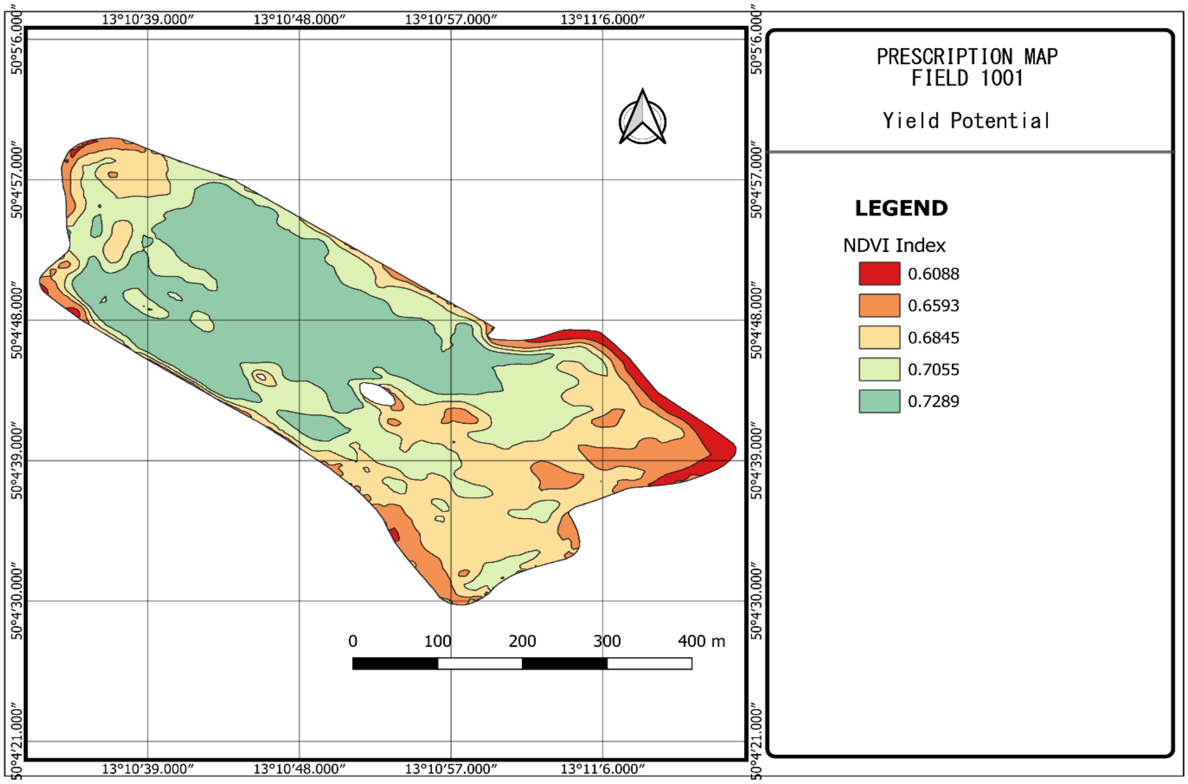


Figure 39 NDVI index map field 1001.

When comparing Figures 37, 38, and 39 and 21, 22, and 23, it is observed that the latter depicts the conductivity class within this particular area. The findings indicate a positive correlation between soil conductivity and vegetation health, as the higher NDVI index values were observed in connection with greater conductivity levels. Another piece of evidence for this claim comes from Zhang et al. (2011), who found that crop canopies with higher conductivity levels can absorb more red light and reflect more near-infrared light, which results in higher NDVI values.

When looking at NDVI patterns over the fields, it is possible to find areas with consistently higher NDVI values. These areas show that plants are multiplying. These zones generally have a greater capacity for crop production than zones with lower NDVI levels. Integrating NDVI data into prescription maps can provide valuable information for the variable rate application of inputs. Areas characterized by high NDVI values may be allocated lower rates of fertilizer compared to areas with lower NDVI values, thereby ensuring targeted application of inputs to areas with the greatest need. It is also possible to measure crop productivity and forecast future yield using NDVI, which assesses the condition and health of crops and has a strong correlation with crop yield (Kourouma et al., 2021).

5.4 Crop Yield and Economic Impact in the Barely Field

The results regarding grain yield across several fields suggest that this specific seeding style may be the optimal choice for soils with variable conductivity levels. The model can assist farmers in maximizing their economic income per unit of land by optimizing seeding ratios according to yield potential and conductivity levels. Enhanced profitability can result in improved financial stability for farmers and increased investment returns. A model was conducted to show the benefit of using this seeding style in various soil conditions in field 7701.

Table 11 Average grain yield from field 7701.

Sowing Variant	Conductivity				
	3	**4**	**5**	**6**	**7**
2 MGS	5.380	4.286	4.518	5.161	5.705
3 MGS	4.626	4.635	4.448	5.410	4.916
4 MGS	4.824	4.721	4.741	5.175	5.755
5 MGS	4.204	4.848	5.203	5.347	6.637
Average	**4.758**	**4.622**	**4.728**	**5.273**	**5.753**

Table 11 displays the grain yield observed in field 7701. The maximum yield is selected from each seeding ratio across various degrees of conductivity, as indicated in the table. The seeding ratios with 2, 3, 4, and MGS/ha values are recorded as 97, 146, 195, and 244 kg/ha, respectively. This field employs a seeding ratio of 4 MGS/ha or 195 kg/ha for the current season. The conductivity level will generally be low to high in numbers 1–5—tables 12 and 13 present a result analysis between the model and the observed reality.

Table 12 A model economic result from field 7701.

Conductivity Classes	Area [ha]	Seeding Ratio [MGS/ha]	Yield [ton/ha]	Yield Total [ton]	Selling Price [Kc/ton]*	Total Earning
1	7.1334	2	5.3802	38.3793	5,000.00 Kč	191,896.62 Kč
2	9.5093	5	4.8483	46.1041	5,000.00 Kč	230,520.50 Kč
3	11.1960	5	5.2032	58.2550	5,000.00 Kč	291,274.65 Kč
4	9.3361	3	5.4099	50.5078	5,000.00 Kč	252,538.92 Kč
5	3.9221	5	6.6373	26.0323	5,000.00 Kč	130,161.40 Kč
Total						**1,096,392.09 Kč**

**The price information gained from the farmer*

Table 13 Reality economic result from field 7701

Conductivity Classes	Area [ha]	Seeding Ratio [MGS/ha]	Yield [ton/ha]	Yield Total [ton]	Selling Price [Kc/ton]*	Total Earning
1	7.1334	4	4.8236	34.4089	5,000.00 Kč	172,044.26 Kč
2	9.5093	4	4.7207	44.8907	5,000.00 Kč	224,453.59 Kč
3	11.1960	4	4.7414	53.0846	5,000.00 Kč	265,423.13 Kč
4	9.3361	4	5.1749	48.3139	5,000.00 Kč	241,569.50 Kč
5	3.9221	4	5.7549	22.5716	5,000.00 Kč	112,858.23 Kč
Total						**1,016,348.70 Kč**

**The price information gained from the farmer*

According to the data in Table 12, the model's predictions demonstrate a range of seeding ratios across several conductivity classes, spanning from 2 MSG/ha to 5 MGS/ha. A positive correlation exists between conductivity levels and yield when employing a high seeding ratio. Nevertheless, the model with conductivity level 4 reveals a noteworthy observation: the seeding ratio of 3 MGS/ha exhibits a better yield. However, when referring to Table 11, it can be observed that there is no significant difference in yield between planting ratios of 3 MGS/ha and 5 MGS/ha. Alternatively, we apply a conductivity level of 4 at a 5 MGS/ha rate.

Table 13 presents the actual outcomes, while the model tends to predict larger yields for specific conductivity classes than the exact results. In conductivity class 5, the model's forecast indicates a 6.6373 tons/ha production, but the observed yield is documented as 5.1749 tons/ha. Furthermore, it is worth noting that the model's projected total earnings amount to 1,096,392.09 Kč, whereas the actual data reveal total earnings of 1,016,348.70 Kč. With the model, the income can increase by 80,043.38 Kč significantly or 8% more than the actual income.

Table 14 Total seed expenditure for field 7701 from the model.

Conductivity Classes	Area [ha]	Seeding Ratio [MGS/ha]	Seeding [kg/ha]	Seed [ton]	Seed Price [Kc/ton]*	Total Expend
1	7.1334	2	97	0.6919	10,000.00 Kč	6,919.43 Kč
2	9.5093	5	244	2.3203	10,000.00 Kč	23,202.61 Kč
3	11.1960	5	244	2.7318	10,000.00 Kč	27,318.19 Kč
4	9.3361	3	146	1.3631	10,000.00 Kč	13,630.73 Kč
5	3.9221	5	244	0.9570	10,000.00 Kč	9,570.02 Kč
Total						**80,641.00 Kč**

**The price information gained from the farmer*

Table 15 Total seed expenditure for field 7701 from the reality.

Conductivity Classes	Area [ha]	Seeding Ratio [MGS/ha]	Seeding [kg/ha]	Seed [ton]	Seed Price [Kc/ton]*	Total Expend
1	7.1334	4	195	1.39101	10,000.00 Kč	13,910.20 Kč
2	9.5093	4	195	1.8543	10,000.00 Kč	18,543.07 Kč
3	11.1960	4	195	2.1832	10,000.00 Kč	21,832.16 Kč
4	9.3361	4	195	1.8205	10,000.00 Kč	18,205.43 Kč
5	3.9221	4	195	0.7648	10,000.00 Kč	7,648.17 Kč
Total						**80,139.04 Kč**

**The price information gained from the farmer*

A comparison between the total seed expense for field 7701, as presented in Table 14 of the model, and Table 15, which shows the actual expenditure, highlights several notable differences. It is important to note that the specific ratios differ between the model and the actual data. Although the model's total seed expense is 80,641.00 Kč, the exact amount is slightly less at 80,139.04 Kč. The model exhibits an increase of 501.95 Kč, equivalent to a 0.6% increase compared to reality. When the seed expenses have been subtracted from the profits in both the model and reality, it is observed that the model generates a higher profit, approximately 8.5% of the actual income.

This study provides that applying this particular seeding technique can potentially optimize farmers' economic revenue per unit of land while increasing their financial stability. The adoption of sensitivity analysis in a thorough investigation of seeding ratios has promise for yielding valuable insights into optimizing seed expenditure and maximizing crop yields.

5.5 Variable Seeding and Agro-Environmental Practices in the Corn Field

When attempting to analyze the land and its components separately and generate application maps and zones, it is typically necessary to take into account three key factors: the data that will serve as the foundation for zone creation, the methodology for processing the data (specifically, classification), and the most suitable number of zones to divide the field into (Fridgen et al., 2004).

Variable seeding encompasses more than simply altering the seed. The study indicated the findings derived from the varied planting of spring barley. Managing a specific site encompasses procedures, including tillage, sowing, fertilization, and pesticide treatment. Numerous requirements emerge throughout the sowing process, posing challenges in prioritization. Ensuring respect for habitat conditions while establishing field crop stands is crucial at the onset of the new growing season. Aside from the option of variable seeding, various other characteristics can be adjusted to ensure the effective germination and growth of crops. The utilization of variable seeding is commonly linked to implementing a corn stand, a practice that has been employed for an extended duration. Furthermore, ongoing research and development focuses on modifying the sowing depth and pressure applied to seed columns, particularly in the context of corn cultivation.

In response to societal demands to enhance the non-production aspects of agriculture and mitigate its negative impact on the environment, alternative approaches are being explored to achieve these objectives. The farmers are cognizant of this requirement and seek efficient, yet mostly versatile, methodologies that they devise and use in their fields.

Implementing greening in the spraying rows of the applicators guarantees a diverse array of agricultural functions unrelated to productivity. The ecological advantage of greened spraying rows is influenced by factors such as the plot's location, the selected species for greening, the management system, and the duration of stay on the site. Greened spraying rows are commonly employed in conventional agriculture to cultivate field crops, although they can also be utilized in organic farming.

Multiple technologies and alternatives exist for creating a sown track row. The diagram presented in Figure 40 illustrates the integration of many agricultural practices, including the utilization of a front-mounted cultivator for locally targeted row preparation, corn sowing, and the application of a seeder mounted on a front-mounted cultivator for sowing the spaying row in the required sections of the plot.

Figure 40 Establishing a maize stand with the simultaneous sowing of spraying rows (photo by Kroulík).

The operational testing was conducted in 2023 at Zemědělské akciové společnosti Mžany a.s. The spraying rows had a width of 3 meters. A combination consisting of many components was planted in the row (Figure 41).

Figure 41 Examples of the greening of the row on the plot in the stands of corn (Photo by Tošovský).

The process of greening trajectories is inherently linked to a decrease in the extent of the primary crop on the land block, or a portion thereof, resulting in a decline in yield relative to its overall cultivated area. While maize, sunflower, and sorghum are not commonly recognized as plants that exhibit a compensating effect, which is linked to enhanced biomass production and subsequent rise in main product yield when the plant space is expanded, it is worth noting that this effect has been empirically confirmed. The number of individuals planting in the peripheral rows was augmented to 95,000 per hectare. According to Figure 20, the second row from the belt was planted with a density of 90,000 individuals per hectare. The usual seeding rate for maize in the remaining rows was 85,000 individuals per hectare, with an inter-row spacing of 0.75 m. A Hybrid LG 31.305 variety was planted.

The graph depicted in Figure 42 assesses the quantity of individuals within the row based on the seeding configurations. The observed data indicates a positive correlation between the quantity of plants and the track line.

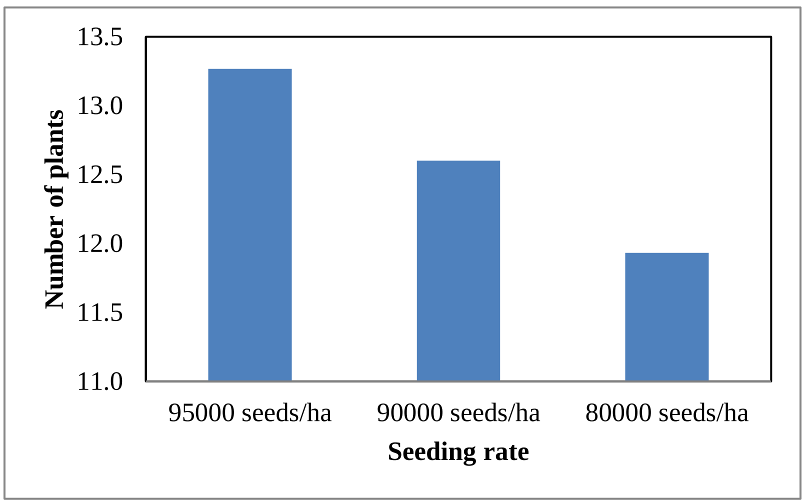


Figure 42 Number of plants (2m of row) in the corn field.

Before harvesting, intact plants were collected from distinct variations within the row, and an assessment was conducted on the biometric markers of the stand. The specimens were collected from a 4-meter row. The study assessed various plant characteristics, including plant height, leaf count, number of mature and undeveloped corn stalks, plant weight, and corn stalk weight. The values for the different variants are documented in Table 16.

Table 16 Corn plant evaluation results.

Rows	Length of plants (cm)	Number of leafs	Developed corn stalks	Undeveloped corn stalks	Weight of plants (g)	Weight of stalks (g)
A	223.7	12.9	1.0	0.6	93.9	198.4
B	235.4	13.4	1.1	0.6	103.5	204.4
C	245.0	13.5	1.1	0.6	108.6	214.6
D	226.7	13.2	1.3	0.7	108.2	248.2
E	248.2	13.4	1.0	0.7	102.6	217.3
F	254.9	13.8	1.0	0.8	105.5	205.7

The observed trend in the values likely indicates the impact of the larger plant population on the overall characteristics of the stand, as well as the positioning of the row relative to the cardinal points. Specifically, a row with a greater number of plants in an open north direction exhibited a decrease in stalk weight and yield. Conversely, an increase in seeding on the southern side resulted in a higher stalk yield (see Figure 43).

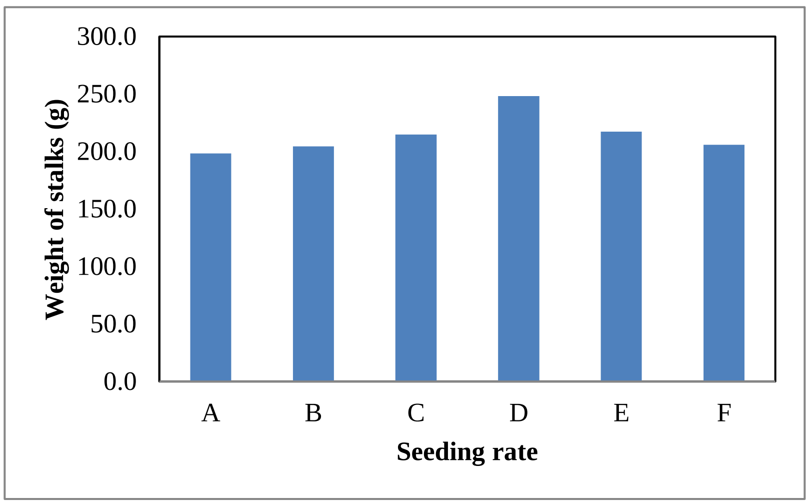


Figure 43 Weight of stalks from individual corn rows.

5.6 Water Management and Soil Health through Modified Tillage Practices in Sugar Beet Cultivation

In a similar manner, a sugar beet stand was created. Figure 44 depicts a collection of cultivators and a seeder used for sowing between rows. The monitoring of the modified tillage was conducted concurrently with the installation of the stand. This involved excluding the pre-sowing preparation and replacing the row with strip tillage. An indication that can be used to assess the impact of modified tillage is the facilitation of infiltration and the enhancement of water absorption into the soil.

Figure 44 Establishing a sugar beet stand with the simultaneous sowing of spraying rows (photo by Kroulík).

An examination of the water infiltration process in the sugar beet stand was conducted. The movement of water in the soil profile was shown using the blue food dye E133. An aqueous solution was put to the soil surface and allowed to penetrate spontaneously. Following 24 hours, the soil profile was exposed, and three replicates of separate portions were captured for each variant. The analysis was conducted using the BMPTool software. The whitish hue signifies the presence of water that has penetrated. The infiltration pattern exhibits a selective movement of water into the treated soil profile throughout the process of modified soil treatment. Unlike the updated technique, the classic pre-sowing preparation did not exhibit the preferential flow of water (Figure 45 and 46). The phenomenon of preferred water flow plays a significant role in enhancing the efficiency of precipitation utilization and increasing the accessibility of water resources for plant growth.

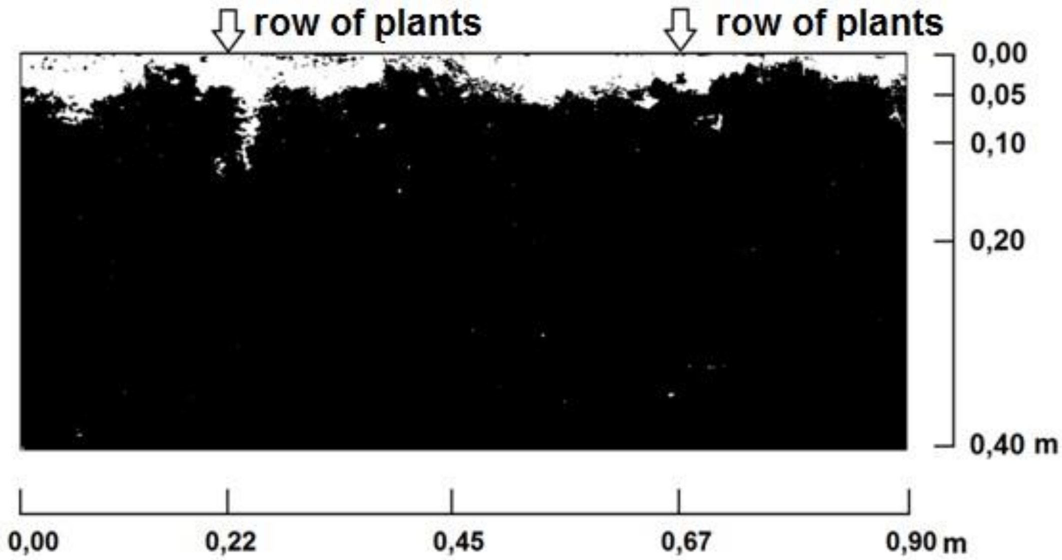


Figure 45 Character of water infiltration in the soil profile for the variants pre-sowing preparation. Arrows indicate the positions of the sugar beet row plants.

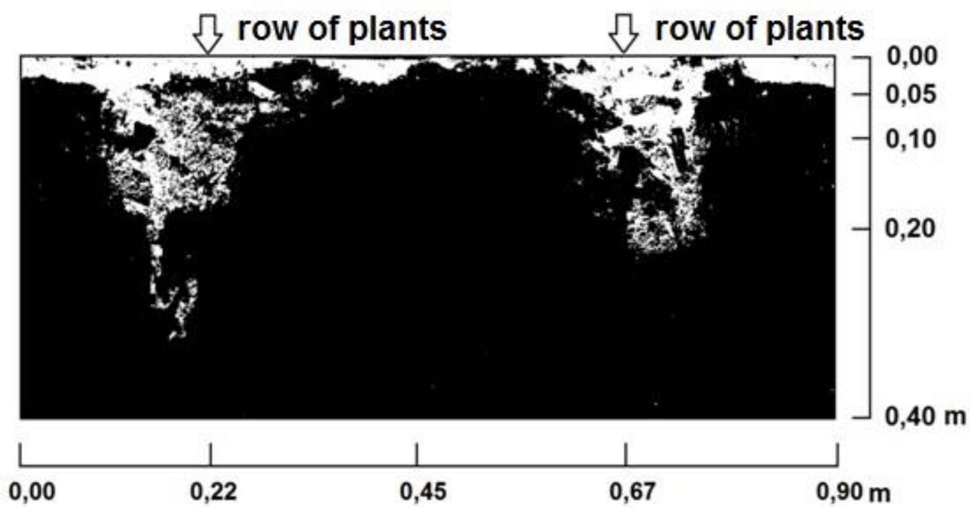


Figure 46 Character of water infiltration in the soil profile for the modified strip preparation. Arrows indicate the positions of the sugar beet row plants.

The implementation of green spraying rows necessitates the meticulous preparation and processing of ingredients to guarantee their efficacy over an extended period of time. In this scenario, preparation entails engaging in computer-based work within the workplace, utilizing relevant document and GIS applications.

6 CONCLUSIONS

This study investigates the implementation of modern agricultural methodologies, emphasizing tillage strategies, variable seeding methods, and water management approaches to maximize crop yield, improve economic gains, and foster environmental sustainability. This study addresses the difficulties of rapidly growing worldwide populations and the imperative for ecological sustainability in food production. The primary emphasizes the application of precision agriculture technologies and innovative farming approaches regarding barley, corn, and sugar beet cultivation.

Field tests demonstrate the intricate interaction of soil characteristics, planting techniques, and crop yield. Spring barley field's prescription maps offer valuable information for implementing site-specific management strategies to maximize plant establishment and yield outcomes. The study reviewed the literature to provide an established basis for the experimental design and subsequent field implementation. Field studies were conducted in several agricultural environments, encompassing different seeding rates, tillage intensities, and evaluations of water infiltration. The evaluation process involved a detailed assessment of biometric indicators related to plant development and studies of soil physical properties and infiltration analysis. A comprehensive analysis was conducted to examine the economic implications of various agricultural methods and gain valuable insights into their cost-effectiveness and profitability.

The research shows the effectiveness of precision agriculture methods, such as NDVI mapping and variable seeding, in enhancing crop management and resource allocation. Significant gains in crop yield and economic returns were observed by implementing variable rate input applications and adopting conservation tillage practices. Higher conductivity levels were generally linked to higher productivity across several seeding ratios. Moreover, the influence of planting ratio on grain yield has shown variability among different conductivity classes, highlighting the necessity for customized management strategies.

Biometric indicators used to test plants and soils showed more evidence about how soil conductivity and seeding ratio affect important agronomic factors like plant height, grain weight, and moisture content. Correlation analysis allowed us to observe significant correlations between seeding ratio, plant characteristics, and grain production. These findings underscore the need to control seed density to improve agricultural productivity while minimizing resource waste. This study shows that prescription maps based on conductivity maps help control the amount of variable rate input, find the best seeding ratios, and get the highest crop yields in various soil conditions.

In addition, the implementation of variable seeding and agro-environmental techniques, such as using green spraying rows and modified tillage, highlights the significance of comprehensive strategies in achieving sustainable crop management. Farmers may improve water management, soil health, and crop yield, reduce environmental impact and promote long-term agricultural sustainability by incorporating cutting-edge technologies and techniques into their field operations.

The proposition argues that the use of precision agriculture methods, which are guided by comprehensive soil conductivity mapping and customized seeding strategies, has the potential to enhance crop productivity and maximize resource efficiency within contemporary agricultural systems. Implementing cutting-edge technologies and tailored management strategies can optimize crop production, reduce ecological footprints, and improve the long-term viability of agriculture.

Nevertheless, additional investigation and implementation of these methods will be imperative in guaranteeing food security and environmental preservation amidst the ever-changing ecological obstacles. Farmers can ensure food security, environmental conservation, and economic advancement for subsequent generations through the facilitation of knowledge exchange (such as Agricultural Knowledge and Innovation Systems) and capacity-building projects.

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