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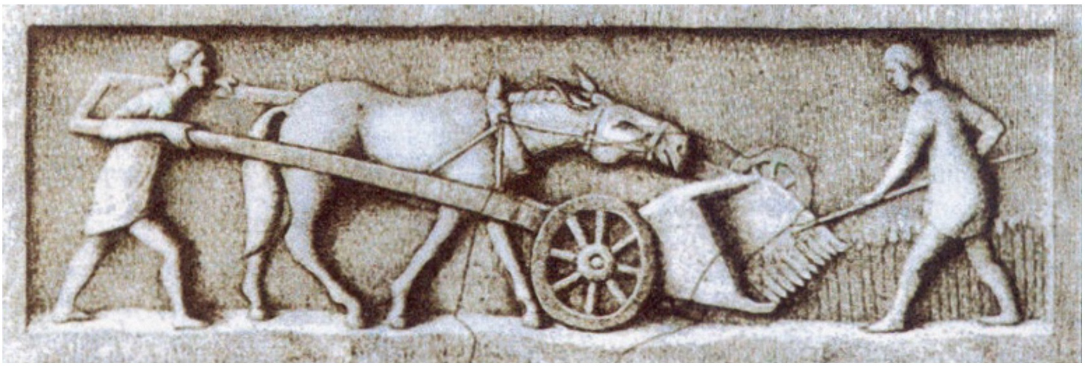

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Relationship between nutrition factors and development of food pad dermatitis (FPD)

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Abstract: Nowadays, foot pad dermatitis and the associated loss of production and income is one of the major problems in intensive broiler chicken production. The third most valuable part of a broiler chicken is the legs. In the case of FPD, losses are realised as animals with foot pad dermatitis (FDP) eat, drink, and move less, and their performance is reduced, which causes serious loss of income. It also raises animal welfare concerns and can cause food safety problems. Development of the FPD and its frequency is influenced by several factors, individually or in combination: genetics, management, and feeding. In this article, we review the feeding causes of the development of FDP. Feedstuffs, rich in soluble NSP substances, low energy concentration in the diet, or luxury protein supply lead to low quality of the litter, predisposing birds to FPD. In addition, some minerals (Na, K, Cl) stimulate water consumption, while deficiency of others (Zn, Cu, Mn) affects epithelial tissue development and thus might provoke FPD.

Keywords: nutrition, poultry, foot pad dermatitis

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Introduction

Foot pad dermatitis (FPD) or contact dermatitis is a frequent inflammatory process in poultry species, which most commonly occurs in broiler chicken and turkey flocks. This is a disease which can cause foot pad change, from the surface to the deep skin layer, and depending on the condition, it may indirectly cause significant losses in production (Pié Orpí, 2020).

FPD is not a new problem, as it was already described in the 1980s (Greene et al., 1985; Mcferran et al., 1983). The disease probably existed even before this period, but no great importance was attached to it. This is supported by a publication of Greene et al. (1985), in which a skin disease affecting commercial broilers in Northern Ireland in 1978 was reported. Before this, little research was done on the disease because it was not considered to cause serious economic consequences, so the reasons for its development and the underlying problems were not in the focus of research. Before the 1980s, the chicken leg had minimal economic importance and together with the feather and blood, was a useless part of the chicken body (Shepherd & Fairchild, 2010).

However, from the mid-1980s, the demand for legs suddenly and continuously increased. Within a short period hicken legs, which were considered worthless, have become a valuable product of the poultry industry due to the intensively increasing market for it in Asia. The demand for quality foot ends was such high that the local production on the Asian continent was not able to meet it alone. Therefore, Far East became a net importer of chicken legs, which urged Europe and America to try to supply. Today about 60% of the US income from poultry export to China is realised in the form of paws comprising up to 300 thousand tons (Market Intelligence Team, 2020). However, legs are marketable only if they are served in perfect physical condition (Christensen, 1996). This change made the chicken leg the third most valuable product of the broiler chicken industry, following the breast and the wing (Shepherd & Fairchild, 2010). In China (Hong Kong), Thailand, and some other Far East countries, the popularity of legs (or rather paws) is constantly high and still increasing, while the price is often even beyond that of chicken meat. However, in the US and the European Union, only negligible quantities can be sold on a few sub-markets (Berkhout, n.d.).

However, the development of plantar ulcers is not only a marketing issue, but other economic consequences are also important, as animal weight gain is regularly reduced due to FPD (Martland, 1985). This results from reduced activity of the affected animals, so they move less due to the sore walk. As in FPD, there is constant inflammation on the foot, and some of the energy and nutrients are taken with the feed being used to recover, so a lower amount of nutrients remains available for growth. Furthermore, reduced activity can lead to decreased feed and water intake, resulting in weight loss, increased susceptibility to secondary infections, and consequently, higher mortality rate and seized product at the slaughterhouse (Pié Orpí, 2020). According to Jim (n.d.) prevalence of plantar ulcer is estimated to be between 20-100% within each flock.

As it was mentioned above, FPD is not only an economic problem, but it has an animal welfare approach, as well. Plantar ulcer must be painful (Algers & Berg, 2001), but it has not yet been scientifically evaluated (Heitmann et al., 2018). However, it was revealed that the gait of birds affected by FPD becomes unstable (Harms & Simpson, 1975), and also their posture is less stable (Hester, 1994). In other livestock species, gain stability is an important indicator of foot pain, as it is reported for cattle, (Weary et al., 2006), for sheep (Gigliuto et al., 2014) and for swine (Grégoire et al., 2013) too. Thus, FPD might be a potential indicator of animal welfare also in poultry.

However, there is still another food safety approach, as ulcers might affect product quality and generate potential food chain hazards due to the prevalence of secondary infections. In such cases, the first line of defence, the skin itself, is damaged, so the lesions give direct way for bacteria (e.g., *Staphylococcus aureus* and *E. coli*) to enter, they reach the bloodstream, and with that, they can be spread in the body (Pié Orpí, 2020; Shepherd & Fairchild, 2010).

Development of Foot Pad Dermatitis

Based on our knowledge, many factors play a role in the development of FPD (e.g., genetics, management, and nutrition). Most of them can be responsible even alone for the disease, but usually, they occur in combination with each other. The most important factors proven to be involved in the development of foot ulcers are genotype and sex; stocking density; microclimate of the building (room temperature, humidity, and ventilation, light regime/season); physical and microbiological status of the litter (type of bedding material, hygiene and depth of litter); type and setting of certain technological elements, primarily drinkers; feed composition (excessive amount of some nutrients, lack of others); and related to this structure of the intestinal mucosa and composition of the intestinal microflora (Amer, 2020; Swiatkiewicz et al., 2017).

Nutritional factors are especially important,

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as they affect water intake, moisture content and viscosity of the digesta, consistency of the excreta, and thus litter quality (Swiatkiewicz et al., 2017). This article aims to provide an overview of nutritional factors involved in the development of FPD.

Nutrition and FPD

Based on literature data, the energy, protein, fat, vitamin, and mineral content of the diet might contribute to the development of inflammation, thus to the development of FPD (Jeon et al., 2020). de Jong et al. (2015) found that when feeding a *low-energy* feed mixture, the severity of inflammatory changes in the foot pads increases in broiler chicken flocks. Since the feed consumption of birds is a function of the energy concentration in the diet, reduced energy content increases the feed intake and, thus, the protein and mineral intake. Simultaneously, water consumption is enhanced, accompanied by the elevated moisture content of the excreta and, consequently, of the litter. Wet litter softens the surface of the foot pad, thus predisposing to the formation of plantar ulcers.

As fat is a good energy source for birds, energy concentration also depends on the *fat content* of the diet. Low-quality fats reduce digestibility and result in pasty excreta, impairs litter quality (Pié Orpí, 2020). As digestibility depends on the fatty acid composition of the dietary lipids and unsaturated fatty acids, they have better bioavailability than saturated ones. Diets rich in unsaturated fatty acids have higher energy content and better intestinal absorption rate than those contain mainly saturated lipid sources (Celebi & Utlu, 2006). Birds fed a high-fat diet are also more prone to FPD due to producing more viscous excreta (Bilgili et al., 2006). However, in a recent study by Fuhrmann and Kamphues (2016), high dietary fat concentration (11%) did not significantly affect litter quality and FPD incidence compared to a diet with normal fat content (5.5%).

Some other components in the feed are also proven to influence the prevalence of FPD. Based on literature data, one of the most important predisposing dietary factors is the group of *nonstarch polysaccharides (NSP)* (J. Hess et al., 2004). These fibre components reduce the energy concentration of the feed and exert an anti-nutritive effect by limiting the access of digestive enzymes to nutrients, slowing down the movement of the digesta in the intestine (Khadem et al., 2016; Knudsen, 2014). In addition, the soluble fraction of NSP absorbs water; the viscosity of the digesta is increasing (Hetland et al., 2004), which negatively affects the digestibility and absorption of nutrients (Cozannet et al., 2017). Altogether, the higher the NSP content of the diet, the lower the metabolizable energy content and feed efficiency (Zduńczyk et al., 2020). However, the presence of NSP substances in poultry diet is inevitable, as common components like soybean meal (210g/kg) or wheat (113g/kg) have relatively high fibre content (Zduńczyk et al., 2020). Therefore, there are currently two options to prevent the harmful effect of NSP substances. We might replace the NSP-rich ingredients in the diet or at least reduce their inclusion rate. However, it is not easy because there are no optimal alternatives.

The other option is to degrade the NSP substances in the feed, which can be reached with fortifying the diet with *exogenous fibrinolytic enzymes* (like xylanase, glucanase, mannanase). They enhance the digestion of polysaccharide complexes; thus, they help to release and digest the starch and protein content of the endosperm (Bedford & Schulze, 1998). In line with this, a commercial xylanase product increased starch digestibility, and AME (apparent metabolizable energy) in chickens fed a wheat/soybean meal-based diet (Choct et al., 1999). Furthermore, xylanase and β-glucanase were successfully used to degrade NSP in wheat- and barley-based poultry diets (Choct, 2006). A new approach involves the use of enzyme cocktails (multi-carbohydrases) and aims to degrade the spectrum of NSP (Cozannet et al., 2017; Mikulski et al., 2017). Nagaraj et al. (2007) showed that an enzyme blend of cellulase, xylanase, galactosidase, amylase, and protease added to the corn/soy diet reduced the viscosity of the digesta and the incidence of FPD lesions in broiler chickens.

Some other feed additives seem to enhance the efficiency of enzyme supplementation. For example, research results of Dersjant-Li et al. (2015) and Flores et al. (2016) have shown that dietary supplementation of feed enzymes (xylanase, amylase, and protease cocktail) combined with probiotic bacteria is also efficient in reducing litter wetness and FPD occurrence. However, there are contradictory results in the literature, like Cengız et al. (2012). It was reported that supplementation of a corn-soy diet with different enzyme preparations (galactosidase, xylanase, protease, amylase, glucanase, or mannanase) did not affect litter moisture and the incidence and severity of FPD. Similar results were observed when a mixture of NSP hydrolyzing enzymes was added to a high barley diet (Cengiz, Köksal, et al., 2012).

According to some literary sources, in the case of *excessive protein intake*, the excess protein in the body of the birds is metabolized into uric acid and excreted from the body. As a result, the nitrogen content of the litter will be higher, which can turn into ammonia and cause inflammation through its corrosive effect, which can contribute to the development of plantar ulcers (Pié Orpí, 2020). This effect is further enhanced by the increased protein intake increases the birds' water consumption and, their water excretion, thus the moisture content of the litter. This, due to the softening of the sole pad, promotes the initiation of inflammatory processes. In line with this, Ferguson et al. (1998) (from 21.5% to 19.6% crude protein) and Bilgili et al. (2006) (from 21.0 to 19.7% crude protein) found that reducing the protein concentration of the feed significantly reduced the moisture content of the litter and, in this connection, the frequency of FPD.

Besides feed energy and fibre, *feed protein source* seems to play a role in FPD. The disease incidence is higher when only plant protein sources are consumed than when the diet contains some proteins of animal origin (Cengiz et al., 2013; Hossain et al., 2013; Nagaraj et al., 2007). Eichner et al. (2007) also reported increased litter moisture and FPD severity in chickens fed an all-vegetable diet based on maize, toasted soybean, and soybean meal, in comparison with birds fed with diets containing 10% poultry by-product meal. However, similar changes were also found in the same experiment when some of the toasted soybean was replaced with corn gluten meal. This suggests that not the protein quality (amino acid composition or digestibility) itself is responsible for the effect. Still, it is rather due to the different electrolyte content of the different protein sources.

Several studies have shown that feed *electrolyte* (Na, K, and Cl) *balance* is an important factor influencing faecal moisture content and severity of FPD. As shown in many studies with broiler chicken and turkey, high Na and K levels and high dietary electrolyte balance increase water intake and thus litter moisture content (Borges et al., 2003; Defra, 1994; Koreleski et al., 2010; Mushtaq et al., 2013; Zdunczyk et al., 2014; Ravindran et al., 2008), which in turn increases/increasing the prevalence and severity of FPD.

Harms and Simpson (1975) found that feed salinity is directly proportional to the severity of foot pad lesions. Birds fed high-salt feed excreted faeces with higher moisture content, resulting in poor litter conditions. It was observed that FPD severity was

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reduced by decreasing supplemental NaCl (Harms & Simpson, 1975). Cengiz, Hess, and Bilgili (2012) represent that a high Na concentration (0.30%) in the diet could increase water consumption and litter moisture, thus increase the incidence and severity of FPD in broiler chickens. Abd El-Wahab et al. (2013) compared the prevalence of FPD in young turkeys fed diets containing normal (0.16% Na, 0.78% K) or excessive (0.31% Na, 1.53% K) amounts of Na and K. They found that high Na and K diets led to increased litter wetness and increased FPD severity. The same results were reported by Fuhrmann and Kamphues (2016) and Koreleski et al. (2010) with a high level of K (1.45% or 1.27% respectively) supply. Similarly, Lichtorowicz et al. (2012) reported that high Na content (0.25%) in the diet of growing female turkeys resulted in higher incidence of FPD. However, in this research the abnormality was not associated with increased litter moisture.

Lack of certain vitamins (biotin, riboflavin, pantothenic acid) and minerals (e.g., zinc) can also increase the frequency of hock burn. Biotin and zinc, as important factors to maintain the optimum skin condition, can potentially prevent or moderate pododermatitis (Swiatkiewicz et al., 2017). Besides zinc, other trace elements like copper, manganese or selenium, might have some role in the development of FPD as they are central ions in certain enzymes responsible for antioxidant defence of membranes and epithelial tissues. Thus their deficiency might increase the susceptibility of foot pad.

El-Wahab et al. (2013) have evaluated the prophylactic effect of high dietary Zn and biotin supplementation on FPD in broiler chickens exposed to critically high (35%) litter moisture. According to their results, a diet containing 113 mg organic Zn/kg (Zn Met) and 2000 μg biotin/kg can reduce the severity of foot dermatitis. Youssef et al. (2012) have also presented beneficial effect of high biotin or Zn supplementation in turkeys but only on dry bedding. According to Sun et al. (2017), high biotin (1521 μg/kg) supplementation is capable to reduce the severity of FPD in broilers. Similar results were found by Zhu et al. (2012) with Peking ducks. However, no positive effect was found with biotin in turkey Mayne et al. (2007).

Zinc alone can also have some preventive effect on the development of contact dermatitis, but its efficiency seems to depend on the chemical form of the supplementation. Saenmahayak et al. (2010) reported that 40 mg/kg organic Zn complex has reduced the incidence of FPD as well as the severity of skin lesions. Also, (Manangi et al., 2012) showed that replacing inorganic trace elements (Zn, Cu, and Mn) with organic, chelated forms has contributed to significant improvements in foot pad health. Similar results were reported by J. B. Hess et al. (2001) Zn-Lys and Zn-Met complexes. There are some experiments with other minerals and other forms (nano). Organic selenium supplementation, for instance, has improved the severity of FPD in ducks (Abdel-Hamid et al., 2020), while nano zinc did not cause any significant improvement (Sevim et al., 2021).

Summary

In conclusion, foot pad disease is the result of multifactorial interactions. Several parameters are confirmed to contribute to its development, even focusing on the nutrition of birds alone. Therefore, optimal feed composition and nutrient content are key issues in preventing hock burn.

It is also clear, that though most of the predisposing factors are already known, the exact mechanism and interactions are not clarified yet. In addition, it can be established that this common problem can only be successfully alleviated with a complex approach or prevention.

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Impact of N Supply on Some Leaf Characteristics of Maize Crop

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Abstract: Nitrogen (N) is an essential nutrient widely used in maize crop production. Application of a high N rate is commonly practiced by growers as a "guarantee" of optimal growth and yield. However, excessive nitrogen consumption can cause wastage, negatively impact plants, and adversely affects the environment. This paper reports on the impact of N supply on leaf characteristics in maize. Maize was grown in an experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Hungary, during the spring and summer of 2021 (May-October). Four observation plots consisting of 10^2 m area size were evaluated for various N levels (0, 50, 100, and 150 kg ha^{-1} N a.i) with marked plants sampling in four replications. Data collection on leaf traits viz. leaf number $plant^{-1}$ (B), leaf number $plant^{-1}$ (S), temperature 0 °C (leaf surface), SPAD, leaf length (cm), leaf width (cm), and leaf area (cm^2) were measured one week after application in weekly sequences of N until the eighth week. The results showed that nitrogen fertilizer application increased the leaf number $plant^{-1}$ (B), temperature, SPAD, and leaf width while contrasting with leaf number $plant^{-1}$ (S). However, there was no difference in leaf length for all treatments studied. Although an increase occurred up to the use of 100 N. Whereas, 150 N treatment showed low performance and exhibited a negative correlation for all traits except temperature and number of leaves (S). The results suggest that treatment of 100 N produced the best results in most traits studied. Furthermore, detailed research study is needed to confirm the findings, as many other environmental factors influence maize plant growth.

Keywords: SPAD, leaf traits, LA, nitrogen, maize

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Introduction

Maize (*Zea mays* L.), generally known as corn, is one of the major grain crops cultivated in many parts of the world. It's a good source of carbohydrates, vitamins, minerals, and phytochemicals (Shah et al., 2016). Maize production has expanded globally, surpassing other grain crops, making it the most valued staple food. The United States, China, Brazil, Argentina, and Ukraine were the top 5 maize-producing countries in the world, which produce about 8.02 hundred million tonnes (69.82%) of 1.15 thousand million tonnes, and the amount of maize production in Hungary amounted to 8.23 million tonnes in 2019 (Food and Agriculture Organization of the United Nations, n.d.)).

Globally, the latest challenges are human population growth and global climate change. It may need to manage by enhancing the use of Agro-technological aspects in agriculture. Therefore, more efficient resources, particularly N resources, must be utilized to ensure minimal wastage in crop production. In earlier studies, Urban et al. (2021) and Loch (2015) reported that maize is highly sensitive to nutrient deficiencies, especially in the early stages of growth. As a result, optimizing nutrition during the early vegetative period can boost yields. Nitrogen (N) is not only a required element but is also a limiting factor for the production yield of summer maize (*Zea mays* L.) grains. However, irrational N levels inhibit increased production and result in environmental pollution (Liu et al., 2018).

Loch (2015) underlines that the gradual increase in fertilizer use leads to further increases in average maize yield, except in drought years, an initial average of 6 tonnes ha^{-1} has been restored or exceeds conversely. Maize production can be associated with various reasons where the main reason is that maize is more sensitive to water shortages. According to Pepó (2017), the applications of Agro-technological components can decrease the negative consequences of climate change while also increasing crop production. Precision agriculture technologies can help to offset the effects of weather. This technology is increasingly widely used in agriculture industries of various crops production, including maize. Sensor sensing technology is one of the most vital tools in this methodology (Schepers et al., 1992; Simkó & Veres, 2019).

For crops, a chlorophyll meter Soil Plant Analyzer Development (SPAD-502) provides phenotyping readings and shows the chlorophyll a and chlorophyll b in the thylakoid membrane in leaf mesophyll chloroplast (Kandel, 2020). According to Huang et al. (2006); May (2000), chlorophyll is a green pigment present in the mesosomes of cyanobacteria and chloroplasts of algae and plants. It is a crucial component in the plant for the photosynthesis process, as it absorbs sunlight and uses the energy to synthesis carbohydrates from carbon dioxide and water. In addition, Ghimire et al. (2015) discovered that chlorophyll has direct roles in photosynthesis and hence closely relates to the photosynthesis capacity, development, and yield of crops.

Previous studies indicate that chlorophyll also influences the plant's leaf color, and chlorophyll concentration has a high correlation with the value measured with the Soil Plant Analysis Development (SPAD) meter. The SPAD meter can also estimate the concentration of Chlorophyll in leaves in a non-destructive manner (Amagai et al., 2022; Xiong et al., 2015).

Recently, chlorophyll meters widely used in agricultural systems to guide nitrogen (N) management by monitoring leaf N status. However, the effect of environmental factors and leaf characteristics on leaf N estimates is still unknown (Xiong et al., 2015). There is a non-linear relationship between leaf chlorophyll concentration and N rate, and chlorophyll SPAD value is applied to estimate the effect of N rate on leaf chlorophyll concentration. Kandel (2020); Richardson et al. (2002) reported that this tool is also used in estimating leaf N concentrations using SPAD data collection. The chlorophyll SPAD value quickly and readily assesses the N status of summer maize (Liu et al., 2018). Nitrogen (N) deficiency will have a direct impact on crop productivity. As a result, the elongation rate of maize stems, leaf area, and leaf or canopy net photosynthesis (Pn) are all reduced. Furthermore, it will also cause the hyperspectral reflection of the leaves to become very sensitive to N status, causing the plants to be shorter and have less dry matter. Therefore, early diagnosis of plant nitrogen deficit is essential to optimize the application of N fertilizers and crop yields (Zhao et al., 2003).

Another approach to improving N use efficiency (NUE) involves plant-based strategies that rely on monitoring the N status of crops by measuring chlorophyll content per leaf area (Xiong et al., 2015). The leaf area index (LAI) is a metric that determines the total leaf area for each unit of horizontal surface area. Leaf area index (LAI) is a metric that determines the total leaf area per unit of parallel surface area. LAI is directly involved in radiation capture, photosynthesis, energy exchange with the atmosphere, as well as influencing growth performance and yield. As a

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result, most agronomic investigations involving plant growth and yield analysis involve leaf area (LA) measurements (Berdjour et al., 2020).

When there is an influence of N supply, the physiological characteristics of the plant will be affected, and this can be determined at the field level. However, other environmental factors may have an impact on the outcome (Zhao et al., 2003). Therefore, to study the effects of various nitrogen supplies in maize associated with SPAD readings and leaf characteristics, we conducted maize experiments during the spring-summer 2021 growing season. The main objectives of this study were i) To record the photosynthetic activity of maize plants in various N applications, and ii) To determine the relationship between SPAD values, leaf area, and its characteristics in various N applications.

Materials and Methods

Experimental Site

The research was carried out at an experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Hungary, during the spring and summer of 2021 (May-October). This plot is located at a hilly section of the country near-average climatic zone, 242 m above sea level (47°46′N, 19°21′E) on sandy loam, brown forest soil (Chromic Luvisol). In 2021, the average annual precipitation in Gödöllő was 531.0 mm (20.91 inches), while in Hungary, the estimated precipitation is between 400 to 500 millimeters (15.8 - 19.7 inches) per year. Generally, the west is slightly wetter than the east (Weather and climate, 2021). Maize hybrid seed variety namely MV 277 were sown using Wintersteiger Plotman maize planter machine with 75 thousand plant ha^{-1} planting density.

Treatment

Four observation plots consisting of a 10 m^2 area size were evaluated for various N levels (0, 50, 100, and 150 kg ha^{-1} N a.i) with marked plants sampling in four replications. Data collection on leaf traits viz. leaf number $plant^{-1}$ (B), leaf number $plant^{-1}$ (S), temperature °C (leaf surface), SPAD, leaf length (cm), leaf width (cm), and leaf area (cm^2) were measured one week after application in weekly sequences of N until the eighth week.

Measurement

Data collection on leaf parameters viz. leaf number $plant^{-1}$ (big (B)), leaf number $plant^{-1}$ (small (S)), temperature of leaf surface(0°C), SPAD, leaf length (cm), leaf width (cm), and leaf area (cm^2) were determined weekly. It started from 8 weeks to 16 weeks after planting (until all plants fully dried). The number of leaves of the selected plant was calculated by counting all the green leaves, while SPAD values and leaves temperature were measured on the same spot at the leaf surface. Besides, the Leaf chlorophyll index was measured by using a SPAD meter (SPAD 502 plus, Minolta, Japan). Meanwhile, the estimated leaf area (LA) has followed the procedure introduced by (Elings, 2000) by multiplying the leaf length by its widest width by alpha, where alpha is 0.743 ($L \times W \times \alpha$).

Statistical analysis

One way ANOVA between treatments was performed to compare the leaf number $plant^{-1}$ (B), leaf number $plant^{-1}$ (S), temperature (°C), SPAD, leaf length (cm), leaf width (cm), and leaf area (cm^2) at $P < 0.05$ level of significance. However, Post Hoc Multiple Comparisons using the Least Significant Difference (LSD) were used to compare the mean values of the various levels of nutrient treatments at $P < 0.05$. Analysis was conducted by using the IBM SPSS version 23.

Results and Discussion

The mean, maximum and minimum values, and standard deviations for leaf number plant^{-1} (B), leaf number plant^{-1} (S), temperature (°C), SPAD, leaf length (L), leaf width (W), and leaf area (LA) are shown in Table 1. The mean for leaf number plant^{-1} (B) was 9.87 with Std. Deviation (1.86), where the mean for leaf number plant^{-1} (S) was 1.69 with Std. Deviation (0.66). The leaf number plant^{-1} (B) showed the highest mean compared to the leaf number plant^{-1} (S), while the leaf number plant^{-1} (S) was the more consistent score. The mean for leaf temperature was 240 °C with Std. Deviation (3.85) and minimum and maximum temperature values were 15.30 °C and 34.80 °C, respectively. The SPAD value indicates that the mean value was 45.20 with Std. Deviation, minimum and maximum values were 9.94, 2.30, and 68.20, respectively. The results demonstrated that the mean values for leaf length (L) and leaf width (W) were correlated with leaf area (LA). Potdar and Pawar (1991) found a good correlation between leaf area and various combinations of leaf length (L) and leaf width (W) in the banana (*Musa acuminata* Colla). Also, Peksen (2007) has found a strong relationship between leaf area and a combination of lamina length (L) and lamina width (W) in *Vicia faba* L. by measuring leaf length and leaf width and calculating different combinations.

The ANOVA table (Table 2) illustrates there were highly significant differences in all characteristics measured viz. leaf number plant^{-1} (B), leaf number plant^{-1} (S), temperature (°C), SPAD value, leaf length (L), leaf width (W), and leaf area (LA) between the groups for different nutrient treatment (0, 50,100 and 150 kg ha^{-1} N). The different levels of N treatments had a significant impact on leaf number (big and small), F (3, 1602 and 3, 1504) = [17.892 and 54.196]; $p = 0.000$). Besides, temperature (°C) (F (3,1463) = [4.464], $p = 0.0040$), SPAD (F (3, 1463) = [35.157], p = 0.000), leaf length (L) (F (3,1461) = [5.063], $p = 0.002$), and width (W) (F (3,1462) = [6.283], $p = 0.000$), and leaf area (LA) (F (3,1461) = [8.221], $p = 0.000$).

Leaf number plant^{-1} (B)

Post hoc analysis (Figure 1(a)) using LSD ($P < 0.05$) indicated that there were no significant differences between the 0 N, 50 N, 100 N treatments in leaf number plant^{-1} (B) (M = 9.97, 10.13, 10.12 respectively). However, the 150 N treatment (M = 9.33) differed significantly among the other treatments. The results also showed that the N fertilizer content positively correlated with the plant leaf number $^{-1}$ of 0 N, 50 N, and 100 N but drastically reduced the leaf number plant^{-1} of 150 N treatment. However, many previous studies have proven that giving an extra N fertilizer can inhibit tree growth and leaf production in maize. In contrast to Vos et al. (2005), which stated that leaf appearance rate, leaf development period, and leaf number are not affected by nitrogen supply in maize crops. The average leaf number plant^{-1} (B) by week showed that the highest was in the 3rd weeks with 11 leaves (0 N and 100 N), followed by 10.75 and 10.5 (50 N and 150 N, respectively). The leaves number (B) started to decrease in week 6, and it happened after the plant was in the final stages of the reproductive phase (Figure 2 (a)). This situation occurs because the nutrients were directed toward grain development rather than leaf growth (Kandel, 2020).

Leaf number plant^{-1} (S)

The results of leaf number plant^{-1} (S) in various N treatments are shown in Figure 1(b).

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Table 1: Mean, maximum, minimum and Std Deviation of leaf number plant^{-1} (B), leaf number plant^{-1} (S), temperature (°C), SPAD, leaf length (cm), leaf width (cm) and leaf area (cm^2) for various levels of nutrient treatments (0, 50, 100, and 150 kg ha^{-1} N).

	Leaf number plant^{-1} (B)	Leaf number plant^{-1} (A)	Temperature (°C)	SPAD	Leaf lenght (cm)	Leaf width (cm)	Leaf area (cm^2)
Mean	9.87	1.69	24.00	45.20	67.91	7.43	390.39
Std. Deviation	1.86	0.66	3.85	9.94	18.08	2.55	146.83
Minimum	2.00	1.00	15.30	2.30	5.00	0.40	1.50
Maximum	12.00	3.00	34.8	68.20	97.00	84.00	655.80

Table 2: Analysis of variance for leaf number plant^{-1} (B), leaf plant^{-1} (S), temperature (°C), SPAD, leaf length (L), leaf width (W) and leaf area (LA) for various levels of nutrient treatments (0, 50, 100, and 150 kg ha^{-1} N).

Parameter	Source of variation	Sum of Squares	df	Mean Square	*F*	Sig.
Leaf number plant^{-1} (B)	Between Groups	180.946	3	60.315	17.892	.000
	Within Groups	5400.394	1602	3.371		
	Total	5581.341	1605			
Leaf number plant^{-1} (B)	Between Groups	64.256	3	21.419	54.196	.000
	Within Groups	594.383	1504	.395		
	Total	658.639	1507			
Temperature (°C)	Between Groups	196.789	3	65.596	4.464	.004
	Within Groups	21497.851	1463	14.694		
	Total	21694.640	1466			
SPAD	Between Groups	9747.611	3	3249.204	35.157	.000
	Within Groups	135208.461	1463	92.419		
	Total	144956.072	1466			
Leaf length (cm)	Between Groups	4921.479	3	1640.493	5.063	.002
	Within Groups	473423.114	1461	324.040		
	Total	478344.593	1464			
Leaf width (cm)	Between Groups	121.468	3	40.489	6.283	.000
	Within Groups	9421.174	1462	6.444		
	Total	9542.641	1465			
LA (cm2)	Between Groups	523930.814	3	174643.605	8.221	.000
	Within Groups	31040000.000	1461	21244.002		
	Total	31560000.000	1464			

df: Degrees of freedom; Sig.: Significance; Significance level = $P < 0.05$.

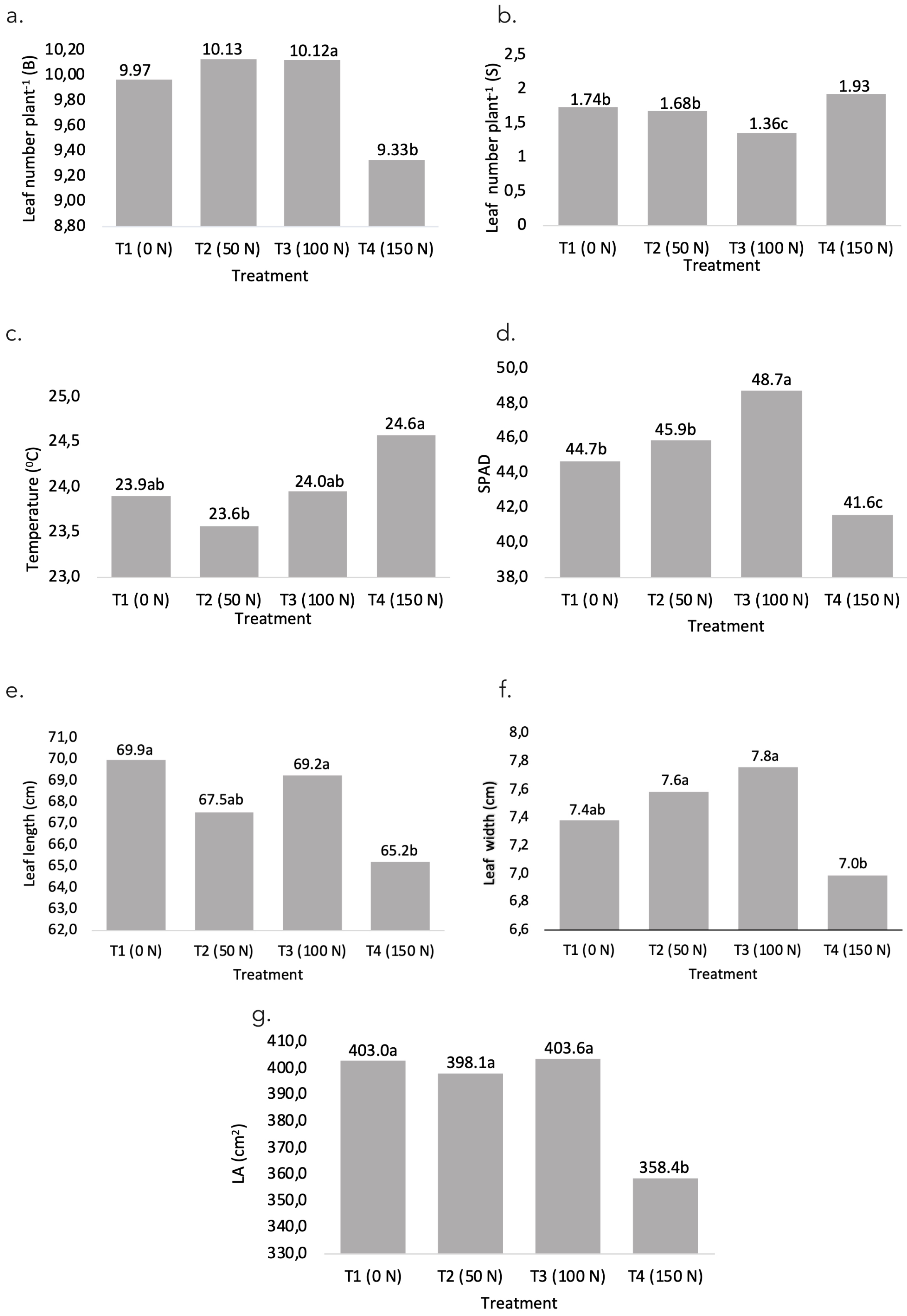

Figure 1: Mean values of (a) leaf number plant^{-1} (B), (b) leaf plant^{-1} (S), (c) temperature (°C), (d) SPAD, (e) leaf length (L), (f) leaf width (W) and (g) leaf area (LA) for various levels of nutrient treatments (0, 50, 100, and 150 kg ha^{-1} N)

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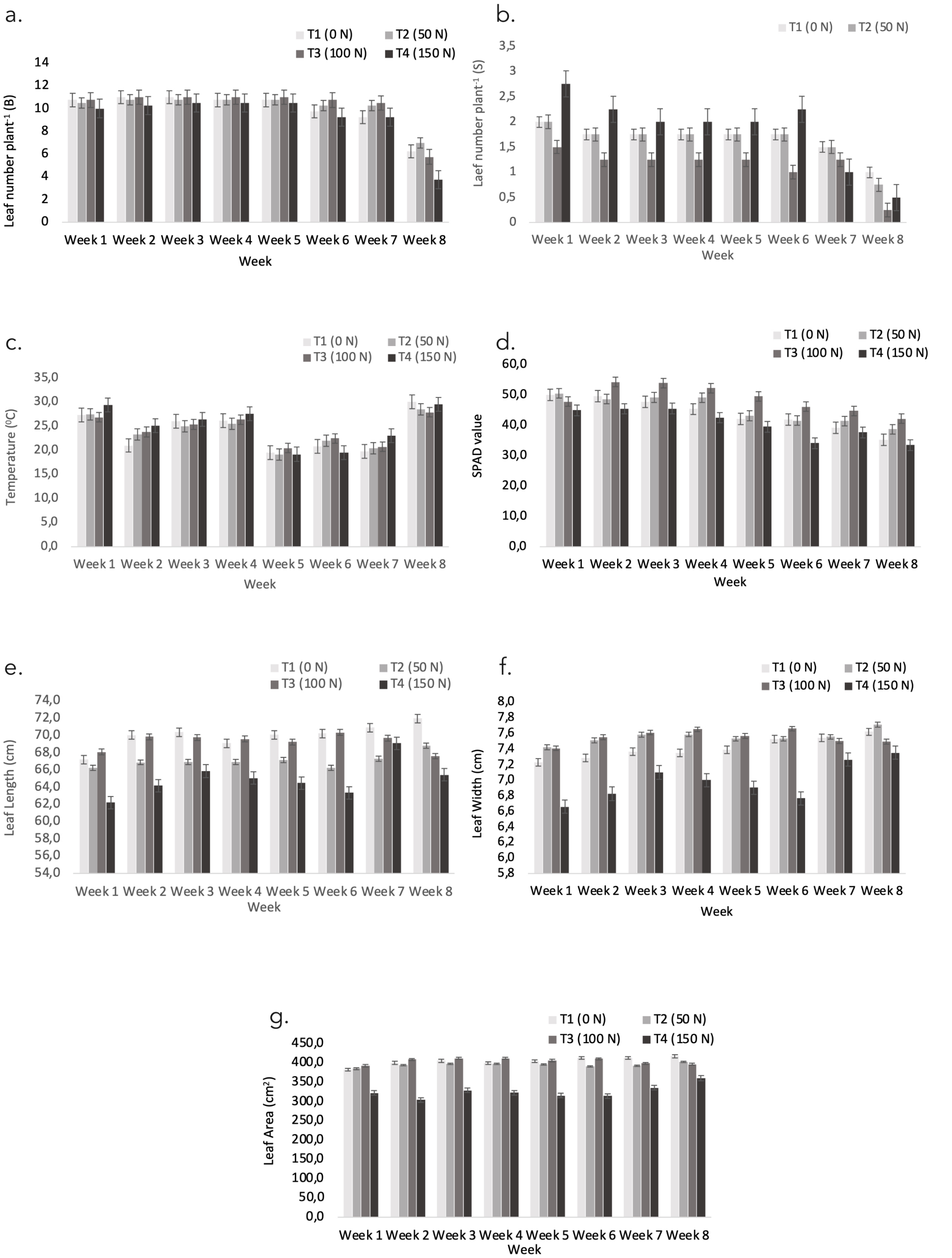

Figure 2: Average of (a) leaf number plant-1, (B), (b) leaf number plant^{-1} (S), (c) temperature (°C), (d) SPAD, (e) leaf length (L), (f) leaf width (W) and (g) leaf area (LA) for various levels of nutrient treatments (0, 50, 100, and 150 kg ha^{-1} N) by week.

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The highest leaf number plant^{-1} (S) was produced by treatment of 150 N (1.93) and was significantly difference ($P < 0.05$) with 0 N, 50 N and 100 N (1.74, 1.68 and 1.36 respectively). Treatment of 150 N also consistently produced the highest average number plant^{-1} for every week up to the 6th week (Figure 2 (b)). This study implies that high nitrogen levels will increase the production number of small leaves. Similar findings were observed by Gungula et al. (2005)), who discovered that higher nitrogen rates produced more leaves and reduced leaf aging.

Temperature

Analysis showed no significant different between means ($P < 0.05$) of treatment 0 N, 50 N 100 N and 150 (23.9 °C, 23.6 °C, 24.0 °C, 24.6 °C respectively) (Figure 1(c)). However, the temperature of leaf in maize was highest in 8th week which is up to 30 °C for treatment 1 (0 N) and the lowest in 5th week which is down to 19.1 °C. In this experiment, treatment of 150 N had a relatively high temperature compared to others with 29.4 °C, 25.1 °C, 26.4 °C, 27.6 °C, 19.2 °C, 19.5 °C, 23.0 °C, 29.6 °C for 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, and 8th week respectively (Figure 2 (c)). Based on the performed evaluation and considering the results, this finding showed that the temperature of the leaves is related to the N application and ambient temperature. The temperature of the plant leaf had a direct influence on the biochemical reactions required for plant physiology. The temperature of the leaves rises as radiant energy is absorbed and drops as sensible and latent heat energy are transferred from the leaves to the air. As a result, environmental factors associated with this energy balance (light intensity, temperature, humidity, airflow velocity, and so on) influence leaf temperature, photosynthesis, and growth (Kitaya, 2019).

SPAD readings

The results in Figure 1(d) revealed that SPAD readings showed high significance in treatment 100 N and 150 N ($P < 0.05$). However, no difference in the treatment of 0 N and 50 N. The SPAD values responded to the application of N were quickly in 0 N, 50 N, and 100 N with 50.0, 50.5, and 47.8 respectively, and the lowest was 150 N (44.9). However, in the 2nd week, the SPAD values of 100 N were increased and produced the highest value and maintained until the 8th week (54.2, 53.9, 52.2, 49.5, 46.1, 44.8, and 42.1), while treatment of 150 N produced the lowest SPAD values viz. 44.9, 45.4, 45.4, 42.5, 39.5, 34.1, 37.6, and 33.5 in 1st week to 8th week respectively (Figure 2(d)). Similar findings revealed that the amount of chlorophyll content that can be extracted decreases in line with the increase in nitrogen levels (Simkó & Veres, 2019). This finding contrasted with Liu et al. (2018), where the value of SPAD chlorophyll increased significantly with the rate of N. However, the recommended treatment was 185 kg N ha^{-1}, which is an appropriate utilization rate for optimal grain yield, photosynthesis, and ultrastructure of chloroplasts. Schepers et al. (1992) also revealed similar findings in which the SPAD value obtained from the SPAD-502 device was directly correlated to the nitrogen status of the plant. Additionally, the SPAD meter is a widely used handheld device to measure leaf chlorophyll in a quick, accurate, and non -destructive manner. It is also a gadget to detect N deficiency in maize and guide N management in Agricultural systems. However, there is a major drawback that leaf greenery can vary between hybrids and is due to other plants and environmental factors (Piekielek et al., 1997; Xiong et al., 2015), including plant growth stage, type of hybrids, the timing of N fertilizer application, and N source (Schepers et al., 1992).

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Leaf length

Leaf length of maize was not significantly different for all treatments measured ($P < 0.05$). However, the highest leaf length was in the treatment of 0 N, followed by 100 N, 50 N, and the lowest was 150 N (Figure 1(e)). The optimum leaf length value showed in the 7th week, and the leaf length value decreased sharply in the 8th week (Figure 2(e)). The results obtained show that the N rate does not affect the leaf length and, these results were correlated to the width and area of the leaves (Peksen, 2007).

Leaf width

The leaf width was not significantly different between N treatments ($P < 0.05$). The highest leaf width was in treatment 100 N, followed by 50 N, 0 N, and the lowest was 150 N (7.8 cm, 7.6 cm, 7.4 cm, and 7.0 cm, respectively). The highest leaf width showed in the 8th week and the lowest in the 1st week. In previous research stated that leaf width has a good correlation between leaf length (L) and leaf width (W), but the LA constant related to L and W varied in different cultivars (Potdar & Pawar, 1991).

Leaf Area (LA)

Post Hoc LSD results ($P < 0.5$) showed a significant difference between the treatment of 0 N, 50 N, and 100 N with 150 N. However, no significant difference between 0 N, 50 N, and 100 N treatments. Treatment of 100 N showed the highest leaf area starting in the 1st week until the 6th week. Besides, treatment of 150 N remained produced the lowest leaf area up to the 8th week (Fig. 2 (g)). The results showed that high N supplementation (150 N) resulted in less leaf area than the other treatments. However, previous related studies have found a positive relationship between N and leaf area. These findings supported by Berdjour et al. (2020); Valentinuz and Tollenaar (2006), who stated that higher N utilization rates influenced leaf area values produce positive effects on cell division and elongation, resulting in increased leaf length and rapid leaf development (Chiesa et al., 2000)). Furthermore, according to Chaudhry and Jamil (1998), higher nitrogen doses promote plant growth rather than yield. Nevertheless, the availability of N has a substantial impact on the development of leaf area only during vegetative growth (Muchow, 1988; Vos et al., 2005).

Conclusion

According to the findings of this study, nitrogen fertilizer application increased the leaf number plant^{-1} (B) up to 100 N and declined significantly at the 150 N. Contrasting results were obtained for the leaf number plant^{-1} (S), where the increase occurred at the treatment of 150 N. Meanwhile, the temperature at the leaf surface was positively associated with the increased in the application of the N rate for all treatments. In the SPAD values (leaf photosynthesis rate), the readings increased directly with the increase of N fertilizer application which decreased with treatment of 150 N, which may be related to the number of leaves in this study. Furthermore, the study's findings showed that leaf length (L) has no direct relationship with leaf width (W). Nonetheless, two of these parameters are directly related to leaf area (LA). The conclusion of this study indicates that N content affects the growth performance of maize crops, and plants from the treatment of 100 N produced the best results in the most parameters measured. Nevertheless, excessive nitrogen application harms plant growth. The environment, soil conditions, precipitation, temperature, pH, and plant variety can influence the plant's ability to absorb nitrogen from the soil.

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Aquacrop model evaluation for generation of irrigation requirement for winter wheat cultivars

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Abstract: Research on water-saving techniques in agriculture is brought forward because of water resource shortages. Optimising irrigation strategies to increase water-use efficiency is an essential factor in water security for the Békés region in Hungary. FAO's AquaCrop model was used to improve water efficiency by simulating crop growth. In our study, the model was calibrated with the field measurements of the MATE ÖVKI Lysimeter Research Station. Four winter wheat varieties were cultivated under non-limiting water conditions. The yields ranged from 5.0 t/ha to 7.6 t/ha in the harvest on the 6th of July 2020. The crop growth was simulated with the actual climatic, vegetation, soil profile, and groundwater data. The AquaCrop simulation resulted in a similar yield data range, with a water productivity range of 1.07-1.23. The crop cycle of the plants was 187 days, while the harvest index was 45% in the model settings. The results led to the conclusion that water optimisation based on climate data and crop yield can help us generate net irrigation requirements. The generation of sprinkler irrigation schedules developed from this research would provide information for farming communities to mitigate the adverse effect of climate change.

Keywords: AquaCrop, irrigation, water productivity, wheat, efficiency

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Introduction

Advance in technology offers help in analysing natural processes. Increase of agricultural productivity essential to meet worldwide food demand. Water from precipitation or irrigation is needed to maintain the soil moisture available for the plants. Water is in continuous circulation, which leads to a dynamic change of water resources (Brouwer & Heibloem, 1986), strongly influenced by actual water use.

Surface and groundwater sources are exploited for domestic, industrial, and agricultural uses, where agriculture is the largest water user, representing around 75% (Wallace, 2000) of the total water extraction. As the world population grows (United Nations, 2019), the available agricultural land has decreased from 0.38 to 0.28 ha person-1 in the period from 1970 to 1999 (Howell, 2001). The farmers' attempt to adapt to the more frequent weather fluctuations can help meet food demand with increased productivity. Agricultural production is more and more influenced by climate change, where extremities can negatively affect crop production, resulting in a significant loss of yield.

Farming adaptation should focus on water management issues related to crop evapotranspiration, water shortages during the vegetative periods, increased likelihood of flooding, and reduced water sources (Iglesias & Garrote, 2015). Water use efficiency can be increased by knowing water requirements to find the optimal irrigation timing (Wang et al., 2018).

Irrigation efficiency by flooding is up to 70%, spraying 80%, and micro-irrigation 90%-96%. Water management in crop production is considered a powerful tool to achieve production stability, which can be supported by simulation of the water balance of the root zone during the vegetative period of the crops, using data as described by Raes et al. (2018) in the AquaCrop model.

Different objectives can be taken into account when designing an irrigation system at the field level, such as maximising the benefits and minimising the costs (Holzapfel et al., 2009). Properly validated AquaCrop simulations can determine the field variations of the yield. Abedinpour et al. (2014) described an example for maise, where AquaCrop showed the variations in yield in different scenarios.

Cereals, especially wheat, triticale, and maise, are important crops worldwide for food and feed production. Plant water requirements during the dry and wet years differ for crops and seasons. Zhao et al. (2021) described that higher yield co be achieved by applying irrigation but only to a certain limit where additional amounts of irrigation start to cause a decrease in the yield. Pre-sowing irrigation significantly increased soil moisture for winter wheat, and it positively affected yield in dry conditions. In arid arable lands, water use efficiency increased significantly with the decreasing irrigation level (Salemi et al., 2011) and decreasing crop evapotranspiration (ETc). Therefore, a practical analysis of how to reach a maximum yield is important; otherwise, irrigation could reduce productivity and water use efficiency.

Gravitational force and capillarity drive primarily the water movement in the soil. Physical properties of the soil define how these forces can move or store water in the pores, represented in the pF curve. AquaCrop handles it through its characteristic points. Optimally, the moisture content of the root zone should be around the soil's field capacity (water-holding capacity). When it is around the wilting point, different plants can tolerate water stress differently, as defined in the model's plant parameters. Agricultural management practices, like tillage (Sárdi, 2011), can also affect the actual moisture content of the root zone. Thus, those are also simulated in the model.

The AquaCrop model (Raes et al., 2012; Vanuytrecht et al., 2014) was enriched continuously with an improved parameterisation for solving complex tasks. For example, recently, it was successfully used by Guo et al. (2021) to analyse and optimise irrigation scenarios in a large region. The results showed that the optimised irrigation schedule performed better than the irrigation the farmers applied.

AquaCrop also has been used widely to compute crop water requirements (Saccon, 2018) using the FAO Penman-Monteith calculation (Pereira et al., 2015). It was shown that the effect of climate change has a negative impact on agricultural production and forestry.

In the present study, we are looking into the possibilities of AquaCrop to support farming with information on how to increase irrigation efficiency and productivity. The objective is to improve yield while maximising crop water productivity for four wheat varieties. The optimised irrigation schedule contains reallocated irrigation times between different simulation regions and improved water resource allocation.

Materials and Methods

Field experiments were conducted at the Lysimeter Research Station of MATE ÖVKI in Szarvas, Hungary, during the 2020 grow-

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ing season. The climate in this area is continental. Figure 1 shows the temperature data for the wheat growing season received from the meteorological station at the Lysimeter Research Station for 2020. The precipitation data is presented in Figure 2. The soil type of the study area is clay loam. The MATE ÖVKI agronomic measurements were applied to quantify the biomass parameters.

For this study, the FAO's AquaCrop model was calibrated for the calendar mode and verified with field data of two drought-resistant ('GK Berény' and 'Plainsman V.') and two drought-sensitive ('Midas' and 'PC 84') wheat varieties cultivated at the Lysimeter Research Station. The post-harvest data were compared to those stimulated in AquaCrop 6.1. The modelling framework needs crop information, climate data, soil information and field management, as described by Steduto et al. (2012). We have simulated wheat yield production in different scenarios and water productivity in the model. The input parameters required defining the data for each wheat variety, such as the sowing, seedling, jointing, flowering date, filling to the maturity date and root depth. The wheat production in 2020, as the analysis of the Hungarian Central Statistical Office (HCSO, 2020) showed, was outstanding, higher than in the previous years. From simulated runs, it was evaluated whether irrigation is needed for wheat varieties by the sprinkler method. Different time steps and irrigation amounts were compared based on the allowable depletion percentage of readily available water content in the root zone.

Results

Our study used the AquaCrop model for modelling winter wheat development under certain climatic conditions and irrigation to boost yield and water productivity. Crop parameters were defined using field data from the Lysimeter Research Station. The results show a good representation of the crop varieties and their field performance, similar to the research of Guo et al. (2021).

Non-limiting sprinkler irrigation (Andarzian et al., 2011) was simulated. The irrigation scheduling and timing were set at different scales.

Figure 1 shows the air temperature measured by an automatic weather station (Agromet Solar, Boreas Ltd., Hungary). The mean temperature was 13.3 °C, the minimum was 7.6 °C, and the highest reached 34.9 °C. The dormant phase for wheat varieties starts at 0 °C based on (Porter & Gawith, 1999). The weather extremes stayed inside the cultivar tolerance for production. The average relative humidity for the research was set to 75.9%.

Soil parameters were set to clay-loam (Soil Survey Staff, 1999). Sowing and planting in rainfed farming are primarily based on the rainfall and soil water holding capacity. Weather conditions vary from year to year. Considering that the soil is the ideal environment for plant growth, the average factor input from the Lysimeter Research Station and other fields. The optimum balance between the parameters and input methods to calculate measured data based on a complex process with an accurate yield simulation. The soil model was customised to clay loam texture with 0.03% total salinity and 1.31% on total organic carbon content to represent the growth medium of four wheat cultivars.

Figure 2a) shows the monthly precipitation averages from 1971 to 2000, based on the data collected from the Hungarian Meteorological Service (Met.hu, n.d.). The annual average is 570 mm, where the summer months have higher and the early spring months show lower precipitation. Figure 2b) shows the data for 2020 from January to September measured at the experimental site. Periodic soil water monitoring reflected that the precipitation was relatively high in 2020. The metrological station measured,

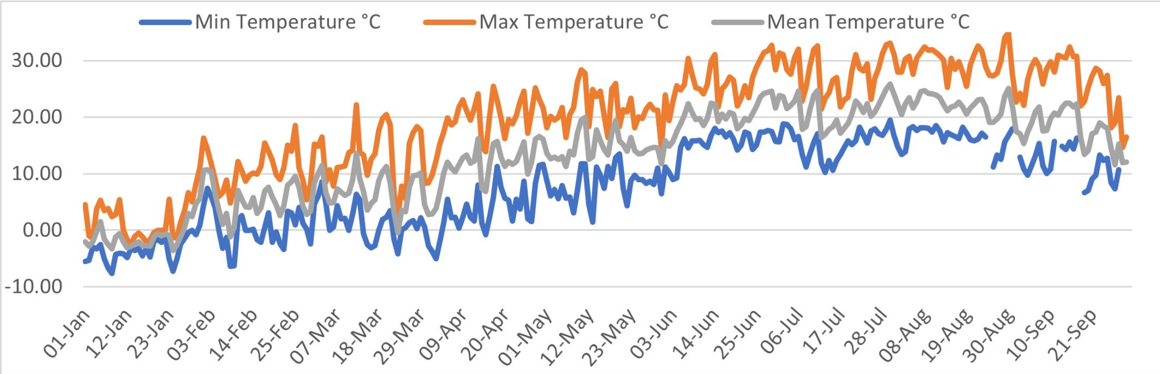

Figure 1: Weather station temperature data of the study area

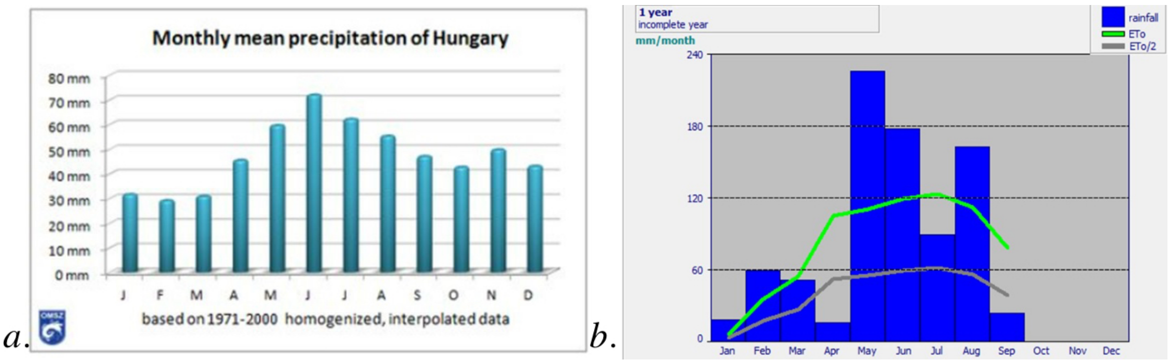

Figure 2: Precipitation a) Monthly averages (1971-2000) (Met.hu, n.d.); b). Actual in situ measurements (January-September 2020) for the location

from January to September, a total rainfall of 827 mm, whereas during the cropping period (the length of it was 187 days), the rainfall was 572 mm.

Daily biomass production and yield response were simulated in the model for wheat, which is an annual crop product. Drought directly reduces crop yield by decreasing the water availability in soil or by decreasing the relative humidity, which increases crop transpiration (Taiz & Zeiger, 2002). Plant water stress occurs when the soil moisture drops below a crop-specific level and the stomatal closure starts. Shams (2022) investigated the effect of climatic stresses on grain spikes under deficit irrigation, where irrigation scheduling is based on the estimation and measurement of soil moisture.

Our focus was on the effects of water retention and soil water movement on biomass production, harvest index, and potential biomass to compare the extension to the farm-scale. Our wheat varieties were not significantly different from the observed and simulated data of Guendouz et al. (2014). Therefore, in cases of limited input factor under semi-arid conditions, the AquaCrop model is promising for estimating crop productivity. The AquaCrop field measurement and modelled data did not show significant differences in our research field. Modelled potential ETo in our model was of 762 mm (Figure 3), while achieved average in each variety is 472 mm of crop evapotranspiration.

The graphs of Figure 4 show that the soil water content stayed relatively close to the

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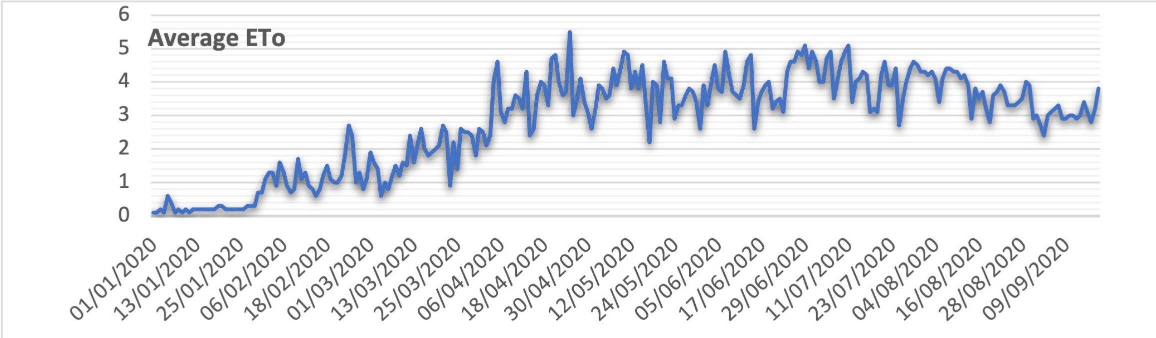

Figure 3: Reference ETo computed in AquaCrop from daily meteorological data of the station

field capacity. This resulted from a very wet year. The produced biomass average of the four varieties was around 6,310 kg. The yields in the research field were achieved in the level of 6.2 tons, 5.0 tons, 6.4 tons, and 7.7 tons, compared to the average grain yield per hectare for the Hungarian climate (Karacsony & Markus, 2007) which were lower (3 to 5 tons). On figure 5 and table 1 when comparing to the simulated irrigation events on AquaCrop for soil moisture, the predicted year had higher precipitation and favourable weather for wheat production. On the contrary, for AquaCrop data calibration, we have achieved the same outcome regarding yield measurements. Scenario analysis of the wheat varieties indicated water productivity (table 1) ranging from 1.17 to 1.14 kg m^{-3} and a yield of 6.1 to 6.2 t ha^{-1} for Plainsman V variety. For variety PC 84 the ET water productivity was at 1.07 and yield ranged from 5,083 to 5,106 kg ha^{-1}. Values from other simulation had minor increases from the first simulative data on AquaCrop.

In intensive agriculture, it is important to have stable water sources for sustainable production. A decline in water sources enhances the efforts to increase water use efficiency (Wang et al., 2018), which results in high yield production. Irrigation efficiency is one of the crucial factors to pay attention to in extreme agricultural conditions.

The simulation results of three scenarios for the four wheat varieties are shown in Table 1. Sprinkler irrigation was applied when the root zone soil moisture dropped below a selected level. It was in the first scenario 60%, the second scenario 75%, and the third scenario 85% of the field capacity. These scenarios were simulated on the four cultivars under the same meteorological conditions, field management, soil profile, and other factors.

Conclusions

After analysing the results, we may conclude that the yield increase was negligible due to the meteorological circumstances at the time of planting was carried out using the paralleling test. Each simulation has provided sufficient outcome regarding harvest index, potential biomass and achieved biomass.

In this study, four wheat varieties cultivated at the MATE ÖVKI Lysimeter Research Station (Szarvas, Hungary) were simulated using the AquaCrop model to describe the growth cycle of winter wheat using three irrigation patterns. Climate, crop, soil, and field management data were defined at the test area for our study. In the growth period, rainfall satisfied the water need for wheat production in the observed year. Furthermore, none of the irrigation schedules resulted in a substantial boost in production.

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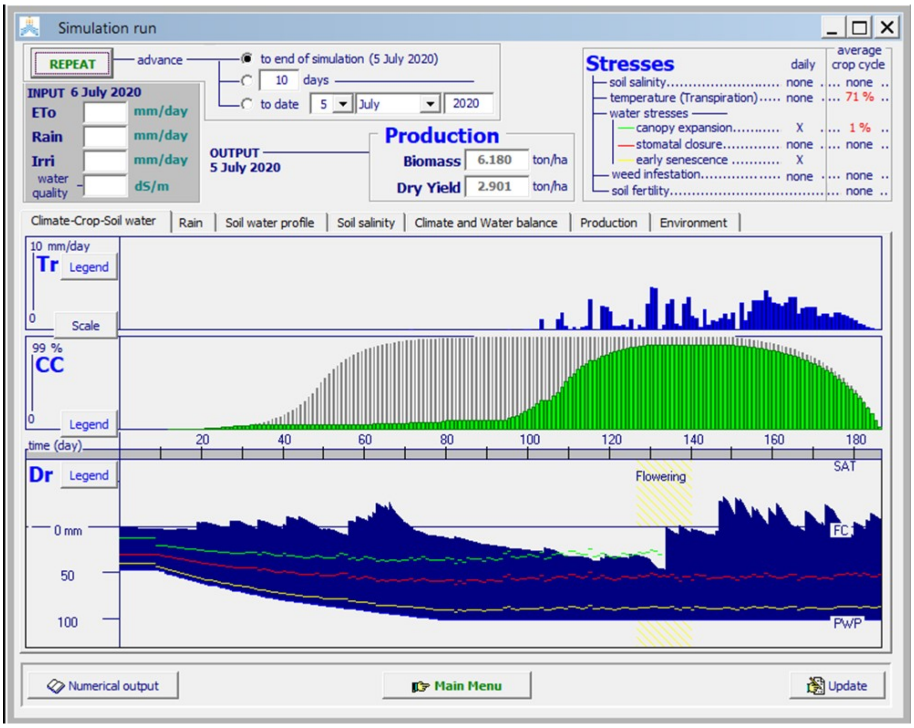
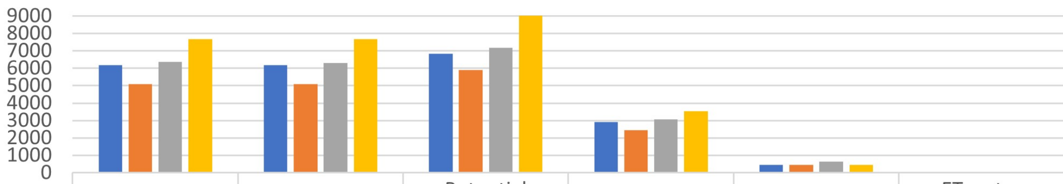


Figure 4: The simulation results of Plainsman V in AquaCrop



	F. measured	Biomass	Potential biomass	Dry yield	ETo	ET water productivity
Plainsman V	6185	6180	6837	2907	462	1.17
PC 84	5075	5083	5906	2430	457	1.07
MIDAS	6360	6313	7161	3073	642	1.23
GK BERENY	7678	7667	9049	3528	462	1.23

Figure 5: Basic simulation run for the wheat varieties for biomass, dry yield, and potential biomass

Modelled vegetation year had a more than average precipitation and favourable weather for wheat production, characterising the most favourable conditions for wheat production. It reached a yield close to the potential genotype yield. Nevertheless, AquaCrop properly simulated the dynamics of soil moisture of the rootzone, crop biomass, and grain yield. The usefulness of the AquaCrop software to model the crop growth in Hungarian circumstances was proved.

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Table 1: Aquacrop generation net irrigation water requirements

Irrigation (mm of water)	Plainsman V	PC 84	MIDAS	GK BERENY
Basic Simulation		No irrigation		
Gen-60%	57	55	59.3	57.7
Gen-75%	40	39.7	39.7	39.5
Gen-85%	40	39.7	45.5	46.4
Water productivity				
Basic Simulation	1.17	1.07	1.23	1.23
Gen-60%	1.14	1.04	1.20	1.19
Gen-75%	1.16	1.07	1.23	1.22
Gen-85%	1.16	1.07	1.24	1.23
Yield (kg/ha)				
Basic Simulation	6180	5083	6313	7667
Gen-60%	6198	5106	6342	7718
Gen-75%	6189	5098	6335	7705
Gen-85%	6189	5098	6327	7689

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MAGYAR AGRÁR- ÉS ÉLETTUDOMÁNYI EGYETEM

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Soil related environmental considerations of farmers in the Great Hungarian Plain

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Abstract: Climate change and associated environmental changes are the major sustainability challenges facing the world today. The selection of appropriate agrotechnological elements is required not only to increase the quality and quantity of food produced but as well as reducing the costs of the farmers and protecting the environment for future generations. In the Great Hungarian Plain, the adoption of recent environmentally friendly technologies is still not sufficient and the region faces various environmental challenges. This study aimed to analyse the economic and environmental consciousness of farmers in the selection of 3 agrotechnological elements (soil protective cultivation, soil reclamation/conditioning, manure application). A pilot study was conducted on 5 representative farmers, in which they were interviewed, and questionnaires were designed to critically analyse farmers' perceptions of the environment based on the opinions of 106 respondents. The result show that farmers are aware of the environmental impacts of selected technologies in their farms. They highlighted some of the environmental challenges they are experiencing including drought, secondary salinization, and unfavourable soil properties. However, they showed more economic than environmental consciousness, as they suggested that it was important to be familiar with economic issues and conditions to ensure higher income. The level of willingness to introduce or apply soil protective cultivation, soil reclamation/conditioning, and manure differed from low to high.

Keywords: environmental consciousness, economic consciousness, reduced tillage, soil conditioning, soil reclamation

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Introduction

The world population is estimated to be 8 billion and is expected to increase to 9 billion soon, hence there is an urgency to increase crop yield to satisfy the world's growing demand for food (Looga et al., 2018). The major sustainability challenges the world is facing today are climate change and associated environmental changes (Abercrombie et al., 2020). With the recent face of climate change and the increase in the world's population, satisfying the needs of the population becomes a great challenge.

The natural resources used in food production are not enough to fulfil the growing demand for agricultural produce and products due to growth in population, urbanization, and increasing income. Maximum food production is also limited by the size of land available, selected agrotechnical methods and environmental challenges. The selection of appropriate agrotechnological elements is required not only to increase the quality and quantity of food produced but as well as reducing the costs to the farmers and protecting the environment for future gener-

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ations. Agriculture's pivotal role in improving the world's economy, reducing poverty, contributing to food security, and rural development is important and cannot be ignored (Mwangi & Kariuki, 2015).

With the growing population, agriculture faces challenges of meeting the food demand of these populations, while attempting to minimize the environmental impacts of selected technologies (Robertson & Swinton, 2005). Knowledge on impacts of farmers selected technologies on the environment, could influence their perception of these technologies and influence their environmental behaviours (Ervin, 1982; Taylor & Miller, 1978). Agriculture has an impact on the environment and ecosystem as a whole (Kanianska, 2016), therefore the elements of agricultural technology such as continuous cropping, conventional tillage, monoculture, choice of nutritional supply to plants, irrigation etc. also involve environmental effects on their own. The major impacts on the environment and ecosystem that we face today as a result of these technologies include the decrease in productivity of the farmlands due to depletion of soil nutrients from runoff and greenhouse gas emissions (Schneider & Kumar, 2008). Thus, the future productivity of these farmlands and the environmental impacts of selected technologies depends on how we perceive the environmental and ecological elements of agricultural ecosystems.

Impacts of soil cultivation methods are visible on the physical, chemical and biological properties of the soil. Methods of soil cultivation include full and conservation tillage. Depending on the selected soil cultivation method each has consequences on the environment, for example, full tillage fractures the soil, disrupts the soil structure, soil temperature (Busari et al., 2015), accelerates the surface runoff and erosion, and releases CO_2 gas to the atmosphere (Lal et al., 2007). Whereas, conservation tillage involves practices that involve minimization of damage to the soil, conserves soil moisture and retain or prevent carbon emission to the atmosphere (Busari et al., 2015). It also reduces the leaching of nitrogen in the soil (Qi et al., 2019; Wang et al., 2020). Reduced tillage, zero tillage, mulching, ridge and contour tillage are some of the conservation cultivation practices. Zero tillage involves minimal disturbance of the soil to enhance soil biological activity, and maintenance of soil cover (crop residue) to reduce the impact on soil from raindrops or soil erosion. Reduced tillage involves the use of primary tillage to minimize the level of soil manipulation. Mulching involves methods of cultivation in which crop residues are left on the soil to supply nutrients to the soil, suppress weed growth and retain soil moisture. Ridge tillage involves the planting of crops along both sides or at the top of the ridges. Soil conservation practices are beneficial in reducing soil erosion, increasing soil productivity, reducing production costs. In soil conservation tillage practice, at least 30% of crop residue is left on the soil surface, this slows down the water movement, and as a result, it minimizes the amount of soil erosion. Additionally, conservation tillage has been found to have benefit predatory soil organisms that can enhance pest control by increasing the population of pest inhibiting organisms (Stinner & House, 1990).

In Hungary, the area cultivated under soil protective tillage is increasing year by year, though full tillage practice is still significant (30-40%) and it was the only soil cultivation method until the end of the 1990s (Birkás et al., 2021). Several measures were put in place to combat damages caused by drought and soil degradation, therefore, conservation tillage was introduced which aimed at reducing the depth of frequently cultivated soil layer and promotes topsoil formation which is rich in organic matter. By the early 2010s, conservation tillage was used on 35-50% of the croplands of Hungary de-

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pending if the season is dry or wet (Birkás et al., 2017). Reduced tillage is now the most dominant form of soil protective management that affects the soil stock in Hungary, however, crop residue management, irrigation management, and fertilizer management applying mineral fertilizers and organic amendments are other forms of soil protective practices that are being practiced in Hungary (Zsembeli et al., 2008).

The world population is growing which puts pressure on the agricultural land to meet the growing demand for agricultural food (Turmel et al., 2015), this has greatly affected soil fertility (FAO, 2017) and quality (Verhulst et al., 2010). For the soil to be healthy it has to be rich in soil organic matter content (SOM), therefore there is the necessity to do regular soil organic matter amendments which helps to improve the soil physical (soil structure, prevent soil erosion and runoff, soil compaction, improves soil temperature and moisture content), biological (soil biomass and diversity of soil organisms) and chemical properties (cation exchange, soil organic carbon, and soil pH) (Wilhelm et al., 1986, 2007) in return improves soil health, which is essential for yield improvement and at the same time it improves the productivity of livestock as well (Turmel et al., 2015).

Soil conditioning involves adding a product to the soil to improve the physical quality of the soil, fertility, and mechanics of the soil. According to research conducted in Karcag region, soil conditioning has a positive effect on agricultural soils as it facilitates vertical movement of the water, improves water holding capacity, increasesorganic matter content and facilitates leaching of excess salts from the root zone. Through the benefits of soil conditioning proven by various studies (Brandsma et al., 1999; Garcia et al., 2020; Zsembeli et al., 2019) soil conditioning can help improving the agricultural productivity of farming land (Kalra et al., 1998).

The main goal of our study was to gain information on what influence farmers in the selection of agrotechnological elements, whether they have more environmental or economic consciousness with special regards to the application of state of the art in soil cultivation, soil reclamation, and organic matter input. The data we collected can be used to encourage environmental awareness among farmers, the results contribute to an increase in quality of crop production, reduce costs and protect the environment for the future generation.

Materials and Methods

There were two sources of data and information involved in this study:

a) Questionnaire based on the TALA method,

b) Pilot study with the Advisory Board (AB) members of the Research Institute of Karcag (RIK)

TALA method

Jász-Nagykun-Szolnok (JNS) is a county in Hungary with many agricultural fields for large farm owners and hobby gardeners who have been practicing agriculture for over 300 years and they still face some challenges in adapting to climate change to optimize their field production capacity and maintenance of sustainable crop production. The adoption of recent environmental-friendly technologies is still low and the region faces various environmental challenges ranging from secondary salinization, methods of soil cultivation to fertilizers being used of which all have an impact on the environment. We elaborated a new technique of data collection called TALA method. TALA method is based on our idea that we should share useful information on the most up-to-date scientific results that can be used by the agricultural practice. TALA comes from the principle of Teaching by Asking and Learning by

Answering. The application of this method is not only to collect information from farmers but also involved a new and interesting way of knowledge transfer to the farmer. This technique worked in two ways, it enlightened the farmers on environmental issues which they may not have known about and at the same time collect data on their environmental and economic consciousness on agricultural technologies. The collected data helped to critically analyse the environmental and economic consciousness of farmers and to encourage the selection of appropriate agrotechnology when conducting farming activities. By use of this method, farmers are be more cooperative and give appropriate feedback, as information is not only taken from them but there is the transfer of knowledge to them. Based on the TALA method, a questionnaire was elaborated and sent to the farmers of JNS county by mail. The TALA questionnaire consisted of 5 topics of environmental issues including statements of the environmental and economic consciousness of the farmers and also the relevant questions on their plans if they want to apply them in the near future:

1. application of water preserving soil cultivation systems,
2. application of soil reclamation and/or soil conditioning,
3. application of manure and/or compost,
4. application of crop residue management,
5. application of region-specific crop varieties (land races).

In this paper, the first three topics out of the total five are discussed that are relevant to the pilot study topics with the AB members.

Application of water preserving soil cultivation systems

Environmental consciousness: According to the research achievements of RIK, land-use change from conventional to reduced tillage can save 200 kg soil organic carbon per hectare and 40 mm of soil moisture in the upper 30 cm depth of a typical soil of the Great Hungarian Plain annually. Due to the lower number of tillage operations, there is a 30-50% decrease in fuel consumption and an environmental load of greenhouse gases can be expected. *Economic consciousness:* Shifting to reduced tillage from conventional probably needs the purchase of new machinery. *Relevant TALA question in the questionnaire:* Do you consider changing the management system of your cropland from conventional to reduced tillage in the near future? If yes, why? If not, why not?

Application of soil reclamation and/or soil conditioning

Environmental consciousness: According to the research achievements of RIK, 6 years of soil conditioning (use of Neosol once a year at a rate of 150 kg/ha) the soil depth with favourable physical, chemical and biological status increased by 10 cm in a meadow chernozem soil. *Economic consciousness:* Without yield depression, about one third of the autumn basic fertilizer can be saved. The cost of soil conditioning per hectare is about 25-30 thousand HUF per year. *Relevant TALA question in the questionnaire:* Do you plan to use a soil conditioner in your area in the near future? If yes, why? If not, why not?

Application of manure and/or compost

Environmental consciousness: According to the research achievements of RIK, the basic autumn fertilizers can be replaced with compost without yield depression. In addition, the organic matter and lime content of compost significantly improves soil cultivability, reduces soil acidity, and provides nutrients for the crops for several years. *Economic consciousness:* The cost of using compost per hectare is about 50,000 HUF per year, or 100,000 HUF every three years. *Relevant TALA question in the questionnaire:* Do you plan to use manure/compost in your area in the near future? If yes, why? If not, why not?

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Pilot study with the Advisory Board members
A pilot study was conducted on 5 farmers of the Advisory Board of RIK, Hungarian University of Agriculture and Life Sciences. In 2014, the director of RIK formed an advisory board (AB) with the goal to make a formal and informal platform to link agricultural research and practice. The AB members, who cultivate more than 10,000 ha of land. These representatives (executive managers) of farms typical in the Great Hungarian Plain were the best people to link us with the local agricultural practice and provide answers to different soil related environmental challenges experienced by them and how they tackle these issues. They were interviewed about three issues relevant to soil related environmental topics being important for the farmers of the Great Hungarian Plain and are in harmony with the first 3 topics of the TALA questionnaire:

1. adaptation to extreme agroecological conditions by conversion from conventional to a water preserving soil cultivation system or by irrigation,
2. protection against soil degradation by soil reclamation and/or soil conditioning,
3. enhancement of soil fertility by the application of manure or compost.

The data collected was to critically analyse the soil related environmental consciousness of farmers and gave information how to encourage appropriate agrotechnology selection when conducting farming activities. Through the answers to the questions involved in the questionnaire, we get to know more what influences farmers in the selection of agrotechnological elements, whether they have sufficient environmental and professional considerations.

We conducted a combined assessment of the answers gained from the questionnaires and the opinions of the AB members. The form of data obtained during the investigation was qualitative and was subjected to simple processing in Microsoft Excel to calculate percentages. A chi-squared test was used to determine if there is a relationship between the interest or difference among the groups of farmers responding yes and no to the specific questions involved in the TALA questionnaire. A significance level of 0.05 was selected, which indicates a 5% risk of concluding that an association between the variables when there is no actual association. To simplify the study the questionnaire was made to respond yes and no, yes indicates the consciousness of each farmer in each question while, the answer no, means that exists an opportunity to share information to create consciousness. The null hypothesis was that there is no difference between the groups of farmers responding yes and no, hence there are farmers with and without the willingness to introduce or apply the specific investigated agrotechnical element equally. Each surveyed topic was tested statistically to clarify the level of consciousness. The number of possible outcomes in the given chi-square is 2, the degree of freedom is 1 ($2 - 1 = 1$). The critical value (3.8) was used to tell the boundary of extreme that we need to reject the hypothesis.

Results

Application of water preserving soil cultivation systems
One of the AB members thinks that the most important possibility to accommodate the extreme agroecological conditions is the application of water preserving soil cultivation. The principle is the reduction of the number of tillage operations to avoid drying out of the soil. They introduced the application of water preserving soil cultivation in 2017. The main limiting factor of the high price (30-35million HUF) of the specific machinery needed. The other main possibility of accommodation is irrigation. Recently they irrigate about 100 ha, but they want to enlarge

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the irrigated area. The main limiting factor of the development of irrigation is bureaucracy. There are several proposals announced for the development of irrigation, but it is almost impossible to fulfil all the requirements in due time.

"Irrigation, irrigation, irrigation" – was the opinion of another manager of the AB. He thinks that irrigation should be used in larger areas. He mentioned another possibility of accommodation, namely the mitigation of the heat stress of the crops ensured by early sowing. They also use foliar fertilization to make the crops stronger so less sensitive to stresses. They are continuously investing in the machinery of conservation tillage, especially they believe in deep loosening.

There are several farms where irrigation has been applied for decades. Beyond irrigation, they also consider conservation tillage to be the most important accommodation possibility under extreme agro-ecological conditions. Nevertheless, converting from conventional to conservation tillage is just under process which needs to purchase new machinery.

On some farms, to mitigate the unfavourable relief of the irrigated plots, they applied a grader (creating a flat soil surface) and created surface drains. This operation ensured a much favourable water regime of the soil, no excess water has occurred since it was done. It has significance when a high amount of rainfall takes place in the vegetation period. According to their experiences, 20% of loss could be expected if the soil relief was not even.

The AB member involved in organic farming told that irrigation was not allowed to be applied for them except for vegetables. They do not plan the introduction of irrigation in the farm, they rather apply moisture-saving soil cultivation methods. The tillage they apply is based on deep loosening. In the old days, it was taught that deep loosening must be carried out every 4 years, but recently 2-year frequency is more rational. The manager thinks that the purchase of energy and water-saving machinery should be subsidized by the state. Irrigation in itself is not suitable to mitigate the harmful effect of climate change. Recently there are several forums about the development of irrigation but most of the people talking about irrigation are not experts. Beyond irrigation, the proper selection of crop varieties and hybrids is also of great importance, especially in terms of their stress tolerance. They think that the production of region-specific varieties is a key factor in the accommodation of extreme ecological conditions.

In topic 1, the responses to the question in the questionnaire if the farmers would consider changing the management system of their cropland from conventional to water preserving tillage are shown in Figure 1.

The descriptive analysis revealed that among the interviewed farmers 36% would consider changing the management system of their crops from conventional to reduced tillage while 64% would not. The study shows out of the 36% that would consider change, 68% was due to the positive experiences they have had when applying, 18% of the respondent would consider changing due to the belief that it has a positive environmental impact, 11% of the respondents said they may consider under subsidy and 3% stated their belief on positive economic impact as being the reason for wanting to change to reduced tillage. Out of the 64% that would not consider changing their management practices, 74% said no due to the requirement of changing the machinery and insufficient land, 15% due to high soil compaction, 10% due to their age and lack of interest as being the reason for not considering change, and 1% would not consider due to plant protection problems.

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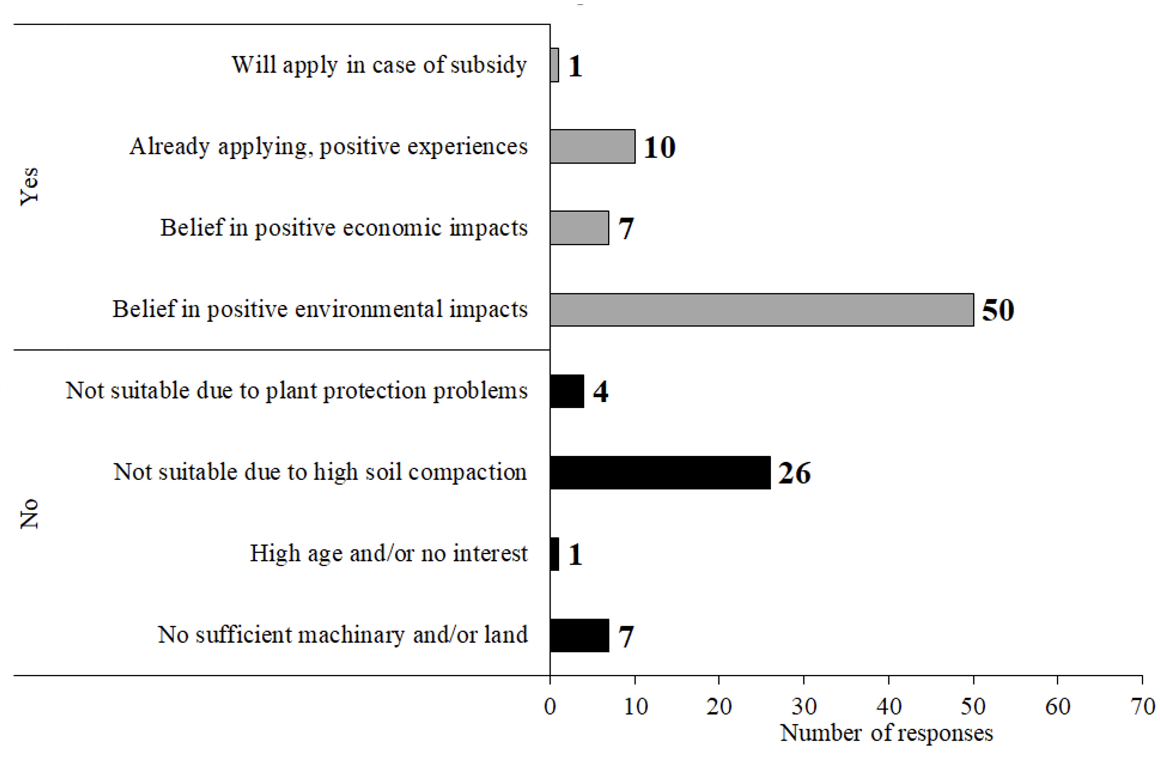

Figure 1: Opinions of 106 farmers about the conversion from conventional to a water preserving soil cultivation system

Application of soil reclamation and/or soil conditioning

Recently, there are no direct subsidies especially dedicated to soil reclamation, when there was, it was very useful, according to the opinion of the interviewed farmers. They do some soil reclamation, approximately 1/3 of their lands is reclaimed where cereals, alfalfa are produced and also the pastures. In the Great Hungarian Plain, there are extended areas with salt-affected soils, even there are salty spots in the plots with better soils too. Recently, farmers generally do not reclaim the chemically degraded areas but often keep them as a fallow, which meets the requirements of fallow regulations by the European Union (EU). They think that greening is a potential kind of payment support given to farmers for them to adopt or maintain farming practices that help meet the environmental and climate aims. Through greening, farmers are receiving rewards from the EU for conserving the natural resources and maintaining public goods, which are beneficial to the public and are not reflected in market prices.

They also use the salt-affected areas to meet the requirements of fallowing. Some areas with salt-affected soils (SAS) are not under irrigation and reclaimed by liming (low dose of 300 kg/ha), but that is not really typical. SAS are utilized by growing relatively salt-tolerant crops (mixture of clover and grass), but most of the farmers have been struggling with this problem for decades. Some other farmers working on the worst SAS created fishponds, which is an intensive use of areas with unfavourable soil properties, especially on heavy textured clay soils with low water permeability. On the areas where only spots of salinization appear, farmers prefer growing alfalfa for seed production, and they do not plough. According to their observation, the fructification (formation of seeds) of alfalfa is more successful on sodic soils. All the interviewed farmers highlighted the importance of liming, they suggested that liming should be subsidized.

Regarding soil conditioning, they also have the opinion that the selection that of the proper product is very problematic, therefore they need support in this respect. Without researched based establishment, most of them consider some soil conditioners as effective as 'blessed' water. Plenty of farmers have already tried soil conditioning in production of different crops, but so far, they could not figure out the positive effect of the soil conditioner they applied. Nevertheless, they did not say it was not efficient at all. The selection of soil conditioner that is effective for their conditions is very difficult because there are too many offers but no background of the scientific establishment. One of the managers had negative opinion about soil conditioning as there are too many companies and dealers praising their products, but he could not be persuaded by any of them showing evidence about significant differences due to the application. For justification, the help of agricultural research institutes like RIK would be very helpful, as they said.

In topic 2, the responses to the question in the questionnaire if the farmers would consider applying soil reclamation and/or conditioning are shown in Figure 2.

The result of the analysis of the questionnaires indicated that 52% of respondent farmers would consider applying soil reclamation on their farm in the future, while 48% would not. Out of the 52% who would consider applying the soil conditioner, 55% were already applying and they have a positive experience, 22% would consider but on small scale, 16% believe in its positive environmental impact, 5% would consider applying because it increases yield and its cost-efficient and 2% gave no explanation why they would consider applying conditioners. Out of the 48% of the respondents who would not consider applying the soil conditioner, 37% had no interest, 29% considered soil conditioner to be too expensive, 18% preferred applying the manure instead, 14% had no information regarding soil conditioner and 2% did not explain.

Application of manure and/or compost

Farmers in the Great Hungarian Plain used to have a sufficient amount of manure before the close of most of the dairy cattle farms. In general, the applied manure only on the irrigated areas every 3–4 years, always under ploughed. The distribution was a time and labour-consuming activity, needing four workers for more than a month. They think that the high yields that could be achieved on the irrigated areas were also due to the more favourable soil structure generated by the application of manure.

The general problem was that where there is no animal husbandry in or near the farm, they do not use manure. The application of mineral fertilizers is mostly based on analytical surveys but also influenced by the actual financial possibility. Sometimes they applied chemical amendments to reclaim the soil but these can be considered only trials.

Only two of the interviewed farmers use manure on 15% of the area (they have a pig farm and some beef cattle). Where they deal with animal husbandry, they prefer the utilization of manure generated by the animals. When they apply manure, they always mix it into the topsoil by ploughing (it means they do not use it on SAS). On the better farms, plant nutrition is strictly based on the result of laboratory analysis of the soil including organic fertilization plans.

Another importance of manure application was highlighted by farmers doing organic farming. They think that one of the fundamental bases of organic farming is the application of manure. The distribution is very expensive but there are no other options. Or-

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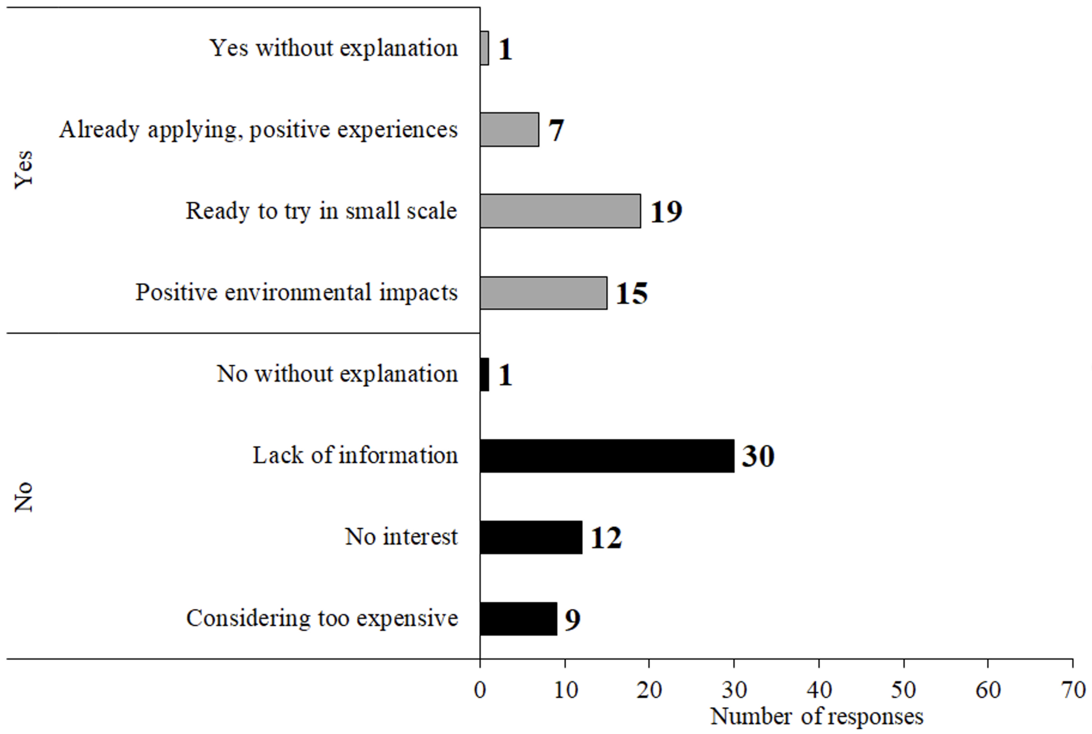

Figure 2: Opinions of 106 farmers about the application of soil reclamation and/or conditioning

ganic farmers apply manure every four years as the worst case, but they try to do it more frequently. The manure is processed, they make compost of it by adding some herbs to it. They also use dolomite and alginate to reclaim their soils.

In topic 3, the responses to the question in the questionnaire if the farmers want to apply manure are shown in Figure 3.

The result of the analysis showed that 88% of the farmers would consider the application of manure and/or compost instead of mineral fertilizers, while 12% of the respondent would not. Out of the 88% that would consider, 63% would consider due to the positive environmental impact, 27% due to believing in its positive economic impact, 7% were already considering, while 3% would consider but did not give any explanation. Out of the 12% of the respondents that would not consider manure application, 33% of the respondents would not because they harvest the straw for litter only (livestock keepers) and do not utilize further. 33% had negative experiences, 25% had no interest, while 8% did not give any explanation.

Discussion

The results of the chi-squared test used for analysing the willingness of the farmers to introduce or apply the investigated agrotechnical elements are shown Table 1.

In the topic of soil cultivation, since the p value $\leq \alpha$, we rejected the null hypothesis. This means that statistically, the investigated farmers differ in this respect. We consider a low level of willingness of them to change their soil cultivation methods from conventional to reduced/water preserving tillage as the rate of yeses was statistically low. In the topic of soil reclamation/conditioning, since the p value $> \alpha$, we did not reject the null

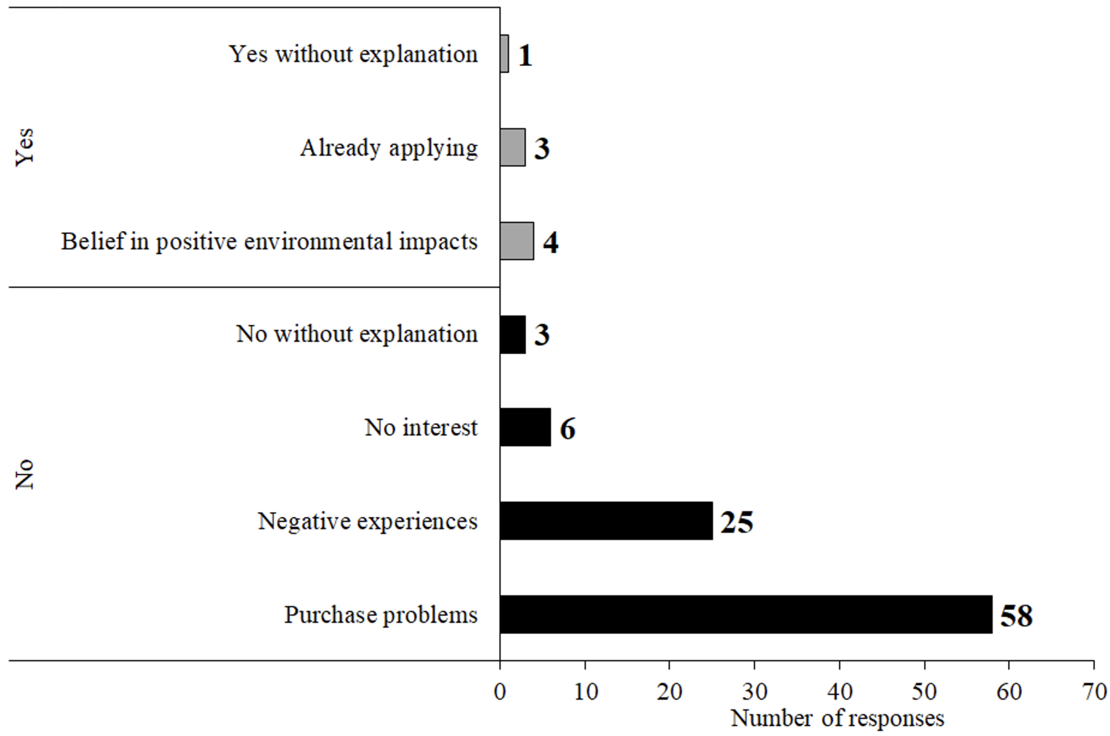

Figure 3: Opinions of 104 farmers about manure/compost application

Table 1: Result of the chi-squared test regarding the investigated topics

Topic	Yes	No	χ^2	*P* value	Level of willingness
Soil cultivation	37	69	9.66	0.00	Low
Soil reclamation/conditioning	54	52	0.03	0.85	Moderate
Manure/compost application					
92	12	61.53	0.00	High	

hypothesis. This means that statistically the investigated farmers do not differ in this respect. We consider a moderate level of willingness of them to apply soil amendments/-conditioners as the number of yeses and nos was almost equal. In the topic of manure/-compost application, since the p value $> \alpha$, we did not reject the null hypothesis. This means that there is only 43% probability the two groups of farmers differ from each other. We consider a moderate level of willingness of them to apply compost on their lands as the number of yeses and nos was close to each other.

Conclusions

Soil degradation is a problem that the farmers have been facing for many years and its continuing to spread across the farmer over the years. Recently, they cannot reclaim all their land, one farm manager mentioned that he can only be able to reclaim 1/3 of his total farmland due to lack of subsidies, on affected lands they produce cereals, alfalfa, and keep them as fallow. They also produce salt-tolerant crops (mixture of clover and grass) and create fishponds which are more successful grown on sodic soils.

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The managers of the interviewed farms experience secondary salinization as they irrigate their farmlands. They face problems in water management especially in the irrigated plots due to high unexpected rainfall after they have irrigated their plots. Another farm manager could not irrigate his farm as he has an outdated irrigation system and the other was due to the issue with water quality as it has high salt concentration and other pollutants.

The supply of plant nutrition and soil conditioning by the farmers for organic fertilizer was based on financial possibility and raring of the animal in the farm to supply the farm with the manures. For those who do not keep or have stopped raring animals, they do not supply organic fertilizers to their farms. The farm managers have no confidence in soil conditioning as they say there are many companies and dealers but they are not so reliable as they lack scientific proof.

Based on the result of the analyses, we found that the greater number of the farmers are both economic and environmental conscious, as the result of the study showed that the majority are aware of the environmental impacts of the investigated agrotechnological elements. The availability of cheaper alternatives, costs, profits, and lack of interest as being factors that influence farmers' decisions in the selection of agrotechnological elements. Even those who consider changing to environment-friendly technologies would only do it under subsidies due to the high cost involved and they would only try the technologies under small-scale production. We do believe that the collected information can be used to encourage environmental awareness among farmers, the results contribute to an increase in quality of crop production, reduce costs and protect the environment for the future generation.

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Monitoring of plant growth through methods of phenotyping and image analysis

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Abstract: With the rapid development of imaging technology, computing power, and algorithms, computer vision has revolutionized thoroughly plant phenotyping and is now a major tool for phenotypic analysis. Those reasons constructed the base for developing image-based plant phenotyping methods, it is a priority for the complementary or even alternative to the manual measurement. Nonetheless, the use of computer vision technology to analyze plant phenotypic traits can be affected by a lot of factors such as research environment, imaging system, and model selection. The field of plant phenotyping is developing rapidly at the moment. Image-based plant phenotyping has stated proven to be in precision agriculture, providing a quantitative basis for the description of plant-environment interactions.

Keywords: phenotyping, image-analysis, plants' growth, agricultural

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Introduction

Open-source image analysis software with plant phenotyping using computer vision is a key source in hydroponic cultivation. The former is performed in an outdoor and indoor installation or in a greenhouse under controlled conditions (Quigley et al., 2009). It may be carried out within a facility that includes providing light for plant growth, accessibility to the nutrient solution, and electrical power. The growing plants are set in a growth chamber and periodically soaked with nutrient solution. In addition, the hydroponic system gives the chance to control the entire growth chamber environment precisely. The hydroponic system is a modern technique of agriculture that is still under development. Recently, limited studies have been performed which suggested that hydroponics is performed without soil or any solid media; thus, the main observed problems to tackle the growth process. Zhou et al. (2016) conducted a study titled "ROSCC: An Efficient Remote Sensing Observation-Sharing Method Based on Cloud Computing for Soil Moisture Mapping in Precision Agriculture." This research was published in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. The paper focused on the development of a method called ROSCC, which utilizes cloud computing to enhance remote sensing observation-sharing for soil moisture mapping in precision agriculture. The authors present their findings and discuss the efficiency and effectiveness of the proposed method in accurately mapping soil moisture levels, which is crucial for optimizing agricultural practices and improving crop productivity.

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The groundbreaking work of Castelló Ferrer et al. (2017) introduced the Personal Food Computer, a novel device designed for precise monitoring and management of environmental conditions to enhance crop cultivation. It was reported that the hydroponic system provides better control of plant growth and nutrient availability and prevents the plant from various diseases and root rot. However, during plant growth from sowing to harvest time, the method adopted in the hydroponic system requires expertise in domain knowledge of plants (Fox, 2006), environment control, and operations to maintain and control the growth of the plant.
In the Proceedings of the Future Technologies Conference (FTC) 2018, Ferrer et al. (2018) introduced the Personal Food Computer as an innovative device for controlled-environment-agriculture, revolutionizing food production methods.

Materials and Methods

An open-source image analysis software with an aimed package for plant phenotyping using computer vision was solicited for our experiment. The software is called PlantCV and is built based on modular functions, it is applicable to a wide range of plant types and different imaging systems, and it has multiple functions where the use of each one is centered on the context of an overall image-processing workflow. Nonetheless, the software is new and under continuous development where new functionalities are added on a regular basis. PlantCV currently supports the analysis of standard RGB color images, standard grayscale images, thermal infrared images, grayscale images from chlorophyll fluorescence imaging systems, and hyperspectral images. Support for additional image types is under development. The modular functions of which PlantCV is composed can be rearranged and adjusted quickly and easily. Workflows do not need to be linear. A global variable "debug" allows the user to print out the resulting image. The debug has three modes: either None, 'plot', or 'print'. If set to 'print' then the function prints the image out to a file, or if using a Jupyter notebook we could set debug to 'plot' to have the images plot to the screen. Debug mode allows users to visualize and optimize each step on individual test images and small test sets before workflows are deployed over whole datasets. In order to run the pant CV code, we need to previously have two required inputs:

1. **Image:** Plant CV process the Images regardless of what type of camera was used, particularly in our project, we used Raspberry PI camera. The processing works better if the images are of good lighting and the background's color is different from the plant's material.
2. **Output directory:** We need to select and name an output directory where the output images from each step will be saved.

Figure 1: Input image

In the input image as shown in Figure 1, we have the input image. As we mentioned before, our particular image was captured by Raspberry PI camera, this means that Plant CV works on images not captured with spe-

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cialized VIS image capture conditions. In our project, we used Plant CV to decompose the contours that constitute each plant. Our main interest was to use plant processing, therefore we needed to sort out contours and cluster them together in some way. In order to be able to arrive at the final result, which is color values. There are several steps that we need to follow until color values for each plant pixel are processed.

If the background is foreseeable, the program starts with defining the background. For our particular image, the program did some pre-masking of the background, in order to keep all plant information while removing the background. Thresholding is the simplest method of segmenting images, as it can be used for creating binary images. Generally, we need to select one of the color channels before performing a binary threshold on any image. The plant CV code as shown converts the RGB image to HSV color space and then extract the 's' or saturation channel, but if some of the plant's information is missed or disappeared then the resulting channels may be combined in more steps.

The code below shows the first section of Plant CV code:

```
#!/usr /bin/env python

import os
import argparse
from plantcv import plantcv as
   ↪pcv

### Parse command-line
   ↪arguments
def options ():

parser = argparse.
   ↪ArgumentParser (
   ↪description="Imaging
   ↪processing with o p e n c y )
parser.add_argument ("-i", "
   ↪-image", help="Input image
   ↪ file.    , reguired=True)
parser.add_argument ("-o", "--
   ↪cutdir", help="Output
   ↪directory for image files.
   ↪    , required=False)
parser.add_argument ("-r", "--
   ↪r e s u l t , help=rresult
   ↪file.    , required=False)
parser.add argument ("-w", "-
   ↪  writeimg  ", help="write
   ↪out images.   , default=
   ↪False, action="store true"
   ↪)
```

The code starts by importing necessary packages of libraries, and by defining the inputs. One important thing before running the program is to make sure that plant CV is installed. We easily installed it from PyPI, by running the following command in the terminal as an administrator:

```
<pip install plantcv>.
```

The code of the main code is the following:

```
def main ():
# Get options
args = options ()
pcv.params.debug = args.debug #
   ↪ set debug mode
pcv.params.debug_outdir = args.
   ↪outdir # set output
   ↪directory
# Read image
img, path, filename = pcv.
   ↪readimage (filename=args.
   ↪image)
```

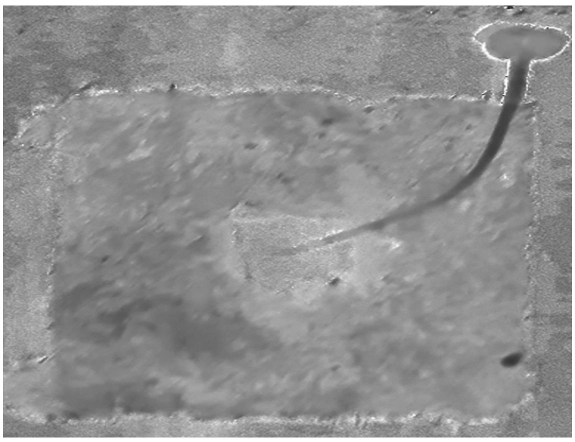

Figure 2: lab-blue-yellow

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The returns are img, path, and image filename. The filename is the image file to be read which includes the path. The image presented in Figure 2 of the PlantCV research showcased a lab environment where the plant is visualized using a color representation of blue and yellow. The command reads the image into numpy ndarray(NumPy is an N-dimensional array type called ndarray.) and splits the path and image filename. This is a parameter of the OpenCV function imread.

In the following command, we convert RGB to HSV and extract the saturation channel.

The code to read the image is the following:

```
# Read image
img, path, filename = pcv.
    ↪readimage (filename=args.
    ↪image)
# Convert RGB to HSV and
    ↪extract the saturation
    ↪channel
== pcv.rgb2gray_hsv (rgb_img=
    ↪img, channel='s')
```

The HSV color space has 3 channels: ‘h’ the Hue, ‘s’ the Saturation, and the’v’ Value, or intensity. The Hue channel represents the "color".

The code of the saturation channel from original RGB image converted to HSV color space:

```
# Convert RGB to LAB and
    ↪extract the Blue channel
b = pcv.rgb2gray_lab (rgb_img=
    ↪img, channel='b')
# Threshold the blue image
b_thresh = pcv.threshold.binary
(gray_img = b, threshold-160,
    ↪max_value-255, object_type
    ↪='light')
b_cnt = pcv.threshold.binary
(gray_img=b, threshold-160,
    ↪max_value=255, object_type
    ↪='light')
```

In order to threshold the saturation image, we apply the following code:

```
# Threshold the saturation
    ↪image
s_thresh = pcv.threshold.binary
    ↪ (gray_img=s, threshold
    ↪-85, max_value=255,
    ↪object_type='light')
```

The saturation channel is thresholded, which means the code created a binary image from a gray image based on the threshold values. Our object in this project was the plant which is light. The threshold creates a binary image from the gray image based on the threshold values that can be adjusted depending on the quality of our image, in our case used 85 for the threshold and 255 pixels as a maximum value.

In the next step, again depending on the level of lighting, the code can be modified to better manipulate the background. The original image is converted from an RGB image to LAB color space and the blue-yellow channel is extracted.

The image as shown in figure 3 is then again thresholded and there is an optional fill step that the code runs or not depending on the image, in our case, it was not needed.

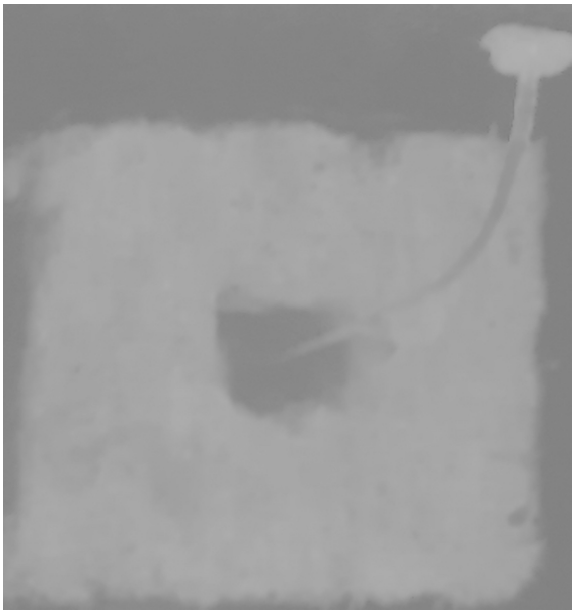

Figure 3: Blue-yellow channel from LAB color space from the original image.

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Figure 4: Binary Threshold blue-yellow channel image.

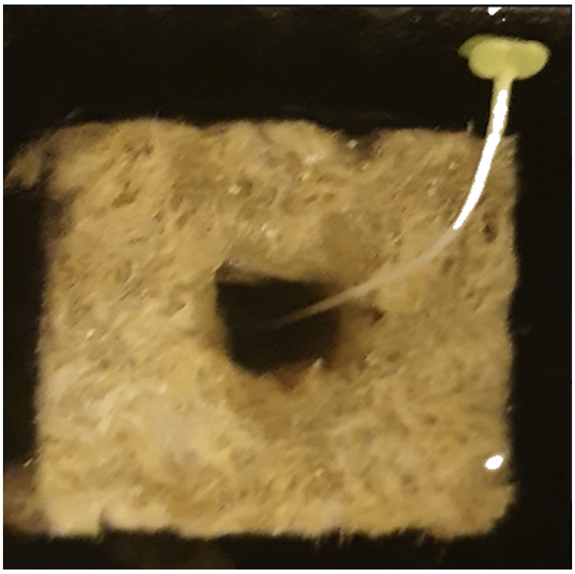

Figure 6: Masked image with the background removed

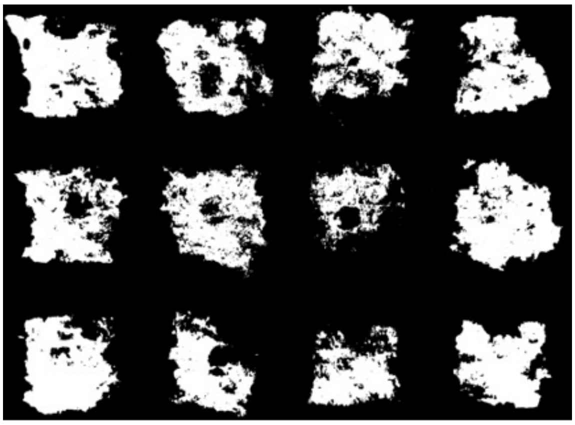

Figure 5: binary_threshold_128

After this step, the resulted in the binary image as in figure 4 was applied as an image mask over the original image, to remove as much background with simple thresholding in figure 5 without missing out any plant material.

The following code is for masked image with background removed.

```
# Apply Mask (for VIS images ,
    ↪mask_color=white)
masked = pcv.apply_mask(img=img
    ↪, mask=bs , mask_color='
    ↪white')
```

After getting the masked image in figure 6 with the background slightly removed. The next step from the code is capturing the plant in the masked image from the last figure. The masked green-magenta and blue-yellow channels are taken out. The two channels are thresholded to show different sections of the plant.

The small objects are filled. The image taken has very green leaves, but often (especially with stress treatments) there are yellowing leaves, red leaves, or regions of necrosis. The different thresholding channels capture different regions of the plant, then are combined into a mask for the image that was previously masked. In the following the applied code of RGB to LAB conversion code and the resulted image is shown in figure 7:

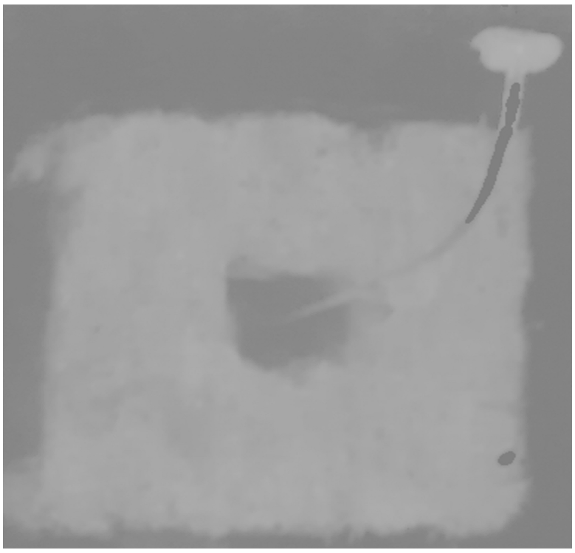

Figure 7: Thresholded LAB channel image

```
# Convert RGB to LAB and
   ↪extract the Green-Magenta
   ↪and Blue-Yellow channels
masked_a = pcv.rgb2gray_lab(
   ↪rgb_img=masked, channel='a
   ↪')
masked_b = pcv.rgb2gray_lab(
   ↪rgb_img=masked, channel='b
   ↪')
# Threshold the green-magenta
   ↪and blue images
maskeda_thresh = pcv.threshold.
   ↪binary(gray_img=masked_a,
   ↪threshold=115, max_value
   ↪=255, object_type='dark')
maskeda_threshl = pcv.threshold
   ↪.binary(gray_img=masked_a,
   ↪ threshold=135, max_value
   ↪=255, object_type='light')
masked_thresh = pcv.threshold.
   ↪binary(gray_img=masked_b,
   ↪threshold=128, max_value
   ↪=255, object_type='light')

# Join the thresholded
   ↪saturation and blue-yellow
   ↪ images (OR)
abl = pcv.logical_or(bin_img1=
   ↪maskeda_thresh, bin_img2=
   ↪masked_thresh)
ab = pcv.logical_or(bin_img1=
   ↪maskeda_threshl, bin_img2=
   ↪abl)

# Fill small objects
ab_fill = pcv.fill(bin_img=ab,
   ↪size=200)

# Apply mask (for VIS images,
   ↪mask color=white)
masked2 = pcv.apply_mask(img=
   ↪masked, mask=ab_fill,
   ↪mask_color='white')
```

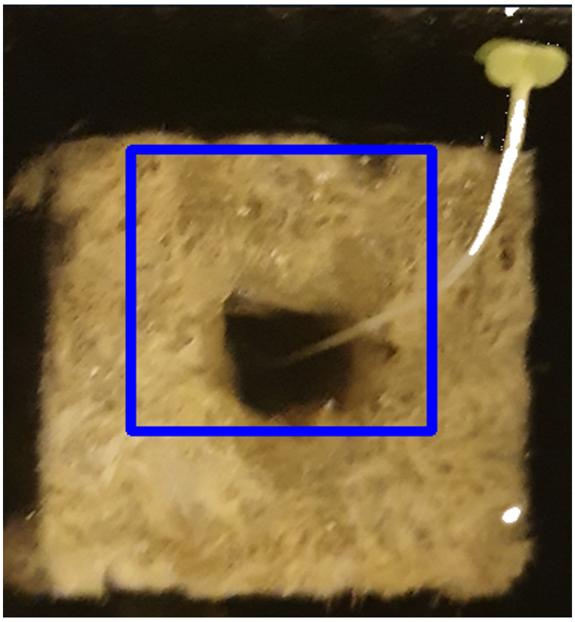

Figure 8: Region of interest drawn into

For the identification process within the image, Plant CV is based on contours in OpenCV. A rectangular region of interest is determined as in figure 8.
The code *defining region of interest:*

```
#Object combine: kept objects
obj, mask = pcv.
   ↪object_composition(img=img
   ↪, contours=roi_objects,
   ↪hierarchy=hierarchy3)
```

Once the region of interest has resulted, the code keeps then the rest of the image overlapping with the region inside the rectangle or cuts the objects to the shape of the region of interest. In our particular case, as seen in the following image. The isolated items now should all be plant material that we are inter-

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ested in. There can be more than one object that makes up the material of the plant, sometimes leaves appear in the images as separate objects.

Figure 9: Outline (blue) of combined objects on the image.

The image in figure 9 represents an outline of combined objects, indicated by the blue lines, overlaid on the original image. The combined objects are a result of the previous image processing and analysis technique applied through plantCV to the image data. This outline helps us identify and visualize the boundaries or contours of the objects detected in the image, providing insights into their spatial distribution.

The final step of the image analysis is to examine the plant material such as horizontal height, shape, or color.

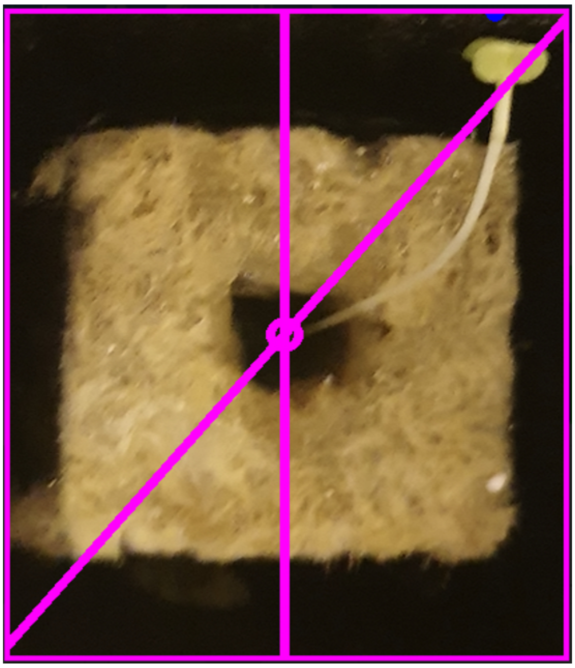

Figure 10: Shape analysis output image.

The image in figure 10 represents the output of shape analysis applied to an image. It typically includes visualizations or graphical representations that provide information about the shapes of objects present in the image. This includes the features as the contour lines and bounding lines that help characterize the shapes and structures within the image. The shape analysis output image serves as a visual representation of the results obtained from analyzing the shapes of objects, aiding in understanding the spatial organization and properties of the objects in the image.

Discussion

Conducting a comprehensive analysis of a plant's characteristics, encompassing factors such as its horizontal height, shape, and colour, yields invaluable insights that can be leveraged in advanced stages of plant recognition and understanding its growth trajectory. By scrutinizing these plant materials, we acquire a wealth of useful information that can be harnessed for diverse purposes, including not only recognizing the plant it-

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self but also elucidating the various developmental steps it undergoes.

In the publication "OpenAG: A Globally Distributed Network of Food Computing" by Harper and Siller (2015), featured in IEEE Pervasive Computing, the concept of a globally distributed network of food computing is introduced. This innovative approach leverages advanced technologies, such as PlantCV and pervasive computing, to revolutionize food production and address challenges in agriculture (Harper & Siller, 2015). The utilization of PlantCV software has revolutionized our ability to analyse images captured through cutting-edge devices like Raspberry PI. This software package, specifically designed for plant phenotyping and the application of phenomics technologies, including PlantCV and image analysis, offers promising solutions to overcome the challenges associated with phenotyping and enhance our understanding of plant characteristics and growth processes (Furbank & Tester, 2011), empowers researchers by providing a cohesive programming and documentation interface. Through PlantCV, an extensive collection of image analysis techniques sourced from diverse packages and algorithms seamlessly converge, facilitating an integrated and comprehensive approach to image analysis.

Exploring the vast potential of an Internet of Things (IoT)-based growing chamber system in tandem with Global Positioning System (GPS) technology represents a fertile area of research. The synergistic amalgamation of these two domains opens up new horizons in plant cultivation. By harnessing the capabilities of IoT, we can accurately detect and map the geographical locations of green growing chamber users across the globe. This spatial awareness not only enables us to identify clusters of green growing chambers but also facilitates the gathering of vital image analysis data. Such data, once recorded and curated within an application, can be effortlessly shared among users, fostering a community of practice where individuals can exchange invaluable insights and best practices pertaining to optimal plant growth. The study conducted by Abdullah et al. (2016) exemplifies the tremendous potential of this approach in enhancing plant cultivation methodologies and promoting sustainable practices.

We can say that delving into the minute details of a plant's material composition, encompassing attributes such as its horizontal height, shape, and colour, provides a rich tapestry of information that can be instrumental in various stages of plant understanding and recognition. With the aid of sophisticated software packages like PlantCV, researchers can harness the power of image analysis techniques, seamlessly integrated from multiple sources, to unlock new insights and correlations. Moreover, the advent of IoT-based growing chamber systems coupled with GPS technology holds tremendous promise for the future of plant cultivation, facilitating global collaboration, knowledge sharing, and the adoption of sustainable practices.

In our experimer, as mentioned earlier we followed several processes to get a pseudo-colored image as figure 11 of our plant and we were interested in calculating the Excess Green Index (ExG) for a specific pixel within the image. This index serves as a valuable metric for assessing the vegetation's health and stress levels. To illustrate the calculation process, let's consider our scenario where we have a dataset comprising 9 distinct plants(9 rockwool cubes), and our objective is to evaluate the vegetation quality for each individual plant. To achieve this, we need to perform the Excess Green Index calculations separately for each plant, utilizing their respective RGB images.

To calculate the Excess Green Index (ExG) for each plant, we have followed these steps:

1. We began by converting the RGB image of

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each plant into the ExG index using the following formula: ExG = 2 × Green – Red – Blue

By substituting the corresponding pixel values of the Green (G), Red (R), and Blue (B) channels into the equation, we could obtain the ExG index value for each pixel within the plant region of interest.

2. Once the ExG values are computed for all pixels within the plant region of interest, we calculated the average ExG value for that specific plant. This was accomplished by taking the mean of all the ExG values obtained from the pixels within the plant's region.

3. Finally, we compared the average ExG value of each plant to a predetermined threshold or range established for evaluating vegetation health. This threshold serves as a benchmark against which the vegetation quality of each individual plant can be assessed. By analyzing the ExG values in relation to the threshold, we could identify variations or differences in the health of the individual plants.

By performing these calculations for each plant, we gained the ability to assess the vegetation quality on an individual basis. A comprehensive understanding of the characteristics and health status of each plant is achieved. This approach allows for targeted analysis and evaluation of vegetation attributes, as opposed to treating the plants as a collective group.

The Excess Green Index (ExG) serves as a valuable vegetation index, quantifying the excess amount of green color present in an image. By leveraging this index, researchers and practitioners can gain insights into vegetation health and stress levels. It provides a quantitative measure that reflects the abundance of green color in relation to the red and blue channels, offering valuable information about the density and vigor of the plant material.

By incorporating the Excess Green Index into our analysis, we made informed decisions regarding plant health, stress management, and overall vegetation quality. Here's an example of how we use the Excess Green Index:

1. We obtained an RGB image of the plant we wanted to analyze.
2. We convert the RGB image to the LAB color space. This was done using the image processing libraries of PlantCV mentioned earlier.
3. We extracted the individual channels from the LAB image: L (lightness), a (green-magenta), and b (blue yellow).
4. We calculated the Excess Green Index (ExG) using the previously stated formula.
5. We applied a threshold to the ExG image to segment regions with high vegetation density. This was done by selecting an appropriate threshold value to distinguish between healthy vegetation and other objects or background, thanks to the palntCV opensource libraries, this step was not challenging.
6. We analysed the segmented regions to extract relevant information and performed further computations based on our specific objective.

By utilizing the Excess Green Index, we could identify and analyze areas of interest in the image that correspond to healthy vegetation based on their green color characteristics.

1. RGB values for the pixel of interest:
   Red (R) = 100
   Green (G) = 150
   Blue (B) = 80
2. We converted the RGB values to a range of 0-1 by dividing each value by 255:
   $R = 100/255 = 0.392$
   $G = 150/255 = 0.588$
   $B = 80/255 = 0.314$
3. We calculated the Excess Green Index (ExG):
   $ExG = 2 \times G - R - B$

$$= 2 \times 0.588 - 0.392 - 0.314$$
$$= 1.176 - 0.392 - 0.314$$
$$= 0.47$$

The Excess Green Index (ExG) for the given pixel is 0.47. This value represents the excess amount of green color in relation to the red and blue channels. We performed similar calculations for other pixels in the image to obtain their corresponding ExG values.

The Excess Green Index (ExG) itself does not provide a direct measure of vegetation health or quality. Instead, it quantifies the relative amount of green color present in an image compared to the red and blue channels. It can be used as a vegetation index to assess the density or presence of vegetation in an image.

To determine whether the vegetation is good or not based on the ExG value, we would typically need to establish a threshold or range specific to experiment. This threshold can be determined through experimentation, field observations, or by comparing the ExG values of known healthy and unhealthy vegetation samples.

For example, in the conducted experiment, we determined that vegetation with an ExG value above 0.5 is considered good, and this way we could compare the calculated ExG value of a pixel or region to this threshold. When the ExG value was above the threshold, we classified it as healthy vegetation. Conversely, when the ExG value was below the threshold, we indicated less healthy or sparse vegetation.

It's important to note that the interpretation of vegetation health based on an index like ExG can vary depending on the specific context, plant species, environmental conditions, and other factors. Therefore, it is recommended to validate and calibrate the threshold values based on our specific application and domain knowledge.

In conclusion, the Excess Green Index (ExG) and PlantCV software play a significant role in the monitoring of plant growth through advanced methods of phenotyping and image analysis. The ExG serves as a valuable vegetation index, providing insights into the health, stress, and density of plants based on their green color characteristics. By calculating the ExG for specific pixels or regions within RGB images of plants, researchers and practitioners can assess vegetation quality on an individual plant basis.

The PlantCV software, specifically designed for plant phenotyping, enables the analysis of images captured through various platforms like Raspberry Pi. It provides a comprehensive collection of image analysis techniques, integrating algorithms from different source packages. This software offers a common programming interface and documentation, simplifying the implementation of image analysis procedures for plant studies.

By utilizing PlantCV and the ExG index, researchers can extract useful information from plant materials such as height, shape, and color, aiding in plant recognition and understanding growth stages. This integration of advanced imaging techniques with phenotyping methods allows for non-destructive and high-throughput analysis of plant traits. In line with the Food and Agriculture Organization of the United Nations (FAO) report on 'The state of food and agriculture: Climate change, agriculture, and food security' (2016), the utilization of Excess Green Index (ExG), PlantCV, and image analysis techniques play a pivotal role in monitoring plant growth and addressing the challenges of climate change in the agricultural sector (FAO, 2016).

Moreover, the combination of IoT-based growing chambers and GPS systems presents an exciting area of research. By tracking the locations of green growing chamber users on world maps, it becomes possible to collect and share recorded image analysis data. This exchange of information facilitates thedissemination of good practices for grow-

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ing plants, contributing to advancements in the field of plant science.

In summary, the utilization of the Excess Green Index, along with PlantCV software and emerging technologies, enables efficient monitoring of plant growth. By employing image analysis techniques and phenotyping methods, researchers can extract valuable insights regarding vegetation health, stress levels, and growth patterns. This holistic approach to plant analysis fosters advancements in agricultural practices, crop breeding, and the understanding of plant physiology, ultimately leading to improved plant productivity and sustainable agriculture.

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Source of the graphics

Front cover:
Gallo-Roman harvesting machine, called Vallus. Source: U. Troitzsch - W. Weber (1987): Die Technik : Von den Anfangen bis zur Gegenwart

Rear cover:
Portrait of Columella, in Jean de Tournes, Insignium aliquot virorum icones. Lugduni: Apud Ioan. Tornaesium 1559. Centre d'Études Supérieures de la Renaissance - Tours

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Lucius Junius Moderatus Columella

(AD 4 – 70) is the most important writer on agriculture of the Roman empire. His De Re Rustica in twelve volumes has been completely preserved and forms an important source on agriculture. This book was translated to many languages and used as a basic work in agricultural education until the end of the 19th Century.