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THESIS TITLE

Agronomic Impact on crop yields

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List of Abbreviation

FAO	Food and Agriculture Organization
EU	European Union
USA	The United States of America
V	Vegetative
R	Reproductive
GDD	Growing Degree Days
K	Potassium
N	Nitrogen
P	Phosphorus
Fl	Floury
FI	Flint
su	Sugary
Su	Starchy
Wx	Waxy
Wx	Non-waxy
LAI	Leaf area index
ITTA	International Institute of Tropical Agriculture
USDA	United States Department of Agriculture
DAS	Days after sowing
F	Fahrenheit

1.0. INTRODUCTION

Maize, scientifically known as *Zea mays L.*, is a highly valuable crop globally, with over 150 million hectares of annual cultivated area and a grain harvest of nearly 800 million tons (FAOSTAT 2007). According to FAO data from 2018, maize was grown on over 194 million hectares of land. For grain maize and silage maize, the cultivated area in the 27 member states of the European Union (EU) in 2007 totaled 8.3 million hectares. A total of 48.5 million tons of grain was produced annually. France, Romania, Germany, Hungary, and Italy are the top producers of maize, with maize cultivated on more than a million hectares in each of these countries (EUROSTAT 2007).

Maize is the "queen of cereals" worldwide due to its maximum yield potential among all cereals. The United States of America (USA), which contributes around 35 percent of the world's total maize production, is the most significant producer of this crop. It is the backbone of the US economy and is referred to as the mother grain of Americans. Additionally, maize is one of the most adaptable crops and can be cultivated in various environments.

In developing nations, maize is grown on about 100 million hectares, with low- and lower-middle-income countries accounting for nearly 70% of the total production (FAOSTAT,2010). Maize is expected to be in even greater demand in the developing world, with projections indicating that its need will double by 2050. Furthermore, by 2025, maize output is anticipated to exceed that of all other crops worldwide, as well as in the developing world (Rosegrant et al. 2008). Maize is the main food crop in a vast portion of Africa; in Eastern and Southern Africa, and accounts for an average of 32% of calories consumed and reaches 51% in some nations.

The world's third-largest crop, after rice and wheat, is maize (*Zea mays L.*) according to Sandhu, Singh, & Malhi (2007). Around the world, maize is regarded as a staple cuisine. *Zea mays L.*, a monocotyledonous annual plant with two chromosomes in each cell, is a member of the Gramineae grass family and the maideas tribe. It needs a precise amount of water and a specific type of climate to thrive. The plant needs a temperature between 15 and 20 °C to germinate, which is most significant.

Maize plays a remarkable role in global trade and the economy as a grain crop used for food, feed, and industrial purposes. Several million people in the developing globe also use maize as a staple grain and rely on it for their protein and energy needs. Thus, maize is a crucial source of protein for both people and animals. Through thorough processing, corn is transformed into a diverse range of products such as cornmeal, grits, starch, flour, tortillas, snacks, and breakfast cereals.

The maize kernel is a flavorful and nutritious part of the plant that contains various vitamins and minerals, including selenium, folic acid, N-p-coumaryl tryptamine, and N-ferrulyl tryptamine. It also has essential vitamins such as vitamin B1 (thiamine), vitamin B2 (niacin), vitamin B3 (riboflavin), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), vitamin C, vitamin E, and vitamin K. Moreover, potassium, which is not typically present in a regular human diet, is a significant nutrient found in the maize kernel (Kumar & Jhariya, 2013).

According to Evans and Fisher (1999), yield is the product's mass at the final harvest, with a predetermined amount of dry matter. Crop yield is generally understood as the quantity of harvested goods in a given area (the portion of harvested goods/crop area) (Benson & Fermont, 2011). The genetic potential of the genotype employed, the soil's features, the field management techniques, and agro-climatic conditions all affect the grain production of maize (Jockovi'c et al. 2010). Potential yield is a crop's highest yield in a particular climate (Evans and Fisher, 1999). Solar radiation, soil type, temperature, plant density, the genetic potential of a given genotype, biotic and abiotic restrictions, and other factors all play a significant role in determining potential output (Van & Rabbinge, 1997; Liu et al.2016; Ndhleve et al. 2017).

Maize production and yield are managed and controlled using various techniques, such as the type of seeding, planting density, nitrogen(N) treatment rate, and timing. Studies by Bian et al. (2016), Chen et al. (2011), Innocent and Leo (2014), and Ning et al. (2012) have explored these different methods. These agronomic practices initially affect the growth, distribution, and function of the root system before impacting the aboveground components and final yield. Additional research by Guan et al. (2014), Hammer et al. (2009), and Zhao et al. (2016) have also demonstrated this relationship between agronomic techniques, root growth, and yield.

The use of improved varieties, irrigation, appropriate sowing time, optimal plant population, and balanced fertilizer application are well-known inputs that can significantly increase crop yield. Maize, in particular, has the highest grain yield potential among cereal crops. To fully utilize this potential, it is essential to understand the morphological and physiological interactions between plants in a community and identify management practices that promote optimal growth under the prevailing environmental conditions. One of the most critical agronomic practices that affect grain yield and other essential attributes of maize is plant density

(Songoai, 2001). The principal goal of this study was to assess the effect of agronomic impacts on maize yields. Specifically, the study was conducted to;

i. Evaluate the effect of three different planting densities on the yield of hybrid maize and
ii. Evaluate the effect plant density on the phenology of hybrid maize.

1.1. Statement of Hypothesis

Null hypothesis: there is no significant effect of plant population density on the yield of maize

Alternate hypothesis: there is a significant effect of plant population density on the yield of maize.

2.0. LITERATURE REVIEW

2.1. Maize Origin

It may be challenging to pinpoint with certainty the origin of Maize (*Zea mays L.*) (Brown and Darrah 1985). However, it was thought to be the sole significant cereal native to the Western Hemisphere; coming from Mexico, it migrated north to Canada and south to Argentina. In Mexico's Tehuacan Valley, the oldest (7000 years) ancient maize was found (Brown and Darrah, 1985, Zarrillo *et al.* 2008). Unfortunately, the female inflorescence of this 5000 BC maize had become so specialized that natural seed dissemination was no longer possible. As a result, the oldest corn on record relied on man for survival.

Several origin models have been proposed over the years, with just two receiving severe consideration today. The first is that teosinte (*Zea mexicana*) is the wild predecessor of maize; the second is that a now-extinct wild pod maize was the progenitor of cultivated maize. While some maize learners appear to favour the first speculation, others are similarly confident of the second. Besides its potential role in maize origin, teosinte has significantly impacted its evolution. Introgression involving maize and teosinte has most likely ensued for centuries and persists to this day in Mexico. The influences are visible in both species' cytology and morphology.

Kogbe and Adediran, (2003) and Stephanie and Brown, (2008) recorded maize as one of the grass family's most versatile and adaptable members. Maize evolution produced genotypes with modifications for various environments, including the tropics and temperate zones, sea level and 12,000 feet above sea level, and growing seasons ranging through six weeks to thirteen months (Stephanie and Brown, 2008). After its discovery, maize swiftly reached Asia, Africa, and Europe. Despite being brought to Africa soon after its discovery, a large portion of the maize grown there was later brought there by immigrants from the southern United States, Mexico, and some parts of eastern South America (Brown and Darrah, 1985).

It is important to note however that there are still some debates and uncertainty surrounding the exact origins of maize, and there are other competing theories about its origins.

2.2. Worldwide production of maize

According to the Food and Agriculture Organization of the United Nations (FAO), global maize production will be around 1,096 million metric tons in 2021. This makes it, along with wheat and rice, one of the world's most widely grown crops. (FAO, 2021). The top maize producers are the United States, China, Brazil, Mexico, and Argentina. The United States produces 362 million metric tons of maize, accounting for roughly one-third of global production.

China's estimated 210 million metric tons output is the world's second-largest producer. Brazil, Mexico, and Argentina contribute significantly to global production, with estimated outputs of approximately 94 million metric tons, 29 million metric tons, and 26 million metric tons, respectively, USDA Foreign Agricultural Service (2021).

Most maize is used as animal feed, with an estimated consumption of 688 million metric tons. Humans consume a smaller portion of it, either as a staple food or as an ingredient in a variety of processed foods. A total of 130 million metric tons are used for industrial purposes, such as ethanol. (FAO, 2021).

Maize is a critical crop for food security as well as economic development. In many developing nations, mainly in Africa and Latin America, it is an important source of calories and protein. It also provides a substantial source of income for smallholder farmers, particularly in developing countries (International Maize and Wheat Improvement Center, 2021).

2.3. Biology of Maize

The maize plant is a member of the grass family (Poaceae). A single culm with up to 30 leaves is supported by a tall, leafy structure with a fibrous root system, making it a typical tropical plant. However, it is vulnerable to weed invasion (Paliwal, 2000).

One or two lateral branches emerge more clearly from the leaf axils in the plant's upper portion (Paliwal, 2000). The female inflorescence, which consists of silk that grows into an ear well protected by the shell leaves, and serves as the plant's storing component, terminates these. Additionally, the plant is finished off with a male inflorescence, which has multiple lateral branches with male flowers and a tassel with a noticeable central spike. These male flowers all release a lot of pollen grains (Paliwal, 2000).

Monoecious plants, such as maize, produce inflorescences of unisexual blooms that are always borne in different sections of the plant. The axillary bud apices give rise to the female inflorescence, the ear, and the highest growth tip at the top of the plant produces the male inflorescence, the tassel. However, Paliwal (2000) emphasized that corn, like all plants, maintains a homeostatic balance between the roots and shoots. Therefore, more assimilate flows to the root system, and root growth is favoured above shoot growth if a soil-acquired supply, such as water or nutrients, is inadequate. In the same way, more assimilate will be devoted to root growth and outgrowth; if radiation is not enough for development due to shadowing or foggy situations, the shoot ratio will decrease.

2.4. Taxonomy of Maize

Table 1: Taxonomy of maize

Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Liliopsida
Subclass	Commelinidae
Order	Cyperales
Family	Poaceae
Subfamily	Panicoideae
Genus	*Zea*
Species	*Zea mays*

2.5. Soil Requirements of Maize

Regarding soil quality, maize is the most demanding crop among the related cereal species (Nagy,2006). High yields can be expected only on deeply tilled soil with a high organic fraction, humus, and nutrient content, medium heavy loam, where penetrating roots can find water even during dry periods. Soil's genetic and physical properties should respond to plant demands. Roots require the proper balance of water and air and rapid warming, characteristic of loam-type soils. The best maize soils have a pH of 6.6 - 7.5, but their tolerance is greater: 5.5 – 8.

Soils should be kept calcium-saturated to ensure safe fertility maintenance (Menybért, 1985). Maize can be grown successfully on Chernozem, meadow chernozem, brown forest soils, and heavy meadow soils that have enough air, appropriate water balance, a thick productive level, and warm up easily, but subsoil loosening is required (Nagy, 2006).

Maize is hugely prone to compaction (Stefanovits, 1975). Maize is grown on better soils around the world because it is less tolerant than wheat. As a result, maize is very responsive to agronomic interventions such as tillage, nutrition, and fertilizer composition. High yield depends on soil physical conditions, water management, and heat management (Menybért, 1985).

The amount and timing of precipitation, also the physical conditions of the soil, influence the available water supply. However, water availability may not correspond to its total amount because the root system's ability to absorb water is frequently impaired. The precipitation measured throughout the winter and the growing season is an essential component of water resources. Therefore, soil water content should be monitored regularly. Yields are highly correlated with soil water content in July, followed by that in May. (Huzsvai & Nagy 2005).

Maize is grown on sandy soils in Hungary as well. However, such crops' success depends on the ratio of organic components, proper nutrition, and water management. Plants can easily be scorched on loose, easily moving, wind-blown sands with a low fraction of colloids (Nagy, 2006).

Maize adapts well to a variety of soil types and is not overly demanding. Except for highly shallow, drought-stricken, or waterlogged soils, almost all soils may be considered in Hungary. Soil aeration is also an important precondition for yield (Nagy, 2006).

2.6. Water Requirements of Maize

Maize plantation uses considerable amounts of water through the growing period. The water taken is up and transpired into the atmosphere of the environment. Water requirement is an important physiological term; it represents the water quantity which continuously secures sufficient moisture for plants' tissues, mainly in the leaves, under various air temperatures and humidity. This value expresses the water potential of the plant (Nagy, 2006). Water requirement is a genetically coded property modified by the existing ecological conditions. One of the characteristics is the variability experienced during the growing season, as being genetically low during the first part of development, then towards the end of formation and filly of kernels. Depending on the atmospheric conditions, the water requirement of maize varies from day to day. With increasing temperature, evapotranspiration increases in parallel with other life processes called thermoregulation. As the relative humidity declines, the water uptake of the air is stimulated as an effect of hydro regulation (Nagy, 2006).

2.7. Temperature Requirement for Maize

Temperature is critical during the first few weeks of growth, from planting to tasseling. During the seasons when the weather is relatively cool, the development of maize plants is delayed. It cannot be compensated for later, even during favorable weather at the end of the summer. In May, cool spells can cause frost damage. Minor frosts (-1, -2) have no effect on seedlings except that they may turn yellow or become partially burned, but frosts of -3 to -6 kill aerial plant parts (Nagy 2006).

Because maize is a subtropical climate plant, it requires heat. Its vulnerability is demonstrated during a cool spring: it turns yellow and stops growing even in May due to low temperatures. Late frost may also kill most of the leaves on mature plants, but these may regenerate and produce acceptable yields. Summer temperatures are usually adequate, but drought periods cause crop damage (Láng 1976).

The cardinal germination temperatures are a minimum of 8-10°C, 31-33°C being the optimum, and a maximum of 40-44°C. Up to the optimum, the time required for germination becomes significantly shorter (Nagy, 2006). Maize cannot grow where the summer mean temperature is less than 19°C and the nights are colder than 13°C. Some studies have found that temperature is most critical from planting to germination and from flowering to maturity. In contrast, others have found that it is only vital during the latter period (Nagy, 2006).

2.8. Growth stages of maize

Maize, like any other plant, undergoes growth stages characterized by physiological, anatomical, and morphological changes. Several classification approaches can be used to determine the development stage of a maize crop. On the other hand, the Iowa State classification approach is the most widely used system (Ritchie et al. 1993). This system categorizes maize growth and development as vegetative (V) or reproductive (R).

According to Ritchie et al. (1993) and Nleya et al. (2019), when the coleoptile penetrates the soil surface, the VE (emergence) takes place, and the vegetative phases are numbered as V1, V2, V3, and Vn until the tassel emerges (VT). The visual distinction between the leaf blade, sheath, and stalk of the corn plant marks the collar, which determines the number of visible leaf collars and vegetative growth stages. The sum of leaves varies due to the corn hybrid and environmental conditions. The first reproductive stage is silking (R1), and the last is maturity (R6). Maize requires a warm, humid environment for germination and emergence within 4 to 6 days of planting. The availability of ideal temperature and soil water is crucial. Scarcity of soil water result in delay in germination and emergence are, while excessive water slows emergence and root development. Cool soil temperatures or low spring air temperatures in residue-covered soils may result in slow germination. Seed germination may also be delayed by temperatures below 50°F. Maize should be planted at a depth of 3.81cm to 5.08cm, ideally (Nleya et al., 2019).

The coleoptile, also known as the "spike," is the first leafy structure to emerge above ground in corn. This is followed by true leaves. Optimal soil conditions that promote vigorous growth and development of corn include warmth, moisture, and good aeration. new leaves sprout from a single growing point located near the stem's tip. This growing point remains below the soil surface for the first four weeks after planting. During this time, the plant can withstand light frost or minor hail but is highly susceptible to flood damage, which can cause significant yield losses. Initially, corn roots do not explore a large soil volume, but they grow rapidly as the plant develops. Corn has two types of roots: seminal and nodal. Seminal roots appear after germination and stop growing at the V3 growth stage, but they continue to function throughout the plant's life. Nodal roots start forming at the V1 growth stage and continue growing until the kernel blister stage. By the V6 growth stage, nodal roots become the primary source of water and nutrients for the plant (Nleya et al., 2019).

2.8.1. Six-Leaf (V6) to Seven-Leaf (V7) Stage

Rapid stem elongation and the development of ear shoots begin at the V6 stage. Every three days, a new leaf emerges. When the developing point is above the ground surface, frost or hail can cause significant damage to the corn plant. However, the root system is fully grown and dispersed in the soil, improving the plant's ability to absorb nutrients. At the V6 growth stage, it is crucial to scout the crop to determine whether additional fertilizer is required. Side dressing nitrogen (N) is most effective when applied between V6 and V8 growth stages (Nleya et al., 2019).

2.8.2. Eight-Leaf (V8) to Eleven-Leaf (V11) Stage

At this stage, numerous ear shoots, which have the potential to develop into ears, are present. However, only one or two upper shoots will ultimately develop into ears that can be harvested. The corn hybrid determines the number of ears produced, with fertile crossbreeds producing more than an ear when planted in low plant populations. Deficits in macronutrients and micronutrients may appear at this stage. Nutrient deficiencies, if not corrected, can severely limit leaf growth. The plant rapidly grows by V10, with new leaves emerging every 2 to 3 days and it requires substantial water and nutrient resources to sustain this rate. However, various factors such as pests, high temperatures, nutrient deficiency, and water scarcity can impede the growth and development (Nleya et al. 2019).

2.8.3. Twelve-Leaf (V12) stage to more leaves

The number of leaves on a maize crop is determined by its maturity rating and type. Silage maize, for instance, may contain extra leaves than grain maize. The more leaves there are, the higher the maturity rating. At the V12 growth stage, the possible grains per ear and ear size are revealed. The rate of corn plant development at the V12 stage is influenced by hybrid maturity. Early maturing hybrids progress through these stages more quickly, resulting in smaller ears than late-maturing hybrids. However, yield variations between early and late hybrids can be balanced by raising plant density if there is enough water and nutrient support Nleya et al. (2019). At this growth stage, the corn plant's water demand is at its peak, and it can consume up to a quarter inch of water per day. Additionally, the plant requires large amounts of nitrogen, phosphorus, and potassium. Crop failure can occur due to acute hailstorms that strip off leaves and break tassels (Nleya et al. 2019).

2.8.4. Tasseling (VT)

Tasseling takes place 2 to 3 days before silking. The plant has grown to its maximum peak, and the final branch of the tassel is evident, but no surfacing of silk yet from the ear shoot. Time interval between VT and R1 is dependent on the maize hybrid and conditions of the environment. The effect of a hailstorm may be extremely severe due to the emergence of all the leaves. Any tassel damage or complete loss may result in poor grain formation (Nleya et al. 2019).

2.8.5 Silk (R1) Stage

Ritchie et al. (1993) and Nleya et al. (2019) observed that the first stage of the reproductive period is marked by the appearance of silk (R1). Each potential kernel (ovule) produces its silk on the ear. Soon after the V12 stage, silks begin to elongate. Silks emerges and collects pollen shed from the tassel. Within 24 hours, pollen collected fertilizes ovules on the cob, developing into kernels. Unfavorable environmental situations in the phase of reproduction can rigorously reduce yield. Ears are barren in the absence of fertilization (Nleya et al. 2019). The silks continue to grow until pollen is captured and germinates, at which point they degrade. Drought stress, for example, can cause silk elongation and emergence to be delayed. Pollen shed and silk emergence are synchronized under favourable environmental conditions, so silk receptivity is unimportant. Insect pests, such as corn rootworms, feed on silks, resulting in lower yields.

2.8.6. Kernel Blister Stage (R2)

Formation of kernels commences after pollination. According to Nleya et al. (2019), the kernels take on a whitish, blister-like appearance and emerge between 10 to 14 days after silking. During this time, the silks will have turned brown and dried out. As the plant transitions into the kernel fill stage, starch accumulates in the kernels. By the R2 stage, which is characterized by the formation of the radicle, coleoptile, and the first embryonic leaf in the embryo, the kernel's moisture content reaches around 85%. However, any significant stress during the pre-blister and blister stages can lead to kernel abortion, which in turn reduces the number of grains on the cob. It takes approximately 960 growing-degree days (GDD) for the plant to attain physiological maturity at this stage.

2.8.7 Kernel Milk Stage (R3)

Nleya et al. (2019) stated that the kernel milk stage begins roughly 22 days after silking. The kernels appear primarily yellow, with rapid starch collection and a milky white fluid inside. Cell division in the endosperm is complete, and kernel growth occurs mainly through cell expansion and starch accumulation. However, severe stress during this period can still lead to kernel abortion and reduced size and weight. The moisture content of the kernel is typically around 80%, and it takes approximately 880 growing degree days (GDD) to achieve physiological maturity. While not as critical as the R1 stage, the kernel milk stage can still be affected by stress, which can impact the kernel's size and weight.

2.8.8. Physiological Maturity (R6)

According to (Nleya *et al.* 2019), when the maize plant reaches the R6 stage, it attains physiological maturity, which occurs around 55 to 65 days after silking. The moisture content of the kernels ranges from 30% to 35%. The starch line has advanced to the tip of the kernel, and a black layer has formed at the base of the mature kernels. The black layer forms from the kernel tips to the basal kernels. At this point, any severe stress has little impact on grain yield. It is advisable to let the crop dry in the field at this stage, as it reduces drying costs if the crop is to be harvested for grain. Maize can be safely stored for less than six months with a moisture content of 15%. To prevent spoilage, maize must be dried to 12% moisture before long-term storage.

Table 2: Growth and development stages in maize

Vegetative stages		Reproductive stages	
VE	Emergence	R1	Silking- silks visible outside the husks
V1	First leaf collar	R2	Blister- kernels are white and resemble a blister in shape
V2	Second leaf collar	R3	Milk- kernels are yellow on the outside with a milky inner fluid
V3	Third leaf collar	R4	Dough- milky inner fluid thickens to a pasty consistency
Vn	nth leaf collar visible	R5	Dent- nearly all kernels are denting
VT	Tasselling- the branch of the tassel is obvious	R6	Physiological maturity- the black abscission layer has formed

Source: Ritchie, S.W., J.J. Hanway, G.O. Benson, and J.C. Herman. 1993

2.9. Types of Maize

Maize varieties can be classified based on kernel type: dent, flint, flour, sweet, pop, and pod corn. Except for pod maize, these classifications are centered on the kernel's mass, quality and endosperm composition pattern.

2.9.1. Dent Maize

Dents are the offspring of a cross between the late-flowering Southern Dent. Dent corn is distinguished by the corneous, horny endosperm on the sides and back of the kernels. In contrast, the inner core is a soft, floury endosperm that spreads to the crown of the endosperm and collapses to yield a distinct indentation upon drying. Denting severity differs according to genetic background. Dent maize is primarily for as livestock feed, in industry, and as a staple food (Brown, 1985).

2.9.2. Flint Maize

Flint maize is characterized by a tough, glassy or corneous endosperm layer that envelops a small, soft, granular core. The ratio of soft to corneous starch can vary between different varieties. The kernels themselves are typically round and smooth, while the ears are long and slender with a relatively small number of kernel rows. Compared to dent strains, flint corn matures faster, has better germination rates, and exhibits greater spring vigour and tillering while producing fewer prop roots in temperate regions. These qualities make it a popular choice for both animal feed and human consumption (Brown, 1985).

2.9.3. Flour Maize

Flour maize is an ancient variety of corn that can be traced back to the Aztecs and Incas. These types of maize have a soft starch and a minimal amount of hard, vitreous endosperm, which gives them an opaque appearance. Due to their uniform shrinkage when dried, they typically do not have any dents. Although they are easy to grind when dry, in wet areas, they are prone to moulding on the mature ear (Brown, 1985).

2.9.4. Pop maize

Among the various maize varieties, popcorn is considered the most primitive. It is distinguished by its hard, corneous endosperm, which contains a small quantity of soft starch. Popcorn kernels are small and can have a round or pointed (resembling rice or pearls) shape. Popcorn is mainly consumed after being freshly popped or used as a primary ingredient in popcorn-based treats. A significant portion of popcorn cultivation occurs under contractual agreements. While the growing conditions for popcorn are similar to those for dent corn, specific methods for harvesting, drying, and storing the crop are necessary to maintain its popping quality (Brown, 1985).

2.9.5. Pod maize

Pod maize is more ornamental. As with other types of maize, the ear is also surrounded by husks. Homozygous pod corn is usually highly self-sterile, whereas heterozygous pod corn is more common. Pod corn exhibits a range of endosperm characteristics, including dent, sweet, waxy, pop, flint, or floury. However, it is primarily regarded as a curiosity and is not grown commercially (Brown, 1985).

2.9.6. Sweet Maize

Sweet maize is grown for its green ears, which are commonly known as sweet corn. These ears are typically harvested when the kernel moisture is approximately 70%, which is about 18 to 20 days after pollination. The sweet maize grain contains a higher sugar content due to one or more recessive mutations that hinder the conversion of sugar to starch during development (Brown, 1985).

2.10. Nutritional value of maize

The maize kernel is a highly nutritious and edible part of the plant, containing a range of vitamins including C, E, and K, as well as B vitamins such as thiamine (B1), niacin (B2), riboflavin (B3), pantothenic acid (B5), pyridoxine (B6), folic acid, selenium, N-p-coumaryl tryptamine, and N-ferrulyl tryptamine. However, potassium is a nutrient that is commonly deficient in the average human diet (Kumar & Jhariya, 2013). A breakdown of the composition of the maize kernel is presented in Table 3

Table 3: Composition per 100g of the edible portion of maize

Carbohydrate	71.88g
Protein	8.84g
Fat	4.57g
Fibre	2.15g
Ash	2.33g
Moisture	10.23g
Phosphorus	348mg
Sodium	15.9mg
Sulfur	114mg
Riboflavin	0.10mg
Amino acids	1.78mg
Minerals	1.5mg
Calcium	10mg
Iron 2,3	2.3mg
Potassium	286mg
Thiamine	0.42mg
Vitamin C	0.12mg
Magnesium	139mg
Copper	0.14mg

Source: Shah, Prasad, and Kumar (2015); Gopalan, Rama Sastri, and Balasubramanian (2007)

2.11. Usefulness of maize

Maize is the most widely produced grain globally (ITTA, 2009), due in part to its numerous applications in food, feed, and industry. It has become the most important feed ingredient for animals, surpassing other grains. Maize has a high energy content and low fibre, making it easily digestible by most livestock species (Du Plessis, 2003). In developed countries, approximately 78% of maize production is utilized as animal feed (Safi et al. 2009). In the United States, maize is the primary feed grain, accounting for more than 90% of feed production and use (USDA, 2012).

The straw from maize plants can be processed into hay and silage for use in dry season feeding, and distillery by-products are also used as livestock feed. Additionally, maize's widespread use, adaptability, low cost, and ready availability have contributed to its extensive use for animal feed.

Maize is widely used in the industry as a food and raw material. A meal is a primary product derived from maize. Cornmeal, grits, starch, flour, tortillas, snacks, chips, thickness, pastes, syrups, sweeteners, maize oil, soft drinks, beer, whisky, and so on are all made from it, as are breakfast cereals. Maize meals are obtained through manual or mechanical milling. A larger percentage of grain is utilized as animal feed and industrial raw material for food and non-food purposes in developed countries (Orhun et al. 2013). The most important raw material for industrial starch is maize. Maize starch is a maize product used to make ceramics, dyes, plastics, oilcloth, paper, paper boards, textiles, cosmetics, and pharmaceuticals.

In developing countries, maize is commonly consumed directly and serves as a staple diet for about 200 million people, primarily in Latin America and Africa (ITTA, 2009). It can be prepared by boiling or roasting fresh, or by drying for later consumption. Maize can also be milled into flour or dough in dry or wet states for various traditional meals. The grain is a rich source of vitamins A, C, and E, as well as proteins like lysine and tryptophan, minerals, and fat (Onimisi et al., 2009; Buah et al., 2009).

Fermented drinks are manufactured industrially from maize. Maize grain starch finds various applications in industries such as textiles, adhesives, fuel (ethanol), and household items like beer, ice cream, syrup, cosmetics, paint, and batteries (Du Plessis, 2003; Yonli et al. 2010). It is also converted into sorbitol, dextrin, sorbic, and lactic acid. Maize grain is further processed into secondary products like corn flakes, popcorn, corn oil, corn syrup, and biofuels.

Maize production, processing, and sales as a commodity, locally and globally, were significant sources of employment and income for thousands of people worldwide (Bourdillon et al. 2003, USDA, 2009).

2.12. Agronomic practices in maize production

2.12.1. Weed control

Weeds are one of the most significant constraints to successful crop production. Weed management is regarded as an essential factor for obtaining achieving higher productivity because during the initial stages of maize growth, weeds become more problematic in periods of uninterrupted rainfall, and they cannot be effectively managed through conventional or customary practices because of the excessive moisture. Controlling weeds in maize is, therefore, critical for increasing productivity. Maize plots where weed control practices were implemented yielded 77% - 96.7% more grains compared to plots that were left weedy as control (Yadav et al., 2018). Weed control in maize can be sophisticated due to the wider row spacing. Crop yield loss could be caused to a large extent by an increase in weed biomass, density, and species (Blackshaw et al. 2002). Weed infestation reduces crop yield significantly, as corn losses of 40- 60% have been reported in pure corn culture (Thobatsi, 2009). According to Sharma et al. (2000), the presence of weeds can reduce 30-50% of maize yield depending on the density and species of the weeds present. Weeds hinder average crop growth by competing for moisture, light space, and plant nutrients. Weeds are a major cause to severe damages to maize crops (Bajwa *et al.*, 2015). Weeds commonly cause devastating maize crop losses (Bajwa et al. 2015). Chikoye et al. (2005) found that in Africa, weeds typically lead to crop losses ranging from 50% to 90%. In some cases, the complete failure of maize crops in Africa has been attributed to the invasion of *Striga asiatica (L.)* weeds, (Khan et al., 2008).

The control of weeds is facing challenges due to insufficient herbicides and mineral fertilizers, as well as a shortage of available labour for weeding. This often leads to delays in weeding, which can result in economic losses that could have been prevented (Nyanga et al., 2012). In Africa, weed control mainly relies on manual labor using hand hoes, but this approach is becoming less practical due to the limited availability of labor in rural areas Weed control in Africa is primarily done by hand hoeing, but this is only feasible in small areas due to rising labour constraints in rural districts (Nyamangara et al., 2014).

Furthermore, soil fertility decline has resulted in the occurrenc of damaging weeds such as Striga, *Richardia scabra L.*, and *Cynodon dactylon L.*, and *Richardia scabra L.*, which are difficult to manage and cause considerable crop losses (Reda et al., 2005). Farmers in advanced regions like, such as Australia utilize herbicides extensively to manage weeds due to their reliance on high agricultural inputs (CropLife/Grains Research and Development Corporation, 2008). When herbicides are properly administered, they can reduce yield losses caused by weeds by up to 13%, making them a useful weed control method. When herbicides are properly administered, they can reduce yield losses caused by weeds by up to 13%, making them a useful weed control method (Oerke and Dehne, 2004).

Mechanical control of weeds growing between rows is time-consuming. As a result, herbicides are used to control weeds in developed countries. Using herbicides to control weeds is a necessary subsitute to manual weeding manual weeding because it is more cost effective, quicker, and yields better resultsin (Chikoye et al. 2005; Kumar et al. 2017). However, herbicide pollution of surface and groundwater is a major health concern for humans (Abdin et al. 2000). To address this issue, cover crops are widely employed as substitute for herbicides and ploughs. Cover crops are grown to inhibit the development of weed populations, manage soil disease, enrich soil through nitrogen fixation, improve soil structure, prevent nitrogen absorption, increase soil organic matter, and reduce soil erosion (Kruidhof et al. 2008). When a legume cover crop, like common vetch is used, it can provide most of the nitrogen (N) needed for maize to achieve its maximum yield (Bayer *et al.* 2000).

2.12.2. Weeds of Maize

According to Sanodiya *et al.* (2013), the most common weeds associated with maize were *Echinochloa colona* (15.4%), *Digitaria sanguinalis* (13.1%), *Cyperus rotundus* (16.2%), and *Commelina communis* (14.0%). Dicot weeds included *Phyllanthus niruri* (14.4%) and *Eclipta alba* (13.6%). Many other minor weeds (13.3%) were present in the maize ecosystem at the 60 DAS stage. Ram et al. (2017) conducted a field study on maize in Hyderabad and discovered these major weed species, namely, *Trianthema portulacastrum, Euphorbia geneculata, Chenopodium album, Cynodon dactylon, Commelina benghalensis, Cyperus rotundus, Melilotus alba, Echinochloa colona, Digera muricata, Amaranthus viridis, Trichodesma indicum, Parthenium hysterophorus, Dactyloctenium aegyptium, Eragrostis cilianensis, Digitaria sanguinalis.* These weed species comprised broadleaved weeds, grasses, and sedges. Common weeds of maize in Hungary include the perennial *Cynodon dactylon L.*, the annual warm demanding *Chenopodium album L., Abutilon theophrasti Medicus*, the perennial *Convolvulus arvensis L., Panicum miliaceum L., Amaranthus chlorostachys L., Elymus repens (L.)* Gould., *Ambrosia artemisiifolia L.* and *Lathyrus tuberosus L.*

2.12.3. Yield losses due to weeds

The growth of weeds that are not controlled has been shown to have a significant negative impact on Kharif maize grain yield in Kashmir's silty clay loam soil. According to Bahar et al. (2009), uncontrolled weed growth caused a 73.4% reduction in yield. Walia et al. (2007) reported yield losses of up to 68.9% and 28-100%, respectively, due to severe weed infestation resulting from wider row spacing and frequent rains during the rainy season. In another study, Dalley et al. (2006) found that season-long weed competition in maize caused a reduction in grain yields of more than 90%, while Reddy and Tyagi (2005) observed losses ranging from 40% to 80%. Globally, weeds cause significant yield losses, with an average loss of 12.8% when weed control methods are used and 37% when no weed control methods are used (Oerke and Dehne, 2004). However, Dogan et al. (2006) found that allowing weeds to compete with the crop from sowing to harvest led to a 43% reduction in corn yield.

2.12.4. Water and nitrogen management

Water and nitrogen (N) are critical for the growth of maize and are the primary factors limiting their yield. The optimal amount of irrigation and nitrogen inputs required for maximum yield varies significantly depending on the region, climate and soil characteristics, management practices, hybrid, and other factors (Liu and Zhang, 2007; Irmak, 2015). In addition, plant traits such as leaf area index (LAI), photosynthesis rate, radiation/light interception and use efficiency, leaf area duration, net assimilation rate, chlorophyll content, Rubisco activity, shoot weight, plant N uptake, and thus biomass production and grain yield can be influenced by limited N availability and water deficits in the crop root zone (Eck,1984;; McCullough et al.1994; Pandey et al. 1984, 2005; Muchow, 1988).

Furthermore, balancing water and N are essential for achieving high quality maize crops (Mason and D'Croz-Mason, 2002). Overirrigation can result in anaerobic conditions in the plant root zone, negatively impacting plant water and nutrient uptake and increasing leaching potential, resulting in decreased productivity.

Poor management of nitrogen and irrigation has led to environmental issues in water and air quality, particularly for maize production over the last few years, which has the highest percentage of nitrogen losses among all cereals (Zhang et al. 2015; Zill'en et al. 2008; Aneja et al. 2009) have increased over the last few decades. According to Snyder (2012), maize accounts for the largest proportion of annual nitrogen consumption, ranging from 37% to 51%.

Liu et al. (2003) found that a nitrogen (N) supply rate of 180 kg per hectare could lead to high maize yields. However, excessive application of N has not increased grain yield and has instead led to significant N loss through leaching, which can have adverse effects on the environment and human health (Snyder et al. 2007). Therefore, it is crucial to reduce N application rates in agricultural production, especially among smallholders who use traditional farming methods.

2.12.5. Plant Density

Plant density is the ratio of one square meter of ground. Since maize has a low tillering capacity and a short flowering time frame compared to other cereals, differences in plant density have a greater impact on maize yield. By creating better crop types, a conducive climate for growth and a soil with ideal plant population ha-1, agricultural inputs can be increased to their maximum potential. Optimal plant population is required for maximum production (Gustavo et al., 2006, Trenton et al., 2006). There are two main factors that influence the rise in maize crop production. The total number of plants in the field at maturity directly relates to the amount of grain produced, thus the first factor is maintaining the highest plant population per unit area. The increase in maize crop yield is dependent on two major factors. Plant population declines can be caused by various factors such as low germination, bird damage during seed germination, pest and disease attack in the planting season, wind related lodging or strays causing damage and so on.

The genetic ability of a hybrid is the second factor, and it plays a significant role in determining whether increase or decreases since grain output takes into account both seed number and size. However, the agroecological environment will determine the optimal population density, particularly the amount of rainfall received. For example, according to Mohammadi et al. (2012), because the crop and the weeds compete for light, increasing maize plant density and reducing maize row spacing decreased weed output. Forcella et al. (1992) found that increasing maize densities can minimize the use of herbicides, lowering cultivation costs and environmental risks.

Williams et al. (2014), that because of the huge site and context dependence of weed dominance, maize planting patterns may not always meaningfully impact on weed control. According to research by Hammer et al. (2009) maize grain production rose at a pace of 0.01 t/ha/year at a low density of 10,000 plants/ha but climbed at a rate of 0.11 t/ha/year at a high density of 79, 000 plants/ha. Plant population had a considerable impact on grain production, moisture, test weight, and stalk lodging according to discovered that plant population significantly affected grain yield, moisture, test weight, and stalk lodging according to Widdicombe and Thelen (2002). Surprisingly, the highest grain yield was obtained in the study at the highest plant density (90,000 plants/hectare).

Whenever cultivated at an increased population density, Sangoi (2001) recorded high maize yields. According to Weiner et al. (2001) high planting density can also lead in excellent group organization and maximum sunlight exposure.

Concentrated populations lead to the majority of plants remaining barren, smaller ear and ear size, crop vulnerability to lodging, disease, and pests, and reduced yields per unit of area (Nasir, 2000). A dense plant population is what leads to maize plants lodging (Trenton & Joseph, 2007).

The majority of plants in a high population have smaller, barrener ears, and the crop is more prone to lodging and pest attack. Due to fewer than ideal plants, low plant density lowers yield per unit area (Cardwell, 1982).

Sárvári (2005) suggested that plant density has a notable influence on yield. As plant density increases, the yield per plant tends to decrease, but the yield per unit area increases until the optimal number of plants per hectare is reached. According to Vad et al. (2007), achieving the optimal plant density is crucial for sustainable maize production. In addition to genotype and agrotechnical factors such as fertilization, ecological factors such as water supply, rainfall amount and distribution, and soil physical and chemical properties significantly impact the optimal plant density of maize.

Pepo et al. (2006) reported that increasing population density results in only slight increases in yield (0.2-1.6 t per hectare). Dawadi and Sah (2012) discovered that the highest yield (11.19 t per hectare) was obtained at a plant density of 74074 plants per hectare compared to a plant density of 55555 plants per hectare. There was no significant difference in yield between 66666 plants per hectare and 83333 plants per hectare (10.54 t per hectare).

2.13. Leaf Area

The structure of the maize leaf canopy is determined by various plant variables such as the number and length of internodes, leaf blade area, number, angle, orientation, and functional period. These factors influence the plant height, as well as the structure and function of the leaf canopy. As the plant grows, leaf traits such as angle, number, and internode growth may change, contributing to canopy development. The mature leaf canopy is established at tassel maturity, and there are several studies that describe the structure and function of the maize leaf canopy. (Stewart et al. 2003; Maddonni et al. 2001; Valentinuz et al. 2006).

According to research by Dwyer et al. (1986), the development of maize leaf area is influenced by growing degree days and available moisture. High plant density can cause a reduction in light intensity within the leaf canopy, resulting in lower grain yield. Recent studies have found that newer maize hybrids tend to have higher photosynthetic rates than older hybrids at high plant densities, leading to higher grain yields (Dwyer et al. 1991). Maintaining reasonable photosynthetic rates at higher plant densities can help light penetrate the ear leaf area, resulting in higher grain yield. A study on maize defoliation using standard hybrids found that ear leaf defoliation, along with the removal of all leaves above the ear leaf at pollen-shed, reduced grain yield by up to 75% in some hybrids (Subdi et al. 2003).

According to research, as plant density increases, the leaf area index (LAI) of maize plants decreases. This is due to increased competition among plants for light, water, and nutrients at higher plant densities. Individual plants produce smaller leaves as a result, resulting in a lower LAI. Chen et al. (2019) discovered that increasing plant density from 75,000 to 150,000 plants per hectare reduced maize plant LAI significantly. According to the findings of the study, high plant densities reduce LAI by increasing inter-plant competition for light and nutrients.

Similarly, Shi et al. (2021) discovered that as plant density increased, maize LAI decreased significantly. According to the study, decreasing plant density could increase LAI and, as a result, maize yield. Furthermore, Marek et al. (2016) discovered that plant density had a significant effect on maize LAI, with higher densities resulting in lower LAI.

2.14. Plant Height

In maize (*Zea mays L.*), plant height is an essential morphological trait influencing yield and yield components. It is a complex trait influenced by various factors, including genetics, environment, and management practices. Taller maize plants have more significant yield potential because they can compete more effectively for light and resources, allowing them to photosynthesize more efficiently and produce more kernels per ear. According to Morris and Rhoads (1997), increasing plant height increased grain yield by increasing the number of ears for each plant and the number of kernels per ear. Similarly, Singh and Singh (2006) discovered that taller maize plants produced more ears and kernels per plant, resulting in a higher grain yield.

Sánchez-López *et al.* (2020) also concluded that hybrids with higher plant height had more ears per plant, more kernels per ear, and higher grain yield. Taller plants also had more leaves, capturing more light and producing more photosynthates, resulting in higher grain yield.

Malaviarachchi et al. (2007) found that increasing plant population led to an increase in plant height. They also observed that planting density had a significant impact on the number of leaves per plant, with the maximum number of leaves recorded at a planting density of 80000 plants per hectare and the minimum at 65000 plants per hectare. These results are consistent with those reported by Zandi (2012), who also found that the highest number of leaves per plant was observed at an optimal planting density.

However, some studies have found that taller maize plants may have a lower yield due to lodging and harvesting difficulties, which can result in kernel shattering and poor grain quality.

Furthermore, taller plants may be more susceptible to pest and disease damage because they are more exposed.

Khan *et al.* (2006) found that taller plants had lower grain yields than shorter plants and concluded that "plant height substantially affected yield and yield components of maize" and that "lower plant height may be considered as an important trait for increasing kernel yield in maize”.

Li *et al.* (2018) studied the impact of planting density on maize growth, yield, and water use efficiency. They discovered that increasing planting density resulted in taller plants but decreased the number of ears per plant, resulting in a lower grain yield.

Moosavi et al. (2012) discovered that plant density had a significant effect on plant height and stem diameter of forage maize, but not on leaf number per plant. They observed that an increase in plant density resulted in a higher plant height, which may be attributed to increased competition for light between plants and imbalances in the distribution of growth regulators. However, they also noted that the effect of plant density on other morphological traits was not significant. The study concluded that different plant spacings and densities can generally have an impact on maize morphological traits.

2.15. Stem Girth

Stem girth, also known as stem diameter, is a morphological trait associated with maize plant growth and development. It is an indicator of the plant's structural strength, which is important for supporting the plant as it grows taller and produces more ears, kernels, and grain. According to research, stem girth has various effects on maize yield.

Plant density has a significant impact on maize stem girth. As plant density increases, stem girth decreases. This is because when plants are grown in higher densities, they battle for resources such as water, nutrients, and light. This competition can result in reduced growth and development, including a decrease in stem girth.

Wang et al. (2019) found that stem girth positively correlated with the quantity of ears for every plant, kernels per ear, and grain yield. In addition, the study discovered a positive relationship between stem girth and the leaf area index (LAI), which is a measure of the amount of leaf area per unit of ground area. The higher the LAI, the more light the plant can capture and the more photosynthesis can occur, leading to higher grain yields.

In one study conducted in Nigeria, for example, stem girth decreased from 2.5 cm to 2.2 cm as plant density increased from 10,000 to 50,000 plants per hectare (Ogunkunle *et al.* 2011). In a similar vein, a Chinese study discovered that as plant density increased from 52,500 to 97,500 plants per hectare, stem girth decreased from 3.6 cm to 3.3 cm (Li *et al.* 2017).

Prado *et al*. (2021) investigated the effect of plant density on maize yield and quality in a study conducted in Brazil. Stalk diameter decreased from 3.20 cm to 2.85 cm as plant density increased from 40,000 to 100,000 plants per hectare.

2.16. Photosynthetic activity

A plant's ability to photosynthesize is crucial for its growth, development, and yield. Several studies have investigated the effect of plant density on the photosynthetic activity of maize.

One such study by Du et al. (2018) found that increasing plant density from 6.7 to 10.0 plants/m2 resulted in a significant increase in the rate of photosynthesis in maize. Another study by Yao et al. (2017) also reported that higher plant densities (ranging from 60,000 to 90,000 plants/ha) led to increased photosynthetic activity in maize.

Additionally, a study by Li et al. (2020) reported that plant density had a significant effect on the distribution of light within the maize canopy, which in turn affected photosynthetic activity. Specifically, the study found that increasing plant density led to a more uniform distribution of light within the canopy, resulting in increased photosynthetic activity.

Zhang et al. (2019) studied the effect of plant density on photosynthetic rate and yield in different maize varieties and found that increasing plant density up to a certain point (between 6.7 and 8.0 plants/m2) increased the photosynthetic rate and yield in all the maize varieties tested. However, further increases in plant density had a negative effect on both parameters.

Liu et al. (2020) investigated the effect of plant density on photosynthetic capacity and carbon assimilation in maize leaves and also discovered that increasing plant density led to higher photosynthetic rates in the upper and middle leaves of the maize canopy, but not in the lower leaves. This was attributed to a reduction in light availability in the lower canopy due to shading by the upper leaves.

2.17. Number of leaves

The number of leaves on a maize plant is a morphological trait that can influence plant yield. Photosynthesis, the means by which plants convert light energy into chemical energy in the form of sugars, relies heavily on leaves. Therefore, the more leaves a plant has, the more light it can capture, and photosynthesis can occur, potentially leading to higher grain yields.

Khan (2013) investigated the influence of various plant densities on the number of maize leaves (40,000, 60,000, 80,000, and 100,000 plants per hectare). The findings revealed that as plant density increased, so did the number of leaves per plant. In particular, at 40,000 plants per hectare, the average number of leaves per plant was 12.4, whereas, at 100,000 plants per hectare, the average number of leaves per plant was 9.3. In contrast, a study conducted by Duvick et al. (2004) reported that increasing plant density from 55,000 to 80,000 plants per hectare reduced the number of leaves per plant from 15.5 to 14.1.

Additionally, Huang and Tollenaar (1992) discovered that increasing plant density from 25,000 to 90,000 plants per hectare decreased the number of leaves per plant from 18.7 to 12.9.

3.0 MATERIALS AND METHODS

3.1. Site Description

The experiment was carried out at the research farm of the Hungarian University of Agriculture and Life Sciences from May to August 2022. The research site is at 47.59373°N, 19.36518° or 19° 21' 55" east, Pest, Godollo, Hungary. Hungary receives 400-550 mm of annual precipitation on average, with monthly maximum and minimum temperatures of -10oC and 30oC, respectively. There was a long dry spell reducing the annual rainfall to 100mm in 2022. The experimental growing season lasted from May to August 2022. The area's predominant soil type is brown forest, which is distinguished by a fine-drained subsoil that is brownish in colour. The pH of the soil at the research site was 6.5, making it nearly neutral.

Table 3: Physico-chemical properties of the experimental site

Characteristics	Value
KA	45
pH (H20)	7.21
Humus (%)	2.65
CaCO3 (%)	1.86
AL-P2O5 (mg/kg)	643
AL-K2O (mg/kg)	293
CaCl-Mg (mg/Kg)	129
N min (0-60cm: Kg/ha)	67.4

3.2. Treatments, experimental design and procedures

The experiment included one treatment (plant density) with three levels (100, 75, and 50 percent population) laid out in randomized complete block design (RCBD), with two replications of each treatment. Margitta, a maize variety from the FAO group FAO 280, was used as a test crop because it is well-adapted and widely used by farmers in Hungary.

The experimental area was thoroughly cleaned, ploughed, and prepared, and each plot was levelled with a combinator. The experimental unit (plot) was 30 m x 10 m in size, with four (4) rows of 10 m in length. The inter and intra-row spacings were 0.75 m and 0.25 m, respectively, and each hole received two maize seeds.

Thinning and supplying were done at the appropriate time four (4) weeks after germination. The outermost rows of each plot served as borders, while the two middle rows served as harvestable rows. The seeds were planted on 5th May 2022.

3.3. Characteristics of Test Crop

- Hybrid- Margitta (FAO 280)
- Type of kernel- Dent
- Use- Grain
- Suggested plant density- 65 to 70,000 stem/ha
- Kernel row number- 16 to 18 pcs
- Kernel/cob ration- 86.8%
- Length of cob- 21 to 22 cm

3.4. Data Collection

The data collection was separated into two parts, which included growth and yield parameters.

3.4.1. The growth parameters:

- Leaf number per plant using visual count of fifteen randomly selected plants.
- Plant height using a tape measure of fifteen randomly selected plants. Plant height (cm) was measured from the base of the plant to the uppermost leaves using a tape measurement.
- Number of leaves by visual count of fifteen randomly selected plants when the plant attained silking stage.
- Stem girth of fifteen randomly selected plants using a vernier calliper.
- Leaf areas were measured from fifteen randomly selected plants from each plot. It was calculated by multiplying the leaf length and breadth (LxB) of the individual plant.
- The photosynthetic activity (nmol/cm2) was measured randomly from five selected plants per plot, with the use of the chlorophyll meter.

3.4.2. The yield parameters:

Ten plants were selected at random for yield measurements.

- Number of lines per cob of ten randomly selected plants.
- Weight of cob of ten randomly selected plants.

- Number of seeds per line of ten randomly selected plants.
- Length of lines per cob was measured from ten randomly selected harvested cob.

The number of lines per cob and length per cob were calculated by physical counting while the weight of cobs was estimated with the use of a laboratory weighing scale (g).

3.5. Data Analysis

The collected data were subjected to the analysis of variance (ANOVA) procedures, using Excel software, 2011. The difference among the treatment means was compared using the Least Significant Difference (LSD) test at a 0.05 probability level.

Picture 1: pictorial view of the experimental plot taken on 24th August, 2022.

4.0. RESULTS AND DISCUSSION

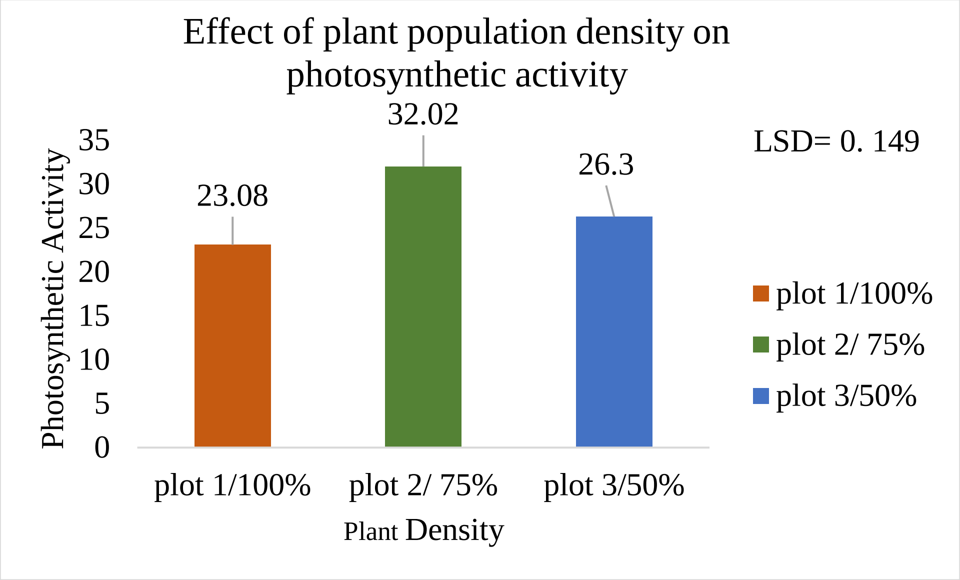

Figure 1: Effect of plant population density on photosynthetic activity

Figure 1 above shows the outcome of the three dissimilar plant population densities on the photosynthetic action of maize. It can be observed that plot 2 with a 75% plant population recorded the highest photosynthetic activity with a value of 32.02, which was followed by plot 3 with a 50% plant population with a value of 26.3 and finally plot 1 with a 100% population having the least photosynthetic activity of 23.08. However, no significant differences (P>0.05) were observed among all the treatments applied. The finding is in contrast with Du et al. (2018) who discovered that enhancing plant density from 6.7 to 10.0 plants/m2 resulted in a significant increase in the rate of photosynthesis in maize. This may be due to shading and less light interception by individual plants which can limit photosynthetic activity in the high-density population. Another reason could be due to variations in leaf area between the different plant densities.

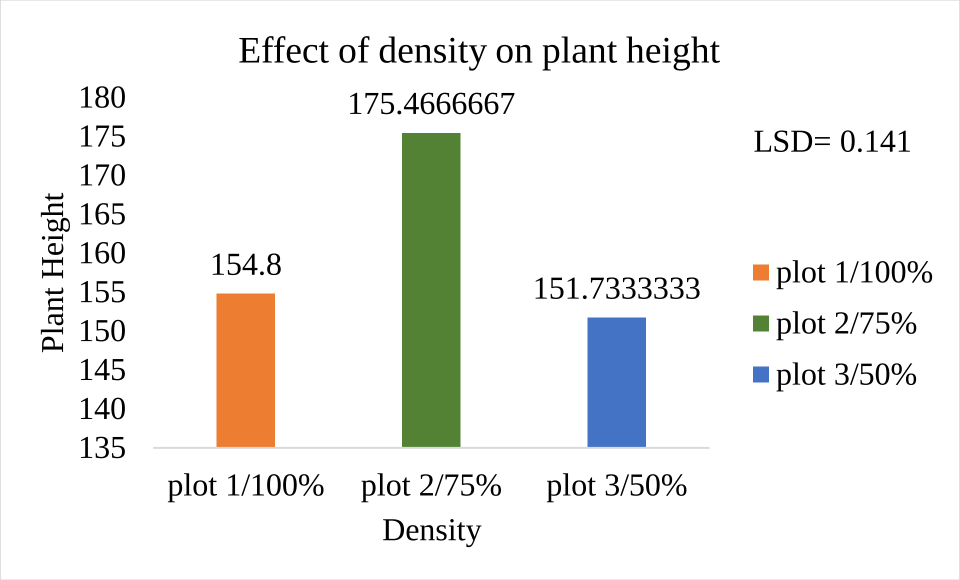

Figure 2: Effect of plant population density on plant height

Figure 2 depicts the effect of plant density on the plant height of maize. The results show there were significant differences among all the treatments at a probability level of 0.05. Plot 2 with 75% population density recorded the highest value of 175.47cm, followed by plot 1 with 100% population density recording the second highest value of 154.8cm and plot 3 being the least with a value of 151.73cm. This result contradicts the research conducted by Malaviarachchi *et al.* (2007) whose findings reported higher plant height with a rise in plant population. The reason for this result could be due to increased competition between plants for resources such as nutrients, light and water.

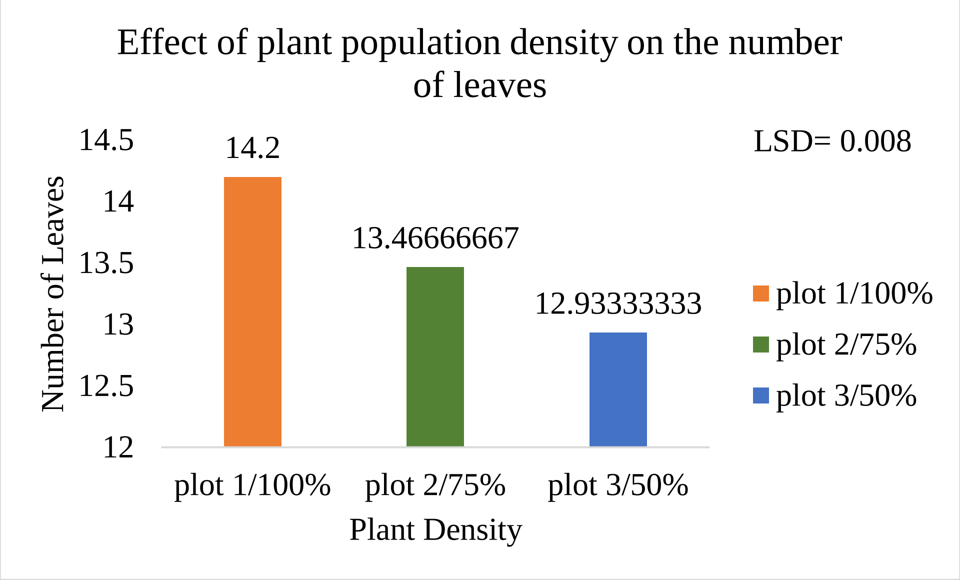

Figure 3: Effect of plant population density on the number of leaves

Figure 3 depicts the effect of plant population density on the number of leaves of maize. From the graph, plot 1 with a 100% plant population had the highest value of 14.2, followed by plot 2(75%) which recorded the second highest value of 13.47 and finally plot 3 with a 50% population recorded the least value of 12.93. the bar chart shows significant differences (P<0.05) among the plots. It can be observed from the results above that the plant density had a significant influence on the number of leaves of the maize plant. This result is in accordance with reports from Huang and Tollenaar (1992) and Khan (2013) whose findings revealed that as plant density increased, so did the number of leaves per plant. The reason for the above result could be due to shading. Higher plant density can also lead to greater shading among the plants hence shading stimulates plants to grow taller to reach for sunlight, which in turn results in more leaves to accommodate a greater photosynthetic area and capture more sunlight.

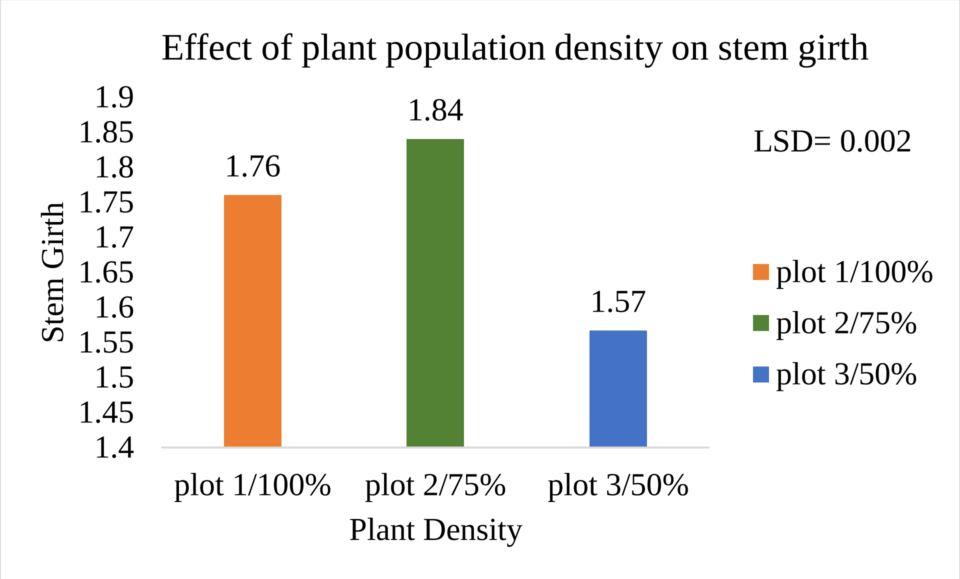

Figure 4: Effect of plant population density on stem girth

Figure 4 above depicts the effect of plant population density on the stem girth of maize. It can be observed plot 2 with a 75% population recorded the highest value of 1.84cm, followed by plot 1 with a 100% plant population recording a value of 1.76cm. Comparison between the 3 plots indicates significant differences (P<0.05) among them. The results contravene the findings of Ogunkunle et al. (2011) and Li et al. (2017) who reported that stem girth decreased from 2.5 cm to 2.2 cm and 3.6 cm to 3.3 cm respectively as plant density increased from 10,000 to 50,000 and 52,500 to 97,500 plants per hectare. This result could be attributed to plant growth and development, which can be influenced by plant density, influence stem girth. Taller, thinner plants can result from high-density populations, whereas shorter, sturdier plants with thicker stems can result from low-density populations.

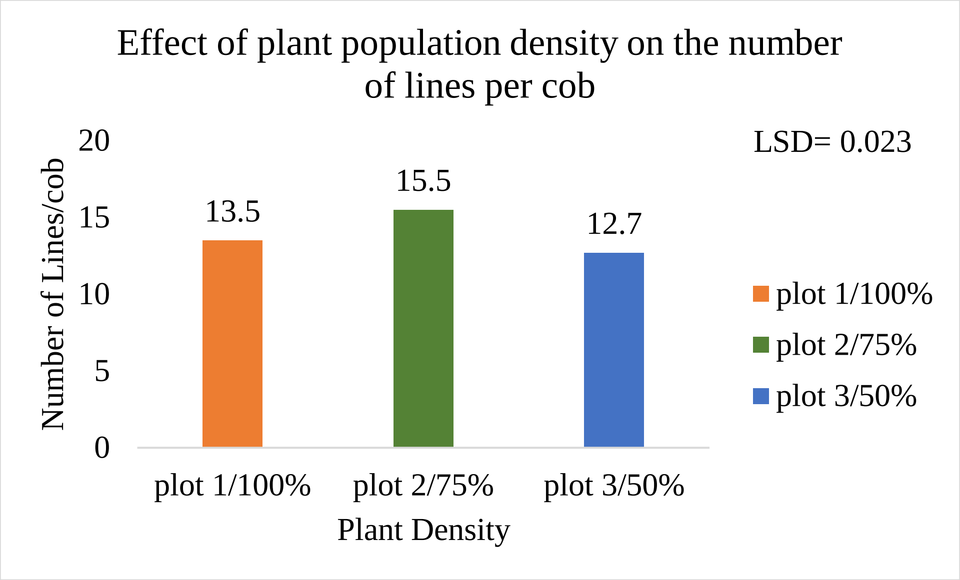

Figure 5: Effect of plant population density on the number of lines per cob

Figure 5 shows the effect of plant population density on the number of lines per cob of maize. The statistical analysis illustrates significant differences among the different levels of plant population. From the graph above, it can be observed that plot 2 with 75% plant population had the maximum number of lines per cob with a value of 15.5. This was followed by plot one with a value of 13.5 and finally, the least being plot 3 with a value of 12.7. Comparison among the plots showed significant differences at $P<0.05$. Plot 2 was significantly different from plot 3 so is plot 1 significantly different from plot 3. This result misaligns with the findings of Sharifi et al. (2009) who reported that the quantity of grain rows/ear was not substantially affected by plant population density. The possible reason for the result obtained could be competition for resources such as water, nutrients, and sunlight. In high-density populations, this could result in lower kernel production per row on cobs due to a lack of resources to support the development of a large number of kernels.

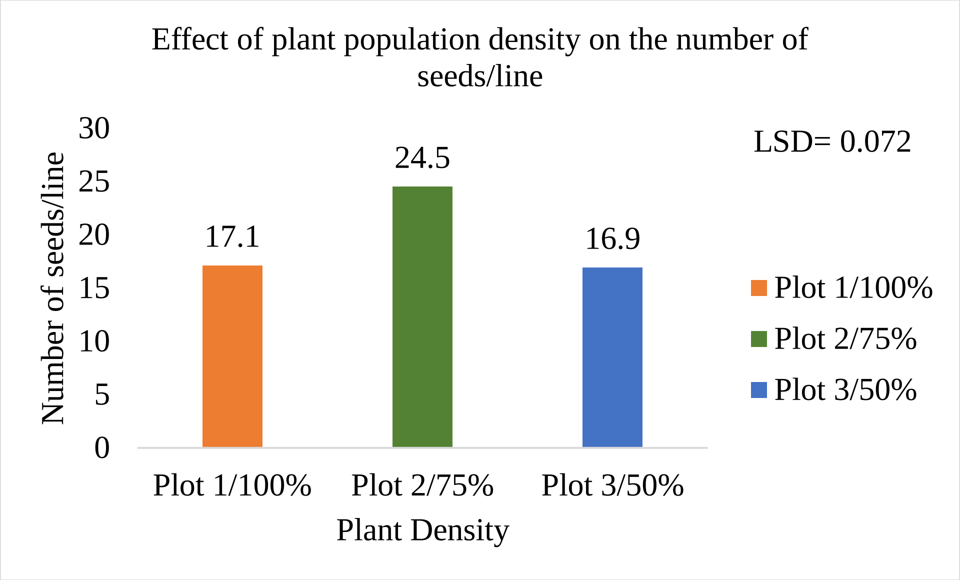

Figure 6: Effect of plant population density on the number of lines seeds per line

Figure 6 demonstrates the effect of plant population density on the number of seeds per line of maize. Plot 2 with 75% population density recorded the highest number of seeds per line at a value of 24.5. Plot 1 had the second highest value of 17.1 whiles plot 3 recorded the least number of seeds per line at a value of 16.9. There were significant differences among the various plots upon analysis at a probability of 0.05. Comparing plots 2 and 3 gave a significant difference so did plots 1 and 2. This was in agreement with studies by Sharifi *et al*. (2009) and Abuzar *et al*. (2011) when plant population density significantly affected the number of kernels/rows. The findings could be attributed to a variety of factors, including the availability of resources such as water, nutrients, and light. Higher plant densities can increase resource competition, reducing the number of seeds produced per plant and line. Maize plants may also respond differently to changes in plant density, resulting in variations in plant growth and development. Lower plant densities can result in more branching and larger ears, resulting in more seeds per line.

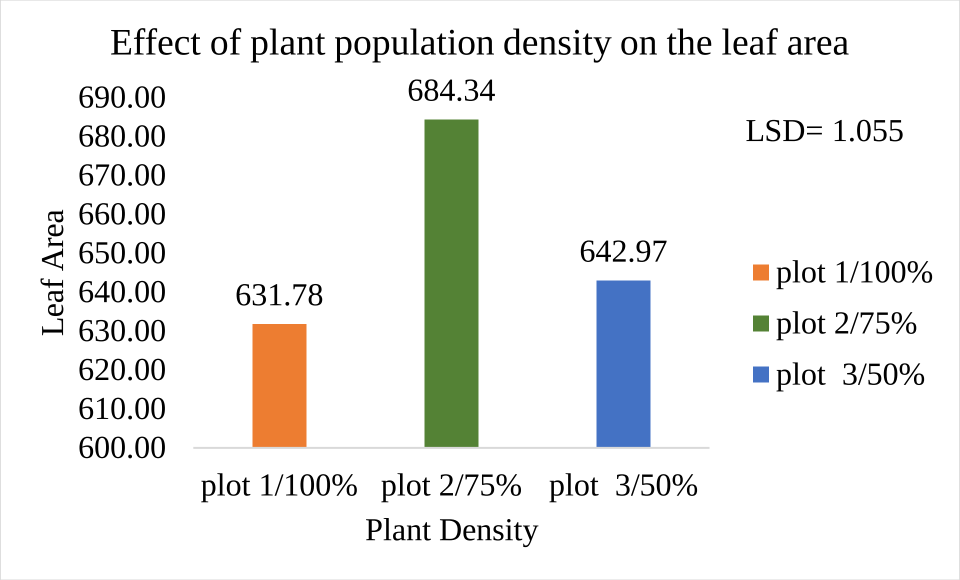

Figure 7: Effect of plant population density on the leaf area

Figure 7 shows the effect of plant population density on the leaf area of maize. Statistical analysis at a probability of 0.05 illustrated no significant differences among the different population densities. From the graph it can be observed that plot 2 with a 75% plant population had the highest leaf area with a value of 684.34cm2, plot 3 with a 50% plant population recorded the second highest with a value of 642.97cm2 whiles plot 1 with 100% recorded the least value of 631.78cm2. Although these values were recorded, the impact of population density on the leaf area was not significant across all plots. This result contradicts the findings of Shi *et al.* (2021) and Marek *et al*. (2016) determined that as plant density increased, maize LAI decreased significantly. According to the study, optimizing plant density could be an effective way to maximize maize yield. This could be because environmental conditions such as soil quality, moisture, temperature, and light availability can be similar across plant densities, masking any potential differences in leaf area. It could also be because the management practices used for all plant densities were similar, resulting in similar growth rates and leaf areas.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the study, the following conclusions can be drawn.

- Although the effect of the three different plant densities on the photosynthetic activity of maize was not significantly different, plot 2 with 75% population recorded the highest value.
- The plant density of maize has a significant effect on plant height. Plot 2 with 75% population density recorded the highest value.
- Regarding the effect of plant density number of leaves of maize, the study found a significant difference among 100, 75 and 50% treatments applied. The number of leaves decreased with decreasing population.
- The three planting densities had significant differences on the stem girth with the treatment of 75% recording the highest value.
- Furthermore, the effect of plant density on the number of lines per cob of maize showed a significant difference among the 3 treatments applied.
- Plant density effect on the number of seeds per line of maize showed significant differences among the three treatments with plot 2 recording the highest value as well.
- Finally, regarding the effect of plant density on the leaf area, the study discovered no significant differences among the 3 plant population densities of maize.

5.2. Recommendation

The study recommends further research be done to agree or contravene with these findings. The reason being that it was a really dry year during the experimental period, hence in a normal year with adequate rainfall, higher plant population density could produce higher yield.

Summary

Thesis title: Agronomic impact on crop yields

Author name: Dr. Katalin Maria Kassai

Course, level of education: MSc Crop Production Engineering

Host Department/Institute: Institute of Agronomy

***Primary thesis advisor:* Dr Katalin Maria Kassai**

This thesis aimed to evaluate the effect of plant population density on maize yield. Maize is a highly productive cereal crop, and its yield potential can be maximized through proper agronomic practices such as improved varieties, irrigation, sowing time, plant population, and balanced fertilizer use. Plant population density is one of the most critical factors that can significantly influence grain yield and other essential agronomic attributes of maize.

The experiment was conducted using a Randomized Complete Block Design with three main treatments, including 100%, 75%, and 50% plant population densities, and two replications. The study was carried out during the summer of 2022 at the research farm of the Hungarian University of Agriculture and Life Sciences, Godollo. The maize variety used was margitta, FAO group 280. Various parameters, including plant height, number of leaves, stem girth, leaf area, photosynthetic activity, number of lines per cob of ten randomly selected plants, and number of seeds per line, were evaluated.

The data collected were subjected to Analysis of Variance (ANOVA) and Microsoft Excel 11, and the treatment means were separated using the Least Significant Difference (LSD) at a 5% level of probability. The results indicated that plant population density significantly affected plant height, number of leaves, stem girth, number of lines per cob of ten randomly selected plants, and number of seeds per line. However, there were no significant differences in the effect of plant population density on leaf area and photosynthetic activity.

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Appendices

Appendix I: Analysis of Variance for the effect of plant density on photosynthetic ability

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	205.0173	2	102.5087	1.880042	0.194866	3.885294
Within Groups	654.296	12	54.52467			
Total	859.3133	14				

Appendix II: Least Significant difference at 5% probability level

Plots	Abs of diff of averages	LSD
1 and 2	8.94	0.149432
2 and 3	5.72	
1 and 3	3.22	

Appendix III; Analysis of Variance on the effect of plant density on plant height

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4998.933	2	2499.467	16.62336	0.0000048	3.219942
Within Groups	6315.067	42	150.3587			
Total	11314	44				

Appendix IV: Least Significant difference at 5% probability level

Plots	Abs of diff of averages	LSD
1 and 2	20.66666667	0.141154

2 and 3	23.73333333	
1 and 3	3.066666667	

Appendix V: analysis of Variance on the effect of plant density on the number of leaves

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.13333	2	6.066667	11.04624	0.00014	3.219942
Within Groups	23.06667	42	0.549206			
Total	35.2	44				

Appendix VI: Least Significant difference at 5% probability level

Plots	abs of diff of averages	LSD
1 and 2	0.733333333	0.008531
2 and 3	0.533333333	
1 and 3	1.266666667	

Appendix VII: Analysis of Variance on the effect of plant density on stem girth

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.592444	2	0.296222	6.204122	0.004358	3.219942
Within Groups	2.005333	42	0.047746			
Total	2.597778	44				

Appendix VII: Least Significant difference at 5% probability level

Plots	Abs of diff of average	LSD
1 and 2	0.08	0.002515
2 and 3	0.273333333	
1 and 3	0.193333333	

Appendix IX: Effect of plant density on number of lines per cob

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	41.6	2	20.8	7.682627	0.002284	3.354131
Within Groups	73.1	27	2.707407			
Total	114.7	29				

Appendix X: Least Significant difference at 5% probability level

Plots	Abs of diff of average	LSD
1 and 2	2	0.023275
2 and 3	2.8	
1 and 3	0.8	

Appendix XI: Analysis of Variance on the effect of plant population on the number of seeds per line

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	375.2	2	187.6	7.2329	0.003052	3.354131
Within Groups	700.3	27	25.93704			

Total	1075.5	29

Appendix XII: Least Significant difference at 5% probability level

Plots	Abs of diff of average	LSD
1 and 2	7.4	0.072039
2 and 3	7.6	
1 and 3	0.2	

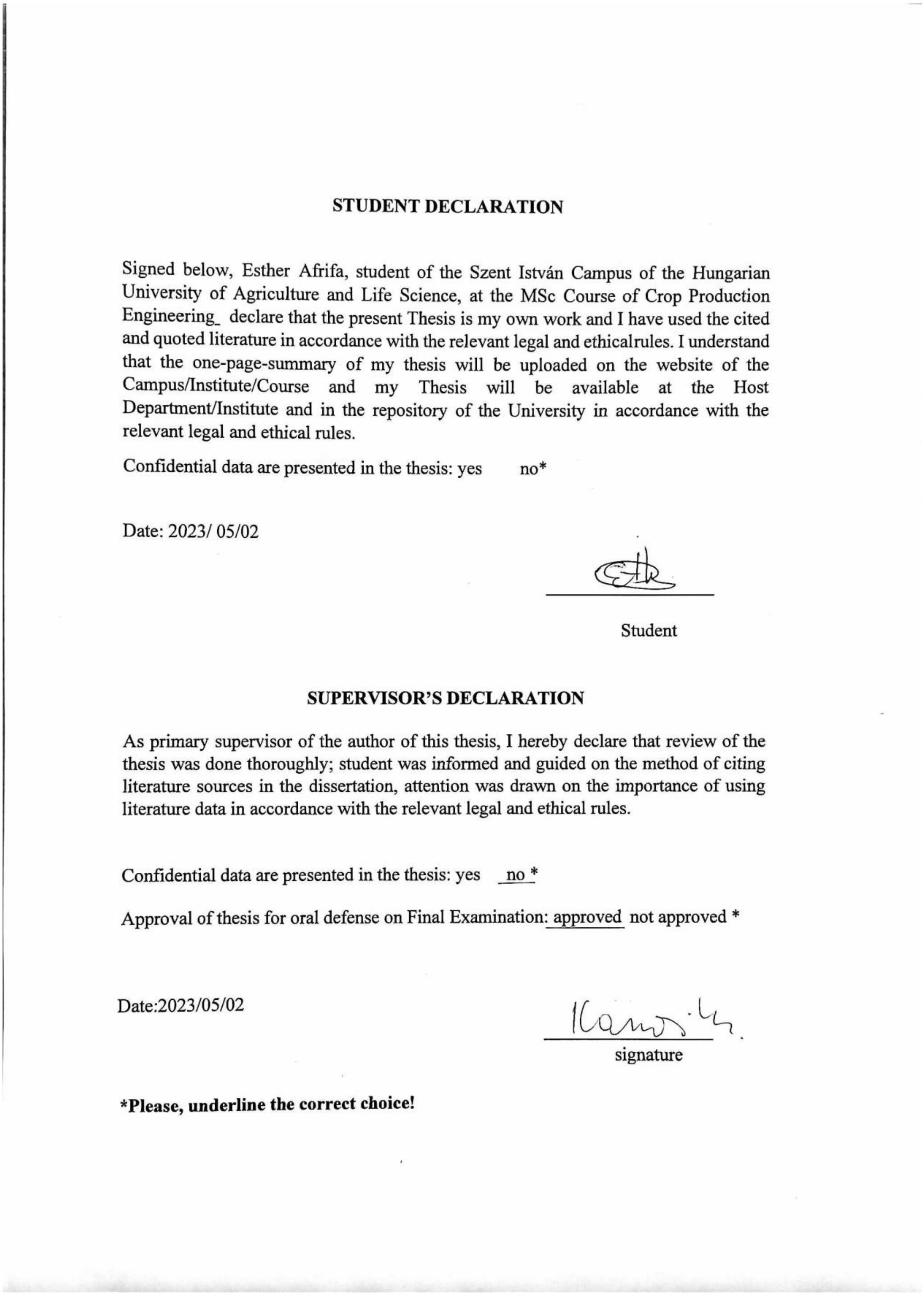
Appendix XIII: Analysis of Variance on the effect of plant population density on leaf area

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22997.35	2	11498.68	1.367338	0.265892	3.219942
Within Groups	353200.5	42	8409.535			
Total	376197.8	44				

XIV: Least Significant difference at 5% probability level

Plots	Abs of diff of averages	LSD
1 and 2	52.56333333	1.055635
2 and 3	41.36666667	
1 and 3	11.19666667	



STUDENT DECLARATION

Signed below, Esther Afrifa, student of the Szent István Campus of the Hungarian University of Agriculture and Life Science, at the MSc Course of Crop Production Engineering_ declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethicalrules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no*

Date: 2023/ 05/02

Student

SUPERVISOR'S DECLARATION

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.

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Approval of thesis for oral defense on Final Examination: [✓ approved] not approved *

Date:2023/05/02

signature

***Please, underline the correct choice!**

DEDICATION

I commit this work to my parents, Mr. Afrifa Yeboah and Mrs. Cecilia Afrifa, my siblings Dorcas Afrifa and Edward Afrifa Manu and to all my loved ones for their support and prayers.