Hungarian University of Agriculture and Life Sciences

THE IMPACTS OF COVER CROP INTERCROPPING TOWARDS MAIZE GROWTH DEVELOPMENT AND YIELD QUALITY

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1. INTRODUCTION AND OBJECTIVES

Maize is consumed by the global population either directly as human food or indirectly through animal feed. In some countries, maize biofuel is already used as one of the fuels for daily vehicles. Maize cultivation is facing various challenges in the form of abiotic stresses and the shrinking of fertile arable land. The persistent climate change has caused intensified and prolonged extreme weather patterns, including drought and extremely high temperatures. The recent drought in 2022 proved the negative impact of extreme weather conditions on maize production in Hungary and all of Europe.

Sustainable intensification in maize cultivation is one of the ways of ensuring global food security and potentially generating energy as a fossil fuel alternative. Intercropping is not a new agricultural method, as it has been documented in various ancient histories. Intercropping systems have been proven to offer various benefits to soil health and quality. The biodiversity in intercropping also improves the crop's resilience towards extreme weather patterns. However, the application of intercropping in large-scale farming is still a challenge for farmers to be involved. The extra knowledge required in managing the system, extra input and labour costs, and, most importantly, the fear of yield loss is one of the reasons farmers are avoiding this system even with the soil-improving benefits provided. It is also important to identify the compatible species combination that not only increases land production but also saves the fertilizer requirement.

1.1 The objectives of this study

i. To evaluate the influence of intercropping different cover crop species on maize vegetative development, yield production, and yield quality.
ii. To determine the effect of nitrogen levels in monocropped and intercropped maize cultivation
iii. To investigate the potential use of cover crops in alleviating salinity and drought stress in maize growth development.

2. MATERIALS AND METHODS

2.1 EXPERIMENTAL RESEARCH 1: Germination test of cover crop under different temperatures and salinity levels

The trial was conducted in the laboratory of the Crop Production Institute of the Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary. Three species of leguminous crops, *Medicago sativa* var. Plato (alfalfa), *Cicer arietinum* var. Dora (chickpeas), and *Trifolium pratense* var. Altaswede (red clover) were germinated at five different NaCl treatments (0%, 0.5%, 1%, 1.5%, and 2%) and at two different temperatures (10°C and 20°C). All seeds were germinated on 13.5 cm Petri dishes containing a single layer of Whatman filter paper in a Memmert-type climatic chamber at 70% moisture. Each treatment was repeated four times, with each petri dish filled with 20 seeds, except for chickpeas, with only 10 seeds per petri dish. All seeds were allowed to germinate at each treatment for 10 days.

The germination rate, radicle, and plumule length were collected after day 10 and were analyzed using Microsoft Excel 2010 for charts, while IBM SPSS Statistics 27 was used for the analysis of variance (ANOVA).

2.2 EXPERIMENTAL RESEARCH 2: Germination test of 16 maize varieties under different temperature and salinity levels

Sixteen maize varieties were used to study the interaction of salinity and temperature on maize seed germination quality. V1 (B1026/17), V2 (TK222/17), V3 (TK15/DV), V4 (TK1083/18), V5 (TK623/18), V6 (MCS901/19), V7 (TK256/17), V8 (GK155), V9 (GK131), V10 (GK154x155), V11 (Szegedi 521), V12 (GK 154), V13 (GK 150), V14 (GK 140), V15 (GK 144x150), and V16 (Margitta). The varieties consisted of nine parental lines, four single-cross hybrids, one three-cross, one double-cross hybrid, and one commercially available hybrid, Margitta hybrid. The seeds were germinated at three different temperatures (15°C, 20°C, and 35°C), with 20°C chosen as the optimal temperature for maize germination. Two sodium chloride (NaCl) concentrations, 0 mM (control) and 100 mM (8.6 dS/m) were used to test the simultaneous effect of temperature and salt stress on germination. Each treatment was repeated four times for all 16 maize varieties. Six seeds from each variety were placed on a 9 cm petri dish containing single-layer filter paper and 10 mL of solution. The Petri dishes were sealed with Parafilm sealing film and were incubated in a Memmert climate chamber with a 70% humidity level for 9 days. The germination percentage (GP) and the length of the radicle (RL) and plumule (PL), root: shoot ratio, and the seed vigour index (SVI) were recorded and analysed. Multivariate analysis of variance (MANOVA) and two-way analysis of variance (ANOVA) at a 0.05 probability level were used to analyse the interaction between the independent variables and the dependent variables using IBM SPSS version 27.

2.3 EXPERIMENTAL RESEARCH 3: The Effect of Nitrogen Fertilization on Maize Growth and Yield in Drought Conditions

A field experiment was conducted to investigate the effect of N levels on the yield and quality of maize at an experimental plot of the Department of Agronomy, Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary, in the 2022 and 2023 growing seasons from May to September. The experimental design utilized a randomized complete block design (RCBD) with three replications, each consisting of 10 plants. Maize seeds were sowed at a density of 75,000 plants per hectare. The experimental site consisted of five observation plots with N levels of 0 kg/ha, 50 kg/ha, 100 kg/ha, 150 kg/ha, and 200 kg/ha, with each plot size of 2 × 4 m. Ammonium nitrate was applied at week four after emergence as the main source of N in early June.

Data collection consists of 3 phases: the vegetative stage data, physical yield parameters, and grain chemical quality. Multivariate analysis of variance (MANOVA) and two-way analysis of variance (ANOVA) at a 0.05 probability level were used to analyse the interaction between the independent variables and the dependent variables using IBM SPSS.

2.4 EXPERIMENTAL RESEARCH 4: The impact of intercropping in alleviating drought and salinity stress in maize cultivation (Pot trial)

The pot trial was conducted in the open area of the experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary, from June to October 2024. The Margitta maize variety was also used in this trial, while alfalfa (*Medicago sativa* var. Plato), white mustard (*Sinapis alba* var. Maryna), and mung bean (*Vigna radiata* L.) were used as the cover crops. Each of the 26 cm pots contained two maize seeds, and each cover crop was sown around the maize seeds the same day as the maize sowing. Alfalfa and white mustard were applied at the rate of 2 g/m^2, while the mung bean was maintained at four plants per pot. The control pots only contain maize without any cover crops. All intercrop and mono-crop pots were subjected to four replications. The pots were subjected to three different treatments: no stress (NS), non-irrigated to impose drought stress (DS), and salinity stress (SS) by application of 100 mM NaCl weekly. The NS and SS pots were irrigated with an automated irrigation system at the rate of 1.3 L per day, while the DS pots were irrigated manually once a week at the rate of 1.3 L per pot until the V7 stage.

The soil moisture and soil temperatures were recorded weekly prior to the daily and weekly irrigation schedule until R1. The vegetative growth, flowering days, and yield quantity were measured and statistically analysed. The dry mass of the aboveground material of the cover crop was also recorded at the end of the study.

2.5 EXPERIMENTAL RESEARCH 5 & 6: Integration of various cover crop species on maize cultivation under different nitrogen levels

The trials were conducted at the experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary, in the 2023 and 2024 growing seasons with different cover crop species tested in each year while the Margitta maize variety was used in both years. In the 2023 trial, four cover crop species were separately integrated in maize rows, including *Medicago sativa* var. Plato (alfalfa), *Trifolium pratense* var. Altaswede (red clover), *Trifolium incarnatum* var. Contea (crimson clover), and *Trifolium repens* var. Romena (white clover). The seeds were purchased from the local producer. As the trial progressed, we eliminated white clover due to its failure to establish itself in the trial plots. Whereas in 2024, trial with alfalfa (*Medicago sativa* var. Plato) was repeated in addition to white mustard (*Sinapis alba* var. Maryna) and mung bean (*Vigna radiata* L.).

The 2023 trials were conducted using a randomized complete block design (RCBD) with three replications, with each replicate consisting of 10 plants, while the 2024 trial was conducted using a strip plot design with three replications, with each replicate consisting of 5 plants. Maize seeds were sown using a Wintersteiger Plotman planter and were planted at a density of 75,000 plants per hectare. The cover crop seeds were applied one day after the sowing by broadcasting the seeds into the soil between the maize rows. The beans were planted at the rate of 4 plants per maize, while the alfalfa and white mustard were applied at the rate of 6 g/m^2. The clover species, including the white clover, were broadcasted at the rate of 4 g/m^2, and the control plot only contained maize plants. After four weeks of maize emergence (V5-V6), N treatment in the form of ammonium nitrate was applied at the levels of 0 kg/ha, 50 kg/ha, 100 kg/ ha, 150 kg/ha, and 200 kg/ha in each of the intercrop and mono-crop plot.

Data collection consists of 3 phases: the vegetative stage data, physical yield parameters, and grain chemical quality. Multivariate analysis of variance (MANOVA) and two-way analysis of variance (ANOVA) at a 0.05 probability level were used to analyse the interaction between the independent variables and the dependent variables using IBM SPSS.

3. RESULTS AND DISCUSSION

3.1 EXPERIMENTAL RESEARCH 1: Germination test of cover crop under different temperature and salinity levels

The germination percentage (GP) of all three cover crop species decreased as the saline concentration reached 1% in both temperature conditions, and all three crops failed to germinate at 2% NaCl. The increase in temperature from 10°C to 20°C improved the GP of all three species, which germinated in 0.5% and 0% saline solution. At 1% NaCl, alfalfa had the highest GP at 20°C but the lowest GP at 10 °C. Meanwhile, red clover had the highest GP at 10°C compared to the other crops, while chickpea was severely affected by the 1% NaCl as the temperature increased to 20°C. Finally, only alfalfa seeds germinated at 1.5% NaCl at 20°C. Meanwhile, the increase in temperature only severely affected the radicle and plumule growth as salt concentration reached 1% for red clover and chickpeas but not for alfalfa. Furthermore, alfalfa also produced the longest radicle and plumule at 20°C in the presence of NaCl, followed by red clover, while chickpeas produced the longest radicle in the presence of 0.5% NaCl at 20°C. Similarly to the GP, alfalfa also produced significantly the shortest radicle and plumule in 1% NaCl at 10°C compared to the other two crops in the same condition. Identically to the RL, chickpeas also produced the longest plumule in the presence of 0.5% NaCl but were severely affected as the salt concentration increased to 1%. Interestingly, alfalfa exposed to 1.5% NaCl at 20°C produced longer radicle and plumule than at 10°C but with a lower salt concentration of 1%.

In conclusion, based on the investigation, increases in salt stress negatively affect the germination and seedling growth of all three crop species in both growing temperatures. In this trial, elevation in salt concentration reduced the germination rate and inhibited radicle and shoot elongation on all three legume species. Based on the germination parameter results, it can be concluded that alfalfa has the highest salt tolerance, followed by red clover and lastly, chickpeas. Furthermore, the germination data reveals that alfalfa had higher salt stress tolerance during germination at 20°C and was more sensitive to salt stress at a lower temperature of 10°C. Based on our results, a slightly saline condition at 0.5% may improve chickpea germination performance to germinate.

3.2 EXPERIMENTAL RESEARCH 2: Germination test of 16 maize varieties under different temperature and salinity levels

The ANOVA results showed a significant effect between the day, salinity, temperature, and variety and their combination on maize germination percentage (GP), radicle length (RL), and plumule length (PL). Maize achieved the highest GP at day 7 of incubation at 20°C and 35°C but needed 9 days to reach the maximum percentage at 15 °C. The salt stress reduced the GP, especially at higher temperatures and reached constant GP on day 5 at both 20°C and 35°C. Meanwhile, the radicle and plumule growth results also showed a growing trend as the incubation days were reduced in length with stress, with a significant percentage reduction at 20°C and 35°C compared to 15°C. Meanwhile, the colder temperature improved the root: shoot ratio, but the salt stress imposed significantly reduced the ratio at all three temperatures. Besides that, the seed vigour index was reduced with the presence of both temperature and salt stress compared to the optimum temperature of 20°C without salt stress present.

Under 100 mM NaCl condition, each variety showed the highest germination performance at different incubation temperatures. Based on the germination parameters studied in this trial, V1 (B1026/17), V10 (GK154x155), and V16 (Margitta) had the highest tolerance to a combination of two abiotic stresses. In contrast, V9 (GK 131) and V13 (GK 150) were the most vulnerable to salt stress, especially at 20°C and 35°C. Meanwhile, all varieties displayed significantly similar sensitivity to the low temperature of 15°C and while most varieties showed the highest growth at 20°C, V4 (TK1083/18), V5 (TK 623/18), V12 (GK 154), and V14 (GK 144) had the highest seedling growth at 35°C.

Based on our results, the temperature changes affected the germination qualities of maize seeds incubated in saline solution, indicating the role of temperature in maize salinity stress response. Combining 100 mM NaCl and a temperature of 35°C decreased the GP and seedlings' growth compared to high-temperature stress alone. At a lower temperature of 15°C, the difference in germination performances was insignificant with or without salt stress. Lastly, we also found that genetic variability within a species leads to differential phenotypic responses between the varieties, even under optimal and stressed growing conditions.

3.3 EXPERIMENTAL RESEARCH 3: The Effect of Nitrogen Fertilization on Maize Growth and Yield in Drought Condition

The ANOVA proved that the year, N treatments, and the interaction between these factors significantly affected maize generative performances, yield quantity, and grain chemical composition. The results showed that maize produced greater vegetative growth and higher yield in 2023 compared to 2022. The grain in 2023 also produced significantly higher starch than in 2022. However, higher protein content was produced in 2022 regardless of the N supply, while significantly higher oil content was produced in 2022 at a higher N rate of 150 – 200 kg/ha. In both years, the maize's whole performance gradually improved as the N rate increased. In both years, the maize reached the kernel weight and kernel number per ear at 150 kg/ha N. The starch content in 2023 continuously increased as N increased to 200 kg/ha, but the starch content in 2022 showed no significant increase at 150 kg/ha and 200 kg/ha N.

Based on the data from the meteorological tower at the experimental field, the field received significantly lower precipitation and higher temperatures in 2022 compared to 2023. Our results showed that the drought caused significant damage to the maize growth and yield harvested. Our result also found that drought stress and high temperatures in 2022 significantly decreased starch content but increased protein and oil content in maize grains. Drought stress experienced throughout the grain-filling stage leads to a decline in photosynthetic activity, triggers premature senescence, and decreases the length of the grain-filling duration. Increasing the N levels helps to increase the growth and yield, but it did not reach the same level as maize cultivated in better climatic conditions. The study also found that farmers should avoid the application of N more than 150 kg/ha to maintain the economic benefit of the maize production.

3.4 EXPERIMENTAL RESEARCH 4: The effect of different cover crops on maize growth development under drought and salinity stress (Pot trial)

The ANOVA results found that the type of cover crops and stress treatments, significantly affected the soil moisture, soil temperature, maize leaves area, SPAD value and flowering parameters. Meanwhile, maize height, ear weight and ear length were only significantly affected by individual effects of the factors. The salinity and drought treatment decreased the soil moisture content compared to the no stress treatment, with drought treatment causing the worst moisture loss.

The presence of alfalfa, mung bean, and white mustard lowered the soil temperature at NS and SS treatment. The soil coverage by alfalfa was found to be the best in retaining soil moisture and temperature in drought conditions compared to the mung bean and white mustard. Regarding maize performance, intercropping leguminous crops significantly improved the maize vegetative growth in stress conditions, while white mustard was detrimental to maize growth.

Furthermore, it was discovered that maize-legume intercropping improved maize flowering performance by reducing the anthesis-silking index (ASI) in salinity and drought stress. In contrast, sole maize and maize intercropped with white mustard had significantly higher ASI, which reduced the successful pollination rate and affected maize ear formation. The legumes intercropping also produced maize ears with significantly higher than no covered pots, while white mustard caused a significant decrease in the ear size produced. Lastly, in NS and SS, mung bean produced the highest biomass compared to alfalfa, while alfalfa produced the highest biomass in drought conditions.

In conclusion, the DS was more detrimental to the growth of maize than the SS in both mono-crop and intercropped systems with higher ASI, which caused failed pollination that affected yield formation. Even though SS was less damaging than DS in this experiment, the stress imposed by the presence of salt significantly reduced maize vegetative and reproductive growth. In terms of maize's best companion, alfalfa was the best choice to plant in drought conditions as it improved the maize performance and also produced significantly the highest biomass at the end of the experiment. Meanwhile, mung bean also improved maize performance in NS and SS while producing heavier dry biomass to alfalfa in both NS and SS conditions. Besides the potential seeds harvested, the higher residue produced also shows the multipurpose properties of this bean species. Lastly, white mustard had a low survival rate in dry conditions, causing exposure to the soil surface, which increased the temperature and moisture evaporation in drought conditions. Besides that, intercropping maize with white mustard revealed a competitive effect on the maize, resulting in a reduction in vegetative growth and reproductive development in NS and SS. It can be concluded that white mustard competes for water and nutrients with the main cash crop, in this case, maize compared to the leguminous cover crops.

3.5 EXPERIMENTAL RESEARCH 5: Integration of different leguminous cover crops on maize cultivation under various nitrogen levels in 2023

The ANOVA revealed that the cover crop types and N treatment had significant effects on all maize generative performances, yield quantity, and grain chemical composition, which included plant height, SPAD values, LAI, kernel weight, and grain starch content. The interaction between these factors also had significant effects on all dependent variables except for maize leave area, ear length, and grain: cob ratio.

Maize intercropped with red clover (MRC), crimson clover (MCR), and alfalfa (MA) produced a significant height improvement at low N levels of 0 and 50 kg/ha. At 100 – 200 kg/ha N, no significant height differences were observed between the MCR, MRC, and MM, while alfalfa reduced the maize height at 100 and 150 kg/ha N. Besides that, MCR and MRC also improved the maize leave area and leaves area index (LAI) compared to the MA, which was also influenced by N levels. All three cover crops improved maize SPAD readings at 0 and 50 kg/ha, but as the N level increased to 200 kg/ha, only MCR and MRC improved maize SPAD levels, with MRC producing the highest value.

Furthermore, all three cover crops also significantly improved maize ear length (EL) and ear weight (EW) at 0 and 50 kg/ha N, while only MCR and MRC improved EL and EW at 150 and 200 kg/ha N compared to MM. The MCR and MRC also increased EW as N increased to 200 kg/ha while MM reached a maximum EW level at 150 kg/ha N. Meanwhile, the intercropped system also produced higher grain:cob ratio (G:C) and kernel weight per ear (KW) compared to MM at 0 kg/ha N. The MRC and MCR improved both variables at 150 and 200 kg/ha, while MA only improved the G:C ratio. The elevation in N levels improved the MM TKW against the intercropped system except for MRC. Increasing the N level by more than 150 kg/ha significantly decreased the TKW in MRC.

The NIR analysis found that MRC produced higher oil, protein, and starch content than MM, regardless of the N levels. The MCR also produced higher starch content at all N levels. However, the protein content showed significant differences only with addition of N fertilizer, and the oil content produced a higher value than MM at N levels between 100 – 200 kg/ha. Meanwhile, MA improved maize starch content only at lower 0 and 50 kg/ha N but showed no significant difference at a higher N rate than MM. MA increased maize protein content in the presence of N treatment, while the oil content was not improved except at 50 kg/ha N. Lastly, the dry mass data showed that red clover produced the highest dry mass from the aboveground residues, followed by alfalfa and crimson clover. Based on our results, intercropping maize with leguminous cover crops could improve maize performance with the right choice of cover crop species and N rates of 150 kg/ha for optimum yield production.

3.6 EXPERIMENTAL RESEARCH 6: Integration of leguminous and *Brassicaceae* cover crops on maize cultivation under various nitrogen levels in 2024

The ANOVA revealed that the cover crop types, N treatments, and their interaction significantly affected all maize generative performances, yield quantity, and grain chemical composition, which included plant height, SPAD values, LAI, kernel weight, and grain starch content. The study found that intercropping maize with white mustard (MWM) significantly reduced all maize growth and yield parameters except for protein content. White mustard caused a reduction of around 20.3 – 27.4% in maize TKW and 1.04 – 2.2% starch reduction in maize kernel. However, MWM produced the highest protein content at 100 kg/ha compared to the other treatments, but the percentage was lower than that of MM at 150 and 200 kg/ha N.

Meanwhile, it was discovered that maize intercropped with mung bean (MMB) had better growth and yield performance except for the protein content at almost all N levels. It was found that MMB produced up to 14.5% lower protein content than MM. Nevertheless, MMB produced significantly the highest yield quantity elevation, including 29.8% grain number, 34.5% kernel weight/ear, 16.35% TKW, and 2.2 % starch content compared to MM.

The results also showed that the MA had higher growing and yield performance compared to the MA cultivated in 2023, especially at higher N levels between 100 and 200 kg/ha N. In 2024, MA improved maize grain: cob ratio, kernel weight/ ears, and TKW at almost all N levels. MA also improved maize starch content with N treatments, but there was no significant difference in the oil content, while protein content was only significantly higher at 200 kg/ha N.

Lastly, all cover crops achieved the highest dry mass at 150 kg/ha N, with mung bean showing the highest value compared to alfalfa and white mustard. Besides that, mung bean also managed to produce seeds, which was also significantly affected by the increase in N rate.

In conclusion, the success of the intercropping system was highly influenced by species combination, nitrogen levels, and climatic factors.

Intercropping maize with leguminous cover crops could improve maize performance, while the white mustard from the *Brassicaceae* family was detrimental to the companion maize plant unless a higher protein content was demanded. The inconsistent MA performance between the two years showed that leguminous intercropping may not bring significant improvement to maize yield production while requiring extra cost in terms of seeds and management.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The study performed on the germination test on three different legume species, alfalfa, red clover, and chickpeas, revealed the significant effect of temperature and salinity in influencing the seedlings' germination rate, radicle length, and plumule. The study found that increasing the temperature improved the germination rate at low salt concentrations in all three species, but increasing salt concentration reduced the germination rate at higher temperatures for red clover and chickpeas. Alfalfa displayed a higher tolerance to salt stress with the highest germination rate at 20°C and 1% NaCl and the ability to germinate at 1.5% NaCl. Besides that, the radicle and plumule growth also showed a gradual reduction as the salt concentration increased in all temperatures, while higher temperatures improved the final length of the radicle and plumules compared to low temperatures. Based on all the parameters, it was concluded that chickpeas had the lowest tolerance to salt stress compared to alfalfa and red clover.

Besides that, the study performed on several maize varieties found the significant effects of incubation days, salinity, temperature, and their interaction on maize germination performance. The study found that the combination of high temperature and salinity was more detrimental to germination initiation and seedlings' growth than the combination of low temperature and salt stress. At low temperatures, germination performance was significantly lowest regardless of the presence of salt stress. Furthermore, within the same species, the varietal effect was significantly affecting the high temperature and salt tolerance in maize. Under salt stress conditions, several varieties performed better at 35°C than at 20°C. The established Margitta variety proved to have the most tolerance to salt stress and high temperature, with an excellent germination percentage and seedling growth compared to the other tested varieties. This result provides an important input for farmers in choosing the appropriate varieties that are most compatible with their land soil and climate conditions.

Furthermore, the study also discovered the impact of different climatic conditions on nitrogen fertilizer efficiency in maize crop development. The results revealed that maize cultivated in 2023 was more productive than maize in 2022 in growth and yield productivity. The meteorological tower in the study site recorded that the field received significantly higher precipitation and lower average temperature in 2023 than in 2022. The grain number and TKW results showed that the optimum rate of N fertiliser was between 100 and 150 kg/ha. Regarding grain nutrient content, the drier climate in 2022 produced grains with lower starch but higher protein and oil than grain produced in 2023. Meanwhile, to produce grains with optimum starch content, 150 kg/ha N was the ideal rate in 2022, while in the wet year of 2023, increasing the N rate up to 200 kg/ha was still beneficial in influencing the increase in grain starch content.

The pot trial revealed drought stress was more detrimental than salt stress in maize development. The study found drought stress stunted maize vegetative growth and increased the anthesis-silking index, preventing successful pollination more severe than salt stress. Intercropping alfalfa or mung bean with maize improved the performance of maize crops in salt and drought stress conditions. However, alfalfa's beneficial effect on maize growth was superior than mung bean in drought conditions. Intercropping white mustard and maize amplified the abiotic stress effects as this species competes with the essential element of maize crops. Maize intercropped with white mustards had worse vegetative growth and reproductive development than sole maize without companion crops.

The intercropped field trials found that integrating leguminous cover crops promoted maize productivity. In both studies, planting the companion leguminous crop seeds immediately after maize sowing improved the maize yield productivity. It was revealed that mung bean, red clover, and crimson clover improved various vegetative and yield parameters in maize, which were also positively influenced by the N level. Based on the TKW and starch content results, all leguminous cover crops tested have the potential to reduce the N requirement in maize cultivation compared to *Brassicaceae* species. Alfalfa provided better benefits to maize at lower N levels in the wetter year 2023 but did not change maize performance at higher N levels. However, in the relatively drier year of 2024, alfalfa significantly improved the maize performance at all N levels. The study also showed that white mustard was not a compatible companion to maize crop as it reduced maize vegetative growth, yield quantity, and grain starch content. However, intercropping maize and white mustard significantly increased the protein content in maize compared to intercropping maize-leguminous species.

Therefore, all the data presented from all six studies will provide several guidelines for farmers and producers in selecting the most appropriate crop species and varieties to be cultivated, especially in abiotic stress conditions. The studies also showed the optimum nitrogen level application in various intercropping and climate conditions. The final maize yield quantity harvested and chemical composition should be considered by farmers when deciding on the compatible intercropping combination. Lastly, the results will hopefully encourage farmers to intensify their land production in a more sustainable direction.

4.2 Recommendation

In this study, we broadcasted the cover crop seeds between the maize rows. Future studies should consider using an interseeder machine between the maize rows to plant the cover crops. Drilling the cover crop seeds into the soil allows seeds to be in full contact with the soil particles and allows a higher germination rate than the broadcasting technique. Besides reducing the amount of cover crop seeds required, it can save more time and energy required for the cover crop integration between the maize.

Future studies should include the land equivalent ratio (LER) and nitrogen use efficiency (NUE) analysis in the intercropping studies. The LER study requires the cover crop cultivation to be planted separately and requires an extra study area. Overall, economic benefits analysis should be carried out with consideration of every input required for the intercropping system.

Future studies should investigate the impact of white mustard sowing time in relation to maize sowing time in reducing the competition effects in maize. White mustard is a very vigorous species that enters the reproductive stage after 4 weeks of planting. Meanwhile, maize was only at the V4 stage at the same length of period.

Future studies should also consider the study on impact of mixed cover species intercropped with maize instead on single species cover crop intercropping. However, optimum rate of each species in the mixtures should be carefully calculated to minimise negative implication on main crop development and yield.

In this study, we carried out a pot trial to investigate the effects of intercropping in salt and drought stress conditions. This study can be improved by increasing the sample size and usage of bigger pots for maize cultivation. The drought plots should be protected from being exposed to natural precipitation. The nodulation density of the leguminous cover crop can also be analysed throughout the study.

Besides that, future studies should also investigate the effect of the intercrop system on the yield and nutrient composition produced by the cover crop species. As cover crops have value in forage industries, the potential profit added is essential to compensate for the additional seed cost farmers invest.

Further studies should also investigate the effects of delayed nitrogen application on the nodulation formation in the intercropping system.

5. NEW SCIENTIFIC RESULTS

1. The study found that alfalfa has the highest salt tolerance in the germination stage compared to red clover and chickpeas.

2. Genetic variability in maize significantly influences maize salt tolerance. High temperature conditions intensified saline stress during the germination phase of maize more significantly than lower temperatures.

3. Drought conditions in 2022 severely decreased maize productivity but increased the protein content regardless of the N levels. Application of nitrogen over 150 kg/ha was not economical as it did not improve the yield quantity and starch content in the dry year. However, increasing N to 200 kg/ha increased starch content in the wet year 2023 but not the yield quantity.

4. Alfalfa and mung bean species helped in increasing salt and drought stress tolerance in maize cultivation. However, alfalfa was more recommended in drought stress conditions than mung bean.

5. The leguminous intercropping system allows maize to increase yield performance at a higher nitrogen level of 150 kg/ha, which was stagnant in the mono-crop maize system.

6. White mustard was not suitable for intercropping with maize as it heavily competes for nutrients and water, which negatively affected the growth and maize yield. However, white mustard improved maize protein content compared to leguminous companion crops.

7. Based on the experimental field weather conditions, simultaneous maize and cover crop sowing allowed better cover crop establishment. Early cover crop sowing helped the crop to be stronger against warmer and drier weather in the later growing period. The early establishment also allowed the cover crops to utilise maximum solar radiation before being covered by maize canopy. Besides that, early sowing may allow the rhizobium nodule to form before chemical nitrogen application.

6. PUBLICATIONS

6.1 List of Publications Related to the Topic of Dissertation

1. **Khalid, N.,** Tarnawa, Á., Balla, I., Omar, S., Abd Ghani, R., Jolánkai, M. and Kende, Z. (2023). Combination Effect of Temperature and Salinity Stress on Germination of Different Maize (Zea mays L.) Varieties. Agriculture, 13(10), p.1932. https://doi.org/10.3390/agriculture13091836.

2. **Khalid, N**., Sghaier, A.H., Jolánkai, M., and Tarnawa, Á. (2023). The role of temperature on the germination activity of leguminous crops exposed to saline conditions. Időjárás, 127(2), pp.253–265. https://doi.org/10.28974/idojaras.2023.2.6.

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5. Omar, S., Abd Ghani, R., **Khalid, N**., Jolánkai, M., Tarnawa, Á., Percze, A., Mikó, P.P. and Kende, Z., (2023). Effects of Seed Quality and Hybrid Type on Maize Germination and Yield in Hungary. Agriculture,13(9), p.1836. https://doi.org/10.3390/agriculture13091836.

6. Binti Omar, S., Binti Abd Ghani, R., **Binti Khalid, N**., Tarnawa, Á., Kende, Z., Kassai, M. K. and Jolankai, M. (2023). Impact of N Supply on Some Leaf Characteristics of Maize Crop. COLUMELLA – Journal of Agricultural and Environmental Sciences, 10(1), 15–25. https://doi.org/10.18380/SZIE.COLUM.2023.10.1.15.

6.2 Conference Presentation Related to the Dissertation Topic

1. **Khalid, N**., Sghaier, A.H., Jolánkai, M., Balla, I. (2023) The role of temperature on the germination activity of leguminous crops exposed to saline conditions. Oral presented in The Youth Science Forum, 8 June 2023, Keszthely, Hungary.

2. Omar, S., Abd Ghani, R., **Khalid, N.**, & Jolánkai, M. (2023). Evaluation of maize inbred lines and hybrids for agronomic characteristics, yield, and grain quality. Oral presented in Youth Science Forum, 8 June 2023, Keszthely, Hungary.

6.3 Other Scientific Publications of The Author

1. Abd Ghani, R., Omar, S., Jolánkai, M., Tarnawa, Á., Kende, Z., **Khalid, N.**, Gyuricza, C. and Kassai, M.K. (2023). Soilless Culture Applications for Early Development of Soybean Crop (Glycine max L. Merr). Agriculture, 13(9), p.1713. https://doi.org/10.3390/agriculture13091713.

2. Abd Ghani, R., Omar, S., Jolánkai, M., Tarnawa, Á., **Khalid, N**., Kassai, M.K. and Kende, Z. (2023). Response of Shoot and Root Growth, Yield, and Chemical Composition to Nutrient Concentrations in Soybean Varieties Grown under Soilless and Controlled Environment Conditions. Agriculture, 13(10), p.1925. https://doi.org/10.3390/agriculture13101925.

3. Abd Ghani, R., Jolánkai, M., Omar, S., **Khalid, N**., & Tarnawa, Á. (2023). Influence of temperature and variety on seed germination of soybean (Glycine max L. Merr) at different germination times. Acta Agraria Debreceniensis, 2, 5-12. https://doi.org/10.34101/actaagrar/2/13171.

6.3 Other Conference Presentation

1. Sghaier, A.H., Khalid, N., Omar, S., Varga, A., and Kende, Z. Methodological approaches to the germination of sunflower and oilseed rape in vitro. Oral presented in Youth Science Forum, 8 June 2023, Keszthely, Hungary.

2. Abd Ghani, R., Kende, Z., Tarnawa, Á. Omar, S., Kassai, M.K., Jolánkai, M., & Khalid, N. (2023). Nitrogen nutrition and weed management effects on yield and chemical composition of soybean (Glycine max L. Merr). Oral presented in Youth Science Forum, 8 June 2023, Keszthely, Hungary.