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RESEARCH ARTICLE

MAIZE-SOYBEAN INTERCROPPING WITH ORGANIC FERTILIZATION AS A SOLUTION TO ENHANCE CROP AND SOIL PRODUCTIVITY

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Abstract

An ever-increasing population and a decreasing cultivated land are challenging global food security. There is a massive difference between domestic production and demand. It is critical to improve the various index of land in order to secure food for future generations. Intercropping maize and soybeans can be a successful approach for addressing the gap between supply and demand. Due to low crop production per unit area, insufficient crop diversity, a lack of quality seeds and fertilizers, poor crop management, and the unfavorable effects of climate change. The experiment was conducted to understand the relationship of maize-soybean intercropping system with farm yard manure as a source of fertilizer. Our results showed that the farm yard manure has positively affected the overall soil fertility and also improved the crops production. Farm yard manure addition has given more fruitful results under maize-soybean intercropping. Maize-soybean intercropping with farm yard manure had a significant impact on growth and grain yield of both maize and soybean. The agronomic parameters; plant height, shoot dry matter yield, grain yield and nitrogen uptake were recorded highest in the farm yard manure treatment under maize-soybean intercropping. Similarly, soil building attributes; soil pH, total organic carbon, dissolved organic carbon and soil mineral nitrogen were positively affected by the interaction of farm yard manure and maize-soybean intercropping. Overall, we have concluded that maize-soybean intercropping system is most resilient cropping system with the implementation of farm yard manure to improve the crop productivity, soil health and to overcome the impact of climate change.

Introduction:-

In Pakistan, in future, crop productivity will be affected by the irrational cropping system adopted by the farming community. The existing cropping systems in the country showed a declining trend in production because of none judiciously use of applied (cultivation, fertilizers and pesticides) resources. Until these challenges are handled on scientific lines, the declining yield trend combined with rapid population growth will remain a severe pressure and

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threat in the country (Rasool et al., 2007). In Pakistan, rainfed and irrigated agriculture need to be redesigned according to the need of local community and available resources. Therefore, it is necessary to introduce new cropping technology (Maize-Soybean Strip Intercropping Technology) in Pakistan under organic farming system so that it is environmental friendly and sustainable (Raza et al., 2020). The evaluation of maize-soybean strip intercropping itself will be a big achievement for food, feed and forage purposes that can be grown under limited water and nutrient resources in dryland areas of Punjab (Iqbal et al., 2019).

Furthermore, introduction of mechanical agriculture has been required by decreasing labour availability and growing population (Ven Den Berg et al., 2007; Zhang et al., 2017). Modernization needs a changing room demand under intercropping situations; this is determined by the crop width setting. Crop strips of the proper thickness reduce the risks posed by mechanical tools or procedures (Xiwen et al., 2015). In the future, crop production will be impacted by the farming population in Pakistan. The existing cropping system in all arid and irrigated areas like (Wheat fallow system) showed a turn down trend in production because of not sensible use of natural resource (soil, water, light and radiation use) and applied inputs (nutrients and cultivation). With the rapid increase of population decrease in yield of crops is a serious issue and will remain a serious danger in the country till the time these issues are not inscribe on scientific lines. In Pakistan, agriculture (Rainfed /Irrigated) needs to be modifying with the needs of local people. The cropping method, which is more effective in using the available resources and less reliant on applied resources, needs to be rejuvenated. Agronomy experts and policymakers are increasingly interested in incorporating legumes (Soybean, for example, is a nitrogen-fixing crop) into existing cropping schemes to bring down outsider nitrogen inputs and boost natural nitrogen fixation (Rose et al., 2019). Therefore, to achieve large crop yields with fewer inputs, researchers have established several intercropping systems. Researchers have already established the benefits and worth of the maize and soybean strip-intercropping system. (Yu et al., 2016; Du et al., 2018; Iqbal et al., 2019; Raza et al., 2019).

Among the cereal-legumes strip-intercropping technology, the maize and soyabean strip-intercropping system is the best is the best intercropping system in terms of yield strength (resource utilization. i.e.; light, land, water and some nutrients (Iqbal et al., 2019; Raza et al., 2020), and financial profit (Raza et al.,2019). In the maize and soyabean strip-intercropping system, sometimes maize yield is equal or often it is greater than the sole maize yield (Feng et al., 2019; Raze et al., 2020). Such intercropping improves the soil quality (Chen et al., 2019) and increases the accessibility of vital plant’s nutrients, i.e. NPK, to intercrop species (Zhou et al., 2019). This scheme can also be the future planting system that will successfully replace the rainfed areas with the summer fallow system.

Maize-soybean is multipurpose crops, and these crops will address the food, feed and forage issues. In addition, this method may provide biodiversity by making more productive use of natural resources, particularly sunlight, which is the most important factor in the strip intercropping technology (Xia et al., 2019). The strip intercropping system of maize and soybean strips will be helpful in minimizing the evaporation losses of summer rainfall water, high fertilizer uses and cultivation compared to traditional cropping systems in the country's rainfed regions. The water deltas for maize and soybean are 15cm and 10cm, respectively, implying that the intercropping system of maize and soybean would be a viable crop system for water-stressed regions and countries like Pakistan (Olmedo & Vyn, 2021).

Substantially, under the maize-soybean intercropping system, soybean being an effective N fixing crop could meet the partial N demand for maize, which will decrease the N application rate for maize (Du et al., 2018). Resource productivity research will definitely minimize farmer’s spending in the form of unsustainable summer irrigation for moisture storage and weed control and intense chemical spray in the form of fertilizers and application of herbicides in the hope of having a good yield (Nemecek et al., 2008).

The maize-soybean strip intercropping system will provide an alternative cropping system in Pakistan that will increase cereal and legume production by replacing the exhaustive cropping system, especially in dry land agriculture. As a result, with a feasible site-specific technology for the country's major agro-ecological regions, it can provide productivity, entrepreneurship, and inhibit rural migration to urban areas, allowing small farm farmers to grow more and understand sustainable resource use pathways (Chen et al.,2017)

Materials and Methods:-

Research Location

The field experiment was done at PMAS-Arid Agriculture Research Farm Koont Chakwal Road, Rawalpindi in Punjab Province with latitude of 33.6492N, longitude 73.081E and altitude of 508m above sea level. The experimental site features sub-tropical and humid conditions. During the experiment, the temperature of the site varied from 23°C to 40°C, with an average of 31°C.

Planting Material

Maize (Monsanto-6317) and soybean (NARC-2016) was selected for planting during the experiment. The variety of maize and soybean was planted in spring season. The sole verities of maize and soybean were also planted.

Treatments

Cropping Systems

Sole Maize (SM)
Sole Soybean (SS)
Maize-soybean Intercropping (IMS) with ratio of 2:2

Nutrient Management

Control (C)
Farm Yard Manure (FYM) applied at recommended dose of N

1. For sole maize recommended dose of N is 250kg/ha.
2. For sole soybean recommended dose of N is 25kg/ha.
3. For maize-soybean strip intercropping recommended dose of N is 72kg/ha.

Planting Pattern

1. R×R spacing for sole maize and soybean was 60cm and 50cm, respectively.
2. R×R spacing for intercropping maize and soybean was 40cm.
3. P×P distance of sole maize and soybean was 24 and 20cm, respectively
4. P×P of intercropping maize and soybean was 17 and 10cm, respectively.

Cultivars

NARC-16 cultivar of soybean and Monsanto 6317 cultivar of maize was used in the experiment.

Soil Analysis

The pH of the soil was determined by using pH meter with combined electrode (Model – Hanna, sensitivity ± 0.01). Prior to the estimation of pH, the instrument was calibrated with buffer solutions of pH 4, 7 and 10.20 g air dried soil was mixed with 20 ml deionized water to make 1:1 slurry. The slurry was agitated thoroughly for 30 minutes to stabilize the pH and then combined electrode was immersed to take the reading. The same procedure was adopted for each sample (Lu, 2000). The total organic carbon (TOC) and dissolved organic matter (DOC) were determined using the Walkley-Black method, with slight modifications (Nelson and Sommers, 1996). Soil mineral nitrogen was determined by the Kjeldahl method (Bremner, 1996).

Measurement of Ammonia (NH_3) volatilization

The dynamic chamber method was employed for NH_3 volatilization collection. The NH_3 collection device (Fig. 1) includes a soil incubating jar with an air inlet opening by the side to allow air exchange within the soil chamber. It also consisted of another jar that contained 30 ml of 0.05 mol/l H_2SO_4 for NH_3 gas trapping, this jar was stopped and fitted with an inlet and outlet pipe. The outlet pipe was connected to the airflow meter while the inlet pipe was connected to the soil chamber. The airflow meter was also connected to the vacuum pump. Te basic principle behind the NH_3 volatilization collection device is for the vacuum to serve as a power source. Here, the NH_3 in the soil chamber is replaced by air while the evaporated air enters the absorption jar together with the pumping airflow. This device ensures aeration and traps NH_3 loss through the volatilization process. The NH_3 gas was sampled for one hour per sampling period with airflow of 2 l min^{-1}. Ammonia volatilization was monitored consecutively for the first 5 days and continued every week till day 49 after treatment application. The gas trapped in 0.05 mol/l H_2SO_4 at each sampling time was analyzed calorimetrically on a UV-spectrophotometer using the nesslerization method. Briefly, an aliquot of 5 ml of the NH_3 trapped in 0.05 mol/l H_2SO_4 was pipetted into a test tube followed by the addition of 200µml of the ammonia color reagent (nesslerization reagent) (Andreas et al., 2006). The mixture was shaken vigorously on a vortex shaker and left for 15 min to enhance coloration at room temperature. Absorbance was thereafter read on a UV–VIS spectrophotometer at 425 nm. The NH_3 emission was calculated using the equation below, (Rafael, 2011)

$$ER = Q\,(C_e - C_i)W_m T_{std} Pa \,/\, 10^6 V_m T_a P_{std} \times 10^3$$

Where, ER: emission rate (mg min^{-1}). Q: Air flow rate into the chamber (l min^{-1}). C_e: gas concentration of air leaving the chamber (mg kg^{-1}). C_i: gas concentration of air entering the chamber (mg kg^{-1}). W_m: Molecular weight of the gas (g mol^{-1}). V_m: molar volume at standard temperature (0 °C) and pressure (101.325 kPa), 22.4 l mol^{-1}. T_{std}: standard temperature, 273.15 K. Ta: temperature of the sample air, K (273.15 + sample air °C). P_{std}: standard pressure, 101.325 kPa. Pa: local barometric pressure, kPa.

Measurement of Nitrous Oxide (N_2O) emission

The assessment of N_2O emission from soil was performed following standard protocols (Rochette et al., 2012). Briefly, air was sampled from static chambers [0.4 m × 0.8 m × 0.3 m (L × W × H)] mounted over a base (0.09 m high) inserted 0.06 m into the soil. The headspace volume of the chambers averaged 105.6 L. The chambers were equipped with three internal fans to homogenize the internal atmosphere, a probe thermometer for monitoring the chamber air temperature, and a rubber septum from which air samples were taken through a plastic tube closed by a three-way "luer-lock" valve. Gas was sampled between 10 and 12 a.m. on a daily basis for the first 45 days. Afterwards, samples were collected at least every other day. Chambers were closed and sealed with water to avoid air exchange between the chamber and the atmosphere. Time zero samples were collected outside the chamber, while the samples from the chambers atmosphere were collected after 15, 30, and 45 min. The fans built in the chamber were activated for only 30s prior to sample collection to minimize bias in N_2O efflux resulting from forced convection of the internal atmosphere of the chambers. The samples were collected with a set of two 60 mL polypropylene syringes united by three-way "luer-lock" valves, totaling 120 mL of sampling volume. The syringes were stored in a cooler and analyzed within 3h after collection. Soil N_2O-N emissions were determined as follows:

$$Q = (N \times MWR \times P \times V)/(R \times T) \qquad (1)$$
$$f = (\Delta Q/\Delta t)/A \qquad (2)$$

Where: Q is the mass of N_2O-N inside chamber (ng N_2O-N); N is the concentration of N_2O measured by the gas analyzer (nmol N_2O mol^{-1} air); MWR is the molecular mass ratio of N_2O to N_2O -N (28 ng N nmol−1 N2O); P is the partial gas pressure (assumed as 1 atm); V is the volume of the chamber (L); R is the ideal gas constant (0.0821 atm L mol^{-1} K^{-1}); T is the gas temperature (K); f is the N_2O-N flux (ng N_2O-N m^{-2} min^{-1}); ΔQ is the linear change in the N_2O concentration (ng N_2O-N) inside the chamber over time (Δt, min−1); and A is the basal area of the chamber (m^2). The results were then extrapolated to a daily basis (Rochette et al., 2012). The N_2O emission factor (EF_{N20-N}, % N applied and emitted as N_2O) for farm yard manure treatment was calculated based on Eq. (3):

$$EF_{N2O\text{-}N} = (N_2O–N_F - N_2O\text{-}N_C)/140 \text{ kg N ha}^{-1} \times 100 \qquad (3)$$

Where: N_2O-$N_{F/C}$ is the cumulative N_2O-N emission (kg N_2O -N ha^{-1}) from the fertilized and control treatment, respectively, under maize-soybean intercropping system.

Agronomic Analysis

The agronomic and yield parameters of maize and soybean were taken from each experimental unit. It includes plant height (cm), shoot dry matter yield (kg/ha), grain yield (kg/ha) and nitrogen uptake (kg/ha) for maize. Similarly, plant height (cm), shoot dry matter yield (kg/ha), grain yield (kg/ha) and nitrogen uptake (kg/ha) with addition of number of nodules per plant were the traits for soybean, Plant height was taken from 10 random plants from each plot using measuring rod. Shoot dry matter yield was determined by harvesting plants from area of 1 m^2 with help of quadrate, dried these samples in oven at 120 Celsius for 24 hours and then weighted. Similarly, plants from 1 m^2 were harvested and then threshed to calculate grain yield of wheat using analytical balance. Nitrogen content is an important factor in crop yield estimation therefore we have determined the value of nitrogen uptake for both crops using Kjeldahl method (Bremner, 1996). Number of nodules per plant in soybean was estimated by counting manually the nodules present in the roots of 10 randomly selected plants for analysis.

Statistical Analysis

The data obtained in this study were subjected to one-way analysis of variance (ANOVA) using Genstat10.3.00 software (VSN international limited) and means were separated by least significance difference (LSD) test ($P \leq 0.05$).

Results and Discussion:-

Initial Soil Analysis

The basic physio-chemical analysis of soil was carried out before sowing of maize-soybean strip intercropping system to find the general behavior of soil. Analysis showed that soil EC 0.79 (µS/cm), SAP 19.4 (kg/ha), SAK 280 (kg/ha) and soil mineral nitrogen 28.2 (kg/ha). TOC was 29.3 (Mg/ha) and DOC was 30.5 (kg/ha).

The soil was neither sodic nor saline as both pH and EC was in acceptable range viz., < 8.6 and < 4 dS/m, respectively.

Table 1:- Estimation of soil attributes before the experiment.

Sr#	Soil Characteristics	Unit	Spring (2022)
1.	pH		8.02±0.02
2.	EC	(µS/cm)	0.79±0.09
3.	Soil Mineral Nitrogen	(Kg/ha)	28.2±2.9
4.	Soil Available Phosphorus (SAP)	(Kg/ha)	19.4±1.0
5.	Soil Available Potassium (SAK)	(Kg/ha)	280±11.5
6.	Soil Total Organic Carbon (TOC)	(Mg/ha)	29.3±1.5
7.	Soil Dissolved Organic Carbon (DOC)	(Kg/ha)	30.5±1.2

Final Soil Analysis

Measurement of Soil pH

Soil pH was determined through all the treatments after the harvesting of crop. The pH value which was noted is higher in intercropping treatments as compared to both sole treatments. In the maize-soybean (MS) intercropping treatments pH reaches up to 8.57 under control and FYM. While the less pH was calculated in sole soybean (SS) under control and FYM ranges 8.35 and 8.37 respectively. The percentage increase of pH of intercropping maize-soybean (MS) over sole crops under control was 2.63% and 2.38%, respectively. There was non-significant difference between the both main treatments.

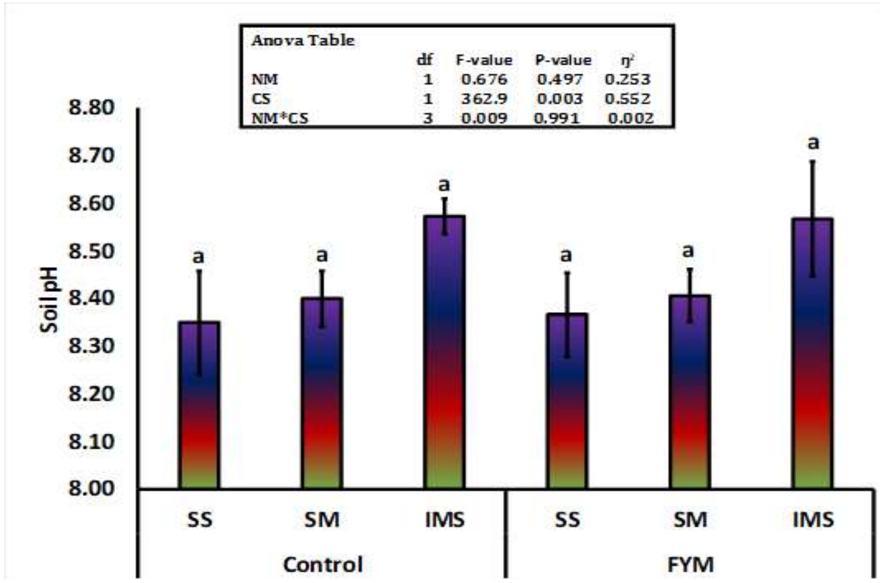

Figure 1:- Soil pH, affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Measurement of Soil Mineral Nitrogen (kg/ha)

Soil mineral nitrogen was also measured after the harvesting of crop. The differences between the treatments were also revealed. The low to high trend again goes with sole cropping to intercropping. The lowest value was noted in sole maize (SM) under control which was 20.54 (kg/ha), likewise the maximum soil mineral nitrogen under control block was measured in maize-soybean (MS) intercropping at 35.91 (kg/ha). Percentage increase from intercropped treatment to sole crop was 74.82%. The highest value was noted in maize-soybean (MS) intercropping under FYM at 59.43 (kg/ha), in FYM the minimum value of soil mineral nitrogen which I got was 45.08 (kg/ha) of sole maize (SM). Percentage increase of soil mineral nitrogen of intercropped over sole treatment was 9.67%. I noted the clearly significant difference between all treatments.

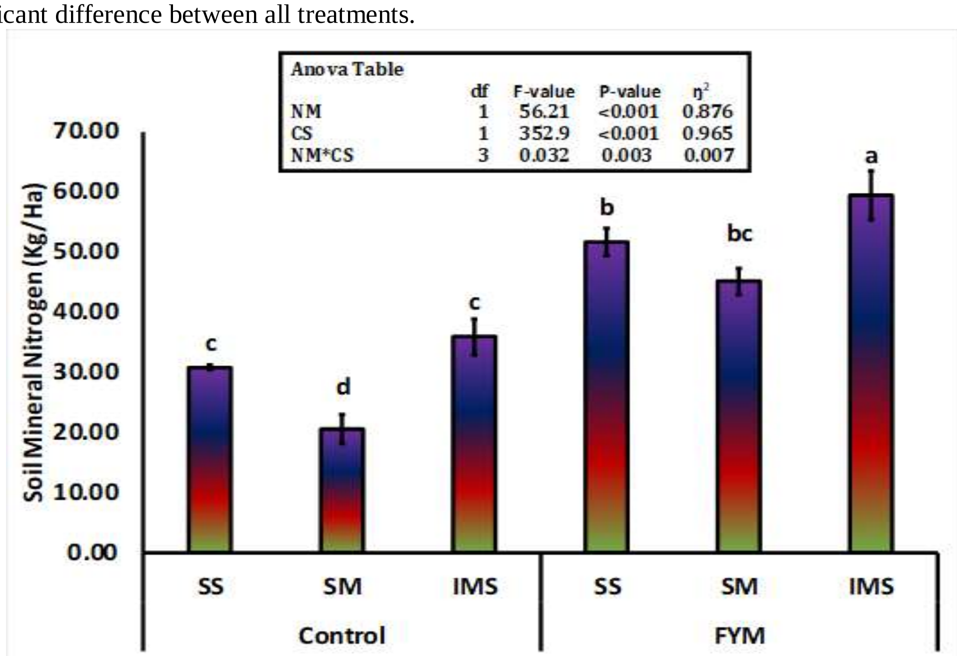

Figure 2:- Soil mineral nitrogen (kg/ha) affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Measurement of Total Organic Carbon (Mg/ha)

Total organic carbon (TOC) was measured from all treatments under control and FYM cropping. The maximum TOC values under control treatment was measured in intercropping maize-soybean (MS) which was 31.17 (Mg/ha) and in FYM it was 45.09 (Mg/ha). The percentage increase ratio was 44.65% from FYM to control treatment. Similarly, the minimum values in both treatments (control and FYM) were observed in sole soybean (SS). The obtained values were 27.68 (Mg/ha) and 40.02 (Mg/ha) respectively. The percentage increase difference was 44.58%. There was significant difference between all treatments.

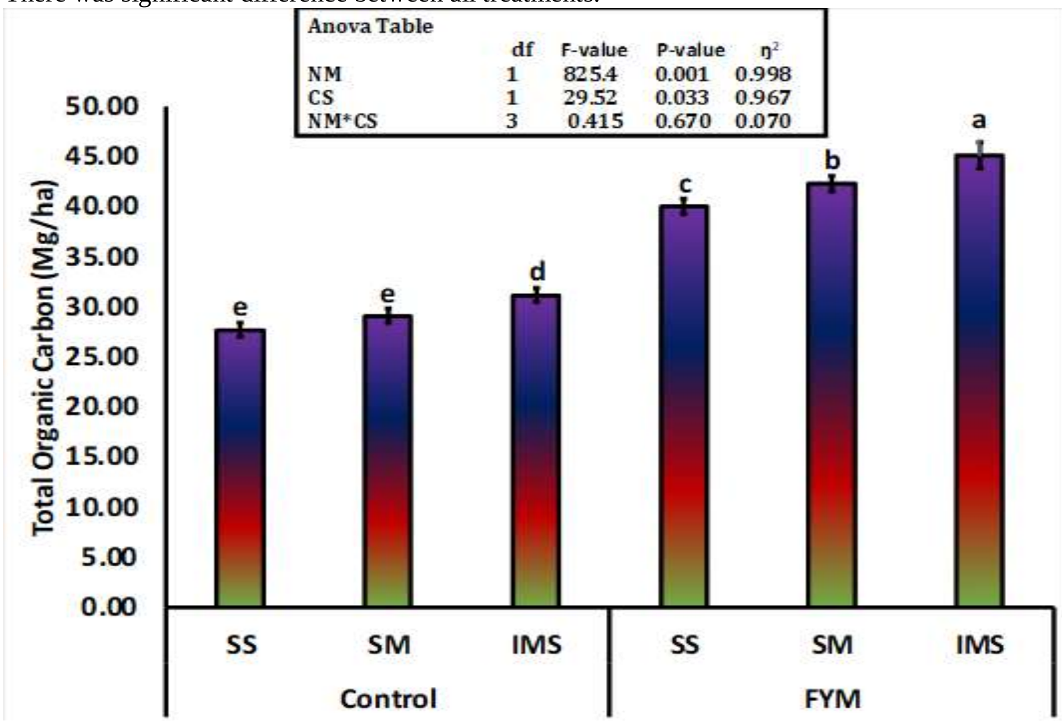

Figure 3:- Total organic carbon (Mg/ha) of soil affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Measurement of Dissolved Organic Carbon (DOC) (kg/ha)

After the harvesting of crop DOC was also measured from all treatments. in control treatment the minimum DOC values was recorded in sole soybean which was 26.49 (kg/ha), likewise in FYM it was recorded 42.88 (kg//ha). The percentage increase difference between the both treatments was 61.87%. Similarly, the maximum recorded values under both treatment was 31.46 (kg/ha) and 49.41 (kg/ha). The percentage increase between both treatments was 57.05%. There was clear significance gap between all treatments.

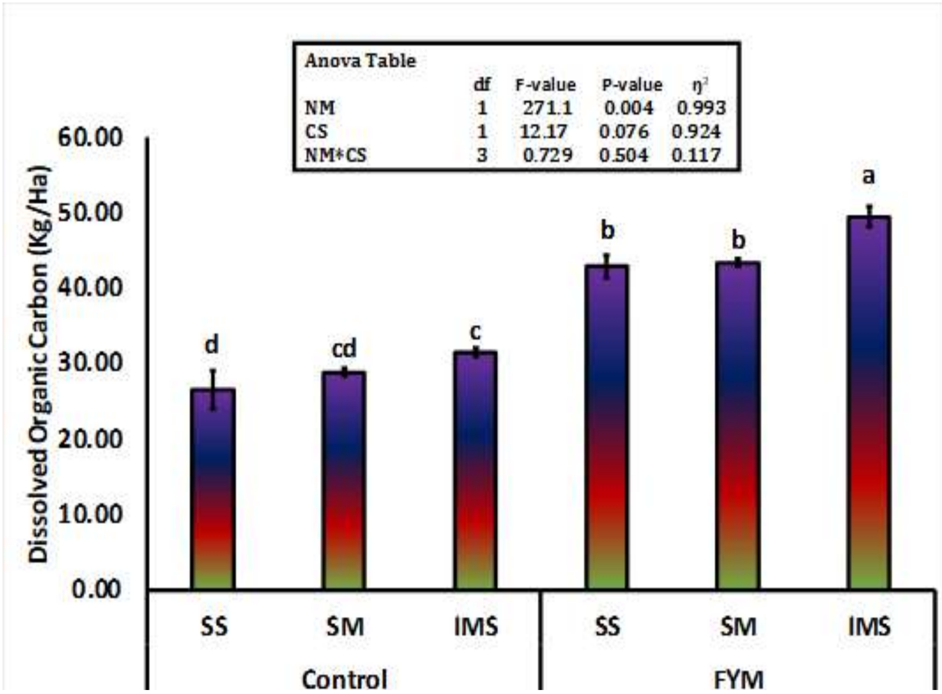

Figure 4:- Dissolved organic carbon (kg/ha) of soil affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Measurement of Ammonia (NH_3) Volatilization

Ammonia (NH_3) volatilization from each treatment of incubation is presented in Table 2. Ammonia emission was highest in sole maize (SM) with control treatment (298.34 kg NH_3 ha^{-1}) followed by sole soybean (SS) of control (nothing applied) (211.76 kg NH_3 ha^{-1}) while minimum emission of ammonia was estimated in maize-soybean intercropped (IMS) with the application of farm yard manure (FYM) (96.50 kg NH_3 ha^{-1}) followed by sole soybean treatment (SS) with amendment of farm yard manure (FYM) (118.21 kg NH_3 ha^{-1}).

Table 2:- Impact of different nutrient managements under different cropping systems on ammonia volatilization

Treatments		**Ammonia Volatilization/Emission (kg NH_3 ha^{-1})**
CS	**NM**	
C	SM	298.34 a
	SS	211.76 b
	IMS	136.88 c
FYM	SM	177.68 bc
	SS	118.21 c
	IMS	96.50 d

NM=Nutrient Management, CS=Cropping System, C=Control, FYM= Farm Yard Manure, SM=Sole Maize, SS=Sole Soybean, IMS=Maize-Soybean Intercropping

Measurement of Nitrous Oxide (N_2O-N) emission

We have calculated the N_2O-N emission in different cropping system treatments with the application of farm yard manure (FYM). Daily emissions of N_2O-N were found varying from 12 to 229 g/ha/day, 5 to 238 g/ha/day and 17 to 178 g/ha/day in sole maize (SM), sole soybean (SS) and intercropped maize-soybean (IMS), respectively (Fig. 5). Significant differences in daily emissions of N_2O-N among SM, SS and IMS were noticed (Fig. 5). However, the highest daily emissions of N_2O-N were observed on day 13 for SM and SS treatments while day 34 was highest observing day of N_2O-N emission in IMS treatment, day significantly higher up to day 39 following RS application (Fig. 5).

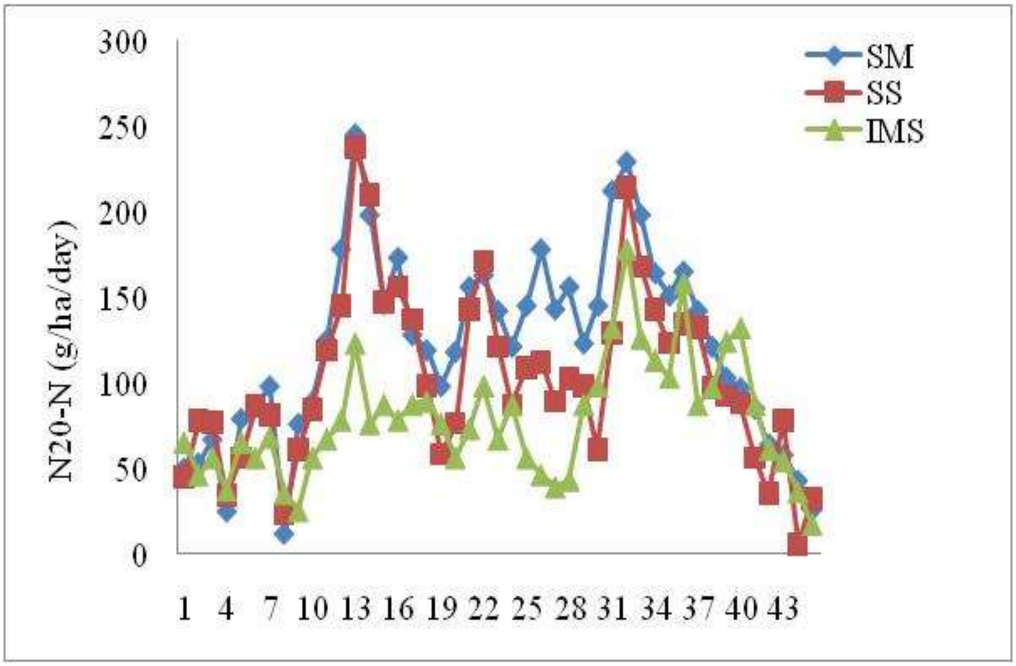

Figure 5:- $N_2$0-N emission from cropping system treatments affected by the application of farm yard manure. SM = Sole Maize; SS = Sole Soybean; IMS = Maize-Soybean Intercropping.

Maize Growth and Yield Attributes

Plant Height (cm)

During the spring season, the experiment conducted involved the assessment of maize plant height under maize-soybean (MS) strip intercropping (SI) conditions. The main treatment categories included Control (C) and Farmyard Manure (FYM), with sub-treatments consisting of sole maize (SM) and intercropping-maize (IM). Notably, the plant height of maize during the spring season exhibited an increase in the FYM intercropping-maize (IM) treatment in comparison to the Control intercropping-maize (IM) treatment. In the context of spring maize-soybean cropping, the plant height in the FYM intercropping-maize (IM) treatment reached 189 cm, demonstrating a significant contrast with the Control intercropping-maize (IM) treatment, which attained a height of 147 cm. Similarly, within the sole maize treatments, FYM sole maize (SM) contributed to a heightened plant height of 172 cm, while the Control sole maize (SM) treatment resulted in a height of 137 cm. Percentage increase of treatments was also calculated, percentage increase of FYM intercropping maize to Control intercropping maize (IM) was 26.84% likewise percentage increase of FYM sole maize (SM) to Control sole maize (SM) was 25.54%.

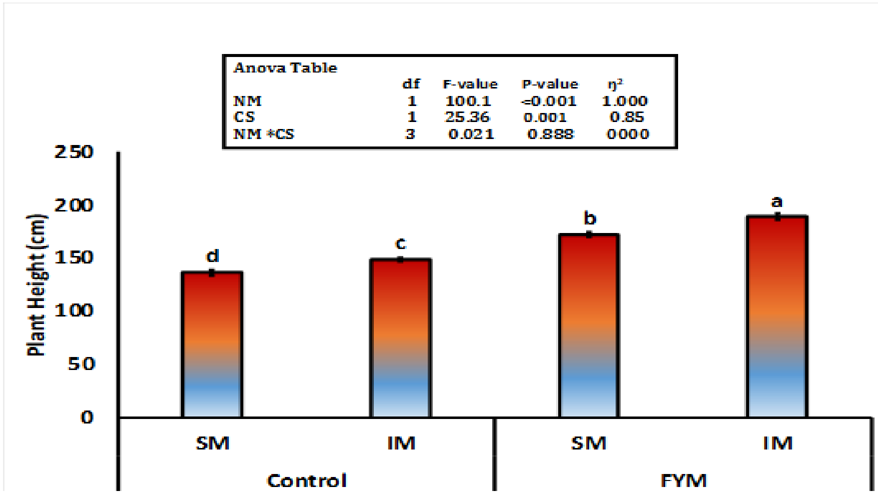

Figure 6:- Plant height (cm) of maize affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Shoot Dry Matter Yield (kg/ha)
In the context of spring maize-soybean (MS) strip intercropping (SI), the shoot dry matter yield (kg/ha) across various treatments exhibited statistically significant differences (P<0.05). The shoot dry matter yield (kg/ha) demonstrated enhancement with the treatments of FYM sole maize (SM) and FYM intercropping maize (IM). The lower values were noted in both treatments under control. Notably, the recorded values for shoot dry matter yield (kg/ha) in FYM sole maize (SM) and FYM intercropping maize (IM) treatments were 15393 (kg/ha) and 17717 (kg/ha), respectively.

Conversely, the lowest observed value was 12267 (kg/ha) and 14352 (kg/ha) in the sole maize (SM) and intercropping maize (IM) under the Control treatment. The percentage increase from FYM sole maize (SM) to Control sole maize (SM) was noted to be 25.36%, while the percentage increase from FYM intercropping maize (IM) to Control intercropping maize (IM) was 23.44%.

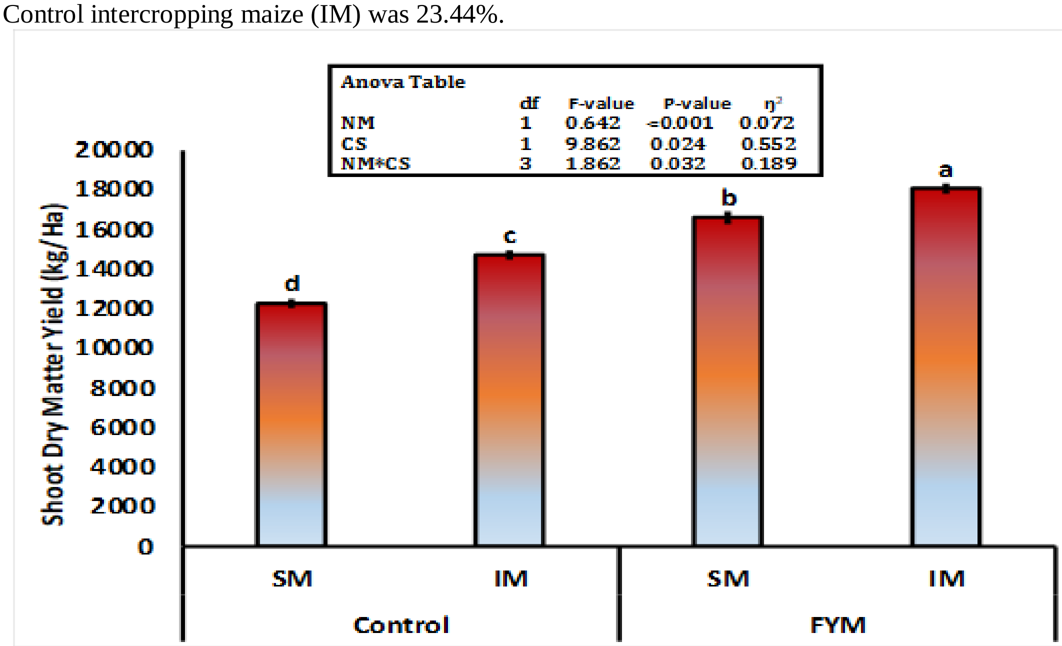

Figure 7:- Shoot dry matter yield (kg/ha) of maize affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Grains Yield (kg/ha)

In the spring maize-soybean (MS) cropping system, a notable divergence in grain yield (kg/ha) among various treatments was observed, demonstrating statistical significance ($P<0.05$). The grain yield (kg/ha) within the maize-soybean (IMS) intercropping system exhibited an augmentation in the treatments involving Farm Yard Manure (FYM) intercropping maize (IM) and sole maize (SM) compared to both treatments under control conditions. During the spring season, the grain yield (kg/ha) for FYM intercropping maize (IM) and FYM sole maize (SM) amounted to 10367 (kg/ha) and 8500 (kg/ha), respectively. Conversely, lower values were recorded for sole maize (SM) and intercropping maize (IM) under control conditions, with values of 6600 (kg/ha) and 7567 (kg/ha), respectively.

The percentage increase from FYM sole maize (SM) to Control sole maize (SM) was determined to be 28.78%, while the percentage increase from FYM intercropping maize (IM) to Control intercropping maize (IM) was notably higher at 37%. The obtained results demonstrated significant disparities among all treatments, underscoring the impact of the applied interventions. Consequently, it is evident that the grain yield (kg/ha) in FYM intercropping maize (IM) treatments exhibited improvements within the maize-soybean (MS) cropping system.

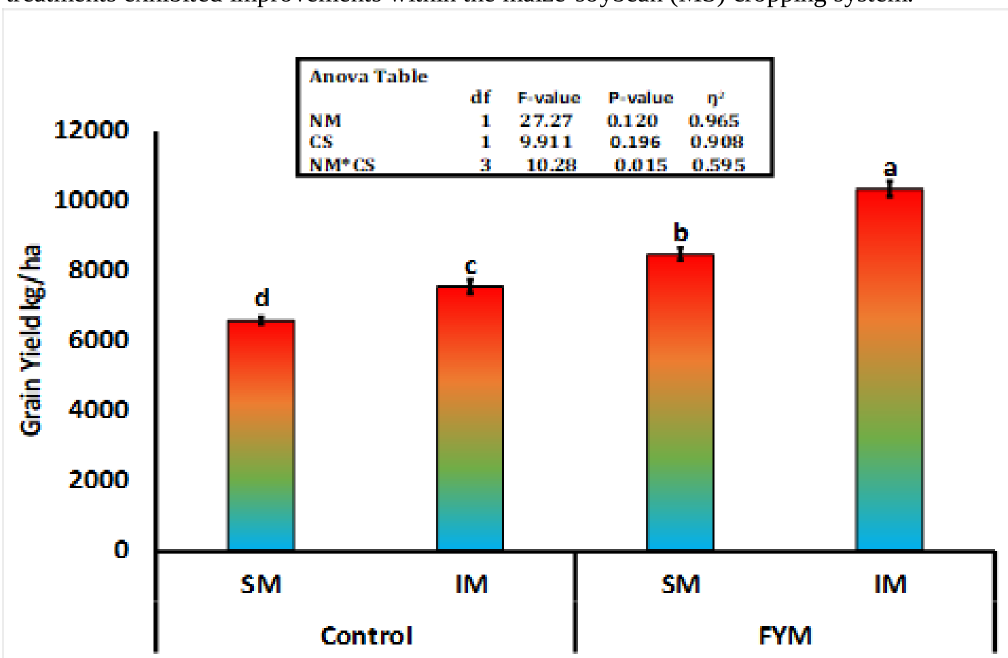

Figure 8:- Grains yield (kg/ha) of maize affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Nitrogen Uptake (Kg/ha)

The influence of maize-soybean (MS) strip intercropping (SI) on nitrogen uptake (kg/ha) is depicted in Figure 8. Specifically, observed values of nitrogen uptake (kg/ha) were 143 (kg/ha) and 175.3 (kg/ha) for FYM sole maize (SM) and FYM intercropping maize (IM) treatments, respectively. On the other hand less values were observed in control sole maize (SM) and control intercropping maize (IM) exhibited values were 58 (kg/ha) and 94 (kg/ha) respectively. The percentage increase from FYM intercropping maize (IM) to control intercropping maize (IM) was determined to be 86.48%. Likewise, the percentage increase from FYM sole maize (SM) to control sole maize (SM) was calculated as 46.5%. Significantly different outcomes were observed among all treatments during the spring season maize-soybean (MS) cultivation.

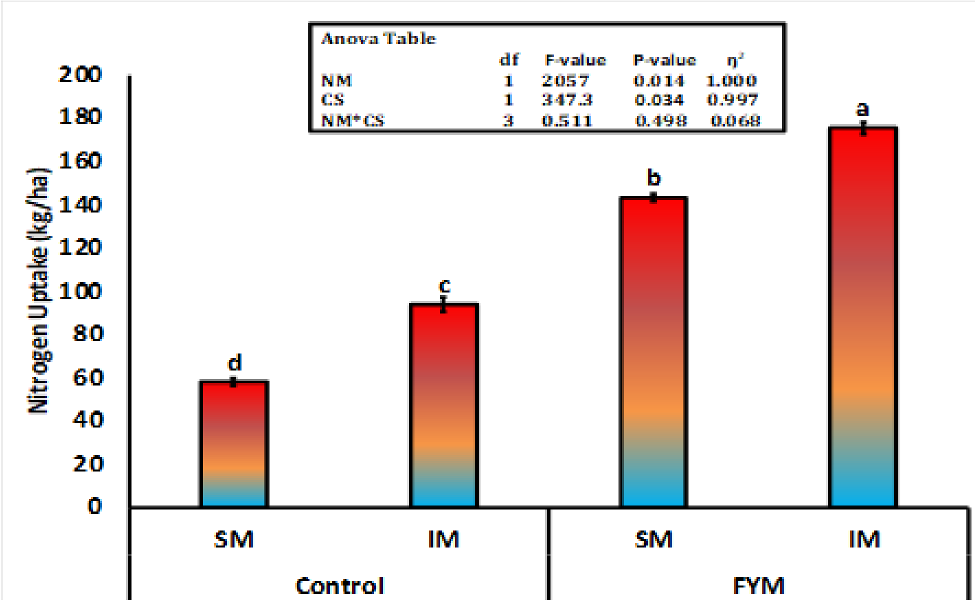

Figure 9:- Nitrogen uptake (kg/ha) of maize affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Soybean Growth and Yield Attributes

Plant Height (cm)

In the spring season, the plant height of sole soybean (SS) and intercropped soybean (IS) in the presence of farmyard manure (FYM) measured 62.2 cm and 67.2 cm respectively. On the other hand, control treatments showed minimum values which were 43.4 cm and 48.6 cm for sole and intercropped soybean. The percentage increase from FYM sole soybean (SS) to control sole soybean (SS) was 43.31% and percentage increase of FYM intercropping soybean (IS) to control intercropping soybean (IS) was 38.27%. These findings were statistically significant across all treatments in the spring season ($P < 0.05$).

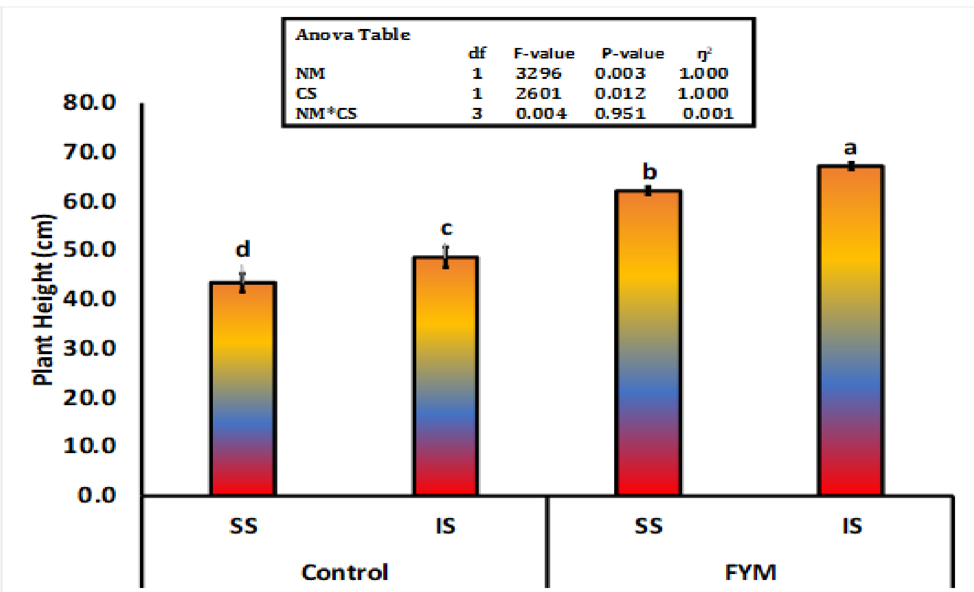

Figure 10:- Plant height (cm) of soybean affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Shoot Dry Matter Yield (kg/ha)

The shoot dry matter yield (kg/ha) was assessed during the spring season within the context of the maize-soybean strip intercropping (MS) experiment. Notably, among all treatments, sole soybean (SS) and intercropping soybean (IS) treatments under FYM exhibited the highest values, registering at 3766.7 (kg/ha) and 4333.3 (kg/ha), respectively. Conversely, the minimum values were observed in sole soybean (SS) and intercropped soybean (IS) under control treatments, amounting to 2466.7 (kg/ha) and 3000 (kg/ha). The percentage increase in shoot dry matter yield (kg/ha) for both the highest treatments was 52.70% and 44.44% compared to sole soybean (SS) and intercropped soybean (IS) under control.

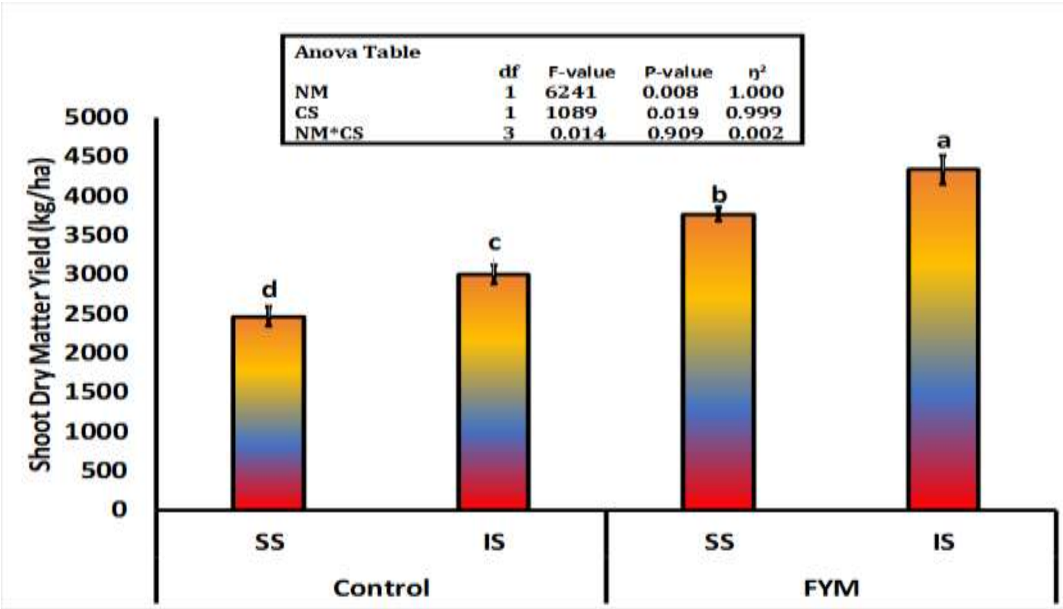

Figure 11:- Shoot dry matter yield (kg/ha) of soybean affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Grain Yield (kg/ha)

The maximum grain yield (kg/ha) values were observed in sole soybean (SS) and intercropping soybean (IS) under the FYM treatment, registering 1650 (kg/ha) and 2037 (kg/ha), respectively. Conversely, the minimum values of 860 (kg/ha) and 1237 (kg/ha) were noted for sole soybean (SS) and intercropping soybean (IS) under the control treatment. The percentage increase in grain yield (kg/ha) for sole soybean (SS) under FYM was calculated as 91.85% compared to sole soybean (SS) under the control treatment. Similarly, the percentage increase for intercropping soybean (IS) under FYM was 66.01% relative to intercropping soybean (IS) under the control treatment.

Upon scrutinizing the spring season data, a conspicuous disparity emerges in grain yield between sole and intercropped soybean. The following figure visually illustrates this noteworthy difference in the grain yield of sole and intercropped soybean.

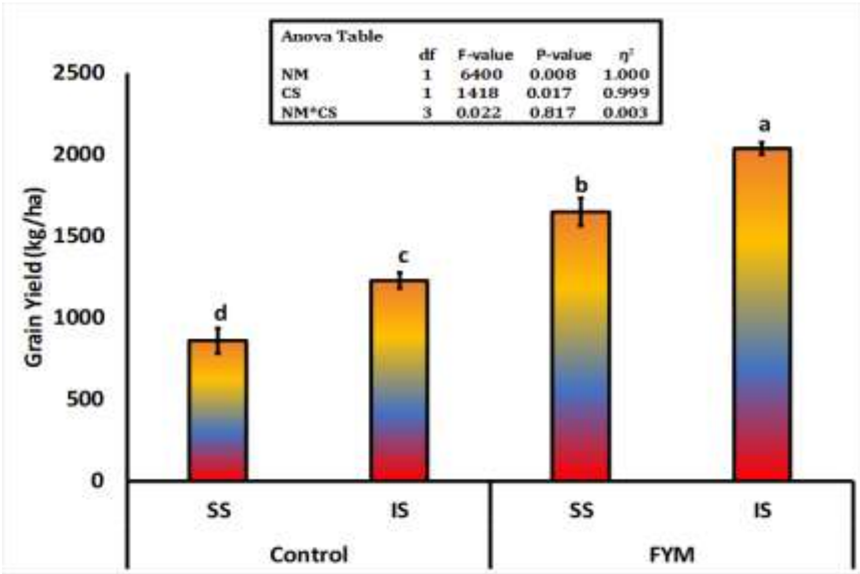

Figure 12:- Grain yield (kg/ha) of soybean affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Number of Nodule per Plant

In the context of spring maize-soybean (MS) intercropping, the number of nodules per plant was examined under Control and Farm Yard Manure (FYM) treatments, as depicted in the Figure 13. Significant differences were observed among all treatments with respect to the number of nodules per plant. The highest values were recorded in sole soybean (SS) and intercropped soybean (IS) under FYM treatments, yielding 30.53 nodules per plant and 37.13 nodules per plant, respectively. In contrast, sole soybean (SS) and intercropped soybean (IS) under control exhibited a lower value of 22.63 and 26 nodules per plant.

The percentage increase in the number of nodules per plant for intercropped soybean (IS) under FYM was notably substantial, registering a 42.80% increment compared to intercropped soybean (IS) under control. Similarly, the percentage increase for sole soybean (SS) under FYM relative to sole soybean (SS) under control was 34.90%.

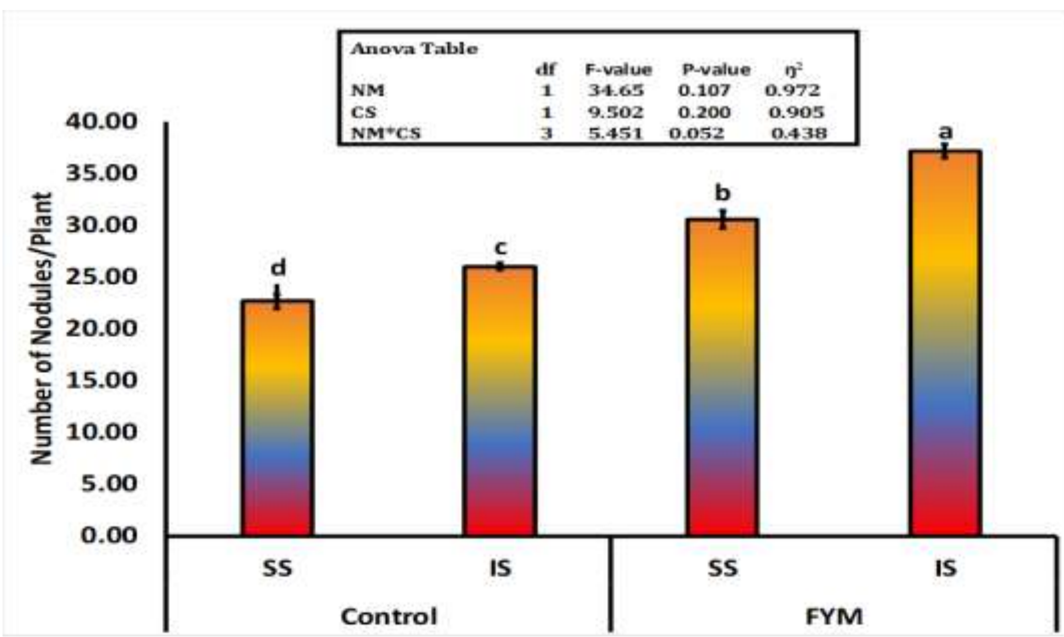

Figure 13:- Number of nodules/plant of soybean affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Nitrogen Uptake (kg/ha)

The nitrogen uptake (kg/ha) was assessed during the spring season within the context of the maize-soybean strip intercropping (MS) experiment. Notably, among all treatments, sole soybean (SS) and intercropping soybean (IS) treatments under FYM exhibited the highest values, registering at 114.6 (kg/ha) and 185.1 (kg/ha), respectively. Conversely, the minimum values were observed in sole soybean (SS) and intercropped soybean (IS) under control treatments, amounting to 51.6 (kg/ha) and 75.6 (kg/ha). The percentage increase in nitrogen uptake (kg/ha) for both the highest treatments was 122% and 144.8% compared to sole soybean (SS) and intercropped soybean (IS) under control.

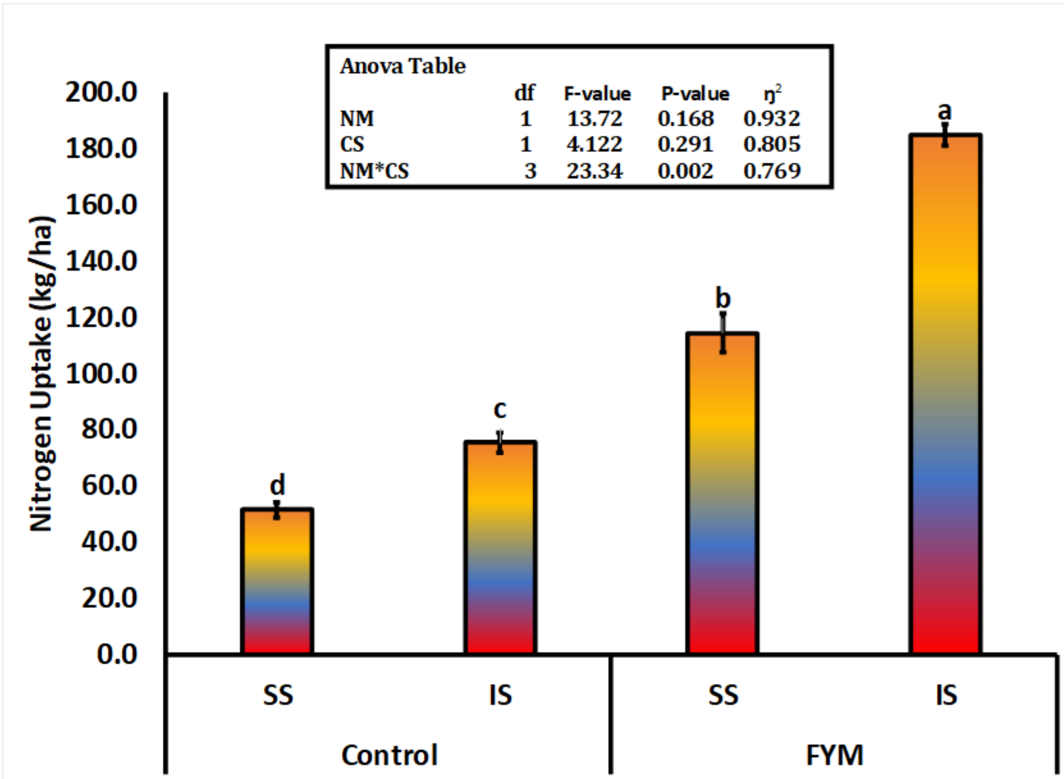

Figure 14:- Nitrogen uptake (kg/ha) of soybean affected by the application of nutrient management and cropping system in maize-soybean strip intercropping.

Discussion:-

Zhang et al. (2017) found the results similar to the current findings, indicating that the application of FYM under cereal-legume intercropping improves the soil physiochemical processes, on the other hand, pH value is positively affected by its application under maize-soybean intercropping but negative consequences has been reported with the urea and DAP fertilizers in sole maize and soybean. Additionally, according to a number of studies, applying farm yard manure stimulated the increase of soil properties like soil mineral nitrogen, soil organic matter that results in boost up the level of pH and dissolved organic matter in the maize-soybean intercropping (Xia et al., 2019). These findings concur with those of Rose et al. (2019) who found that most soils responded to FYM by increasing their dissolved organic matter. Applying farm yard manure might improve and maintain a number of physiological parameters of soil including the potassium and organic matter under rainfed conditions (Xiwen et al., 2015).

The ammonia emission is minimized from the soil where farm yard manure is added and our results corroborates the findings of Ferguson et al. (1984) who reported stabilization in NH_3 volatilization after 12 to 16 days of manure addition. The retardation in the NH_3 emission rate toward the end of the incubation experiment could also be attributed to the gradual dryness of the soil surface resulting from aeration by the air pump as NH_3 emission loss decreases where there is insufficient soil moisture. Reduction in NH_3 volatilization is mainly due to insufficient soil moisture for chemical reactions has been reported by early researchers (Perumal et al., 2015).

This process was augmented by the use of organic sources of N providing labile and readily biodegradable C input (Grave et al., 2015) thus enhancing N dissimilation and N_2O-N losses (Giles et al., 2012). Although significant differences on the N_2O-N emissions from cropping treatments were noticed with the fertilization treatment, the N_2O-N emission increased 2.8-fold in the sole maize (SM) in comparison with intercropped maize-soybean (IMS). Nonetheless, our results corroborate several other studies reporting increased N_2O-N emissions from soil where sole maize with farm yard manure is added (Gonzatto et al., 2013; Aita et al., 2015)

Overall results revealed that maize height increase in intercropping treatments which was also studied by Xia et al. (2019) where they showed that farm yard manure is key source of organic matter which alters the plant attributes like plant height, dry matter yield , grain yield. In the intercropping system of maize-soybean, light was identified as a crucial factor directly influencing crop growth and development, leading to increased plant height and enhancements in various biological aspects of the plants, as highlighted in the study conducted by (Fan et al. 2018). Kumar et al. (2015) and Ghosh et al. (2006) also concluded from their study that soybean height increases when we apply FYM.

These results collectively suggest an enhancement in shoot dry matter yield in both sole and intercropped maize (SM) treatments under FYM. Our findings also matched with the Ghosh et al. (2009) and Hamed et al. (2022) who concluded that when applying FYM the fresh and dry yield of crops increases. Masood et al. (2014) also found that when applying FYM the shoot dry matter yield increases a manure provide excellent source of carbon and nitrogen to plants. Our findings also align with the outcomes reported by Creelman et al. (1990). Kumudini et al. (2001) and Liu et al. (2005) also reported similar findings in their studies, indicating that grains play a significant role in dry matter accumulation under FYM treatment.

Gezahen et al. (2016) signifies a pronounced impact of FYM under intercropping system on nodulation, with notable variations observed across the experimental treatments. Our findings are also matching with observations of Ghosh et al. (2006) who found that farm yard manure with cereal-legume intercropping enhances the number root nodules of legumes.

Grain yield is an important and crucial trait to determine the overall performance of the treatments that were provided to the crop during the experiment. Our results for grain yield were in close proximity with Memon et al. (2012) and Bhat et al. (2013) who have concluded that grain yield increased in FYM applied treatments. EI-Naggar et al. (2012) and Gutu et al. (2015) also resulted from their study that grain yield increases in FYM treatment under cereal-legume intercropping system. Nitrogen uptake gave excellent results under FYM application treatments in maize-soybean intercropping system. Sarwar et al. (2012) also concluded from their study that nitrogen uptake from different crops are greater in FYM applied treatment. These findings also align with the outcomes reported by Xu et al. (2018) and Olmedo et al. (2021).

Conclusion:-

The results of this study underscore the potential of maize-soybean strip intercropping as a sustainable cropping system for enhancing crop productivity, resource use efficiency, and soil health. The adoption of this cropping system, coupled with appropriate nutrient management practices such as FYM application, can contribute to addressing the challenges of declining crop yields, water scarcity, and soil degradation in Pakistan's agricultural landscape. Moreover, the economic benefits of intercropping, as evidenced by increased grain yields and reduced input costs, make it a viable option for smallholder farmers, potentially promoting rural livelihoods and food security.

Overall, the findings of this study support the recommendation for the widespread adoption of maize-soybean strip intercropping as a promising agro-ecological practice in arid and semi arid agro-climatic regions. However, further research is warranted to explore the long-term effects of intercropping on soil fertility, pest and disease management, and ecosystem resilience, as well as to assess its socio-economic impacts on farming communities.

Conflict Of Interest

There is no competing or conflict of interest among the authors

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