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Influence of Planting Systems and Nutrient Management on Maize Growth, Yield and Light Interception in a Maize-soybean Intercropping System

Umesh Kumar Singh[1], Santosh Korav[1], Sourabh Kumar[2], H.T. Sujatha[3]

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ABSTRACT

Background: This research aims to determine the effectiveness of varying planting patterns and nutrient application on maize biomass, yields and light capture in a maize-soybean intercrop production. Its goal is to enhance resource efficiency, increase yields, as well as facilitate sustainable management by analysing effects of planting geometry, nutrient supply and light encoded for the two crops.

Methods: The experiment was conducted during *kharif* season 2023, The treatment consists of four cropping systems in main plots (sole maize (M1), maize + soybean 1:1(M3), maize + soybean 1:2 (M4), maize + soybean 2:3 (M5)) and five nutrient sources in sub plot ((S1) control, (S2) 100% RDF, (S3)70% RDF with two foliar application of Nano NPK, (S4) 70% RDF with two foliar application of Homemade NPK, (S5) 70% RDF with two foliar application Plant extracts) with three replication under split plot design.

Result: The experimental results revealed that, sole maize (M1) recorded significantly highest growth attributes *i.e.* no. of leaves (12.66 plant^{-1}), LAI at maturity (3.85), specific leaf weight (6.12 g cm^{-2}) and leaf area duration (140.91 days), compared to rest of cropping systems. Similarly, 70% RDF with two foliar application of plant extract produced biomass yield by 18% and 48.03% more light transmission ratio over the control. Hence, application of 70% RDF with two foliar sprays of plant extract enhanced crop growth and biomass of sole maize, it can be recommended to the farmer.

Key words: Cropping pattern, Intercropping, Nutrient management, Specific leaf weight.

INTRODUCTION

The global population is projected to reach over 9 billion by 2050. It will require more food for the ever growing population (Chen *et al.,* 2017), which is a major challenge for farmers to increase productivity. For its, higher doses of synthetics to achieve higher yields, reduces soil quality of the farm and causes other harmful effects on environment (Feng *et al.,* 2019). This is a very dangerous aspect for future generations because soil will gradually become infertile. It not only affects crop growth and quality but also has a very negative effect on human races. In Punjab, India, longterm monoculture has a severe influence on soil quality, making difficult sustainable farming. Farmers in this region mostly use the rice-wheat cropping system and apply higher doses of pesticides and inorganic fertilizers to enhance crop yield, but these practices gradually deteriorate soil health and crop ecology. To address these critical difficulties, it will have to make changes to the legume-based cropping system instead of the conventional system. It is an innovative approach for implementation of cereal-legume intercropping systems (Singh *et al.,* 2024).

Among cereals, maize (*Zea mays*) ranks third in global production, following wheat and rice. Maize is also popular as the “Miracle crop” and the “Queen of Cereals,”. India ranks fourth in maize cultivation area and seventh in production, constituting 4% of the world’s maize area and 2% of its total production (DMRI, 2024). In India, the maize production area has expanded to 9.57 million hectares, yielding 28.7 million tons and an average productivity of 3006 kg per hectare (DMRI, 2024). Similarly, soybean stays in demand for its oil and protein content, serving both food and industrial purposes (Meiyu *et al.,* 2023). And also fixes atmosperic nitrogen fixation, which help to reduce additional fertilization to the intercrop (Singh *et al.,* 2023a). The structure of the canopy in intercropping systems significantly influences light distribution, research finding indicated that intercropping can lead to a reduction in cumulative light interception for crops such as maize and soybean by 11.2% and 81.0%, respectively (Kou *et al.,* 2024). Although light interception and transmission are vital for optimizing crop

[1]Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India.
[2]Department of Agronomy, VKS College of Agriculture (Bihar Agriculture University, Sabour), Dumraon-802 136, Bihar, India.
[3]College of Agricultural Sciences, Iruvakki Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shimoga, Shivamogga-577 412, Karnataka, India.

Corresponding Author: Umesh Kumar Singh, Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India. Email: 1999umesh8@gmail.com

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yields, other elements, including planting arrangements, crop architecture and environmental conditions, are also essential in forming overall plant performance and productivity (Ganapathi *et al.,* 2024). The strategic organized rows and effective nutrient management improves light interception, thereby facilitating efficient resource utilization within intercropping systems (Feng *et al.,* 2019).

Chemical fertilizers are frequently used in traditional fertilization techniques (Singh *et al.,* 2023), due to their enormous advantages crop growth, economically feasible innovative alternatives like NPK nano fertilizers, homemade NPK formulations and plant based nutrient extract, are becoming popular. There is limited understanding of optimizing light transmissivity under different row planting systems in maize-soybean intercropping and viable alternatives to inorganic fertilizer reduction are particularly lacking in this region. Therefore, the present study focuses on evaluating the impact of varying row planting systems and alternative fertilization strategies to reduce inorganic fertilizer use. It also examines their effects on light interception and transmission ratios in maize within the intercropping system. By addressing these gaps, the study aims to improve resource use efficiency, enhance crop performance and promote sustainable agricultural practices in maize-soybean intercropping systems.

MATERIALS AND METHODS

The experiment was planned at Lovely Professional University Phagwara, Punjab, during *Kharif* season of 2023. The experimental site was located at a latitude of 31°22′ 31.81″ North and a longitude of 75°23′03.02″ East, with an average elevation of 252 m from mean sea level. The sandy loam soil is predominated which consists pH of 7.2 and an electrical conductivity of 0.32 dS m^{-1}. It has medium organic carbon (0.52%), low available nitrogen (216 kg ha^{-1}), medium available P_2O_5 (34 kg ha^{-1}) and available K_2O (210 kg ha^{-1}). The treatments consist of four cropping systems in main plot *viz* sole maize (60× 20 cm) (M1), maize + soybean 1:1(60 × 20 cm) (M3), maize + soybean 1:2(90 × 20 cm) (M4), maize + soybean 2:3(120 × 20 cm)(M5) and five subplots *i.e.* nutrients level, they are, absolute zero (control) (S1), 100% RDF application (S2), 70% RDF + Nano NPK (S3), 70% RDF + Homemade NPK (S4) and 70% RDF + plant extracts (S5) with three replications. Recommended dose of fertilizers (125:60:30 kg ha^{-1} NPK) is applied with their sources of urea, single super phosphate (SSP) and Muriate of potash (MOP). The Nano NPK, Homemade NPK and Plant extract were sprayed in two splits at 30 and 60 DAS. Punjab Agriculture University package of practices was used for remaining crop management practices (PoP, 2023).

The observations of growth parameters such as no. of leaves, leaf area index, specific leaf area, specific leaf weight and leaf area duration, were recorded by randomly selected five tagged plants from the net plot area. Calculation of growth parameters are given below:

To calculate the Leaf area index (LAI) by using formula (Sestak *et al.,* 1971).

$$LAI = \frac{\text{Leaf area per plant } (dm^2)}{\text{Leaf occupied by the plant } (dm^2)} \quad \ldots. (1)$$

Leaf area duration was calculated by using the LAI with time interval and expressed in days (Sestak *et al.,* 1971).

$$LAD \text{ (days)} = \frac{L_1 + L_2}{2} \times (t_2 - t_1) \quad \ldots. (2)$$

Where,

L_1 and L_2= Leaf area index at times t_1 and t_2, respectively.

Specific leaf area was calculated by the ratio of leaf area to leaf mass. It is a measure of the relative spread of the leaf. It is expressed in cm^2g^{-1}.

$$SLA = \frac{\text{Leaf area } (cm^2)}{\text{Leaf dry weight } (g)} \quad \ldots.(3)$$

Specific leaf weight was calculated by the ratio of leaf dry weight to leaf area. It indicates the leaf thickness and density and is expressed as g cm^{-2}.

$$SLW \text{ (g } cm^{-2}) = \frac{\text{Leaf dry weight } (g)}{\text{Leaf area } (cm^2)} \quad \ldots.(4)$$

Light transmission was measured by using a Lux meter. The intensity of light was recorded both above the maize crop and at the ground surface during the period from 11.30 AM to 12.30 PM. As per Yoshida *et al.* (1972), the light transmission ratio (LTR) and per cent light interception were calculated.

$$LTR (\%) = \frac{\text{Light intensity above the canopy } I_c}{\text{Light intensity at ground surface } I_o} \times 100 \quad \ldots.(5)$$

Percent light interception (PLI) was calculated by formula,

$$PLI = 100 - LTR \quad \ldots.(6)$$

Statistical method

The data were analyzed and interpreted using Fisher's analysis of variance method, as reported by Gomez and Gomez (1984). The least significant difference (LSD) was determined at a significance level of $p \leq 0.05$, with Statistix 10 used to compute the means of the treatments.

RESULTS AND DISCUSSION

Influences of planting system and nutrient management on growth attributes of maize

The different planting systems show distinct effects on the growth attributes of maize crops. The results revealed that sole maize recorded significantly higher leaf number (12.66 $plant^{-1}$), LAI (3.85), LAD (140.91 days) and SLW (6.12 g cm^{-2}) at 90 DAS, which was on par with M3 and M4 and lowest values were found in M5 treatment (Table 1). It might be

due to the appropriate spacing and zero competition between plants in sole crop maize (Singh *et al.,* 2023). Similarly, lowest LAI (2.52) and LAD (92.74 days) were found M4 which was probably due to higher competition between plants for their resources. The significantly higher SLA was observed in M5 (166.57 $cm^2 g^{-1}$) which was on par with M4 (166.49 $cm^2 g^{-1}$) and lowest value was recorded in M1 treatment (163.62 g^{-1}). It was probably due to the inversely proportional relationship between leaf size and specific leaf area (Torrez *et al.,* 2013). In nutrient management, the S5 was recorded significantly higher number of leaves (11.57 $plant^{-1}$), LAI (3.54) and LAD (129.52 days), which was on par with the S4 and the S3. While, the significantly lowest no. of leaves (9.97 $plant^{-1}$), LAI (3.34), LAD (123.36 days) and SLW (5.84 gcm^{-2}) were noticed in S1 (control) (Table 1). This result might be due to higher micronutrient and microbial activity found in plant extract and Homemade NPK (liquid compost) Kantwa *et al.,* 2023 and Chandukishore *et al.* (2023). Contradictorily while, high SLA was record in S1 (171.28 $m^2 g^{-1}$) treatment, which was on par with S4 (164.47 $m^2 g^{-1}$) and S3 treatment (163.78 $m^2 g^{-1}$). Interaction effect of growth attributes was significantly influenced with cropping system and nutrient sources except SLA and SLW, these results were corroborated with Kalyanasundaram *et al.* (2021); Katarzyna *et al.* (2021) and Unay *et al.* (2021).

Influences of planting system and nutrient management on maize biological yield

The significantly highest biological yield was recorded in sole maize (132.21 q ha^{-1}), which was on par with M2 (126.79 q ha^{-1}), M3 (118.74q ha^{-1}) and M4 (110.99 q ha^{-1}). No inter competition with soybean. Similarly in nutrient management, significantly higher biological yield was record in S5 (129.02 q ha^{-1}), which was on par with S4(127.57 q ha^{-1}) and S3 treatment (127.21 q ha^{-1}). Similarly and lowest biological yield was recorded in S1 treatment (101.44 q ha^{-1}). It might be plant extract have higher micro-nutrients which enhance the nutrient efficiency inside the plant metabolism, similar result was followed by Chandukishore *et al.* (2023); Choudhary *et al.* (2024) and Garg *et al.* (2024). There was significant interaction noticed between planting systems and nutrient sources. Results are corroborated with Umesh *et al.* (2024) and Dudwal *et al.* (2021).

Influences of planting systems and nutrient management on light transmission ratio and light interception in maize

The sole maize (M1) was recorded significantly maximum LTR (52.63%,), which was on par with M3 (39.46%), M4 (38.96%) and lowest was found in M5 (20.34). M1 treatment recorded 158% more LTR over M5 treatments. It was due to less light interception (Mo *et al.,* 2015). While, M5 (77.69%) treatment observed significantly highest light interception (LI), which was on par with M4 (74.59%) and M3 (70.21%) and lowest was recorded in M1 treatment. It might be due to maximum leaf covered on surface by parahelionastic movement of soybean in intercropping (Chandukishore *et al.,* 2023). In nutrient management, significantly high LTR was recorded in S1 (40.26%), which was on par with S2 (35.06%), S3 (34.81%) and S4 (16.19) and lowest LTR was recorded in S5 (11.55%) treatment. While, S5 (88.45%) was found significantly highest light interception which was on par with S4 (83.81) and lowest was found in S1 (59.75%). It might be due to the foliar application of plant extract enhanced the leaf area which is directly proportional to light interception and indirectly proportional to light transmission ratio (Chandukishore *et al.,* 2023).

Relationship between growth and yield light attributes

The relationship between growth, yield and light attributes were significantly correlated with each other (Fig 1). Light

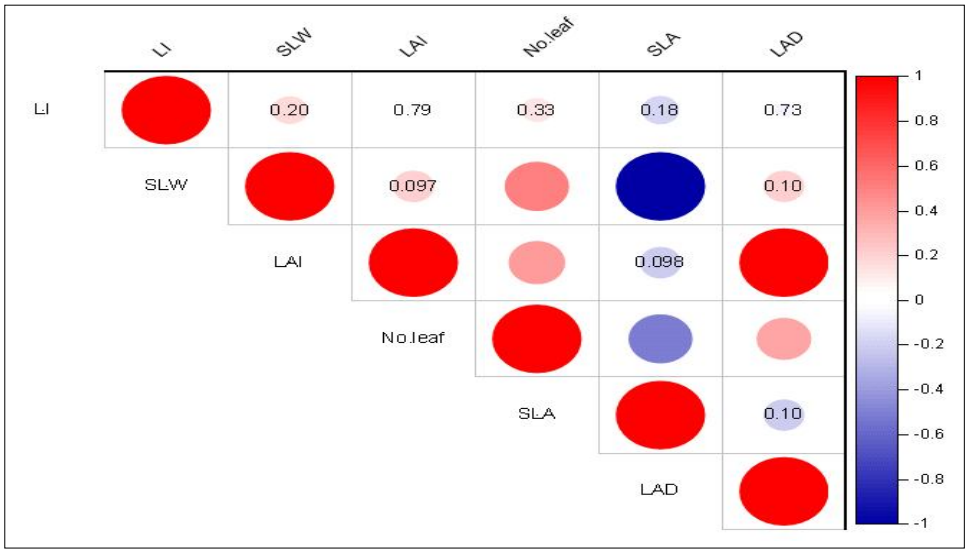


Fig 1: Relationship between growth, yield and light attributes on maize under maize soybean intercropping.

Table 1: Performance of growth, yield and light attributes of maize crop influenced by different planting pattern and nutrient management system.

Treatments	No. of leaves (plant^{-1})	LAI	SLA (m^2g^{-1})	LAD (days)	SLW (gcm^{-2})	Biological yield (q ha^{-1})	LTR (%)	LI (%)
Planting system (M)								
M1	12.66^{a}	3.85^{a}	163.62^{b}	140.91^{a}	6.12^{a}	132.21^{a}	32.8^{a}	67.2^{d}
M3	11.01^{b}	3.82^{a}	164.24^{b}	139.93^{a}	6.09^{a}	126.79^{b}	29.79^{b}	70.21^{c}
M4	10.47^{c}	2.52^{c}	166.49^{a}	92.74^{c}	6.01^{b}	118.74^{c}	25.41^{c}	74.59^{b}
M5	10.06^{d}	3.7^{b}	166.57^{a}	136.69^{b}	6.01^{b}	110.99^{d}	22.31^{d}	77.69^{a}
SEm (±)	0.04	0.02	0.58	0.31	0.02	0.26	0.4	0.4
CD (0.05)	0.15	0.04	2.05	1.09	0.07	0.89	1.44	1.43
Nutrient management (S)								
S1	9.97^{c}	3.34^{c}	171.28^{a}	123.36^{c}	5.84^{b}	101.44^{c}	40.26^{a}	59.75^{d}
S2	11.05^{b}	3.48^{b}	163.02^{b}	127.83^{b}	6.14^{a}	125.68^{b}	35.06^{b}	64.94^{c}
S3	11.29^{ab}	3.51^{b}	163.78^{b}	128.54^{b}	6.11^{a}	127.21^{ab}	34.81^{b}	65.19^{c}
S4	11.37^{ab}	3.51^{ab}	163.60^{b}	128.58^{b}	6.12^{a}	127.57^{ab}	16.19^{c}	83.81^{b}
S5	11.57^{a}	3.54^{a}	164.47^{b}	129.52^{a}	6.08^{a}	129.02^{a}	11.55^{d}	88.45^{a}
SEm (±)	0.12	0.01	0.78	0.31	0.03	0.2	0.53	0.53
CD (0.05)	0.35	0.03	2.25	0.9	0.08	0.57	1.54	1.55
Interaction (M×S)								
SEm (±)	0.10	0.03	1.30	0.70	0.05	2.25	0.90	0.91
CD (0.05)	0.72	0.07	NA	1.9	NA	4.29	3.19	3.2

interception was positively correlated with SLW (0.166), leaf number (0.127) but, negatively correlated with LAI (0.035), SLA (0.174) and LAD (0.046). Similarly, SLW correlated with LI (0.165), LAI (0.216), no of leaf (0.519), LAD (0.213) and negative correlation with SLA (0.99); LAI positively correlated with SLW (0.16) no. of leaf (0.400), LAD (0.998) and negatively correlated with LAI (0.35) and SLA (0.215); No of leaf positively correlated with LI (0.127), SAW (0.519), LAI (0.400), LAD (0.376) and negative with SLA (0.516); SLA was negatively correlated with SLW, LI, LAI, no of leaf and LAD. Similarly, LAD positively correlated with SLW (0.213), LAI (0.998), no of leaf (0.376) and negatively correlated with LI and SLA.

CONCLUSION

Based on the study, it can be concluded that sole maize cultivation performed best, achieving the highest growth, yield attributes and light transmission ratio. Among the nutrient sources, the application of 70% recommended dose of fertilizers (RDF) combined with two foliar applications of plant extract resulted in significantly improved growth attributes. Therefore, the cultivation of sole maize with 70% RDF and two foliar applications of plant extract demonstrated maximum growth, light transmission and yield production compared to other treatment combinations. This approach is recommended for maize farmers in the Indo-Gangetic region to optimize crop performance.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

All authors declared that there is no conflict of interest.

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