RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 58 Issue 5: 800-805 (October 2024)

Maximizing Water Use Efficiency (WUE), Land Utilization Efficiency (LUE) and Competitive Indices of Maize and Soybean Crops Through Intercropping Pattern with Straw Mulching

E. Jeevana Sai[1], Rajeev[1], M. Siyon Kumari[1]

10.18805/IJARe.A-6244

ABSTRACT

Background: Understanding the complex relationship between soil characteristics and crop production is crucial for sustainable agriculture practices. Soil physicochemical properties such as pH, electrical conductivity (EC), organic matter (OM) and nutrient content (*e.g.*, NPK) significantly influence crop yield. Additionally, the application of straw mulch can impact soil moisture retention, there by affecting crop growth and productivity. Intercropping system offers potential advantages in terms of water use efficiency (WUE) and productivity compared to monoculture system.

Methods: The experiment was conducted using a randomised block design (RBD) with three replications. The study included six treatments with different cropping system: T_1 = Monoculture soybean(planting size 30×10 cm), T_2 = Monoculture maize (planting size 45×15 cm),T_3 = Maize + soybean (2:2) line sown,T_4 = Maize intercropping with soybean (2:2) + wheat straw (5 tha^{-1}), T_5 = Maize intercropping with soybean (2:2) + maize straw (5 tha^{-1}), T_6 = Maize intercropping with soybean (2:2) + mustard straw (5 tha^{-1}).

Result: Water use efficiency (WUE) varied among treatments, with the highest WUE (9.44) observed in application of maize straw mulch 5t ha^{-1}, indicating 42.57% increases compared to monoculture maize and 42.17% increases compared to monoculture soybean cultivation. Similarly, superior grain yield (19.30 q ha^{-1}), pod yield (16.29 q ha^{-1}), intercrop yield (35.59 q ha^{-1}), maximum maize equivalent yield (54.33 q ha^{-1}) when comparing the results with and without straw mulch applied to maize and soybean crops. Maize and soybean intercropping system demonstrated superior land utilization efficiency (LER:1.04 to 1.24) and productivity metrics.

Key words: Intercropping, Land productivity, Maize, Soybean, Water use efficiency.

INTRODUCTION

Maize is the second most important cereal crop in the world in terms of acreage and is called the ‘Queen of Cereals’ because to its superior genetic production potential. India rank 4th in area and 7th in production, representing around 4% of the world maize area and 2% of total production. Around sixty-four percent of total production of maize is utilized for poultry feed, with 16% for human use, 19% for industrial starch and beverage and 1% for seed. Maize is a less water demanding crop and gives higher yield per hectare. By growing maize farmers save 90% of water, 70% of power compared to paddy. Soybean (*Glycine max* L.) is commonly referred to as the “miracle crop”. It is the world’s most important seed legume, accounting for 25% of worldwide edible oil, about two-thirds of global protein concentrate for livestock feeding and a vital element in formulated diets for poultry and fish, India has the fourth largest soybean acreage in the world.

According to (NITI Aayog, 2023) estimations, India produce 650 million metric tons of crop residue per year. Currently, there is a surplus of 178 (Mt), with an annual burned of 87 million metric tonnes (Mt) (NITI Aayog, 2023). Despite efforts to mitigate these practices, crop residue burning persist as a major concern, particularly in food bowl of India, contributing significant to peak air pollution levels across the Indo-Gangetic Plains. According to (Singh *et al*., 2020), if current practices persist, emission from CRM are projected to rise by 45% by 2050. These gases include CH_4 (0.66%), N_2O (2.09%), CO (7%) and CO_2 (70%) (Dutta *et al*., 2022), impact on atmospheric chemistry on both a regional and global levels and leading to human health issues (Singh *et al*., 2008), depletion of plant nutrient and has negative effects on the atmosphere, environment and soil health (*Ex situ* Crop Residue management Options (ICAR, 2021). Furthermore, the burning of 1 million metric ton of rice residue releases about 0.2 kg of sulphur dioxide (SO_2), 3.5 kg of nitrogen dioxide (NO_2), 13 kg of particulate matter (PM), 60 kg of carbon monoxide (CO) and 1460 kg of carbon dioxide (CO_2). Rice residue burning in Punjab leads to an average depletion of 35 kg of nitrogen (N), 3 kg of phosphorus (P) and 2.7 kg of sulphur (S) per hectare

[1]Department of Agronomy, School of Agriculture, Lovely professional University, Phagwara-144 401, Punjab, India.

Corresponding Author: Rajeev, Department of Agronomy, School of Agriculture, Lovely professional University, Phagwara-144 401, Punjab, India. Email: rajeev.26421@lpu.co.in

How to cite this article: Sai, E.J., Rajeev and Kumari, M.S. (2024). Maximizing Water Use Efficiency (WUE), Land Utilization Efficiency (LUE) and Competitive Indices of Maize and Soybean Crops Through Intercropping Pattern with Straw Mulching. Indian Journal of Agricultural Research. 58(5): 800-805. doi: 10.18805/IJARe.A-6244.

Submitted: 23-04-2024 **Accepted:** 23-05-2024 **Online:** 14-06-2024

(Parihar *et al*., 2023). According to reports, approximately 40% of absorbed nitrogen (N), 30-35% of absorbed phosphorus (P), 80-85% of absorbed potassium (K) and 40-45% of absorbed sulphur (S) are retained in the vegetative tissues of crop plants. However, some of these nutrients are lost while crop residues are burned (Kumar *et al*., 2019).

In India, two primary methods of straw utilization for sustaining crop productivity and soil fertility are In-situ and Ex-situ strategies can be used to manage crop residue management. *In situ* methods entail the retention or mulching of leftovers in the field, their incorporation into the soil, or the facilitation of decomposition by microbial consortia. *Ex situ* methods involve the process of compressing and moving leftover materials for different purposes that are not within the original location. Various studies have highlighted the efficacy of mulching with different materials in mitigating water evaporation, enhancing fallow efficiency, increasing soil water retention for plant utilization and mitigating salt accumulation in the soil (Li *et al*., 2013). Pervaiz *et al*. (2009) found that use of mulches resulted in significant improvement in soil water content and levels of soil organic matter (SOM), while also reducing soil bilk density and soil strength. Presently, the agricultural sector worldwide is encountering a novel difficulty and the issue of global grain security remains unresolved (Kalugina *et al*., 2014). These issues encompass urbanization and industrialization have caused a steady decline in cultivated lands and the impact of climate change (Hu *et al*., 2016). Intercropping refers to cultivating two crops side by side in rows, resulting in increased yield due to enhanced resource capture and conservation efficiency (Huang *et al*., 2015). This is achieved by improving soil coverage and reducing the amount of light that reaches the ground. An important obstacle is to facilitate the preservation of biodiversity while simultaneously tackling the problem of ensuring food security (Brooker *et al*., 2016), which has restricted the extension of cultivation areas for legumes like soybean; *Glycine max* L.) and cereals (like maize; *Zea mays* L.). The severity of this scenario is increasing in emerging countries such as India, China and Pakistan, where there is a larger population and less arable land (Du, 2017). Hence, given the current situation of few resources such as land and water, as well as the impact of climate change, it is crucial to create innovative methods of farming, such as intercropping or agroforestry. These approaches can enhance multiple cropping index, land utilization rate, so ensuring consistent and high agricultural productivity by efficiency utilizing minimizing impact to the environment, leading to sustainable agricultural development (Luo, 2019). The purpose of the study was to determine (i) land productivity and competitive index of maize and soybean intercropping compared to monoculture cropping of maize and soybean and (ii) asses the effect of improved straw mulch management practices on soil nutrient status, soil moisture content % of MSI cropping system.

MATERIALS AND METHODS

The field study was conducted *Kharif season of* 2021-2022 and 2022-2023 at Lovely Professional University, Punjab located at latitude 31°24′39″N, longitude 75°69′54″W and altitude 245 m above sea level. The experiment was conducted using a randomised block design (RBD) with three replications. The size of each plot was 25 m^2 (5 m in width and 5 m in length). The study included six treatments with different cropping system: T_1 = Monoculture soybean (planting size 30×10 cm), T_2 = Monoculture maize (planting size 45×15 cm),T_3 = Maize + soybean (2:2) line sown, T_4 = Maize intercropping with soybean (2:2) + wheat straw (5t ha^{-1}),T_5 = Maize intercropping with soybean (2:2)+maize straw (5t ha^{-1}), T_6 = Maize intercropping with soybean (2:2) + mustard straw (5 t ha^{-1}). Based on the soil analysis, all plots received N-P_2O_5-K_2O at 120-60-40 N-P-K kg ha^{-1} for maize and 20-60-20 N-P-K kg ha^{-1} for soybean. Fertilizers N, P and K were applied through urea (46% N), diammonium phosphate (DAP, 18% N,46% P_2O) and muriate pf potash (KCL, 60% K_2O respectively. The whole of P, K and 1/3rd of N fertilizer were applied at the sowing time. The remaining rest of N fertilizer was applied at 8-leaf stage of maize. The prescribed agronomic procedures were implemented according to the specific demands of the crops. The maize variety 'Suvarna- NMH 589' and soybean variety 'SL- 5001' were used in the study.

Data analysis

The data was evaluated by statistical analysis using the standard analysis of variance approach for the experimental designs, using the XLSTAT 2024. The treatment means were compared at a significance level of p<0.05 using the student t-test and computing LSD values.

RESULTS AND DISCUSSION

Pearson correlation between soil physiochemical properties and crop production

The Pearson correlation analysis showed that significant correlations between various soil physicochemical properties and crop yields. The analytical findings are shown in (Table 1). The soil pH showed strong negative correlation with soil electrical conductivity (EC) (r=-0.93, p<0.001), organic matter (OM%) (r = -0.89, p<0.001) and nitrogen (N) (r = -0.91, p<0.001). The results indicate a negative correlation between soil pH values and greater levels of soil electrical conductivity (EC), organic matter (OM%), nitrogen (N). However, there were strong positive correlation between soil EC and OM% (r = 0.91, p<0.001), N (r = 0.92, p<0.001), suggesting that higher levels of soil EC contributed with increased levels of OM%, N and P. The results revealed a strong positive correlation between OM% and P (r = 0.97, p<0.001), indicating that higher OM% was associated with higher P levels. The bulk density showed a strong negative correlation with soil EC (r = -0.91, p<0.001), indicating that greater bulk density values were associated with lower soil EC. The variable N showed strong positive relation with both P (r = 0.87, p<0.001) and K (r = 0.90, p<0.001). Similarly, P showed a strong positive correlation between N and K (r = 0.81, p<0.001), indicating that both nutritional levels increase together. The maize grain yield showed weak negative correlation with each variable except for itself. However, it exhibits a significant inverse correlation with soybean pod yield (r = -0.95, p<0.001). There was a strong negative correlation (r = -0.95, p<0.001) between the yield of soybean pods and the yield of maize grains. These results demonstrate the complex correlation between soil properties and crop yield in agricultural system.

Impact of mulch treatments on soil moisture content (%) at various depth (cm) and time intervals (days after planting)

To evaluate the percentage of soil moisture content among three mulch treatments (wheat straw, maize straw, mustard straw mulch(5 t ha^{-1}) and control - nostraw mulch) at four specific time intervals (30, 60, 90 days after planting and at harvest) for two different soil depth (0-15 cm and 15-30 cm) in the crop root zone are depicted in Fig 1(A) and (B), respectively. The maximum soil moisture was recorded at a depth of 0-15 cm WSM plots, followed by the MSM, MTSM and C-SM plots. The WSM plots showed an average increase of 31% compared to the MSM plots, while the MSM plots showed an average increase of 19% compared to the MTSW plots (Fig 1A). The soil moisture retention order at a depth of 15-30 cm was as follows: WSM>MSW>MTSM>C-SM. Although the moisture retention in WMS and MSW was higher compared to MTSM and C-SM, the average increase in moisture was 16.25% in WSM, 8.34% in MSW, 5.12% in MTSM and 2.1% in C-SM (Fig 1B). WMS had the higher moisture content in the top 0-15 cm layer, indicating its superior water absorption compared to all other straw mulch treatments and its more efficient reduction of deep percolation loss. Due to the presence of straw mulch, which act as a physical barrier, the evaporation of soil water is reduced and losses *via* percolation are avoided, resulting in in an increase in moisture retention in the top layer of soil. This has the potential to improve soil health and enhance crop performance. Comparable patters were noted at the soil depth ranging from 15 to 30 cm. Straw mulches can conserve moisture in the soil. (Akhtar *et al*., 2019) reported that wheat straw mulch enhances soil moisture by 7.4% and reduces soil temperature by 3%. The growth of soybean was greatly enhanced by increases in straw mulch and nitrogen. The use of straw mulch at a rate of 6 t/ha, with a nitrogen (N) application rate of 27 kg ha^{-1}, resulted in a significant increase in soybean production.

Enhancing water use efficiency (WUE) and productivity in a maize-soybean intercropping

To evaluate the water use efficiency (WUE) and water productivity measures in a maize + soybean strip intercropping system. The experiment had six treatments, labelled as T_1 to T_6, each indicating a different combination of maize and soybean cropping pattern. The finding revealed that significant variation in crop productivity and water use efficiency across the different treatment conditions. The WUF varied significantly among treatment, with values ranging from 6.62 (sole soybean) to 9.44 (maize straw mulch 5 t ha^{-1}). Treatments that used intercropping often showed that greater water use efficiency (WUE) compared to treatment that only used sole cropping. Additionally, the amount of water needed to produce 1 kg of yield varied from 1059.75 liters (maize straw mulch 5 t ha^{-1}) to 1510.81 liters (sole soybean), showing different levels of water efficiency across various treatment combinations. Treatment maize straw mulch 5 t ha^{-1} has highest water efficiency (WUE = 9.44), indicating that a percentage increases of approximately 42.17% compared to treatment sole soybean, which had the lowest (WUE=6.62). This indicates that the combination used in T_5, which led to an

Table 1: Correlation between soil physiochemical properties and crop yields.

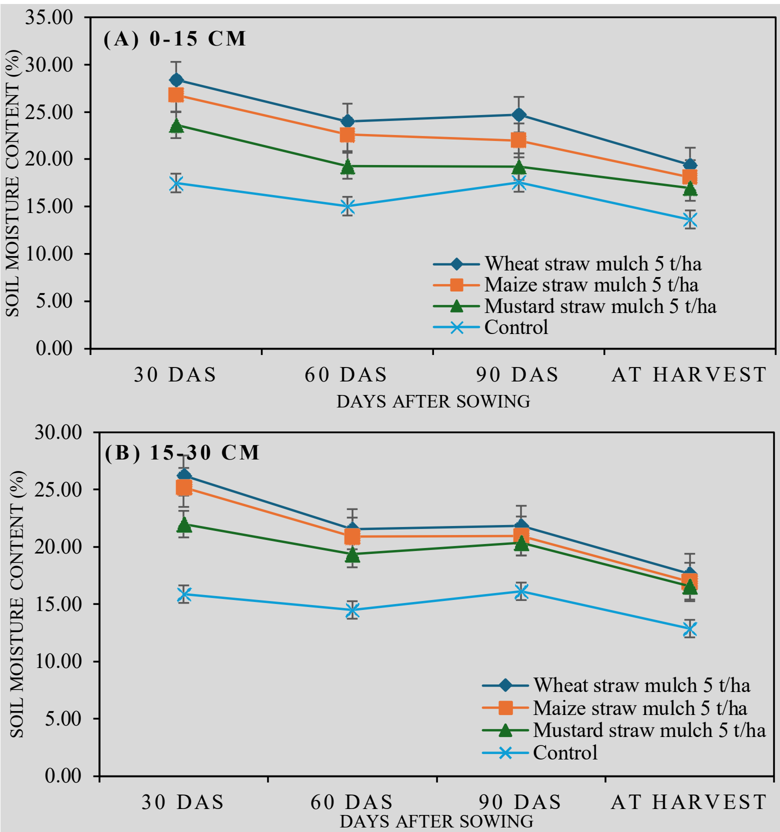
Pearson correlations	Soil pH	Soil EC (ds m^{-1})	OM (%)	Bulk density (kg m^{-3})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Maize grain yield (q ha^{-1})	Soybean pod yield (q ha^{-1})
Soil pH	1	-0.93853	-0.8982	0.79611	-0.91056	-0.87531	-0.77703	-0.07334	-0.20457
Soil EC (ds m^{-1})	-0.93853	1	0.91473	-0.91069	0.92367	0.91709	0.83096	0.10089	0.19227
OM%	-0.8982	0.91473	1	-0.81232	0.89267	0.97313	0.84524	-0.04246	0.31755
Bulk density (kg m^{-3})	0.79611	-0.91069	-0.81232	1	-0.8929	-0.79225	-0.84547	0.0534	-0.33884
N (kg ha^{-1})	-0.91056	0.92367	0.89267	-0.8929	1	0.86879	0.90249	-0.23287	0.49841
P (kg ha^{-1})	-0.87531	0.91709	0.97313	-0.79225	0.86879	1	0.81479	-0.02766	0.29214
K (kg ha^{-1})	-0.77703	0.83096	0.84524	-0.84547	0.90249	0.81479	1	-0.2478	0.47231
Maize grain yield (q ha^{-1})	-0.07334	0.10089	-0.04246	0.0534	-0.23287	-0.02766	-0.2478	1	-0.9452
Soybean pod yield (q ha^{-1})	-0.20457	0.19227	0.31755	-0.33884	0.49841	0.29214	0.47231	-0.9452	1

2- tailed test of significant is used. EC: Electrical conductivity, OM: Organic matter, N: Nitrogen, P: Phosphorus, K: Potassium.

intercrop yield of 3559.33 kg ha^{-1}, was extremely effective in conserving water resources. Similarly, T_5 had the lowest water use (1059.75 lit) per kg of production, indicating a percentage decrease of about 29.91% compared to treatment sole soybean, which had the highest water requirement (1510.81 lit). T_5 had a high yield production in relation to the amount of water used, indicating effective water management strategies in the intercropping system. This indicates that inadequate utilization of water needed for productivity in the cropping system, which only consisting of growing sole soybean. These findings indicate the significant of adoption suitable treatment combination and management techniques to improve water use efficiency and production in agriculture system. Approaches that have been better water use efficiency (WUE) and lower water needs per unit of output show promise for sustainable water management and increased crop yields in maize-soybean intercropping system (Liu *et al*., 2015) found that the use of mulching, enhances water use efficiency (WUE) and grain production, while reducing nitrogen leaching losses in arid agriculture farmlands. (Li *et al*., 1999) conducted three-research and found that mulching had a significant effect on maize yield, increasing them from 13.0 to 15.0%. Additionally, water use efficiency (WUE) was improved from 9.8% to 11.6% (Table 2).

Table 2: Impact of various treatments on the yield and water use efficiency of maize/soybean intercropping.

Treatment	Maize grain yield (kg ha^{-1})	Soybean pod yield (kg ha^{-1})	Intercrop yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Liters to produce 1 kg yield
T_1	-	2496.67	2496.67	6.62	1510.81
T_2	3223.33	-	3223.33	8.55	1170.22
T_3	1630.67	1341.67	2972.33	7.88	1269.04
T_4	1843.33	1506.00	3349.33	8.88	1126.19
T_5	1930.00	1629.33	3559.33	9.44	1059.75
T_6	1776.67	1456.00	3232.67	8.57	1166.84



The vertical bars represent the standard error of the mean.

Fig 1: Effect of straw mulching on soil moisture content at different depth at 0-15 cm and 15-30 cm intervals.

Table 3: The impact of treatments of land equivalent ratio (LER), relative crowding coefficient (RCC), competition ratio (CR) and area time equivalent ratio (ATER).

Treatments	Land equivalent ration (LER)	Relative crowding coefficient (RCC)	Competition ratio (CR)	Area time equivalent ration (ATER)
T_1	1	-	-	-
T_2	1	-	-	-
T_3	1.04	0.075	0.941	0.94
T_4	1.18	0.113	0.948	1.06
T_5	1.25	0.145	0.917	1.13
T_6	1.13	0.099	0.945	1.02

Table 4: Impact of treatments on maize equivalent yield (MEY), maize production efficiency and soybean production efficiency.

Treatments	Maize equivalent yield (MEY) (q ha^{-1})	Maize production efficiency (kg ha^{-1} day^{-1})	Soybean production efficiency (kg ha^{-1} day^{-1})
T_1	-	-	20.81
T_2	-	33.93	-
T_3	45.15	17.16	11.18
T_4	50.81	19.40	12.55
T_5	54.33	20.32	13.58
T_6	49.07	18.70	12.13

Effect of combination between intercropping cropping and straw mulch on land equivalent ration (LER), relative crowding coefficient (RCC), competition ratio (CR) and area time equivalent ration (ATER)

The effectiveness of intercropping in terms of biological productivity was assessed using metrics such as LER, RCC, CR and ATER, which involved comparing the yield of intercropped areas with that of monoculture (Table 3). LER of maize + soybean system grown under combination of maize T_5 (maize straw mulch 5 t ha^{-1}) recorded significantly higher LER value (1.25) followed by the T_4 (1.18) and T6 (1.13). This indicates that 25.0% (0.25 ha), 18.0% (0.18 ha) and 13.0% (0.13 ha) more area would be required by a monoculture cropping system to equal the yield of intercropping system. Treatment T_3 to T_6 achieved greater land utilization efficiency compared to monoculture, with LER values ranging from 1.04 to 1.25. The relative crowding coefficient (RCC) values measures the degree of crop competitiveness within an intercropping system. Treatments T_5 and T_4 showed higher RCC values (0.145 and 0.113), suggesting increased competition between maize and soybean crops. The competition ration (CR) values indicate the relative competitive advantage of either maize or soybean in specific intercropping system. Treatment T_4, T_6 and T_3 have CR values (0.948, 0.945 and 0.941), showing an effective competitive position for either crop. ATER values provide a comprehensive assessment of productivity through a given period. T_5 and T_4 exhibits the highest ATER values (1.13 and 1.01), indicating superior productivity compared to other treatment (Table 3).

Effect maize basedintercropping system on maize equivalent yield (MEY), maize production efficiency (kg ha^{-1} day^{-1}) and soybean production efficiency (kg ha^{-1} day^{-1})

Data in Table 4 show that MEY was significantly the highest in maize + soybean strip intercropping system with maize straw mulch 5 t ha^{-1} (54.33 q ha^{-1}) and the lowest in maize + soybean strip intercropping with only RDF (45.15 q ha^{-1}). The maize production efficiency varied from 17.16 to 33.93 kg ha^{-1} day^{-1}, while in soybean production efficiency varied from 11.18 to 20.81 kg ha^{-1} day^{-1}. The maximum maize production efficiency (20.32 kg ha^{-1} day^{-1}) was obtained in T_5 (maize straw mulch 5 t ha^{-1}) followed by T_4 (wheat straw mulch 5 t ha^{-1}) with production efficiency (19.40 kg ha^{-1} day^{-1}). The lowest production efficiency (17.16 kg ha^{-1} day^{-1}) was found in maize/soybean intercropping (Table 4) owing to lower grain yield in maize despite higher market price in soybean. Similarly, the maximum soybean production efficiency (13.58 kg ha^{-1} day^{-1}) was obtained in T_5 (maize straw mulch 5 t ha^{-1}) followed by T_4 (wheat straw mulch 5 t ha^{-1}) with production efficiency (12.55 kg ha^{-1} day^{-1}). The lowest production efficiency (11.18 kg ha^{-1} day^{-1}) was found in maize/soybean intercropping (Table 4) owing to lower grain yield in soybean despite higher market price in maize. (Reddy *et al*., 2022) findings highest production efficiency was found in fodder bajra (176.8 kg ha^{-1} day^{-1}) with sorghum and maize following at (138.9 kg ha^{-1} day^{-1} and 130.5 kg ha^{-1} day^{-1}). (Layek *et al*., 2014) report that in both years, soybean+ maize with 100% RDN had the highest SEY, whereas soybean + pearl millet with no N produced the lowest.

CONCLUSION

Utilizing wheat straw mulch (5 t ha^{-1}) withmaize + soybean (2:2) was more effective in improving soil organic matter, active carbon and maintains elevated soil moisture levels in comparison to the absences of mulch. Thus, mulching is quite helpful reduction in bulk density results in increased yield and water use efficiency (WUE) of maize. The study has confirmed the premise that straw mulching enhances soil characteristics, preserves residual soil moisture and improves crop and water productivity in maize-based system. To summarize, the results we obtained indicate that enhancing intercropping systems may lead to the conservation of 20-50% of water and land, especially in situations where resources are limited and in the context of climate change. However, additional research is required to evaluate the use of resources an intercropping, particularly in the context of the present climate change scenario.

ACKNOWLEDGEMENT

We thank our gratitude to the Lovely Professional University for Agricultural Research for funding this research. We convey our gratitude to Dr. Rajeev for his assistance in crop management and field observations.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Akhtar, K., Wang, W., Khan, A., Ren, G., Afridi, M.Z., Feng, Y. and Yang, G. (2019). Wheat straw mulching offset soil moisture deficient for improving physiological and growth performance of summer sown soybean. Agricultural Water Management. 2(11): 16-25.

Brooker, R.W., Karley, A.J., Newton, A.C., Pakeman, R.J. and Schob, C. (2016). Facilitation and sustainable agriculture: A mechanistic approach to reconciling crop production and conservation. Functional Ecology. 30(1): 98-107.

Du, J.B. (2017). Maize+ soybean strip intercropping: Achieved a balance between high productivity and sustainability. Journal Integrative Agriculture. 16: 450-459.

Dutta, A., Patra, A., Hazra, K.K., Nath, C.P., Kumar, N. and Rakshit, A. (2022). A state-of-the-art review in crop residue burning in India: previous knowledge, present circumstances and future strategies. Environmental Challenges. 8: 100581. doi: 10.1016/j.envc.2022.100581.

Hu, F., Gan, Y., Chai, Q., Feng, F., Zhao, C., Yu, A. and Zhang, Y. (2016). Boosting system productivity through the improved coordination of interspecific competition in maize/pea intercropping. Field Crops Research. 198: 50-60.

Huang, C., Liu, Q., Heer ink, N., Stomp, T., Li, B., Liu, R. and Zhang, F. (2015). Economic performance and sustainability of a novel intercropping system on the North China Plain. PloS One. 10(8): e0135518. doi: 10.1371/journal.pone.0135518.

Indian Council of Agricultural Research (ICAR), (2021). *Ex situ* crop residue management options. New Delhi: Directorate of Knowledge Management in Agriculture, ICAR. Available from: https://www.icar.org.in/content/ex-situ-crop-residue-management-options.

Kalugina, Z.I. (2014). Agricultural policy in Russia: global challenges and the viability of rural communities. International Journal Social Agriculture Food. 21: 115-131.

Kumar, D., Patel, K.P., Ramani, V.P., Shukla, A.K.and Meena, R.S. (2019). Management of Micronutrients in Soil for the Nutritional Security. In: Nutrient Dynamics for Sustainable Crop Production. [Meena, R.S. (ed.)], Singapore: Springer Nature Pvt. Ltd. pp. 103-134. doi: 10.1007/978-981-13-8660-2_4.

Layek, J., Shivakumar, B.G., Rana, D.S., Munda, S., Lakshman, K., Das, A. and Ramkrishna, G.I. (2014). Soybean-cereal intercropping systems as influenced by nitrogen nutrition. Agronomy Journal. 106(6): 1933-1946.

Li, F.M., Guo, A.H. and Wei, H. (1999). Effects of clear plastic film mulch on yield of spring wheat. Field Crops Research. 63(1): 79-86.

Li, S.X., Wang, Z.H., Li, S.Q., Gao, Y.J. and Tian, X.H. (2013). Effect of plastic sheet mulch, wheat straw mulch and maize growth on water loss by evaporation in dryland areas of China. Agricultural Water Management. 116: 39-49.

Liu, J.L. (2015). Response of nitrogen use efficiency and soil nitrate dynamics to soil mulching in dryland maize (*Zea mays* L.) fields. Nutrient Cycling in Agroecosystems. 101: 271-283.

Luo, Z. (2019). Yield, competition and water use in maize-soybean strip intercropping systems. Field Crop Research. 241: 107560. https://doi.org/10.1016/j.fcr.2019.107560.

NITI Aayog, (2023). https://agricoop.nic.in/sites/default/files/Guidelines.

Parihar, D., Narang, M., Dogra, B., Prakash, A. and Mahadik, A. (2023). Rice residue burning in northern india: An assessment of environmental concerns and potential Solutions- A review. Environmental Research Communications. 5(6). doi: 10.1088/2515-7620/acb6d4.

Pervaiz, Z., Rabbani, M., Pearce, S. and Malik, S. (2009). Determination of genetic variability of Asian rice (*Oryza sativa* L.) varieties using microsatellite markers. African Journal Biotechnology. 8: 5641-5651.

Reddy, A.M., Kumari, C.R., Reddy, B.S. and Reddy, B.R. (2022). Productivity and quality of fodder crops under late-sown conditions in semi-arid Tropics of India. Indian Journal of Agricultural Research. 56(6): 660-665. doi: 10.18805/IJARe.A-6005.

Singh, B., Shan, Y.H., Johnson-Beebout, S.E., Singh, Y. and Buresh, R.J. (2008). Crop residue management for lowland rice-based cropping systems in Asia. Advances in Agronomy. 98: 117-199.

Singh, T., Biswal, A., Mor, S., Ravindra, K., Singh, V. and Mor, S. (2020). A high-resolution emission inventory of air pollutants from primary crop residue burning over Northern India based on VIIRS thermal anomalies. Environmental Pollution. 266(1): 115132. doi: 10.1016/j.envpol.2020.115132.