Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 24 | No. S1 | pp. 375-384 | 2025

Original Research Paper

https://doi.org/10.46488/NEPT.2025.v24iS1.029

Open Access Journal

A Sustainable Approach Toward Food Security: Investigating the Effect of Intercropping on Soil Rhizospheric Activity, Weed Flora and Yield Attributes of Maize (*Zea mays*)

Kritika[1], Arshdeep Singh[1]†, Shimpy Sarkar[2] and Jaspreet Kaur[3]
[1]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara-144411, Punjab, India
[2]Department of Entomology, School of Agriculture, Lovely Professional University, Phagwara-144411, Punjab, India
[3]Faculty of Business and Professional Studies, School of Business, Capilano University, North Vancouver, BC, V7J 3H5, Canada
†Corresponding author: Arshdeep Singh; arshdeep.27269@lpu.co.in

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 24-05-2024
Revised: 13-06-2024
Accepted: 21-06-2024

Key Words:
Zero hunger
Rhizospheric bacteria
Ecofriendly
Soil fertility
Sustainability
Zea mays

ABSTRACT

Maize is one of the staple food crops after wheat and rice crops. There is a reduction in the yield of maize due to biotic and abiotic factors. Due to more spacing in maize weeds are highly infested in the field which leads to reduced fertility of soil and sustainability. To maintain the fertility of soil and reduce the wastage of resources intercropping is the best option. By growing crops in between the rows of maize crops we can increase production and can achieve zero hunger. A field experiment was conducted at Lovely Professional University (Kharif 2022) to check the effect of black gram and French bean as intercrop in maize on weed flora, rhizospheric bacterial count, and yield parameters of maize. The experiment comprised 9 treatments i.e. Sole maize, Sole French bean and Sole black gram, Maize + French bean (1:1, 1:2, 1:3), Maize + black gram (1:1, 1:2, 1:3). Weed density and biomass recorded by quadrant 1 m^2 method at 30 and 60 DAS (Days after sowing). Results of the study showed that minimum weed count of grasses (3.44, 3.26), sedges (3.13, 2.73), and BLW (Broad leaf weed) (3.26, 4.58) at 30 and 60 DAS recorded in those plots where intercropping of maize and black gram practiced in 1:3 proportion. Rhizospheric bacterial count viz. THB (total heterotrophic bacteria) (232.82), NRB (nitrate-reducing bacteria) (41.89), and NB (nitrifying bacteria) (161.86) were recorded highest in Maize + French bean 1:3 at 30 DAS. Whereas THB, NRB, and PSB (phosphate solubilizing bacteria) highest count recorded in Maize + Black gram 1:3 at 90 DAS. In the case of maize yield attributes maize + Black gram 1:2 gave the best result. Land Equivalent ratio and Maize Equivalent yield (2.23, 11671.03 $kg.ha^{-1}$) were recorded maximum in those plots where Maize + Black gram 1:2 proportion was practiced. Intercropping can be used as an eco-friendly alternative to herbicides to reduce the weed population and infestation, which leads to maintaining soil fertility and enhancing sustainability.

INTRODUCTION

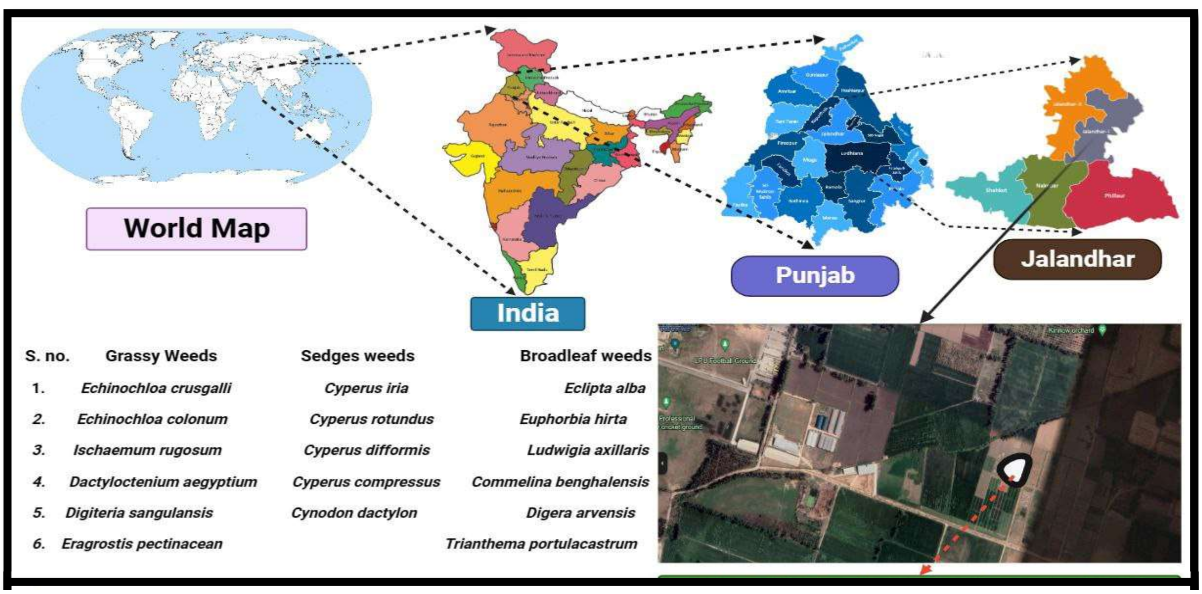
Since maize (*Zea mays*) has a higher yield potential than other cereals, it is grown in a variety of environments and is used for a wide range of purposes, including food, feed, and fodder. In terms of cereal crop production, maize is ranked second only to wheat, after rice; however, it is the most popular crop in Latin America and Africa and ranks third among growing countries in Asia, after rice and wheat. India ranks seventh out of all the countries that produce maize worldwide; based on total area, it is the fourth largest producer of maize globally, accounting for 2% of the total amount produced globally (Economic Survey 2021-22 Statistical Appendix). The use of fertilizers, the introduction of High Yielding Variety (HYV) seeds, and the ease of access to irrigation systems all contributed to a sharp increase in India's maize production. According to the Agricultural Market Intelligence Centre (PJTSAU), Bihar has the most area utilized for maize production at 14.73 lakh acres, followed by Maharashtra and Andhra Pradesh at 8.33 and 4.82 lakh acres, respectively. With 5.18 million tonnes, Karnataka, however, leads the output tables, while Madhya Pradesh and Maharashtra generate 3.58 million and 3.44 million tonnes, respectively (Economic Survey 2021-22 Statistical Appendix). In addition to being high in protein (32.1%), maize also includes significant amounts of vitamins E and A, crude fiber (3-0.8%), carbohydrates (66-75.9%), starch (1-3%), fatty acids (palmitic acid, stearic acid, oleic acid, and nicotinic acid), oil (4%), and riboflavin (Das & Singh (2016). Crop weed competition has lowered global maize production by 37%, which is a significant loss for the growers. Due to rising cultivation costs, small farmers now have an additional strain. However, due to maize's larger row spacing and sluggish development initially, together with friendly weather that encourages luxuriant weed growth that can cut production by 28–100%, the first six weeks following crop planting are the most essential for crop weed competition (Rani et al. 2020). Weeding, whether chemically or non-chemically, is practically necessary during this crucial time. Yield losses can range from 40 to 60% if proper weed control isn't implemented (Choudhary & Dixit 2018). Mechanical and manual weeding methods are costly, and during the monsoon season, persistent rains frequently make timely operations impractical. Microbiological activity in the rhizosphere is significantly higher than in soil that is not near plant roots due to the food supply. The microbes provide the plants, with nourishment in exchange. The rhizosphere is the most active soil environment because of all this activity. Different kinds of chemicals can be produced by free-living, symbiotic, or endophytic root-associated bacteria. By controlling the nutritional and hormonal balance of plants, fostering systemic tolerance to biotic and abiotic stressors, and promoting plant development, rhizosphere bacteria reduce the effects of stress on plants. The extensive monoculture of cereals has raised agricultural yields globally, but it has also ruined the environment, misused resources, and upset the natural equilibrium. Intercropping increases land utilization since different crop species share inputs, light, and space. Intercropping offers several advantages by enabling two or more crops to coexist for a portion of their lifespan. Maize is a widely spread crop that is good for legume growth and enables intercropping (Kritika et al. 2023).

Key objective of the study: To assess the effect of intercropping with legumes on weed dynamics of Maize crops.

MATERIALS AND METHODS

Experimental Site

The research was conducted in the kharif season, 2022 at the agricultural farm of Lovely Professional University, Jalandhar. The farm is situated at 31º22'31.81'' North latitude and 75º23'03.02 East longitude with 252 m average elevation above mean sea level having lower water availability and potential water scarcity (Fig. 1). The climate of the experimental location was subtropical, featuring mild winters, hot summers, and a rainy season with an average annual precipitation of 711 mm. The experiment had a total of 9 treatments with 3 replications i.e., (T_1) Sole Maize (60 cm), (T_2) Sole French bean (20cm), (T_3) Sole Black gram (20cm), (T_4) Maize + French bean (1:1), (T_5) Maize + French bean (1:2), (T_6) Maize + French bean (1:3), (T_7) Maize + Black gram (1:1), (T_8) Maize + Black gram (1:2) and, (T_9) Maize + Black gram (1:3) (Fig. 2). Sole Maize and intercropped maize were provided with the recommended dose of fertilizer of Maize, while in the sole Black gram and French bean plot, recommended doses of the respective legume were provided. The Sandy loam soil contained 0.152% organic carbon (low), available nitrogen (300 kg.ha^{-1}) (medium), available phosphorus (16 kg.ha^{-1}) (high), available potassium



S. no.	Grassy Weeds	Sedges weeds	Broadleaf weeds
1.	*Echinochloa crusgalli*	*Cyperus iria*	*Eclipta alba*
2.	*Echinochloa colonum*	*Cyperus rotundus*	*Euphorbia hirta*
3.	*Ischaemum rugosum*	*Cyperus difformis*	*Ludwigia axillaris*
4.	*Dactyloctenium aegyptium*	*Cyperus compressus*	*Commelina benghalensis*
5.	*Digiteria sangulansis*	*Cynodon dactylon*	*Digera arvensis*
6.	*Eragrostis pectinacean*		*Trianthema portulacastrum*

Fig. 1: The research experimental site.

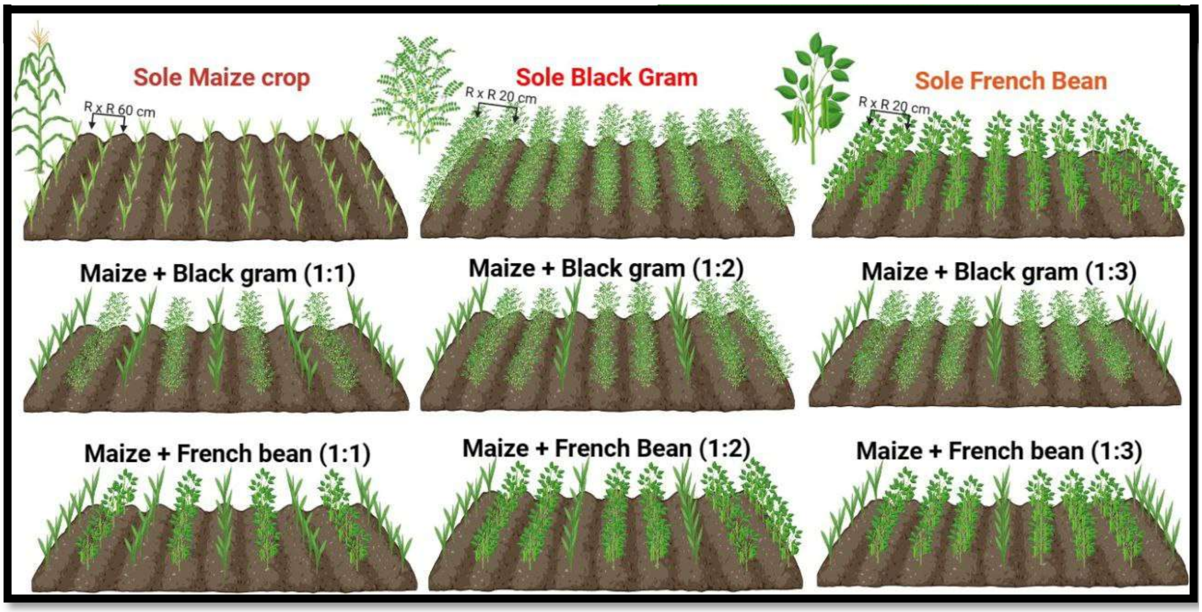


Fig. 2: The treatments' row ratios.

(125 $kg.ha^{-1}$) (medium), electrical conductivity (0.370 dsm^{-1}) (normal), and pH 7.9 (normal).

Weed Density and Weed Biomass

Weed density was calculated with the help of a quadrant of 1 m^2 from each plot at 30 DAS and 60 DAS. A sickle was used to cut the weeds, and an electric balance was used to weigh them. Weeds were then sun-dried for a week, stored in an oven at 42°C, and repeatedly weighed until, after 24 hours, a stable dry weight was reached.

Yield Attributes of Maize

The number of rows cob^{-1}, number of cobs $plant^{-1}$, number of grains row^{-1} cob^{-1}, length of cob, number of pods $plant^{-1}$, and seed pod^{-1} were manually counted when the crop was harvested at its maximum maturity. Cob thickness was recorded with the help of an electric vernier caliper. Following threshing, an electronic weighing scale was used to measure the yield characteristics, including seed index, grain yield, and stover yield. The plant samples were then dried in the sun for three days and then dried in an oven for 72 hours at 60°C to measure the biomass. The seed index was noted with the help of the seed counter. Grain and stover yield were calculated at harvest maturity. The Harvest index was calculated by the formula given by Donald in 1968. Land equivalent ratio and Maize equivalent yield were using the following formula.

$$\text{LER} = \frac{Yield\ of\ intercropped\ maize}{Yield\ of\ sole\ maize} + \frac{Yield\ of\ intercropped\ pulse}{Yiel\ of\ sole\ pulse}$$

$$\text{MEY} = Grain\ yield\ of\ maize + \frac{\text{Yield of intercrop} \times \text{Price of intercrop}}{\text{Price of maize}}$$

Soil Physico-Chemical and Biological Properties

The soil samples were collected before sowing from each plot (Four from the corner and one from the center) and thoroughly homogenized for subsequent analyses. The pH and EC of soil were measured with pH meter and EC meter respectively (Jackson 1973). Walkley & Black (1934) method was used for Organic Carbon estimation. For estimating total nitrogen (N) content, distillation in the Kjeldahl apparatus was performed that was followed by titration with the concentrated H_2SO_4. Available Phosphorus was estimated using Olsen's method (1954) by spectrophotometer at 660 nm wavelength and Available Potassium was determined with the help of a flame photometer as described by Merwin & Peech (1950).

Soil Rhizosphere Bacterial Analysis

Standard approaches (Ellinghausen & Pelczar 1957, Lacey 1997, Collins et al. 2006, Chatterjee et al. 2014, Azmi & Chatterjee 2016) were followed to count the population of several bacterial groups. Phosphate solubilizing bacteria (PSB), nitrate-reducing bacteria (NRB), nitrifying bacteria (NB), aerobic heterotrophic bacteria, or total heterotrophic bacteria (THB) were among the 0.1–1% of soil bacteria that were grown. One-gram samples of soil were suspended in 99 ml of distilled water and diluted to a 10^{-3} ratio. These diluted soil samples were combined with various specialized media to count the number of bacteria belonging to various groups.

Statistical Analysis

ANOVA was carried out on the data by applying the function of Post hoc, Tukey, and Duncan using SPSS 22 software. Homogeneity of variance was adapted, and results were expressed as means ± standard deviation. To find out the most efficient treatment Duncan's multiple range test (DMRT) a mean separation technique was applied with probability $p< 0.05$. Fisher's LSD test as a post hoc test was used to test the significance of the variation components.

RESULTS

Weed Infestation

Incidentally, the weed flora recorded at the experimental site mainly consisted of Grasses, sedges, and broad-leaf weeds as mentioned in Table 1.

Grassy weed density (No.m^{-2}) at 30 and 60 DAS: The density of grassy weeds in sole and intercropped treatments was recorded at 30 and 60 DAS (Tables 2 and 3). The data indicated that at 30 DAS the minimum (3.44 m^{-2}) grassy weed density was measured in Maize + Black gram (1:3) and maximum (5.30 m^{-2}) was observed in Sole Maize followed by Sole French bean (4.93 m^{-2}) which was at par with Sole Black gram (4.78 m^{-2}). At 60 DAS, the minimum (3.26 m^{-2}) grassy weed density was measured in Maize + Black gram (1:3), and the maximum (6.6 m^{-2}) was recorded in Sole Maize followed by Sole French bean (5.46 m^{-2}) and Sole Black gram (4.7 m^{-2}).

Weed sedges density (No.m^{-2}) at 30 and 60 DAS: The density of sedges weeds in sole and intercropped treatments was recorded at 30 and 60 DAS, represented, and discussed below in Tables 2 and 3 respectively. Sedges weed density varied greatly over different treatments. Density was remarkably lower in intercrops than in their sole crops. The data indicated that at 30 DAS, the minimum (3.13 m^{-2}) weed sedge density was recorded in Maize + Black gram (1:3), and maximum (5.19 m^{-2}) was observed in Sole Maize followed by Sole French bean (4.46 m^{-2}) and Sole Black gram (4.41 m^{-2}). At 60 DAS, the minimum (2.73 m^{-2}) weed sedges density was observed in Maize + Black gram (1:3), and maximum (5.19 m^{-2}) was recorded in Sole Maize followed by Sole French bean (4.10 m^{-2}) which was at par with Sole Black gram (4.01 m^{-2}).

Broadleaf weeds density (BLWD) (No.m^{-2}) at 30 and 60 DAS: Broad leaf weed density varied greatly over different treatments and is discussed below. The data indicated that at 30 DAS as seen in Table 2, the minimum (3.26 m^{-2}) BLWD was recorded in Maize + Black gram (1:3), and maximum (6.19 m^{-2}) was observed in Sole Maize followed by Sole French bean (4.97 m^{-2}) and Sole Black gram (4.89 m^{-2}). As seen in Table 3 at 60 DAS, the minimum (4.58 m^{-2}) BLWD was measured in Maize + Black gram (1:3), and the maximum (8.96 m^{-2}) was recorded in Sole Maize followed by Sole French bean (6.50 m^{-2}) which is followed by Sole Black gram (6.16 m^{-2}).

Total weed density (TWD) (No.m^{-2}) at 30 and 60 DAS: The Total weed density was remarkably lower in intercrops than in their sole crops. The data in Table 2 indicated that at 30 DAS, the minimum (5.66 m^{-2}) TWD was measured in Maize + Black gram (1:3) maximum weed density (9.23 m^{-2}) was seen in Sole Maize followed by followed by Sole French bean (7.55 m^{-2}) and Sole Black gram (7.55 m^{-2}). At 60 DAS the data indicated in Table 3, the minimum (5.91 m^{-2}) TWD was measured in Maize + Black gram (1:3), and maximum (12.02 m^{-2}) was observed in Sole Maize followed by Sole French bean (8.87 m^{-2}) which is followed by Sole Black gram (8.33 m^{-2}).

Grass biomass density (g.m^{-2}) at 30 and 60 DAS: The density of grasses weed biomass in sole and intercropped treatments was recorded at 30 and 60 DAS, represented, and discussed below in Tables 4 and 5 respectively. The data

Table 1: Weed infestation species-wise mentioned in the table during the field trial.

S.No.	Grassy weeds	Common name	Sedges weeds	Common name	Broadleaf weeds	Common name
1.	*Echinochloa crusgalli*	Swank	*Cyperus iria*	Chatri wala dila	*Eclipta alba*	Jalbhan grass
2.	*Echinochloa colonum*	Barnyard grass	*Cyperus rotundus*	Nut grass	*Euphorbia hirta*	Dhodhak
3.	*Ischaemum rugosum*	Wrinkle grass	*Cyperus difformis*	Dila motha	*Ludwigia axillaris*	Gharilla
4.	*Dactyloctenium aegyptium*	Egyptian crowfoot grass	*Cyperus compressus*	Motha	*Commelina benghalensis*	Benghal dayflower
5.	*Digiteria sangulansis*	Crab grass	*Cynodon dactylon*	Bermuda grass	*Digera arvensis*	False amaranth
6.	*Eragrostis pectinacean*	Tufted lovegrass			*Trianthema portulacastrum*	Pigweed

Table 2: Effect of intercropping of maize with legumes on weed density at 30 DAS.

Weed density at 30 DAS				
Treatments	Grassy weed density ($No.m^{-2}$)	Sedges weed density ($No.m^{-2}$)	Broadleaf weed density ($No.m^{-2}$)	Total weed density ($No.m^{-2}$)
T_1- Sole Maize	5.30^a (23.00) ± 0.09	5.19^a (22.00) ± 0.17	6.19^a(32.33) ±0.11	9.23^a (76.33) ± 0.23
T_2- Sole French bean	4.93^b(19.67) ± 0.05	4.46^b(15.67) ± 0.06	4.97^b(20.00) ± 0.09	7.55^b(53.67) ± 0.03
T_3- Sole black gram	4.78^{bc} (18.33) ± 0.05	4.41^b(15.33) ± 0.12	4.89^b(19.33) ± 0.14	7.55^b(49.67) ± 0.03
T_4- Maize + French bean (1:1)	4.66^c(17.33) ± 0.06	4.24^b(14.00) ±0.11	4.78^{bc}(18.33) ±0.14	7.52^b(43.67) ± 0.12
T_5-Maize + French bean (1:2)	4.24^e(14.00) ± 0.11	3.86^{bc}(11.33) ± 0.18	4.24^d(14.00) ± 0.11	7.11^c(49.33) ± 0.04
T_6-Maize + French bean (1:3)	4.01^f(12.33) ± 0.14	3.38^{cd}(9.33) ±0.21	3.96^e(12.00) ± 0.12	6.30^d(33.67) ± 0.08
T_7-Maize + Black gram (1:1)	4.46^d(15.67) ± 0.06	4.15^b(13.33) ± 0.13	4.62^c(17.00) ± 0.10	7.50^b(49.67) ± 0.31
T_8-Maize + Black gram (1:2)	3.76^g(10.67) ± 0.14	3.26^d(8.33) ± 0.23	3.61^f(9.67) ± 0.08	5.79^e(33.67) ± 0.15
T_9-Maize + Black gram (1:3)	3.44^h(8.67) ± 0.08	3.13^d(7.33) ± 0.64	3.26^e(7.67) ± 0.16	5.66^e(26.67) ± 0.12

*Data is in the form of mean ± SDM at $p \leq 0.05$. the mean followed by different letters was significantly different at $p \leq 0.05$, according to DMRT for separation of means. Figures in the parenthesis are original values as observation, while without parentheses are transformed ($\sqrt{x+0.5}$) values.

Table 3: Effect of intercropping of maize with legumes on weed density at 60 DAS.

Weed density at 60 DAS				
Treatments	Grassy weed density ($no.m^{-2}$)	Sedges weed density ($No.m^{-2}$)	Broadleaf weed density ($No.m^{-2}$)	Total weed density ($No.m^{-2}$)
T_1- Sole Maize	6.69^a (38.33) ±0.11	5.19^a(22.00) ±0.09	8.96^a (71.67) ± 0.09	12.02^a (132.67)0.11±
T_2- Sole French bean	5.46^b(24.67) ± 0.10	4.10^b(13.00) ±0.11	6.50^b(36.00) ± 0.11	8.87^b(70.00) ± 0.10
T_3- Sole black gram	4.70^c(17.67) ± 0.06	4.01^{bc}(12.33) ±0.18	6.16^c(32.00) ± 0.18	8.33^c(61.33) ± 0.06
T_4- Maize + French bean (1:1)	4.58^{cd}(16.67) ± 0.10	3.76^c(10.67) ±0.14	6.10^c(31.33) ± 0.14	7.92^d(55.00) ± 0.10
T_5-Maize + French bean (1:2)	4.24^{cd}(14.00) ± 0.07	3.32^d(8.00) ±0.14	5.53^d(25.33) ± 0.14	7.62^e(50.67) ± 0.07
T_6-Maize + French bean (1:3)	4.12^d(11.00) ±0.08	2.97^e(6.33) ±0.03	5.12^e(21.33) ± 0.03	6.55^f(36.67) ± 0.08
T_7-Maize + Black gram (1:1)	4.45^{cd}(15.67) ± 0.15	3.44^d(8.67) ±0.08	5.70^d(27.00) ± 0.08	7.85^{de}(54.00) ± 0.15
T_8-Maize + Black gram (1:2)	3.44^e(8.67) ±0.15	2.88^e(5.67) ±0.10	4.62^f(17.00) ± 0.10	6.21^g(32.67) ± 0.15
T_9-Maize + Black gram (1:3)	3.26^e(7.67) ± 0.16	2.73^e(5.00) ±0.18	4.58^f(16.67) ± 0.18	5.91^h(29.33) ± 0.16

*Data is in the form of mean ± SDM at $p \leq 0.05$. the mean followed by different letters was significantly different at $p \leq 0.05$, according to DMRT for separation of means. Figures in the parenthesis are original values as observation, while without parentheses are transformed ($\sqrt{x+0.5}$) values.

indicated that at 30 DAS the minimum (2.52 $g.m^{-2}$) grasses biomass density was recorded in Maize + Black gram (1:3) and maximum (3.69 $g.m^{-2}$) was observed in Sole Maize followed by followed by Sole French bean (3.44 $g.m^{-2}$) and it was at par with Sole Black gram (3.33 $g.m^{-2}$). At 60 DAS, the minimum (2.08 $g.m^{-2}$) grasses biomass density was recorded in Maize + Black gram (1:3), and maximum (4.16 $g.m^{-2}$) was observed in Sole Maize followed by Sole French bean (3.65 $g.m^{-2}$) and Sole Black gram (3.45 $g.m^2$).

Sedges biomass density ($g.m^{-2}$) at 30 and 60 DAS: The sedges biomass density was recorded at 30 and 60 DAS (Tables 4 and 5) in sole and intercropped treatments. The data indicated that at 30 DAS, the minimum (2.24 $g.m^{-2}$) sedges biomass density was recorded in Maize + Black gram (1:3), and maximum (4.05 $g.m^{-2}$) was observed in Sole Maize followed by which was at par with Sole French bean (3.64 $g.m^{-2}$) and Sole Black gram (3.55 $g.m^{-2}$). At 60 DAS, the minimum (1.50 $g.m^{-2}$) sedges biomass density was recorded in Maize + Black gram (1:3), and the maximum (3.56 $g.m^{-2}$) was measured in Sole Maize followed by Sole French bean (2.36 $g.m^{-2}$) and Sole Black gram (2.14 $g.m^{-2}$).

Broadleaf weeds biomass density (BLWBD) ($g.m^{-2}$) at 30 and 60 DAS: The broadleaf weeds biomass density was recorded at 30 and 60 DAS (Table 4 and 5) in sole and intercropped treatments. Broadleaf weed biomass varied greatly over different treatments. The data indicated that at 30 DAS, the minimum (2.33 $g.m^{-2}$) BLWBD was recorded in Maize + Black gram (1:3), and maximum (3.64 $g.m^{-2}$) was observed in Sole Maize followed by which was at par with Sole French bean (3.19 $g.m^{-2}$) and Sole Black gram (3.19 $g.m^{-2}$). At 60 DAS, the minimum (2.67 $g.m^{-2}$) BLWBD was recorded in Maize + Black gram (1:3), and maximum (5.05 $g.m^{-2}$) was observed in Sole Maize followed

Table 4: Effect of intercropping of maize with legumes on weed biomass at 30 DAS.

Weed biomass at 30 DAS				
Treatments	Grassy weed biomass (No.m^{-2})	Sedges weed biomass (No.m^{-2})	Broadleaf weed biomass (No.m^{-2})	Total weed biomass (No. m^{-2})
T_1- Sole Maize	3.69^a (10.17) ± 0.03	4.05^a(12.60) ± 0.03	3.64^a(12.60) ± 0.05	6.21^a(9.83) ± 0.05
T_2- Sole French bean	3.44^b(8.63) ± 0.07	3.64^{ab}(9.83) ± 0.05	3.19^b(9.83) ± 0.02	5.51^b(7.24) ± 0.02
T_3- Sole black gram	3.33^{bc}(8.04) ± 0.03	3.55^{ab}(9.32) ± 0.08	3.18^b(9.32) ± 0.05	5.50^b(7.17) ± 0.05
T_4- Maize + French bean (1:1)	3.31^c(7.90) ± 0.03	3.54^{ab}(9.28) ± 0.02	3.00^{bc}(9.28) ± 0.16	5.34^{bc}(6.30) ± 0.16
T_5-Maize + French bean (1:2)	3.11^d(6.85) ± 0.04	2.79^{cd}(7.72) ± 0.04	2.82^c(7.72) ± 0.07	5.09^d(5.37) ± 0.07
T_6-Maize + French bean (1:3)	2.89^e(5.70) ± 0.02	2.79^{cd}(5.26) ± 0.95	2.58^d(5.26) ± 0.04	4.41^e(4.33) ± 0.04
T_7-Maize + Black gram (1:1)	3.24^c(7.52) ± 0.02	3.28^{bc}(8.87) ± 0.05	2.97^c(8.87) ± 0.03	5.14^{cd}(6.10) ± 0.03
T_8-Maize + Black gram (1:2)	2.73^f(5.00) ± 0.11	2.61^{cd}(4.44) ± 0.01	2.47^{de}(4.44) ± 0.11	3.87^f(3.37) ± 0.11
T_9-Maize + Black gram (1:3)	2.52^g(4.07) ± 0.01	2.24^d(3.02) ± 0.04	2.33^e(3.02) ± 0.16	3.73^f(3.10) ± 0.16

*Data is in the form of mean ± SDM at $p \le 0.05$. the mean followed by different letters was significantly different at $p \le 0.05$, according to DMRT for separation of means. Figures in the parenthesis are original values as observation, while without parentheses are transformed ($\sqrt{x+0.5}$) values.

Table 5: Effect of intercropping of maize with legumes on weed biomass at 60 DAS

Weed biomass at 60 DAS				
Treatments	Grassy weed biomass (g.m^{-2})	Sedges weed biomass (g.m^{-2})	Broadleaf weed biomass (g.m^{-2})	Total weed biomass (g.m^{--2})
T_1- Sole Maize	4.16^a(15.07) ± 0.06	3.56^a(10.31)± 0.36	5.05^a(20.73) ± 0.12	7.29^a(46.11) ± 0.12
T_2- Sole French bean	3.65^b(11.73) ± 0.16	2.36^b(4.92) ± 0.24	4.57^b(16.57) ± 0.05	6.06^b(30.95) ± 0.07
T_3- Sole black gram	3.45^b(7.15) ± 0.35	2.14^b(3.50) ± 0.30	4.48^b(15.87) ± 0.04	5.59^{bc}(25.91) ± 0.05
T_4- Maize + French bean (1:1)	2.95^c(6.70) ± 0.12	1.94^{bc}(2.50) ± 0.16	4.28^c(14.30) ± 0.07	5.43^{bc}(24.28) ± 0.02
T_5-Maize + French bean (1:2)	2.71^{cd}(5.44) ± 0.23	1.85^{bc}(1.88) ± 0.46	3.99^d(12.20) ± 0.05	4.57^{cde}(21.01) ± 0.07
T_6-Maize + French bean (1:3)	2.47^{de}(4.38) ± 0.15	1.83^{bc}(1.76) ± 0.16	3.97^d(12.07) ± 0.03	4.23^{def}(16.56) ± 1.43
T_7-Maize + Black gram (1:1)	2.93^c(6.53) ± 0.13	1.92^{bc}(2.20) ± 0.16	4.11^d(13.07) ± 0.06	5.08^{bcd}(22.27) ± 0.12
T_8-Maize + Black gram (1:2)	2.11^{ef}(2.60) ± 0.07	1.56^c(1.20) ± 0.06	2.81^e(5.33) ± 0.07	3.80^{ef}(10.92) ± 0.09
T_9-Maize + Black gram (1:3)	2.08^f(2.51) ± 0.10	1.50^c(1.14) ± 0.25	2.67^e(4.73) ± 0.09	3.39^f(8.38) ± 0.08

*Data is in the form of mean ± SDM at $p \le 0.05$. the mean followed by different letters was significantly different at $p \le 0.05$, according to DMRT for separation of means. Figures in the parenthesis are original values as observation, while without parentheses are transformed ($\sqrt{x+0.5}$) values.

by Sole French bean (4.57 g.m^{-2}) and Sole Black gram (4.48 g.m^{-2}).

Total weed biomass density (TWBD) (g.m^{-2}) at 30 and 60 DAS: Total weed biomass density varied greatly over different treatments and is discussed in Tables 4 and 5 respectively. The data indicated that at 30 DAS, the minimum (3.73 g.m^{-2}) TWBD was recorded in Maize + Black gram (1:3), and the maximum (6.21 g.m^{-2}) TWBD was recorded in Sole Maize followed by Sole French bean (5.51 g.m^{-2}) which was at par with Sole Black gram (5.50 g.m^{-2}). At 60 DAS, the minimum (3.39 g.m^{-2}) TWBD was observed in Maize + Black gram (1:3), and maximum (7.29 g.m^{-2}) TWBD was recorded in Sole Maize followed by Sole French bean (6.06 g.m^{-2}) which was at par with Sole Black gram (5.59 g.m^{-2}).

Yield Attributes of Maize

Number of cobs plant^{-1}, Length of cob and Cob diameter: The number of cob plant^{-1} was maximum (2) in Maize + Black gram (1:2) and Maize + Black gram (1:3) intercropping system followed by Maize + French bean (1:2) (1.73). The length of cob was maximum (19.33 cm) in Maize + Black gram (1:2) followed by Maize + Black gram (1:2) (18.45 cm) which was almost like Maize + French bean (1:2) (18.36 cm). Cob diameter had similar results i.e., it was maximum (8.37 mm) in Maize + Black gram (1:2) followed by Maize + Black gram (1:3) (8.10 mm) and Maize + French bean (1:2) (8.03 mm) (Table 6).

Number of grains row^{-1}cob^{-1} and, Number of rows cob^{-1}: The maximum number of grains row^{-1} cob^{-1} (484.33) was noticed in Maize + Black gram (1:2) intercropping system

Table 6: Effect of intercropping of maize with legumes on yield attributes of maize.

Treatments	No. of cobs plant^{-1}	Length of cob (cm)	Cob diameter (mm)	No. of rows cob^{-1}	No. of grain rows^{-1} cob^{-1}	Grain yield (kg.ha^{-1})	Stover yield (kg. ha^{-1})	Harvest index (%)	Seed index (g)
T_1	1.00^{c}±0.00	16.70^{d}±0.12	7.37^{e}± 0.2	14.33^{d}±0.47	455.67^{e}±3.7	5434.5^{e} ± 37.16	6597.10^{f} ±38.62	43.78^{d} ±0.05	20.8^{d} ± 0.4
T_4	1.17^{c}0.24±	17.03^{cd}±0.17	7.67^{d}± 0.1	15.33^{c}±0.47	465.33^{d}±3.4	5629.33^{d} ± 18.01	7150.40^{e}±16.51	43.93^{cd}±0.02	22.9^{c} ± 1.4
T_5	1.73^{a}±0.21	18.36^{b}±0.24	8.03^{bc}± 0.1	16.80^{b}±0.43	476.67^{bc}±2.5	5776.33^{b} ± 22.40	7328.40^{c}±27.53	44.15^{bc}±0.04	26.1^{b} ± 0.6
T_6	1.67^{ab}±0.24	18.17^{b}±0.12	7.93^{bc}± 0.0	16.30^{bc}±0.42	474.00^{bc}±0.8	5723.00^{c} ± 8.29	7274.33^{cd}±59.00	44.03^{bcd}±0.02	25.7^{b} ± 0.4
T_7	1.33^{bc}±0.24	17.5^{c}±0.23	7.82^{cd}± 0.1	15.67^{c}±0.47	471.33^{c}±0.9	5696.33^{c} ± 12.71	7223.00^{de}±27.86	43.99^{cd}±0.05	23.3^{c} ± 0.9
T_8	2.00^{a}±0.00	19.33^{a}±0.39	8.37^{a}± 0.1	18.33^{a}±0.47	484.33^{a}±1.7	5911.50^{a} ± 35.72	7519.00^{a}±43.23	45.17^{a}±0.31	28.4^{a} ± 1.0
T_9	2.00^{a}±0.00	18.45^{b}±0.19	8.10^{b}± 0.1	17.27^{b}±0.25	479.00^{b}±2.2	5805.50^{b} ± 19.93	7414.67^{b}±17.00	44.30^{b}±0.10	27.3^{ab} ± 0.2

*Data is in the form of mean ± SDM at $p \leq 0.05$. the mean followed by different letters was significantly different at $p \leq 0.05$, according to DMRT for separation of means. Figures in the parenthesis are original values as observation, while without parentheses are transformed ($\sqrt{x+0.5}$) values.

followed by Maize + Black gram (1:3) (479.00) and Maize + French bean (1:2) (476.67). The lowest (455.67) number of grains row^{-1} cob^{-1} was recorded in sole Maize. The number of rows cob^{-1} was found maximum (18.33) in Maize + Black gram (1:2) followed by Maize + Black gram (1:3) (17.27) and Maize + French bean (1:2) (16.80) (Table 6).

Grain Yield and Stover Yield

Table 6 indicated that the maximum grain yield (5911.50 kg.ha^{-1}) was recorded in Maize + Black gram (1:2) followed by Maize + Black gram (1:3) (5805.50 kg.ha^{-1}) and Maize + French bean (1:2) (5776.33). Similarly, stover yield was also noted as maximum (7519.00 kg.ha^{-1}) in Maize + Black gram (1:2) followed by Maize + Black gram (1:3) (7414.67 kg.ha^{-1}) and Maize + French bean (1:2) (7328.40 kg.ha^{-1}).

Seed Index and Harvest Index

Intercropping of Maize and legumes considerably impacts the Maize's harvest index and seed index (Table 6). It is seen that other treatments with legumes had an almost similar reading, but the maximum seed index (28.40 g) was found in Maize + Black gram (1:2) followed by Maize + Black gram (1:3) (27.30 g) and Maize + French bean (1:2) (26.10 g). Similarly, maximum harvest index (45.17 %) was recorded in Maize + Black gram (1:2) followed by Maize + Black gram (1:2) (44.30%) and Maize + French bean (1:2) (44.15%).

Land Equivalent Ratio and Maize Equivalent Yield

Maize equivalent yield and land equivalent ratio were higher with maize + Black gram intercropping followed by maize + French bean and sole maize (Table 7). LER showed positive influences on the growth and yield of maize and legume intercrops (LER > 1) in Maize + Black gram and maize + French bean intercropping (Table 7). Maximum LER (2.23) is obtained from Maize + Black gram (1:2). Maize + French bean (1:2) and Maize + French bean (1:3) had equal LER (2.16). This indicates that the sole maize crop would need 123% (1.23 ha) and 116% (1.16 ha) more land to produce the same amount as an intercropping system. MEY of sole maize was recorded as a minimum (5434.50 kg.ha^{-1}) and found maximum (11671.03 kg.ha^{-1}) in Maize + Black gram (1:2).

Rhizosphere Soil Bacterial Community

The Rhizosphere soil bacterial community varied greatly over different treatments recorded at 30 and 90 DAS (Fig. 3).

Total heterotrophic bacteria (THB)- The data indicated that at 30 DAS, the minimum (5.08) total heterotrophic bacteria (THB) were recorded in sole maize and maximum (232.82) (THB) was recorded in Maize + French bean (1:3). At 90 DAS, the minimum (20.33) (total heterotrophic

Table 7: Effect of intercropping on Land equivalent ratio (LER) and Maize equivalent yield (MEY $kg.ha^{-1}$)

Treatments	LER	MEY $kg.ha^{-1}$
T1- Sole Maize	$1.00^{e} \pm 0$	$5434^{e}.50$
T2- Sole French bean	$1.00^{e} \pm 0$	-
T3- Sole Black gram	$1.00^{e} \pm 0$	-
T4-Maize+French bean (1:1)	$2.11^{d} \pm 0$	$7916.26^{d} \pm 45.99$
T5-Maize+ French bean (1:2)	$2.16^{c} \pm 0.01$	$8536.81^{c} \pm 104.58$
T6-Maize+French bean (1:3)	$2.16^{c} \pm 0.03$	$8165.19^{d} \pm 57.53$
T7-Maize+ Black gram (1:1)	$2.11^{d} \pm 0.03$	$10969.55^{b} \pm 134.18$
T8-Maize+Black gram (1:2)	$2.23^{a} \pm 0.01$	$11671.03^{a} \pm 229.67$
T9-Maize+Black gram (1:3)	$2.19^{b} \pm 0.01$	$11165.18^{b} \pm 96.44$

bacteria (THB) was measured in sole maize and maximum (341.6) was recorded in maize + black gram (1:3).

Phosphate solubilizing bacteria (PSB)- The 30 DAS data indicated that the minimum (1.83) PSB was recorded in maize + French bean (1:3) and the maximum (18.7) PSB was recorded in sole French bean. AT 90 DAS the PSB minimum (1.12) sole maize and maximum (113.87) was observed in maize + black gram (1:3).

Nitrate-reducing bacteria (NRB)- The 30 DAS data indicated that the minimum (0.49) NRB was observed in sole maize and maximum (41.89) was recorded in maize + French bean (1:3). At 90 DAS the minimum (1.53) was recorded in sole maize and maximum (73.2) was observed in maize + black gram (1:3).

Nitrifying bacteria (NB)- The 30 DAS data indicated that the minimum (0.16) NB was measured in sole maize and maximum (161.86) maize + black gram (1:3) and at 90 DAS minimum (29.18) nitrifying bacteria was recorded and maximum (473.77) (NB) was observed in the sole french bean.

DISCUSSION

The results of the study supported the notion that using maize as an intercrop with black or French beans suppresses weeds. Our findings demonstrated that intercropping systems, namely one row of maize planted with three rows of Black gram and French bean (T_9 and T_6), greatly reduced the density and biomass of weeds. This contrasted with maize monocultures. Because legumes compete with grassy weeds for nutrients, light, and water, they can shade out weed seedlings and grow swiftly, impeding their establishment and growth. Examples of legumes that do this are soybeans, peas, and clover. Certain legumes naturally emit compounds called allelochemicals, which can inhibit the development of neighboring plants, especially grassy weeds (Kanatas et al. 2020). These compounds could possess herbicidal qualities that prevent weeds from germinating and spreading. Studies (Gu et al. 2021) that found intercropping decreased broadleaf weed density by 47% have demonstrated this influence. Yang et al. (2021) report that intercropping dramatically reduces broadleaf weed biomass by 62%. These outcomes show how effective intercropping is in controlling weeds. Legumes and maize interplanted together form a thick canopy that shadows the ground and blocks the light needed for weed germination and growth. The taller maize plants offer shade and compete to reduce weed growth between rows, hence restricting weed establishment and development, while the spreading legume plants fill the interrow areas (Geetha et al. 2019). The

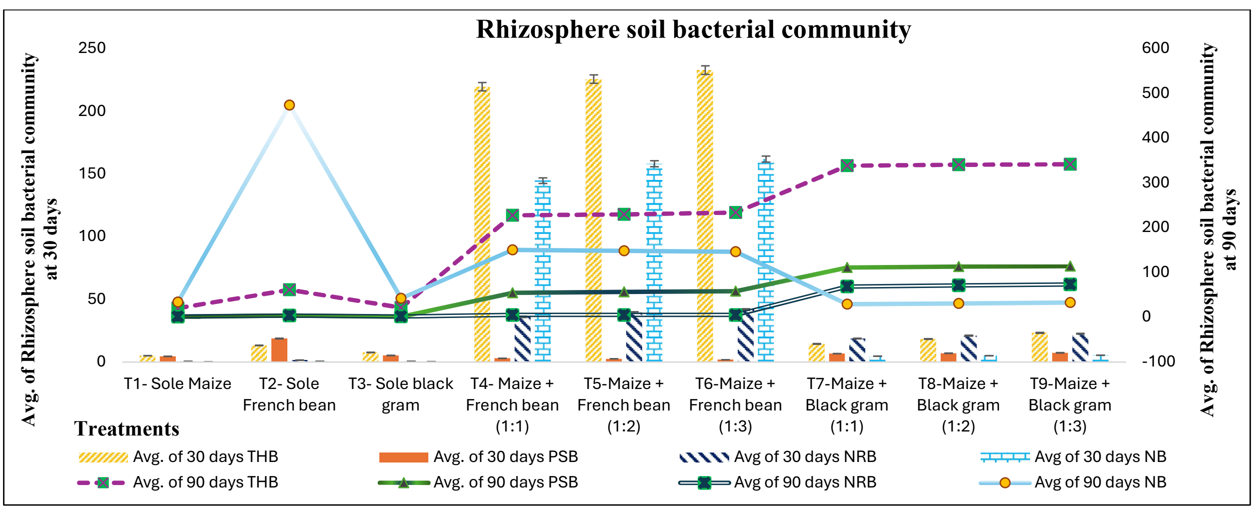


Fig. 3: Rhizosphere soil bacterial community at 30 and 90 DAS.

effective use of resources (such as water, light, and nutrients) is often responsible for intercropping's positive effects on growth and production (Raza et al. 2019). According to the most recent study, intercropping outperforms monocropping in terms of maize's physio-agronomic traits. This is most likely due to nitrogen fixation, which promotes better plant growth and development (Kebede 2021). Prior research has shown that when maize and legumes are interplanted rather than mono-cropped, there is an increase in the cob length, cob weight, number of rows cob^{-1}, 100-grain weight, stover output, and grain yield of the maize crop (Kritika et al. 2023). This is because enough N-fixation promotes increased light absorption, enzyme activity, and chlorophyll in plant leaves. Plots with intercropping produced greater grain and stover yields because intercropping raises yields by increasing total biomass. By adding nitrogen-fixing legumes to the soil, it also increases soil nitrogen, which enhances maize's ability to absorb nutrients. This is explained by legumes' complementing role in intercropping systems as a means of nutritional transmission (Thilakarathna et al. 2016) produced similar results. This might contribute to the explanation of the greater LER and MEY in both intercropping systems. Because of its sensitivity to the spatial arrangement of intercropping component crops, maize has the most significant land equivalent ratio (LER) and maize equivalent yield (MEY). Kintl et al. (2018) observed similar outcomes in their research. Intercropping maize with legumes modifies the chemical and microbiological characteristics of the rhizosphere of maize while also improving its PSB nutrition through the impacts of the rhizosphere. Richard & Ogunjobi (2016) showed that when maize cultivation length increases, so does the THB population. During the 30 DAS planting stage and the 90 DAS harvest, higher THB populations were seen in the intercropping system than in the monocropping system. According to Udom & Benwari (2019), the presence of legumes promotes a high microbial population, which improves soil structure by forming macro-aggregates from micro-aggregates, which are the foundational elements of soil structure. According to Suryanto et al. (2023), a healthy soil structure improves soil moisture and water penetration. Similarly, the PSB population needed time and the right rhizosphere conditions to thrive. Furthermore, the formation of the PSB population in the rhizospheric soil was significantly influenced by the pH and temperature of the soil (Rosalia & Hakim 2021). Early in the intercropping system with French beans, the NRB population was found to be abundant. On the other hand, in the Black gram intercropping system, the NRB population's abundance was noted throughout the mature stage of the maize plant, indicating the legume's synergistic role. The findings showed that legumes had a favorable impact on the NB population growth .because of NB population is growing faster at 90 DAS than at 30 DAS.

CONCLUSIONS

Weed infestation caused a reduction of 40-47% in maize yield. Intercropping of maize with Black gram and French bean had a major effect on maize yield and weed population. A current study suggested that intercropping helps suppress weeds. The method proved efficient in controlling the weeds belonging to different species and helped to increase the bacterial count in the soil thereby improving the soil health and fertility. Maize yield and profitability increased as a result of better soil conditions and free from weed allelopathy effect. As a result, adopting maize + black gram 1:3 proved to be a profitable and efficient substitute for weed control in maize.

REFERENCES

Azmi, S.A. and Chatterjee, S., 2016. Population dynamics of soil bacteria in some areas of Midnapore coastal belt, West Bengal, India. *3 Biotech*, 6, pp.1-7.

Chatterjee, A.K., Chakraborty, R. and Basu, T., 2014. Mechanism of antibacterial activity of copper nanoparticles. *Nanotechnology*, 25(13), p.135101.

Choudhary, V.K. and Dixit, A., 2018. Herbicide weed management on weed dynamics, crop growth and yield in direct-seeded rice. *Indian Journal of Weed Science*, 50(1), pp. 6-12

Collins, K.M., Onwuegbuzie, A.J. and Jiao, Q.G., 2006. Prevalence of mixed-methods sampling designs in social science research. *Evaluation & Research in Education*, 19(2), pp.83-101.

Das, A.K. and Singh, V., 2016. Antioxidative free and bound phenolic constituents in botanical fractions of Indian specialty maize (*Zea mays* L.) genotypes. *Food Chemistry*, 201, pp.298-306.

Donald, C.T., 1968. The breeding of crop ideotypes. *Euphytica*, 17, pp.385-403.

Ellinghausen Jr, H.C. and Pelczar Jr, M.J., 1957. Effect of diphenylamine on pigment production by *Neisseria*. *Journal of Bacteriology*, 73(1), pp.130-132.

Geetha, A., 2019. Chapter-2 Phytotoxicity due to fungicides and herbicides and its impact in crop physiological factors. In: R.K. Naresh, ed. *Advances in Agriculture Sciences*, p.29.

Gu, C., Bastiaans, L., Anten, N.P.R., Makowski, D. and van der Werf, W., 2021. A meta-analysis on weed suppression in annual intercropping. In *Intercropping for sustainability*, 146, pp.263-264).

Jackson, W.A., Flesher, D. and Hageman, R.H., 1973. Nitrate uptake by dark-grown corn seedlings: Some characteristics of apparent induction. *Plant Physiology*, 51(1), pp.120-127.

Kanatas, P., Travlos, I., Papastylianou, P., Gazoulis, I., Kakabouki, I. and Tsekoura, A., 2020. Yield, quality and weed control in soybean crop as affected by several cultural and weed management practices. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 48(1), pp.329-341.

Kebede, E., 2021. Contribution, utilization, and improvement of legumes-driven biological nitrogen fixation in agricultural systems. *Frontiers in Sustainable Food Systems*, 5, p.767998.

Kintl, A., Elbl, J., Lošák, T., Vaverková, M.D. and Nedělník, J., 2018. Mixed intercropping of wheat and white clover to enhance the sustainability of the conventional cropping system: Effects on biomass production and leaching of mineral nitrogen. *Sustainability*, 10(10), p.3367.

Kritika, A.S., Jaswal, A. and Sarkar, S., 2023. Impact on maize (*Zea mays*) productivity and yield parameters with intercropping with French bean (*Phaseolus vulgaris* L) and blackgram (*Vigna mungo*).

Lacey, L.A. (Ed.), 1997. *Manual of techniques in insect pathology*. Academic Press.

Merwin, H. and Peech, M., 1950. The release of potassium upon continuous leaching with acetic acid and different salt solutions. *Proceedings of the Soil Science Society of America*, 15, p.125.

Rani, B.S., Chandrika, V., Sagar, G.K. and Reddy, G.P., 2020. Weed management practices in maize (*Zea mays* L.): A review. *Agricultural Reviews*, 41(4), pp.328-337.

Raza, M.A., Feng, L.Y., van der Werf, W., Cai, G.R., Khalid, M.H.B., Iqbal, N. et al., 2019. Narrow-wide-row planting pattern increases the radiation use efficiency and seed yield of intercrop species in relay-intercropping system. *Food and Energy Security*, 8(3), p.e170.

Richard, P.O. and Ogunjobi, A.A., 2016. Effect of organic and inorganic fertilizer applications on phosphate solubilizing bacteria in the rhizosphere of maize (*Zea mays* L.). *African Journal of Microbiology Research*, 10(48), pp.2021-2028.

Rosalia, A.C.T. and Hakim, L., 2021. Spatial analysis of the impact of flood and drought on food security index. *Nature Environment and Pollution Technology*, 20(2), pp.721-727. http://doi.org/10.46488/NEPT.2021.v20i02.031.

Schmehl, W.R., Olsen, S.R. and Gardner, R., 1954. Effect of method of application on the availability of phosphate for sugar beets. *American Society of Sugar Beet Technologists,* 8(2), pp. 363-369.

Suryanto, S., Trinugroho, I., Susilowati, F., Aboyitungiye, J.B. and Hapsari, Y., 2023. The impact of climate change, economic growth, and population growth on food security in Central Java Indonesia. *Nature Environment & Pollution Technology*, 22(2). http://doi.org/10.46488/NEPT.2023.v22i02.048.

Thilakarathna, M.S., McElroy, M.S., Chapagain, T., Papadopoulos, Y.A. and Raizada, M.N., 2016. Belowground nitrogen transfer from legumes to non-legumes under managed herbaceous cropping systems: A review. *Agronomy for Sustainable Development*, 36, pp.1-16.

Udom, B. and Benwari, A., 2019. Soil structure, organic matter and microbial diversity in soil under some tropical cover crops. *Asian Journal of Biological Sciences*, 12(4), pp.742-749.

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), pp.29-38.

Yang, H., Zhang, W. and Li, L., 2021. Intercropping: Feed more people and build more sustainable agroecosystems. *Frontiers in Agricultural Science and Engineering*, 8, pp.373-386.

ORCID DETAILS OF THE AUTHORS

Kritika: https://orcid.org/0009-0002-5702-7215
Arshdeep Singh: https://orcid.org/0000-0001-8199-3494
Shimpy Sarkar: https://orcid.org/0000-0003-2856-9461
Jaspreet Kaur: https://orcid.org/0009-0002-6884-2223