E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(1): 98-101
Received: 03-11-2025
Accepted: 08-12-2025

Gaini Sairam
Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

M Malla Reddy
Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

B Padmaja
Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

K Sridhar
Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

D Vijaya Lakshmi
Department of Soil Science and Agricultural Chemistry, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

PC Latha
Department of Agricultural Microbiology, ICAR- Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana, India

Corresponding Author:
Gaini Sairam
Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India

Soil microbial population as influenced by drone and robotic herbicide application and mechanical intercultivation under normal and high density planting system cotton

Gaini Sairam, M Malla Reddy, B Padmaja, K Sridhar, D Vijaya Lakshmi and PC Latha

DOI: https://www.doi.org/10.33545/2618060X.2026.v9.i1b.4578

Abstract
The present study was conducted at Regional Agricultural Research Station during (RARS), Palem, Nagarkurnool during *kharif* 2023 and 2024 to evaluate plant density and weed management methods influence on soil microbial populations under normal planting (90 × 60 cm) and high density planting (80 × 20 cm) and herbicide application through drone spaying, robotic spraying, manual knapsack spraying and robotic mechanical intercultivation in cotton. High density planting recoded significantly higher microbial populations of bacteria, fungi and actinomycetes at 30, 60, 90 DAS compared to normal planting and found non-significant at harvest. Among weed management methods robotic mechanical weeding recorded significantly higher microbial populations at 30 DAS and found non-significant at 60, 90 DAS and harvest. Herbicide application through drone, robot and manual knapsack spraying significantly reduced the microbial populations compared to weed free and weedy check treatments at 30 DAS only and at 60, 90 DAS and harvest there was no significance effect of applied herbicide. The aim of the study was to determine the effect of plant density and weed management methods on soil microbial populations (bacteria, fungi and actinomycetes).

Keywords: Drone, robot, high density planting, soil microbes

1. Introduction
Cotton also known as 'white gold' is important commercial fibre crop of India and Telangana. In India cotton occupies 11.23 million hectares area with 30.69 million bales and 465 kg ha^{-1} of production and a productivity, respectively. In Telangana, cotton area is 1.81 million hectares with a production and productivity of 5.55 million bales and 521 kg ha^{-1}, respectively, UPAg, (2024-25). Cotton plays a major role in sustaining the livelihoods of about 40-50 million people in cotton processing and trade in India. The microbial populations were found in rhizosphere soil with high plant population due to more root activity.

Traditionally, cotton grown at wider spacing between rows and plants in a row in well drained, high fertile, heavy soils. Due to slow initial growth, cotton faces severe weed competition at early stages and the yield losses may range from 50 to 85 per cent (Venugopalan *et al*., 2009) [4]. Critical period of crop weed competition of cotton is around 15 to 60 days (Sharma, 2008) [8] weed competition is severe during early stages than three weeks after sowing. Pre emergence pendimethalin and post emergence quizalofop ethyl + pyrithiobac sodium application controls the weeds effectively in cotton (Ali *et al*., 2013) [1] using UAV and knapsack sprayer showed significant effect on weed parameters compared to control (Chen *et al*., 2019) [3]. Herbicides application significantly influences the microbial populations immediately after application for a short period (Tyagi *et al.*, 2018) [12], pendimethalin application higher than recommended dose reduces the microbial population significantly, but untreated soils had highest microbial populations (Oyeleke *et al*., 2011) [7], pre and post emergence herbicides reduced the microbial populations compared to non-herbicide applied treatments and followed similar trend as untreated plots at later stages (Shivashankar *et al.*, 2016) [9], beyond 40 days of herbicide

application and up to harvest microbial populations increased considerably, indicating there was no long term effect of herbicides application on soil flora and fauna (Tyagi *et al.*, 2018) [12]. Thus, studying the effect of herbicides on soil microbial populations is more important as they govern the soil biological processes.

2. Materials and Methods

A field experiment was conducted at Regional Agricultural Research Station (RARS), Palem, Nagarkurnool under Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana. The experiment was laid out in strip plot design with two vertical factors: D_1- normal planting (90 × 60 cm) and D_2- high density planting (80 × 20 cm) with six horizontal factors W_1- Drone spraying of pendimethalin 38.7% CS 677.25 g a.i ha^{-1} as PE *fb* pyrithiobac sodium 6% w/w + quizalofop ethyl 4% w/w EC 125 g a.i ha^{-1} as POE at 2-3 leaf stage of weeds *fb* mechanical intercultivation at 60 DAS, W_2- robotic spraying of pendimethalin 38.7% CS 677.25 g a.i ha^{-1} as PE *fb* pyrithiobac sodium 6% w/w + quizalofop ethyl 4% w/w EC 125 g a.i ha^{-1} as POE at 2-3 leaf stage of weeds *fb* mechanical intercultivation at 60 DAS, W_3- manual spraying of pendimethalin 38.7% CS 677.25 g a.i ha^{-1} as PE *fb* pyrithiobac sodium 6% w/w + quizalofop ethyl 4% w/w EC 125 g a.i ha^{-1} as POE at 2-3 leaf stage of weeds *fb* mechanical intercultivation at 60 DAS, W_4- robotic- mechanical intercultivation at 20, 40 and 60 DAS, W_5- weed free check (Mechanical intercultivation at 20, 40 and 60 DAS + intra row hand weeding) and W_6- weedy check, in a sandy loam textured soil, with neutral reaction, low in organic carbon, available nitrogen and high in available phosphorus and potassium. The soil samples were collected from the experimental plot and the enumeration of bacteria, fungi and actinomycetes was counted by using serial dilution technique (Subba Rao, 1988) [11] at 30, 60, 90 DAS and harvest. Nutrient agar media used for bacteria (Allen, 1953) [2], Rose Bengal media for fungi and actinomycetes (Martin, 1950) [6] isolation. The data was statistically analyzed after log transformation as per the procedure given by Gomez and Gomez (1984) [5].

3. Results and Discussion

3.1 Influence of plant density on microbial populations

At 30 DAS, high density planting recorded significantly high bacterial (1.43, 1.43 × 10^6 CFU g^{-1} soil), fungi (1.14, 1.14 × 10^3 CFU g^{-1} soil) and actinomycetes (1.20, 1.19 × 10^4 CFU g^{-1} soil) populations compared to normal planting, bacteria (1.40, 1.40 × 10^6 CFU g^{-1} soil), fungi (1.13, 1.12 × 10^3 CFU g^{-1} soil) and actinomycetes (1.17, 1.17 × 10^4 CFU g^{-1} soil) populations during 2023 and 2024, respectively. Similar trend was observed during both the years of experimentation at 60 and 90 DAS. At harvest there was no significant influence of plant density on soil microbial populations.

3.2 Influence of weed management methods on microbial populations

At 30 DAS during 2023 and 2024, significantly higher bacterial (1.50, 1.49 × 10^6 CFU g^{-1} soil), (1.50, 1.49 × 10^6 CFU g^{-1} soil) fungi (1.19, 1.18 × 10^3 CFU g^{-1} soil), (1.18, 1.18 × 10^3 CFU g^{-1} soil) and actinomycetes (1.29, 1.29 × 10^4 CFU g^{-1} soil), (1.29, 1.29 × 10^4 CFU g^{-1} soil) population was found with W_6- weedy check and W_5- weed free, respectively were on par with each other. Among weed management methods, W_4- robotic mechanical intercultivation significantly higher bacterial (1.48, 1.47 × 10^6 CFU g^{-1} soil), fungi (1.18, 1.18 × 10^3 CFU g^{-1} soil) and actinomycetes (1.29, 1.29 × 10^4 CFU g^{-1} soil) populations over rest of weed management treatments *viz.*, W_1- drone spraying, W_2- robotic spraying and W_3- manual spraying. At 60, 90 DAS and harvest, microbial populations were non significantly influenced by the weed management methods. Application of pendimethalin and pyrithiobac sodium + quizalofop ethyl significantly reduced the microbial population (bacteria, fungi and actinomycetes) compared to weed free and weedy check, initially for a short period of time. Later, there was no significant difference in microbial population, due to herbicide degradation by microbes as a caron source for multiplication and there was no long term effect of herbicides application on beneficial microbes. These results are corroborated by Shivashankar (2016) [9], Dubey *et al*. (2018) [4] and Siddagangamma *et al*. (2021) [10].

Table 1: Effect of plant density and weed management method on bacterial population (× 10^6 CFU g^{-1} soil) in soil rhizosphere of cotton

Treatment	30 DAS			60 DAS			90 DAS			Harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
Plant density												
D_1: 90 × 60 cm	1.40 (25.77)	1.40 (25.73)	1.40 (25.75)	1.52 (33.08)	1.51 (32.73)	1.52 (32.91)	1.52 (32.89)	1.51 (32.55)	1.52 (32.78)	1.50 (31.39)	1.51 (32.37)	1.51 (31.88)
D_2: 80 × 20 cm	1.43 (27.19)	1.43 (27.29)	1.43 (27.24)	1.54 (34.94)	1.55 (35.63)	1.55 (35.29)	1.54 (34.65)	1.54 (34.85)	1.54 (34.75)	1.49 (32.31)	1.52 (32.88)	1.51 (32.60)
SE(m)±	0.00	0.00	-	0.00	0.00	-	0.00	0.25	-	0.02	0.00	-
CD (P=0.05)	0.02	0.01	-	0.01	0.01	-	0.01	1.14	-	NS	NS	-
Weed management method												
W_1	1.34 (21.93)	1.35 (22.38)	1.35 (22.16)	1.52 (33.36)	1.51 (33.73)	1.52 (33.55)	1.52 (32.99)	1.52 (33.23)	1.52 (33.11)	1.42 (30.24)	1.51 (32.10)	1.47 (31.17)
W_2	1.32 (21.14)	1.34 (22.24)	1.33 (21.69)	1.52 (33.31)	1.52 (33.43)	1.52 (33.37)	1.51 (32.41)	1.51 (32.66)	1.51 (32.54)	1.47 (29.54)	1.51 (32.08)	1.49 (30.81)
W_3	1.35 (22.38)	1.36 (22.74)	1.36 (22.56)	1.52 (33.54)	1.53 (34.06)	1.53 (33.80)	1.52 (33.11)	1.52 (33.31)	1.52 (33.21)	1.50 (31.48)	1.51 (32.16)	1.51 (31.82)
W_4	1.48 (30.39)	1.47 (29.81)	1.48 (30.10)	1.53 (34.01)	1.53 (34.34)	1.53 (34.18)	1.54 (35.04)	1.52 (33.43)	1.54 (33.24)	1.51 (32.09)	1.51 (32.60)	1.51 (32.35)
W_5	1.50 (31.39)	1.49 (30.79)	1.50 (31.09)	1.53 (34.14)	1.54 (34.40)	1.54 (34.27)	1.55 (35.80)	1.54 (34.55)	1.55 (35.18)	1.53 (33.64)	1.52 (33.14)	1.53 (32.89)
W_6	1.50 (31.66)	1.49 (31.10)	1.50 (31.38)	1.55 (35.69)	1.55 (35.14)	1.55 (35.42)	1.52 (33.29)	1.54 (35.03)	1.54 (34.16)	1.53 (34.14)	1.53 (33.65)	1.53 (33.90)
SE(m)±	0.01	0.01	-	0.01	0.01	-	0.01	0.01	-	0.04	0.01	-
CD (P=0.05)	0.02	0.02	-	NS	NS	-	NS	NS	-	NS	NS	-

Interaction												
D × W												
SE(m)±	0.01	0.01	-	0.01	0.01	-	0.01	0.01	-	0.06	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
W × D												
SE(m)±	0.01	0.01	-	0.01	0.01	-	0.01	0.01	-	0.06	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

*Original values are given in the parenthesis, representing data that were logarithmically transformed

W_1: Drone spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_2: Robotic spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_3: Manual spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_4: Robotic- MW at 20, 40 and 60 DAS; W_5: Weed free check (MW at 20, 40 and 60 DAS + intra row Hand weeding); W_6: Weedy check.

Table 2: Effect of plant density and weed management method on fungi population (× 10^3 CFU g^{-1} soil) in soil rhizosphere of cotton

Treatment	30 DAS			60 DAS			90 DAS			Harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
Plant density												
D_1: 90 × 60 cm	1.13 (13.56)	1.12 (13.40)	1.13 (13.48)	1.23 (17.08)	1.22 (16.65)	1.23 (16.87)	1.26 (18.19)	1.26 (18.08)	1.26 (18.14)	1.27 (18.48)	1.26 (18.36)	1.27 (18.42)
D_2: 80 × 20 cm	1.14 (13.85)	1.14 (13.92)	1.14 (13.89)	1.28 (18.88)	1.26 (18.12)	1.28 (18.50)	1.27 (18.68)	1.27 (18.50)	1.27 (18.59)	1.27 (18.77)	1.27 (18.76)	1.27 (18.77)
SE(m)±	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-
CD (P=0.05)	0.01	0.01	-	0.02	0.02	-	0.01	0.01	-	NS	NS	-
Weed management method												
W_1	1.08 (12.14)	1.09 (12.26)	1.09 (12.20)	1.25 (17.73)	1.23 (17.16)	1.24 (17.45)	1.26 (18.41)	1.26 (18.20)	1.26 (18.31)	1.26 (18.41)	1.27 (18.45)	1.27 (18.43)
W_2	1.08 (12.01)	1.08 (12.18)	1.08 (12.10)	1.24 (17.40)	1.22 (16.81)	1.23 (17.11)	1.25 (17.84)	1.25 (17.83)	1.25 (17.84)	1.26 (18.36)	1.26 (18.23)	1.26 (18.30)
W_3	1.09 (12.40)	1.09 (12.29)	1.09 (12.35)	1.26 (18.15)	1.24 (17.33)	1.25 (17.74)	1.27 (18.43)	1.26 (18.21)	1.26 (18.32)	1.27 (18.54)	1.27 (18.48)	1.27 (18.51)
W_4	1.18 (15.01)	1.17 (14.95)	1.18 (14.98)	1.25 (17.94)	1.24 (17.59)	1.24 (17.77)	1.27 (18.49)	1.26 (18.30)	1.26 (18.40)	1.27 (18.60)	1.27 (18.51)	1.27 (18.56)
W_5	1.18 (15.26)	1.18 (15.13)	1.18 (15.20)	1.26 (18.28)	1.24 (17.59)	1.25 (17.94)	1.27 (18.71)	1.27 (18.56)	1.27 (18.64)	1.27 (18.83)	1.27 (18.73)	1.27 (18.78)
W_6	1.19 (15.40)	1.18 (15.15)	1.19 (15.28)	1.26 (18.40)	1.25 (17.83)	1.26 (18.12)	1.27 (18.73)	1.27 (18.64)	1.27 (18.69)	1.28 (18.99)	1.28 (18.98)	1.28 18.99)
SE(m)±	0.00	0.00	-	0.01	0.01	-	0.00	0.00	-	0.00	0.01	-
CD (P=0.05)	0.01	0.01	-	NS	NS	-	NS	NS	-	NS	NS	-
Interaction												
D × W												
SE(m)±	0.00	0.01	-	0.01	0.01	-	0.01	0.01	-	0.01	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
W × D												
SE(m)±	0.00	0.01	-	0.01	0.01	-	0.01	0.01	-	0.01	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

*Original values are given in the parenthesis, representing data that were logarithmically transformed

W_1: Drone spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_2: Robotic spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_3: Manual spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_4: Robotic- MW at 20, 40 and 60 DAS; W_5: Weed free check (MW at 20, 40 and 60 DAS + intra row Hand weeding); W_6: Weedy check.

Table 3: Effect of plant density and weed management method on actinomycetes population (× 10^4 CFU g^{-1} soil) in soil rhizosphere of cotton

Treatment	30 DAS			60 DAS			90 DAS			Harvest		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
Plant density												
D_1: 90 × 60 cm	1.17 (15.26)	1.17 (15.11)	1.17 (15.19)	1.32 (20.31)	1.31 (20.60)	1.32 (20.46)	1.31 (20.23)	1.30 (19.77)	1.31 (19.75)	1.31 (20.51)	1.32 (20.81)	1.32 (20.66)
D_2: 80 × 20 cm	1.20 (16.28)	1.19 (16.12)	1.20 (16.20)	1.36 (22.87)	1.35 (22.22)	1.36 (22.55)	1.31 (20.58)	1.33 (21.24)	1.33 (20.91)	1.32 (20.81)	1.33 (21.24)	1.33 (21.03)
SE(m)±	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-
CD (P=0.05)	0.01	0.02	-	0.01	0.01	-	0.00	0.01	-	NS	NS	-
Weed management method												
W_1	1.09 (12.21)	1.07 (11.73)	1.08 (11.97)	1.33 (21.39)	1.32 (21.16)	1.33 (21.28)	1.31 (20.38)	1.31 (20.38)	1.31 (20.38)	1.31 (20.47)	1.31 (20.63)	1.31 (20.55)
W_2	1.07 (11.83)	1.06 (11.54)	1.07 (11.69)	1.31 (20.65)	1.32 (21.15)	1.32 (20.90)	1.30 (20.11)	1.30 (20.09)	1.30 (20.10)	1.31 (20.22)	1.31 (20.49)	1.31 (20.36
W_3	1.09 (12.33)	1.07 (11.91)	1.08 (12.12)	1.33 (21.48)	1.33 (21.35)	1.33 (21.42)	1.31 (20.43)	1.31 (20.45)	1.31 (20.44)	1.31 (20.64)	1.32 (20.82)	1.32 (20.73)

W_4	1.29 (19.39)	1.28 (19.25)	1.29 (19.32)	1.33 (21.57)	1.33 (21.43)	1.34 (21.50)	1.31 (20.43)	1.31 (20.51)	1.31 (20.47)	1.32 (20.75)	1.33 (21.20)	1.33 (20.98)
W_5	1.29 (19.41)	1.29 (19.34)	1.29 (19.38)	1.34 (21.90)	1.33 (21.53)	1.34 (21.72)	1.31 (20.47)	1.32 (20.68)	1.32 (20.58)	1.32 (20.79)	1.33 (21.41)	1.33 (21.10)
W_6	1.29 (19.43)	1.30 (19.91)	1.30 (19.67)	1.35 (22.54)	1.34 (21.85)	1.35 (22.20)	1.31 (20.61)	1.32 (20.91)	1.32 (20.76)	1.32 (21.12)	1.33 (21.59)	1.33 (21.36)
SE(m)±	0.00	0.01	-	0.01	0.00	-	0.00	0.00	-	0.00	0.01	-
CD (P=0.05)	0.01	0.03	-	NS	NS	-	NS	NS	-	NS	NS	-
Interaction												
D × W												
SE(m)±	0.00	0.01	-	0.01	0.00	-	0.00	0.01	-	0.01	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
W × D												
SE(m)±	0.00	0.01	-	0.01	0.00	-	0.00	0.01	-	0.01	0.01	-
CD (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

*Original values are given in the parenthesis, representing data that were logarithmically transformed

W_1: Drone spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_2: Robotic spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_3: Manual spraying of pendimethalin as PE *fb* pyrithiobac sodium + quizalofop ethyl as PoE *fb* MW at 60 DAS; W_4: Robotic- MW at 20, 40 and 60 DAS; W_5: Weed free check (MW at 20, 40 and 60 DAS + intra row Hand weeding); W_6: Weedy check

4. Conclusion

The experimental results concluded that high density planting recorded significantly higher soil microbial populations (bacteria, fungi and actinomycetes) than normal planting and among the weed management methods herbicide application through drone, robot and manual knapsack spraying significantly reduced the microbial populations than robotic mechanical intercultivation and weed free and weedy check for a initially short period of time and had no long term adverse impact on microbial populations.

5. Acknowledgement

The authors immensely thank the Department of Agronomy, Regional Agricultural Research Station (RARS), Southern Telangana Zone (STZ), Palem, Professor Jayashankar Talangana Agricultural University, Indian Institute of Rice Research, Rajendranagar, Hyderabad and Marut Drone Tech. Pvt. Ltd., Hyderabad and Robot partner, Flic Farm Pvt. Ltd., X-machines brand, Hyderabad, India.

References

1. Ali H, Abid SS, Ahmad S, Sarwar N, Arooj M, Mahmood A, *et al*. Impact of integrated weed management on flat-sown cotton (*Gossypium hirsutum* L.). J Anim Plant Sci. 2013;23(4):1185-1192.
2. Allen MB. The thermophilic aerobic spore-forming bacteria. Bacteriol Rev. 1953;17:125-173.
3. Chen Y, Qi HL, Li GZ, Lan YB. Weed control effect of unmanned aerial vehicle (UAV) application in wheat field. Int J Precis Agric Aviat. 2019;2(2):25-31.
4. Dubey SK, Kumar A, Singh D, Partap T, Chaurasiya A. Effect of different weed control measures on performance of chickpea under irrigated condition. Int J Curr Microbiol Appl Sci. 2018;7(5):3103-3111.
5. Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York: John Wiley & Sons; 1984.
6. Martin JP. Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. Soil Sci. 1950;69(3):251-262.
7. Oyeleke SB, Oyewole OA, Dagunduro JN. Effect of herbicide (pendimethalin) on soil microbial population. J Food Agric Sci. 2011;1(3):40-43.
8. Sharma R. Integrated weed management in field crops. Crop Care. 2008;35(4):41-46.
9. Shivashankar. Studies on weed management practices in irrigated Bt-cotton (*Gossypium hirsutum*). Raichur (India): University of Agricultural Sciences; 2016.
10. Siddagangamma KR, Channabasavanna AS, Mahadevaswamy K, Ajayakumar MY, Yadahalli GS. Effect of herbicides on soil microflora and dehydrogenase activity in transplanted Bt cotton-based intercropping system. Int J Curr Microbiol Appl Sci. 2021;10(1):902-909.
11. Subba Rao NS. Biological nitrogen fixation. New Delhi: Oxford & IBH Publishing Co Pvt Ltd; 1988.
12. Tyagi S, Mandal SK, Kumar R, Kumar S. Effect of different herbicides on soil microbial population dynamics in rabi maize (*Zea mays* L.). Int J Curr Microbiol Appl Sci. 2018;7:3751-3758.
13. Unified Portal for Agricultural Statistics (UPAg). Area and productivity statistics. New Delhi: Department of Agriculture and Farmers Welfare; 2025. https://upag.gov.in/area-productivity
14. Venugopalan MV, Sankaranarayanan K, Blaise D, Nalayini P, Prahraj CS, Gangaiah B. Bt cotton (*Gossypium* spp.) in India and its agronomic requirements—a review. Indian J Agron. 2009;54(4):343-360.