Effect of Drone Application of Pendimethalin on Microbial Population, Nodulation, Weed Control and Yield of Green Gram (*Vigna radiata* L.)

ABSTRACT

A field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, during *Winter*, 2023 to study the effect of pendimethalin application using drone on soil microbial population, nodulation, weed control and yield of green gram. The experiment was laid out in RBD with 12 treatments and 3 replications. The treatments consisted two levels of pendimethalin dosage (0.75 and 1.0 kg ha^{-1}), five levels of spray fluids (40, 50, 60, 70 and 80 litres ha^{-1}) for drone spray compared with manual spray of pendimethalin at 1.0 kg ha^{-1} with 500 litres ha^{-1} spray fluid and control. The results revealed that significantly higher microbial population such as bacteria (17.60 × 10^{6} cfu/g of soil), fungi (14.90 × 10^{3} cfu/g of soil), actinomycetes (42.60 × 10^{4} cfu/g of soil) and rhizobium (21.30 × 10^{5} cfu/g of soil) were recorded with no herbicide application (unweeded control) at 30 DAS than pendimethalin 1.0 kg ha^{-1} application either manual or drone. The lower dose of pendimethalin 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1} was on par with no herbicide application treatment. Significantly higher root nodules per plant^{-1} (17.56 and 22.51) at 30 and 45 DAS was registered under drone spray of pendimethalin 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1}. Higher weed control efficiency (72.6 %) and grain yield (747 kg ha^{-1}) were statistically superior under drone spray of pendimethalin 1.0 kg ha^{-1} with spray fluid of 60 litres ha^{-1} over 40 or 80 litres ha^{-1} spray fluids and was comparable with lower dose of pendimethalin (0.75 kg ha^{-1}) with 60 litres ha^{-1}. Thus, it can be inferred that pendimethalin at 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1} was considered as ideal dose and spray fluid for drone application to get better soil microbial population, nodulation, weed control efficiency and grain yield of green gram.

Keywords: Drone; nodules; microbial population; pendimethalin; Dosage; spray fluid.

1. INTRODUCTION

Pulses are rich source of dietary proteins and inseparable ingredients of vegetarian diet. India contributes about 25 per cent of global pulse production. India is the first largest producer of pulses in the world [1]. Green gram (*Vigna radiata L.*) is one of the most important short-duration pulse crops, found in all type of cropping system in India. It provides a good source of protein (24%), fat (0.6%), carbohydrates (50%), minerals (3.5%) and fibre (0.9%). In India, it is cultivated in an area of 5.13 m.ha, producing 3.08 million tonnes with an average yield of 601 kg ha^{-1}. In Tamil Nadu, it is grown in an area 1.61 lakh ha, producing 0.59 lakh tonnes with the average productivity of 367 kg ha^{-1} [2]. Weeds pose a serious threat to the growth and yield of green gram because of more competition for nutrients, water, space and sunlight. Yield loss in green gram due to weeds to the tune of 60-80% [3]. Being a short duration crop, the control of weeds during critical period of crop weed competition is very important so as to avoid yield loss of green gram [4]. Hand weeding is difficult due to non-availability of labour as well as high cost of weeding [5]. Herbicides are controlling weeds in very broad spectrum with appropriate application [6]. Pre-emergence herbicide pendimethalin used to control the weeds during early phase of crop growth [7]. Conventionally, herbicides are sprayed manually to control weeds, which is time consuming, labour intensive and costly. Further, manual spray of chemicals causes serious health issues to human beings. Recently, drones are being used in many agronomic operations including spraying of nutrient solutions [8] and herbicides [9] mainly due to its coverage, quickly, potentially increasing productivity and reducing labour costs. Prior to a commercial recommendation of drone spray, herbicide dose and spray fluid requirement have to be optimised to have less impact on soil nodulation, increased weed control and grain yield. Studies on these aspects, particularly the effect of drone application of herbicides on soil microbial population, nodulation, weed control and grain yield of green gram is completely lacking. Considering these facts in view, the present study was conducted to optimize the pendimethalin dose and spray fluid for drone application of herbicide in green gram.

2. MATERIALS AND METHODS

2.1. Experimental site

The field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, during *Winter*, 2022. The experimental site is located at latitude of 10º 45’N, longitude of 78º 36’E and at an altitude of 850 m above MSL. The soil type of the experimental field was sandy loam in texture, moderately drained and was sodic in nature with a pH of 8.6. Nutrient status of soil showed that low in available N and medium in available P and K.

2.2. Experimental design and treatment details

The field trail was laid out in Randomized block design (RBD) with twelve treatments and three replications. The area of each treatment was 137.5 m^2 (25 X 5.5). The green gram variety VBN 2 was sown with spacing of 30 X 10 cm. The treatments consisted two levels of pendimethalin active ingredient (0.75 and 1.0 kg ha^{-1}), five level of drone spray fluid requirement (40, 50, 60, 70 and 80 litres ha^{-1}) for drone spray compared with recommended manual spray of pendimethalin at 1.0 kg ha-1 with 500 litres ha^{-1} spray fluid and control.

2.3. Spray equipment

The AD610D model of drone was employed for herbicide spraying. The drone height, velocity, and GPS were pre-determined and controlled by a well-trained operator in automatic mode during herbicide spray. The loading capacity of drone was 10 litres. Flat fan standard nozzle was used. The drone's flying height was kept at one metre. As per the treatment schedule, the spray fluid was adjusted by pulse width modulation signal’s duty cycle [10].

2.4. Observation

Five plants were uprooted from each plot randomly and the roots were carefully washed, nodules were removed and the effective number of nodules $plant^{-1}$ counted at 30 and 45 DAS. The soil microbial population was enumerated at 30 and 45 DAS by serial dilution and spread plate techniques. One gram of the soil samples was added to six test tubes containing 9 ml of distilled water, serially diluted, and spread over nutrient agar [11], rose bengal agar [12], kenknight [13] medium and yeast extract mannitol agar [14] respectively, for the enumeration of total bacteria, fungi, actinomycetes and rhizobium. The plates were incubated at 28°c for 2, 4, 6 and 7 days for bacteria, fungi, actinomycetes and rhizobium respectively. The soil microbial population was calculated using the following formula.

$$\text{CFU/g} = \frac{\text{No. of colony} \times \text{inverse of dilution taken}}{\text{Gram of inoculum taken}}$$

Where, CFU - Colony-forming unit of microorganisms

Weed control efficiency was calculated at 30 DAS [15].

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in unweeded control} - \text{Dry weight of weeds in treated plot}}{\text{Dry weight of weeds in unweeded control}} \times 100$$

Grain yield (kg ha^{-1}) was recorded from the net plot area at harvest stage. All the recorded data were statistically examined as applicable to RBD [16].

3. RESULT AND DISCUSSION

3.1 Effect of herbicide application using drone on rhizobium population and nodulation

Rhizobium population and nodulation at 30 and 45 DAS were significantly influenced by the herbicide application with different doses and spray fluid using drone. The rhizobium population (21.30×10^5 cfu/g of soil) was statistically higher with no herbicide application at 30 DAS than pendimethalin (1.0 kg ha^{-1}) applied treatments (Table 1). This was statistically on par with application of pendimethalin at 0.75kg ha^{-1} with spray fluids of 60, 70 and 80 litres ha^{-1}. Higher dose 1.0 kg ha^{-1} exhibited lesser rhizobium population than no herbicide application. At 45 DAS, the rhizobium population was increased as compared to 30 DAS and the highest value (24.09×10^5 cfu/g of soil) was noticed under no herbicide application. However, it was comparable all pendimethalin applied treatments except treatment T_6 and T_7 where application of pendimethalin 1.0 kg ha^{-1} with spray fluids of 40 and 50 litres ha^{-1}. Variation in rhizobium population was occurred mainly due to herbicide application, herbicide dose and spray fluids which decides the concentration under drone application. Similar results of reduced rhizobium population under pendimethalin application were noticed in chickpea [17].

Drone spray of pendimethalin 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1} registered significantly higher number of nodules $plant^{-1}$ (17.56) than higher dose of pendimethalin as well as unweeded control at 30 DAS. It was statistically on par all the treatments which received lower dose pendimethalin 0.75 kg ha^{-1} irrespective of spray fluids. The reason behind the increased nodulation was application of optimum dose and spray fluid with uniform droplets size and coverage under drone application resulted in effective control of weeds and reduced competition for resources which led to increase in number of nodules. The higher dose of pendimethalin at 1.7 kg ha^{-1} showed inhibitory effects on number of nodules $plant^{-1}$ and also found that lower dose of pendimethalin at 0.9 kg ha^{-1} enhanced the number of nodules $plants^{-1}$ of soybean [18]. At 45 DAS, all the herbicide treatments irrespective of dose, spray fluids and mode of application produced comparable results of nodulation, indicated the reduced effect of pendimethalin on nodulation except control. Lower number of nodules $plant^{-1}$ was recorded under control plot both at 30 and 45 DAS mainly due to higher weed interference and competition for resources which ultimately reduced the nodulation. Similarly, the control plot recorded minimum root nodules, due to more crop weed competition for resources like nutrients, light and moisture [19].

Table 1. Effect of herbicide application using drone on number of nodules plant^{-1}, rhizobium population, WCE and grain yield of green gram

Treatments		Rhizobium population (10^5 cfu/g soil)		No. of. Nodules plant^{-1}		WCE (%)	Grain Yield (Kg ha^{-1})
		30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	
T_1	- DS pendimethalin 0.75 kg ha^{-1} + SF 40 litres ha^{-1}	18.19	21.99	16.79	22.18	50.8	596
T_2	- DS pendimethalin 0.75 kg ha^{-1} + SF 50 litres ha^{-1}	18.59	22.01	16.98	22.26	58.4	642
T_3	- DS pendimethalin 0.75 kg ha^{-1} + SF 60 litres ha^{-1}	19.89	22.31	17.56	22.51	71.1	727
T_4	- DS pendimethalin 0.75 kg ha^{-1} + SF 70 litres ha^{-1}	19.15	22.45	17.11	22.34	55.8	635
T_5	- DS pendimethalin 0.75 kg ha^{-1} + SF 80 litres ha^{-1}	19.49	22.89	17.29	22.42	44.7	512
T_6	- DS pendimethalin 1.0 kg ha^{-1} + SF 40 litres ha^{-1}	14.04	20.82	14.86	21.66	53.2	610
T_7	- DS pendimethalin 1.0 kg ha^{-1} + SF 50 litres ha^{-1}	15.79	20.85	14.97	21.75	68.6	697
T_8	- DS pendimethalin 1.0 kg ha^{-1} + SF 60 litres ha^{-1}	16.17	21.35	15.20	22.09	72.6	747
T_9	- DS pendimethalin 1.0 kg ha^{-1} + SF 70 litres ha^{-1}	16.26	21.89	15.12	21.83	67.1	681
T_{10}	- DS pendimethalin 1.0 kg ha^{-1} + SF 80 litres ha^{-1}	16.71	21.91	15.19	21.91	48.2	567
T_{11}	- MS pendimethalin 1.0 kg ha^{-1} + SF 500 litres ha^{-1}	17.33	21.72	15.11	21.58	66.6	680
T_{12}	- Unweeded Control (No herbicide spray)	21.3	24.09	12.12	17.39	-	370
SEd		**1.20**	**1.36**	**1.08**	**1.13**	**-**	**37**
CD (P=0.05)		**2.50**	**2.84**	**2.24**	**2.34**	**-**	**77**

DS-Drone spray; MS-Manual spray; SF-Spray fluid

3.2 Effect of herbicide application using drone on soil microbial population

Application of pendimethalin with two doses and different spray volumes using drone significantly influenced soil microbial population. Bacterial population (17.60 × 10^6 cfu/g of soil) was significantly greater under no herbicide application than pendimethalin applied plots at 30 DAS. Between the doses of pendimethalin, lower dose 0.75 registered more bacteria than higher doses irrespective of spray fluid. Minimum bacterial population was noticed with application of pendimethalin 1.0 kg ha^{-1} with spray fluid of 40 litres ha^{-1} than other treatments. Application of pendimethalin at 1.0 kg ha^{-1} reduced the microbial population through stimulation or inhibition of synthesis of specific enzymes, effects on cellular membranes, modifications to transport and excretion processes which resulted in killing of microorganisms [20]. With regard to fungi, higher population (14.90 × 10^3 cfu/g of soil) was noticed with no herbicide application than pendimethalin 1.0 kg ha^{-1} applied plots at 30 DAS. However, it was statistically comparable with drone application of pendimethalin 0.75 kg ha^{-1} irrespective of all the spray fluids. Even though, the actinomycetes population (42.60 × 10^4 cfu/g of soil) was numerically higher under control plot, it was statistically comparable with all the pendimethalin applied plots.

At 45 DAS, microbial population was not significantly varied with various treatments. There was an initial reduction in microbial population was noticed at 30 DAS and later the microbial count was increased at 45 DAS mainly due to the end of the half-life period (24.4 to 34.4 days) of pendimethalin [21]. Pendimethalin have toxic effect on microorganisms, but the microbes degrade the herbicide residue and emit carbon, resulted in increased soil microbial population at later period [22]. Application of pendimethalin using drone reduced the microbes at higher dose with lower spray fluid (pendimethalin 1.0 kg ha^{-1} with spray fluid of 40 litres ha^{-1}) mainly due to increased herbicide concentration. Whereas, the lower dose with higher spray fluids reduced the herbicide concentration showed increased microbial population indicates that herbicide dose could to be reduced under drone application.

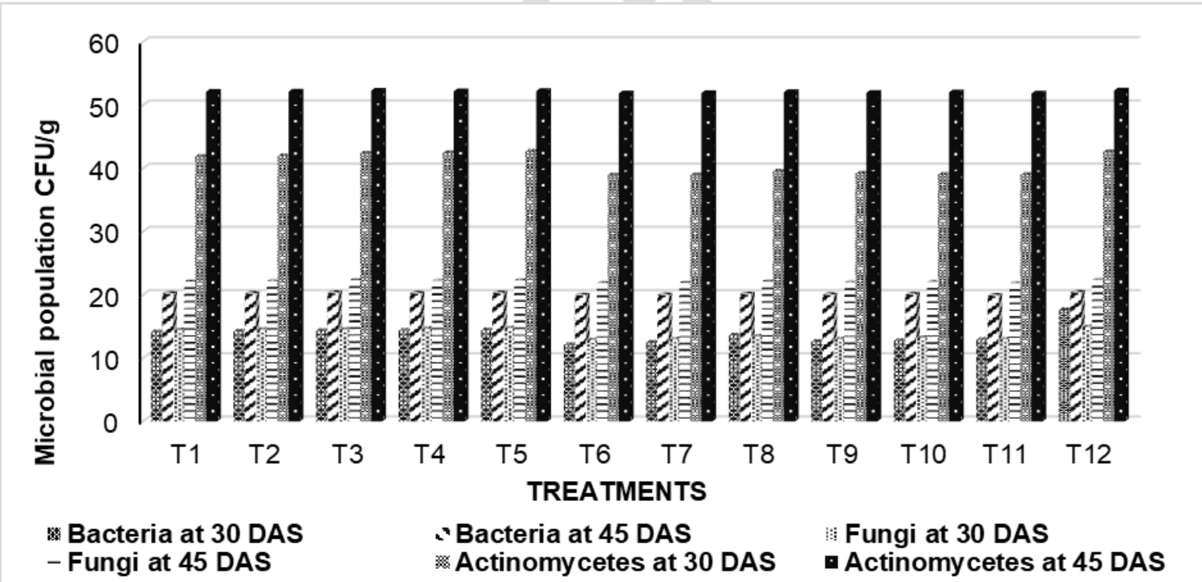

Fig. 1. Effect of various doses of pendimethalin with different spray fluid on microbial population of green gram at 30 and 45 DAS

3.3. Effect of herbicide application using drone on weed control efficiency

Application of pendimethalin 1.0 kg ha^{-1} with spray fluid of 60 litre ha^{-1} using drone recorded higher WCE (72.6%) at 30 DAS than other treatments (Table 1). However, this was on par with pendimethalin 0.75 kg ha^{-1} with spray fluid of 60 litre/ha (68.6%), pendimethalin 1.0 kg ha^{-1} with spray fluids of 50 and 70 litre ha^{-1} and manual spray. Spraying of optimum dose of herbicide and spray fluid provided wider area coverage, greater number of droplet deposits on the soil surface and uniform dissipation of pendimethalin which resulted in reduced weed density [23]. Drone application of pyrazosulfuron-ethyl at 25 g ha^{-1} recorded higher WCE in rice [24]. Minimum WCE (44.7%) was obtained with pendimethalin 0.75 kg ha^{-1} with spray fluid of 80 litre ha^{-1}. Manual spray of pendimethalin 1.0 kg ha^{-1} with spray fluid of 500 litres ha^{-1} registered the WCE of 66.6% which was 6% less than drone application with 60 litre ha^{-1} spray fluid. The enhanced the weed control efficiency due to lower weed dry weight [25].

3.4. Effect of herbicide application using drone on yield

Pendimethalin application through drone positively influenced the green gram yield. Among the treatments, drone application of pendimethalin 1.0 kg ha^{-1} with spray fluid of 60 litres ha^{-1} exhibited statistically higher grain yield (747 kg ha^{-1}) over other treatments and control (Table 1). But it was comparable with application of pendimethalin at 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1} (727 kg ha^{-1}), application of pendimethalin at 1.0 kg ha^{-1} with spray fluids of 50 litres ha^{-1}(697 kg ha^{-1}), 70 litres ha^{-1} (681kg ha^{-1}) and manual spray of pendimethalin 1.0 kg ha^{-1} with spray fluid of 500 litres ha^{-1} (680 kg ha^{-1}). Use of drone for spraying pendimethalin either 0.75 or 1.0 kg ha^{-1} with spray fluid of 60 litres ha^{-1} performed better than the other treatments because of increased spray droplet and uniform coverage of herbicide over the soil surface under drone application resulted in increased weed control favoured better utilization resources, increased nodulation, improved growth and yield parameters, source sink relationship and ultimately higher grain yield. Similarly, increased WCE and grains of maize under drone spray of atrazine with spray fluid of 80 litre ha^{-1} [26]. Even though, pendimethalin had inhibitory effect on soil microbial population during initial period, but they did not affect the yield [27] and [28]. The control plot registered the lowest grain yield (370 kg ha^{-1}) than other treatments. Application of pendimethalin though manual as well as drone produced statistically comparable results indicates that drone could be used for spraying of herbicides under the prevailing labour scarce situation.

4. CONCLUSION

From the experiment, the soil microorganisms including rhizobium were reduced under pendimethalin application as compared to no herbicide applied plots. However, application of pendimethalin 0.75 kg ha^{-1} using drone with spray fluid of 60 litres ha^{-1} produced comparable microbial population, increased nodulation and weed control efficiency and higher grain yield as compared to no herbicide applied plots. The higher dose of pendimethalin 1.0 kg ha^{-1} with spray fluid of 60 litres ha^{-1} registered numerically higher yield than pendimethalin at 0.75 kg ha^{-1} but it reduced the soil microorganisms and nodulation. Hence, it is concluded that lower dose of pendimethalin 0.75 kg ha^{-1} with spray fluid of 60 litres ha^{-1} considered as optimum dose and spray fluid for drone application with better WCE, soil microorganisms, nodulation and higher grain yield of green gram.

REFERENCES

1. Rathika S, Udhaya A, Ramesh T, Shanmugapriya P. Weed management strategies in green gram: A review. The Pharma Innovation Journal. 2023;12(3): 5574-5580.
2. Anonymous. Annual report. Ministry of Agriculture and Farmers Welfare: Government of India. 2020-2021.
3. Kumar N, Hazra KK, Nadarajan N. Efficacy of pre and post-emergence herbicides in rainy season green gram (Vigna radiata). Indian Journal of Agricultural Science. 2017;87(9):1219-1224.
4. Udhaya, A, Rathika S, Ramesh T, Janaki D, Jagadeesan R. Effect of weed management practices on nutrient removal and productivity of irrigated green gram (*Vigna radiata* L.). The Pharma Innovation Journal. 2023;12(6):3160-3163.
5. Ramesh T, Rathika S. Management of emerged weeds in irrigated blackgram (*Vigna mungo* L.) through post emergence herbicides. Legume Research. 2016;39(2):289-292.
6. Ramesh T, Rathika S. Weed management in rice fallow black gram through post-emergence herbicides. Madras Agricultural Journal. 2015;102(10-12):313-316.
7. Ramesh T, Rathika S. Management of *Trianthema portulacastrum* through herbicides in greengram. Indian Journal of Weed Science. 2020;52(3):286-289.

8. Dayana K, Ramesh T, Avudaithai S, Sebastian SP, Rathika S. Feasibility of using drone for foliar spraying of nutrients in irrigated green gram (*Vigna radiata* L.). Ecology, Environment and Conservation. 2022;28:589-594.
9. Zhang K, Chen J, Wang C, Han L, Shang Z, Wang G, Wang M, Deng X, Zhang Y, Wang X, Li P. Evaluation of herbicides aerially applied from a small unmanned aerial vehicle over wheat field. International Journal of Precision Agricultural Aviation. 2020;3(1):49-53.
10. Agurob MC, Bano AJ, Paradela I, Clar S, Aleluya ER, Salaan CJ. Autonomous Vision-based Unmanned Aerial Spray System with Variable Flow for Agricultural Application. IAENG International Journal of Computer Science. 2023;50(3):1-16.
11. Collings CH, Lyne MP. Microbiological methods, 5th Edition, Butter Worth, London. 1968.
12. Kenknight G, Muncie JH. Isolation of phytopathogenic actinomycetes. Phytopathology. 1939;29(11):1000-1001.
13. Martin JP. Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. Soil science. 1950;69(3):215-232.
14. Dundung RVA, Agarwal M, Maurya S. Isolation and characterization of Rhizobium species from cultivated and wild leguminous plants. Journal of Emerging Technologies and Innovative Research. 2019;6(6):1519-1530.
15. Mani VS, Malla ML, Gautam KC. Weed-killing chemicals in potato cultivation. Indian farming. 1973;23(1):17-18.
16. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John Wiley & Sons.1984.
17. Kumar R, Meena RS. Effect of Herbicide on Soil Microorganisms of Chickpea. Vigyan Varta. 2022;3(4):106-108.
18. Abdallah IS, Abdelgawad KF, El-Mogy MM, El-Sawy MB, Mahmoud HA, Fahmy MA. Weed control, growth, nodulation, quality and storability of peas as affected by pre-and post emergence herbicides. Horticulturae. 2021;7(9):307.
19. Shiv S, Agrawal SB, Verma B, Yadav PS, Singh R, Porwal M, Sisodiya J, Patel R. Weed dynamics and productivity of chickpea as affected by weed management practices. Pollution Research. 2023;42(2):21-24.
20. Dubey SK, Kumar A, Singh M, Singh AK, Tyagi S, Kumar V. Effect of six herbicides on soil microbial population and yield in direct seeded rice. Journal of Pharmacognosy and Phytochemistry. 2018;7(4S):83-87.
21. Kočárek M, Artikov H, Voříšek K, Borůvka L. Pendimethalin degradation in soil and its interaction with soil microorganisms. Soil and water research. 2016;11(4):213-219.
22. Singh R, Singh G. Effect of pendimethalin and imazethapyr on the development of microorganisms in vitro and at field conditions. Toxicological & Environmental Chemistry. 2020;102(9):439-454.
23. Sinchana JK, Raj SK. Weed management in pulses: a review. Legume Research-An International Journal. 2023;46(5):533-540.
24. Jeevan N, Pazhanivelan S, Kumaraperumal R, Ragunath K, Arthanari PM, Sritharan N, Karthikkumar A, Manikandan S. Effect of different herbicide spray volumes on weed control efficiency of a battery-operated Unmanned aerial vehicle sprayer in transplanted rice (*Oryza sativa* L.). Journal of Applied and Natural Science. 2023;15(3):972-977.
25. Udhaya A, Rathika S, Ramesh T, Janaki D. Response of green gram under different weed management practices. Ecology, Environment and Conservation. 2021;27(4):1974-1977.
26. Supriya C, Murali Arthanari P, Kumaraperumal R, Sivamurugan AP. Optimization of spray fluid for herbicide hpplication for drones in irrigated Maize (*Zea mays* L.). International Journal of Plant & Soil Science. 2021;33(21):137-145.
27. Oyeleke SB, Oyewole OA, Dagunduro JN. Effect of herbicide (pendimethalin) on soil microbial population. Journal of Food and Agriculture Science. 2011;1(3):40-43.
28. Udhaya, A, Rathika S, Ramesh T, Janaki D, Jagadeesan R. Physiological parameters and yield of green gram as influenced by weed management practices. International Journal of Plant and Soil Science. 2023;35(16):100-106.