PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–08
https://doi.org/10.14719/pst.5372

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Effects of drone-assisted precision weed management on irrigated barnyard millet

Sangeetha Jebalin V V[1], Rathika S[2]*, Ragavan T[1], Baskar M[2], Jeyaprakash P[3], Ramesh T[4], Vallal Kannan S[5], & Sakthivel K[3]

[1]Department of Agronomy, Agricultural College and Research Institute , Tamil Nadu Agricultural University, Madurai 625 104, Tamil Nadu, India
[2]Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute , TNAU, Tiruchirappalli 620 027, Tamil Nadu, India
[3]Department of Genetics and Plant Breeding, ADAC& RI, Tamil Nadu Agricultural University, Tiruchirappalli 620 027, Tamil Nadu, India
[4]Department of Agronomy, ADAC& RI, Tamil Nadu Agricultural University, Tiruchirappalli 620 027, Tamil Nadu, India
[5]Department of Agronomy, Coastal Saline Research Center, Ramanathapuram 623 536, Tamil Nadu, India

*Email: rathikas@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 29 September 2024
Accepted: 20 October 2024
Available online
Version 1.0 : 20 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Jebalin VVS, Rathika S, Ragavan T, Baskar M, Jeyaprakash P, Ramesh T, Kannan SV, Sakthivel K. Effects of drone-assisted precision weed management on irrigated barnyard millet. Plant Science Today.2024;11(sp4):01-08. https://doi.org/10.14719/pst.5372

Abstract

The research experiment was conducted during the 2023-24 *rabi* season, to examine the impact of herbicide dosage and spray volume applied through drones on weed control efficiency, aiming to enhance production and maintain soil and plant health in barnyard millet. The study took place at ADAC&RI, TNAU, Tiruchirappalli, Tamil Nadu, India. The treatments consisted of two levels of pretilachlor (375g/ha and 500g/ha), and three levels of spray volume across two spraying methods (40, 50, and 60 L/ha using EFT E610p 10l agricultural drone model, and 500 L/ha applied manually with knapsack sprayer). Results revealed that the pre-emergence (PE) application of pretilachlor at 500 g/ha with a spray volume of 40 L/ha, 3 days after transplanting (DAT) using a drone resulted in higher weed control efficiency of 91.9% and 89.2 % at 15 DAT and 30 DAT, respectively, along with a higher grain yield of 2195 kg/ha. Enhanced weed control efficiency minimized nutrient removal by weeds, allowing greater nutrient uptake by crops and improved pollen viability, which contributed to higher yield parameters and grain nutrient content without compromising grain quality. Soil health is maintained, supporting nutrient availability and crop uptake without deteriorating the post-harvest nutrient status.

Keywords

drone; herbicide dose; nutrient uptake; soil nutrient; weed control efficiency; yield

Introduction

Small millets play an important role in enhancing the nation's nutritional security due to their rich nutrient content. Barnyard millet offers a comprehensive nutritional profile by containing approximately 8.7% moisture, 10.1% protein, 6.7% crude fiber, 3.9% fat, and 68.8% carbohydrates, providing an energy value of 398 Kcal in 100 g of barnyard millet. Additionally, it boasts 12.5% total dietary fiber, with 4.2% being soluble dietary fiber. Furthermore, it contains essential minerals such as phosphorus (281 mg), iron (5 mg), magnesium (83 mg), and calcium (19 mg) (1) making it an ideal choice for addressing nutrient deficiencies and promoting food security, especially in regions facing malnutrition. They have contributed to the second green revolution with their adaptability to diverse soil conditions. In India, small millets are grown on 423000 hectares, producing 375000 tonnes with an average yield of 885 kg/ha. In Tamil Nadu, small millets are cultivated on 24000 hectares, producing 33000 tonnes, with a productivity rate of

1348 kg/ha (2). Due to the increasing need for sustainable and nutritious food options, there is an urgent necessity to enhance barnyard millet production to satisfy the dietary needs of the rapidly expanding world population. The demand for barnyard millet is rising due to its nutritional advantages, adaptability, and increasing awareness of sustainable food options, as it is nutrient-rich, gluten-free, and high in fiber . Its low glycemic index also makes it beneficial for diabetes management. Governments and organizations are promoting millet as a superfood due to its health benefits. The United Nations declared 2023 as the "International Year of Millets," which further boosted millet consumption globally. Many governments, especially in India and Africa, provide subsidies and support for millet farming. The combination of health consciousness, environmental concerns, and economic viability makes barnyard millet a preferred choice for consumers and increasing demands on production.

Historically, barnyard millet has been a resilient rainfed crop, but it is now undergoing a transformative shift towards irrigated cultivation. This transition is driven by the increasing unpredictability of rainfall patterns, coupled with the growing demand for consistent and higher yields. Weed infestation poses a significant challenge to barnyard millet cultivation, particularly under irrigated conditions (3). The crop's relatively slow initial growth rate renders it highly susceptible to weed competition, leading to substantial yield losses. The prevalence of aggressive weed species, such as grasses and broad leaves, further exacerbates this problem. Conventional herbicide application techniques, including manual spraying, frequently lead to excessive and unwarranted chemical usage, resulting in heightened expenses, environmental issues, and possible crop loss (4). Emerging drone technology offers a promising solution, enabling precise, targeted application of herbicides (5).

Drone spraying offers precise application takes to its targeted spray volume and controlled droplet distribution. It is user-friendly, portable and easy to maintain also can be operated remotely, ensuring a safer option for health (6). Drones equipped with advanced systems can precisely and effectively apply chemicals to crops, minimizing waste and reducing the need for manual labour. The use of drones instead of backpack sprayers has led to a 95-96 per cent reduction in the amount of water needed for herbicide application. This makes drones a superior option for reducing labor in agriculture (7). Drone sprayers saved herbicide application time, water, and labour by up to 85 per cent (8).

Drones are increasingly used for spraying nutrient solutions (9) and herbicides due to their quick coverage, which has the potential to improve productivity and reduce labour costs. Although herbicide application has become a widely adopted method for weed control, the optimal dosage and application methods remain the subject of ongoing research.

Herbicide spraying by drones can provide precise, targeted application, reducing overall chemical usage and environmental impacts (4). However, the impacts of this technology on weed management in barnyard millet remain understudied. Given this background, the present research was conducted to examine the impact of herbicide dosage and spray volume applied via drone and knapsack sprayer on weed control efficiency, soil health through post-harvest nutrient status, and plant health through parameters such as nutrient uptake, yield, pollen viability, and nutrient content in the grain of irrigated barnyard millet.

Materials and Methods

The research experiment was conducted during the *Rabi* season of 2023-24 at ADAC&RI, TNAU, Tiruchirappalli, Tamil Nadu, focusing on the Barnyard millet variety MDU 1. A Randomized Block Design (RBD) with three replications was employed. The experimental field was characterized as sandy clay loam with a pH of 8.6 (sodic soil) and classified as *Vetric Ustropept*. It contains N (199.6 kg/ha), P (18.6 kg/ha), and K (257.4 kg/ha) at before the experiments. The treatment consists of weed management practices using herbicide of two quantities (375 g/ha and 500 g/ha), different levels of spray fluid (40, 50, 60, and 500 L/ha), and two methods of spray (drone and manual spray by knapsack sprayer).

The nursery was raised by adopting recommended agronomic practices given in the TNAU Crop Production Guide 2020 (10). The main field was plowed using a cultivator and secondary tillage was done using a rotovator, resulting in pulverized soil with fine tilth. The field layouts were formed by leveling the fields, and plots measuring 20 x 5 m were formed for each treatment. Eighteen days old seedlings were transplanted into the main field, spaced 25 × 10 cm apart, with one seedling per hill.

The drone EFT E610p 10l Agricultural drone and knapsack sprayer were used for the application of PE herbicide. The flight height, speed, and GPS of the drone were pre-set and managed by a skilled operator in automatic mode during the herbicide application. The drone had a loading capacity of 10 liters and was equipped with a cone -shaped nozzle. It flew at a height of one meter above the crop. The spray fluid was regulated by adjusting the pulse width modulation signal's duty cycle by the treatment schedule. A flat fan type of nozzle was used in the knapsack sprayer. Pre-emergence herbicide pretilachlor was applied on 3 DAT by drone and knapsack sprayer as per the treatments (herbicide dosage and spray volume).

Observations

The following parameters were observed *viz.,* weed control efficiency, pollen viability, yield parameters, yield, grain nutrient content, weed nutrient removal, and crop nutrient uptake and post-harvest soil nutrient levels.

Weed Control Efficiency

It was determined at 15, 30, and 45 DAT using the formula (11)

$$WCE = \frac{W_{pc} - W_{pt}}{W_{pt}}$$ ......(Eqn.1)

Where, Wpc =Weed dry weight in the unweeded control plot , Wpt =Weed dry weight in the treated plot.

Pollen viability

For each treatment, pollen was collected from ten randomly selected plants. Pollen grains were extracted from unopened flowers by gently tapping the stamen onto a glass slide. Subsequent staining with a 2% iodine-potassium iodide solution and microscopic examination determined pollen viability from the total number of pollens extracted by tapping. Fully stained pollen grains were categorized as fertile, whereas grains that were partially stained, deformed, or empty were deemed sterile. Plants containing a mix of fertile and sterile pollen were classified as partially sterile. Pollen fertility was determined using the following formula (12).

$$\text{Pollen viability (\%)} = \frac{\text{No. of round well stained pollens}}{\text{Total no. of pollens observed}} \times 100$$ ......(Eqn.2)

Yield parameters and yield

Productive tillers/m^2, earhead length, test weight (g) of grain, earhead weight (g), number of grains / earhead and yield (kg/ha) were recorded at harvest.

Grain nutrient content

The level of nutrient content and other factors in the grain were estimated by adopting the recommended methods for protein, fat, fiber, total ash, carbohydrate, and moisture and expressed as percent (13). The values of nutrient contents were compared between herbicide-applied plots and non-applied plots.

Weed nutrient removal and Crop nutrient uptake

Weed and plant samples were gathered from each plot to analyze their nutrient content of nitrogen (N) (14), phosphorus (P) (15), and potassium (K) (15). Nutrient removal and uptake were calculated based on their respective NPK concentrations and DMP (dry matter production) and expressed in kg/ha.

Post-harvest soil nutrient analysis

Soil samples were collected from individual crop fields after harvesting. The collected soil was dried in a shaded area, ground into a fine powder, and filtered to remove particles larger than 2 mm. The prepared soil was analyzed to determine its available N (16), P (17), and K content (18).

Statistical analysis

The data on various characteristics were analyzed statistically according to the suggested methods (19). The collected data were compiled, tabulated, and analyzed statistically. One-way ANOVA was conducted using AGRES software to evaluate the treatment effects, with statistical significance determined at a critical difference (CD) corresponding to a probability level of P=0.05%. Non-significant results were marked as 'NS'.

Results and Discussion

Effect of drone-assisted herbicide application on weed control efficiency

The PE application of pretilachlor at 500 g/ha with SF of 40 L/ha through drone achieved the highest weed control efficiency (91.9%, 89.2%, and 82.8% at 15, 30, and 45 DAT) (Table 1). This was followed by the drone application of PE pretilachlor at 500 g/ha with SF of 50 L/ha, and the PE application of pretilachlor by knapsack sprayer at 500 g/ha with spray fluid of 500 L/ha, which was on par.

Table 1. Effect of drone-assisted herbicide application on weed control efficiency in irrigated barnyard millet.

Treatments		Weed Control Efficiency (%)		
		15 DAT	30 DAT	45 DAT
T_1	DS of PE Pretilachlor at the rate 500 g/ha with SF of 40 L/ha	91.9	89.2	82.8
T_2	DS of PE Pretilachlor at the rate 500 g/ha with SF of 50 L/ha	89.4	86.1	78.3
T_3	DS of PE Pretilachlor at the rate 500 g/ha with SF of 60 L/ha	79.5	76.4	67.4
T_4	DS of PE Pretilachlor at the rate 375 g/ha with SF of 40 L/ha	85.4	81.3	73.0
T_5	DS of PE Pretilachlor at the rate 375 g/ha with SF of 50 L/ha	78.5	74.4	66.6
T_6	DS of PE Pretilachlor at the rate 375 g/ha with SF of 60 L/ha	70.6	63.7	50.8
T_7	MS of PE Pretilachlor at the rate 500 g/ha with SF of 500 L/ha	88.4	85.8	78.1
T_8	MS of PE Pretilachlor at the rate 375 g/ha with SF of 500 L/ha	77.9	73.2	63.1
T_9	Unweeded Control	-	-	-

DS - Drone spray, **MS** - Manual spray, **PE** - Pre emergence, **SF** - Spray fluid.

This superior performance can be attributed to the drone's capacity to uniformly apply the herbicide, guaranteeing appropriate concentration for inhibiting early weed proliferation. As a result, herbicide efficacy was optimized, resulting in a substantial decrease in weed density and biomass. Compared to traditional spraying methods, drones offer advantages in terms of liquid distribution uniformity and deeper penetration, facilitating more precise herbicide application. As a result, this method achieved better control of weeds and increased weed control efficiency. These findings align with previous research (20).

Drone-applied PE pretilachlor herbicide at 375 g/ha with a spray volume of 40 L/ha was found to be the next most effective treatment in reducing weed density at 15, 30, and 45 DAT. All other treatments demonstrated inadequate weed control efficiency, proving inadequate in controlling weed population and mitigating crop-weed competition. This inferior performance is likely due to increased weed density, unchecked weed growth, and consequently higher weed dry matter production.

Drone-based spraying offers enhanced adaptability and consistency, with application rates up to 60 times greater than those achieved with knapsack sprayers (21). Drones have demonstrated superior efficacy compared to manual sprayers in herbicide applications (22).

Effect of drone-assisted herbicide application on pollen viability

Pollen is a crucial phase in a plant's life cycle, as viable pollen is essential for effective sexual reproduction. The quality of pollen was evaluated based on its viability and vigor. In the study, the herbicide dose, spray fluid, and application method did not significantly affect pollen quality (Table 2). This lack of impact may be due to limited pesticide accumulation in the reproductive sections or the breakdown of pesticides within the plant before attaining the reproductive stage. Pollen viability refers to the ability of pollen to transport functional sperm cells to the embryo sac after successful pollination (23).

Table 2. Effect of drone-assisted herbicide application on pollen viability of irrigated barnyard millet.

	Treatments	Pollen viability (%)
T_1	DS of PE Pretilachlor at the rate 500 g/ha with SF of 40 L/ha	81.60
T_2	DS of PE Pretilachlor at the rate 500 g/ha with SF of 50 L/ha	81.38
T_3	DS of PE Pretilachlor at the rate 500 g/ha with SF of 60 L/ha	79.22
T_4	DS of PE Pretilachlor at the rate 375 g/ha with SF of 40 L/ha	80.86
T_5	DS of PE Pretilachlor at the rate 375 g/ha with SF of 50 L/ha	78.96
T_6	DS of PE Pretilachlor at the rate 375 g/ha with SF of 60 L/ha	77.48
T_7	MS of PE Pretilachlor at the rate 500 g/ha with SF of 500 L/ha	81.14
T_8	MS of PE Pretilachlor at the rate 375 g/ha with SF of 500 L/ha	78.26
T_9	Unweeded Control	76.52
SEd		3.03
CD (P=0.05)		NS

DS - Drone spray, **MS** - Manual spray, **PE** - Pre emergence, **SF** - Spray fluid.

Effect of drone-assisted herbicide application on yield attributes

The yield parameters of barnyard millet were significantly influenced by two doses of pretilachlor with different spray fluids and methods of spray (Table 3). Pre-emergence herbicide pretilachlor application by drone at 500 g/ha with SF of 40 L/ha registered a higher number of productive tillers (180/m^2), number of grains / earhead (1642), and earhead weight (8.9g). This was followed by PE pretilachlor application by drone at 500 g/ha with the spray fluid of 50 L/ha and PE pretilachlor application at 500 g/ha with SF 500 L/ha with knapsack spray. The success can be attributed to the reduction in crop-weed competition during the early growth stages, which enhanced growth and yield parameters (24).

The lowest productive tillers/m^2 (99), number of grains per earhead (1059), and earhead weight (5.1 g) were recorded in the unweeded control. This might be due to higher competition from weeds, reducing the availability of necessary resources for growth and resulting in lower yield parameters.

Table 3. Effect of drone-assisted herbicide application on yield parameters in irrigated barnyard millet.

Treat-ments	Produc-tive tillers/ m²	No. of grains / earhead	Earhead length (cm)	Earhead weight (g)	Test weight (g)
T_1	180	1642	21.9	8.9	3.6
T_2	168	1533	21.1	8.1	3.6
T_3	135	1302	17.1	6.6	3.5
T_4	151	1412	18.7	7.3	3.5
T_5	133	1291	17.0	6.6	3.5
T_6	117	1167	15.0	5.8	3.4
T_7	165	1530	20.7	7.9	3.6
T_8	132	1278	17.0	6.5	3.5
T_9	99	1059	13.1	5.1	3.4
SEd	5	51	0.7	0.3	0.1
CD	11	108	1.5	0.6	NS

DS - Drone spray, **MS** - Manual spray, **PE** - Pre emergence, **SF** - Spray fluid . The treatment details are provided in Table 1.

Effect of drone-assisted herbicide application on yield

Pre-emergence pretilachlor application through drone significantly influenced the barnyard millet yield (Fig. 1). The maximum yields of grain and straw (2195 kg/ha and 3422 kg/ha, respectively) were achieved with the application of the PE herbicide pretilachlor via drone at a rate of 500 g/ha, utilizing a spray volume of 40 L/ha. This was followed by PE pretilachlor application by drone at 500 g/ha with an SF of 50 L/ha and PE pretilachlor application at 500 g/ha with an SF of 500 L/ha using knapsack spray. Drone application ensures uniform herbicide coverage across the soil surface, resulting in better weed control, better utilization of resources, source-sink relationships, and ultimately higher grain and straw yield (20).

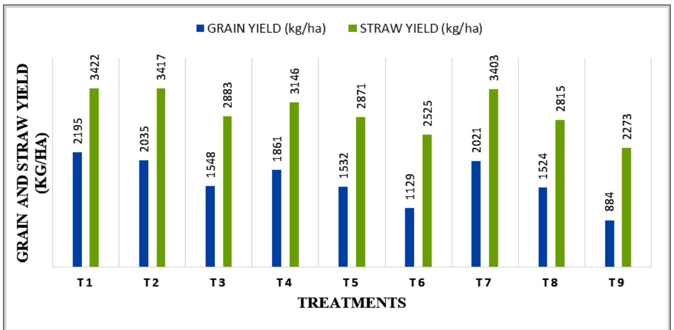

Fig. 1. Effect of drone-assisted herbicide application on grain and straw yields of irrigated barnyard millet. Treatment details are given in Table 1

The application of PE pretilachlor effectively managed a wide range of weeds during the critical period, leading to reduced competition between the crop and weeds. This allowed more nutrients to be available to the crop, resulting in higher yield. These results were consistent with the findings. In situations where labor is scarce, the PE pretilachlor application at 500 g/ha could be used for broad-spectrum weed control, leading to higher grain and straw yields in foxtail millet grown on sandy clay loam soils (25).

The lowest grain and straw yield (885 kg/ha and 2273 kg/ha) were recorded in unweeded control. This is due to intense weed competition, leading to higher weed density and dry weight, which resulted in fewer tillers, shorter plant height, and lower plant dry matter. Similar reductions in barnyard millet grain yield due to weed competition. Unweeded control resulted in a 43.5% decrease in grain yield and a 27% reduction in straw yield compared to plots with one inter-cultivation 20 DAS and one hand weeding 40 DAS (26). Uncontrolled weeds reduced grain and straw yield compared to yields from pre- and post-emergence herbicide applications due to higher weed density and biomass throughout the crop period (27, 28).

Effect of drone-assisted herbicide application on grain nutrient content

The nutrient content of barnyard millet is crucial for ensuring nutritional security, so it is crucial that any management practices do not negatively affect its nutritional composition. In this study, two different levels of pretilachlor and three spray fluid volumes were applied through two spraying methods, with a control plot without herbicides (Table 4). The results showed that neither herbicide levels, spray fluid, nor spray method influenced the grain's nutrient content, thus preserving the millet's genetic potential.

Table 4. Effect of drone-based herbicide application on grain nutrient content of irrigated barnyard millet.

Treatments	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrate (%)
T_1	6.91	5.54	11.72	5.14	71.62
T_2	6.90	5.41	11.70	5.11	71.59
T_3	6.85	5.33	11.61	5.03	71.51
T_4	6.87	5.36	11.65	5.06	71.55
T_5	6.84	5.32	11.57	5.02	71.48
T_6	6.81	5.29	11.52	4.98	71.42
T_7	6.89	5.39	11.68	5.09	71.58
T_8	6.82	5.30	11.55	5.01	71.44
T_9	6.73	5.25	11.51	4.95	71.40
SEd	0.19	0.16	0.24	0.13	1.45
CD (P=0.05)	NS	NS	NS	NS	NS

Table 1 provides details about the treatment.

The nutrient content was as follows: protein (6.73 to 6.91%), fat (5.25 to 5.54%), crude fiber (11.51 to 11.72%), ash (4.95 to 5.14%), and carbohydrates (71.40 to 71.62%) on a dry weight basis. These results align with previous studies (29,30).

Effect of drone-assisted herbicide application on nutrient removal by weeds

Pre-emergence application using drones with varying spray fluid levels significantly impacted nutrient removal by weeds (Table 5). The lowest N (5.82, 10.55, and 13.43 kg/ha), P (1.25, 2.15 and 3.19 kg/ha), and K (4.91, 7.94 and 11.63 kg/ha) removal by weeds were observed with PE pretilachlor application at 500 g/ha using a spray fluid of 40 L/ha by drone at 15, 30, and 45 DAT, respectively. This was followed by the PE application of pretilachlor with the same quantity and SF of 50 L/ha by drone and the same quantity of herbicide with 500 L/ha by knapsack spray on nutrient removal. These treatments recorded lower NPK removal by weeds, mainly because the application of pretilachlor effectively controlled the weeds, resulting in lower weed dry weight, which led to significantly reduced nutrient uptake by the weeds compared to the unweeded control (31).

In contrast, the highest N (11.33, 18.21, and 24.36 kg/ha), P (5.29, 8.73, and 10.80 kg/ha), and K (13.61, 21.28, and 27.83 kg/ha) removal by weeds occurred in the unweeded control at 15, 30, and 45 DAT, respectively. This is likely due to the higher weed density and dry matter production, which led to increased NPK removal by the weeds. Weeds in the unweeded control plots caused higher nutrient removal compared to the lowest removal observed in herbicide-applied plots. These results align with the findings of a previous study (32).

Effect of drone-assisted herbicide application on crop nutrient uptake

Nutrient uptake in barnyard millet was significantly influenced by applying two doses of pretilachlor with different spray fluids using drones and manual spray methods (Table 6). The highest nutrient uptake of N (21.19, 29.54, and 35.79 kg/ha), P (3.94, 6.22, and 8.89 kg/ha), and

Table 5. Effect of drone-assisted herbicide application on nutrient removal by weeds in irrigated barnyard millet.

Treatments	Nutrient removal by weeds (kg/ha)								
	15 DAT			30 DAT			45 DAT		
	N	P	K	N	P	K	N	P	K
T_1	5.82	1.25	4.91	10.55	2.15	7.94	13.43	3.19	11.63
T_2	6.62	1.56	5.83	11.79	2.61	9.27	14.87	3.67	11.68
T_3	9.28	3.05	8.48	14.31	4.43	12.34	17.82	6.57	15.81
T_4	7.81	2.44	6.68	13.08	3.55	10.98	16.38	4.95	13.35
T_5	9.41	3.13	8.62	14.38	4.62	12.59	17.88	6.76	16.06
T_6	10.63	4.31	9.85	15.80	5.58	14.15	19.34	8.93	17.98
T_7	6.75	1.61	5.95	11.86	2.73	9.51	14.92	3.90	11.74
T_8	9.52	3.22	8.79	14.57	4.67	12.83	17.93	6.86	16.42
T_9	11.33	5.29	13.61	18.21	8.73	21.28	24.36	10.80	27.83
SEd	0.33	0.11	0.33	0.55	0.17	0.51	0.66	0.22	0.54
CD (P=0.05)	0.69	0.23	0.71	1.17	0.37	1.08	1.39	0.46	1.15

Treatment details are given in Table 1.

Table 6. Effect of drone-assisted herbicide application on nutrient uptake of irrigated barnyard millet

Treatments	Nutrient uptake (kg/ha)								
	Vegetative stage			Flowering stage			Harvest stage		
	N	P	K	N	P	K	N	P	K
T_1	21.19	3.94	15.91	29.54	6.22	23.34	35.79	8.89	31.87
T_2	20.32	3.92	15.88	29.42	6.21	23.30	33.20	8.23	29.85
T_3	16.08	2.95	12.54	24.26	4.66	15.54	27.75	6.81	23.03
T_4	18.15	3.46	14.01	26.36	5.41	18.50	30.37	7.44	26.26
T_5	15.72	2.92	12.32	24.17	4.65	15.49	27.28	6.64	22.49
T_6	13.87	2.53	10.40	21.86	4.02	11.48	23.93	5.59	19.37
T_7	19.80	3.86	15.52	28.89	6.20	22.03	32.93	8.14	29.14
T_8	15.49	2.86	12.06	24.07	4.63	15.43	26.78	6.46	22.28
T_9	12.21	2.21	8.95	15.69	3.39	9.24	21.27	4.61	16.45
SEd	0.70	0.13	0.50	0.97	0.20	0.67	1.19	0.26	0.92
CD (P=0.05)	1.49	0.27	1.05	2.05	0.43	1.42	2.53	0.55	1.96

Treatment details are given in Table 1.

K (15.91, 23.34, and 31.87 kg/ha) were recorded at the vegetative, flowering, and harvesting stages in the PE pretilachlor application at 500 g/ha with SF of 40 L/ha by drone. Subsequently, the PE pretilachlor application by drone at 500 g/ha with SF of 50 L/ha and PE pretilachlor application at 500 g/ha with SF of 500 L/ha by knapsack sprayer recorded comparable results. There was a significant increase in NPK uptake by barnyard millet due to a decrease in weed density as well as weed biomass and less competition by weeds for nutrients. These results are consistent with the previous findings (33, 34).

Conversely, the lowest nutrient uptake of N (12.21, 15.69 and 21.27 kg/ha), P (2.21, 3.39 and 4.61 kg/ha), and K (8.95, 9.24 and 16.45 kg/ha) were observed at the same stages in the unweeded control. This is likely due to the existence of weed competition throughout the cropping period removes more nutrients resulting in a reduction of NPK. The uncontrolled weed growth in unweeded control resulted in the highest removal of NPK by weeds throughout the crop period which results in lower NPK uptake by barnyard millet.

Post-harvest soil nutrient level

The application of different doses of pretilachlor and spray fluids, whether applied through drones or manual spraying, did not significantly impact the soil nutrient level after the harvest of barnyard millet (Table 7). The available nutrient ranges of N (168-182 kg/ha), P (22.3-23.4 kg/ha), and K (217-231 kg/ha) were recorded in the post-harvest soil. Corresponding findings were also reported by (35 & 36).

Table 7. Effect of drone-assisted herbicide application on post-harvest soil available nutrients in irrigated barnyard millet

Treatments		Soil available nutrients (kg/ha)		
		Nitrogen	Phosphorus	Potassium
T_1	DS of PE Pretilachlor at the rate 500 g/ha with SF of 40 L/ha	182	23.4	231
T_2	DS of PE Pretilachlor at the rate 500 g/ha with SF of 50 L/ha	179	23.3	229
T_3	DS of PE Pretilachlor at the rate 500 g/ha with SF of 60 L/ha	174	22.9	224
T_4	DS of PE Pretilachlor at the rate 375 g/ha with SF of 40 L/ha	175	23.1	226
T_5	DS of PE Pretilachlor at the rate 375 g/ha with SF of 50 L/ha	173	22.8	223
T_6	DS of PE Pretilachlor at the rate 375 g/ha with SF of 60 L/ha	177	22.5	219
T_7	MS of PE Pretilachlor at the rate 500 g/hawith SF of 500 L/ha	178	23.3	228
T_8	MS of PE Pretilachlor at the rate 375 g/hawith SF of 500 L/ha	172	22.7	221
T_9	Unweeded Control	168	22.3	217
SEd		7	0.52	8
CD (P=0.05)		NS	NS	NS

DS - Drone spray, **MS** - Manual spray, **PE** - Pre emergence, **SF** - Spray fluid.

Conclusion

Based on the findings, it can be concluded that drone-assisted PE herbicide application of pretilachlor at 500g/ha with spray fluid of 40 L/ha effectively controlled weeds, improved barnyard millet productivity and maintained pollen viability, nutrient content of grain, and post-harvest soil nutrient status. This method offers a viable solution to the current labour scarcity in agriculture. Given the present circumstances of diminishing labor availability and efficiency, escalating expenses, and health hazards faced by agricultural laborers, the utilization of drones for herbicide application is an optimal answer. This approach offers precision, reduced costs and time, greater uniformity, enhanced efficiency, and minimized risks for laborers, particularly in the cultivation of irrigated barnyard millet.

Acknowledgements

We gratefully acknowledge the funding support received from the TNAU - VCS (V60EP) Scheme, Tamil Nadu Agricultural University, Coimbatore, India.

Authors' contributions

VVS and SR did the conceptualization and methodology of the experiment. VVS collected data, analysed and wrote the first draft of the manuscript. SR supervised the experiment and reviewed and edited the manuscript. TR did the execution of research on agronomic aspects, MB and PJ did the execution of research on soil and plant health management aspects. TR did project administration and validation. SV did an edition on plant health management aspects. VVS, SR, SV, and KS did the final revision of the manuscript. All authors have read and agreed to the published version of the manuscript

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Kaur H, Sharma S. An overview of Barnyard millet (*Echinochloa frumentacea*). J Pharmacogn Phytochem. 2020;9(4):819-822.
2. India Millets Production. Agricultural and Processed Food Products Export Development Authority (APEDA)[Internet]. State Wise Production Data. Last Five Year;2024. Available at: https://apeda.gov.in/milletportal/Production.html.
3. Priyanga M, Ragavan T, Durai Singh R, Prabhaharan J. Effect of establishment methods and weed management practices on weed control in Barnyard millet under irrigated condition. Int J Chem Stud. 2019;7(3):3201-3204.
4. Shanmugapriya P, Rathika S, Ramesh T, Janaki P. Weed management practices in finger millet: A review. Int J Chem Stud. 2020;8(3):2418-2423.
5. Esposito M, Crimaldi M, Cirillo V, Sarghini F, Maggio A. Drone and sensor technology for sustainable weed management: A review. Chem Biol Technol Agric. 2021;8:1-11. https://doi.org/10.1186/s40538-021-00217-8
6. Dutta G, Goswami P. Application of drone in agriculture: A review. Int J Chem. Stud. 2020;8(5):181-187.
7. Vijayakumar S, Mahender Kumar R, Choudhary AK, Deiveegan M, Tuti MD, Sreedevi B, Sundaram RM. Artificial intelligence (AI) and its application in agriculture. Chronicle of Bioresource Management. 2022;6(1):25-31.
8. Hiremath C, Khatri N, Jagtap MP. Comparative studies of knapsack, boom, and drone sprayers for weed management in soybean (*Glycine max* L.). Environ Res. 2024;240(1):117480.
9. Dayana K, Ramesh T, Avudaithai S, Paul Sebastian S, Rathika S. Feasibility of using drone for foliar spraying of nutrients in irrigated green gram (*Vigna radiata* L.). Ecol Environ. Conserv. 2022;28: S548–S553. http://doi.org/10.53550/EEC.2022.v28i01s.074.
10. Crop Production Guide (CPG) - Agriculture. 2020. Tamil Nadu Agricultural University, Coimbatore. p. 137.
11. Mani, VS, Malla, ML, Gautam, KC and Bhagwandas, B. Weed-killing chemicals in potato cultivation. Indian Farming. 1973;23 (8): 17-18.
12. Raj KG, Virmani SS. Genetic of fertility restoration of 'WA'type cytoplasmic male sterility in rice. Crop Sci. 1988;28(5):787-92. https://doi.org/10.2135/cropsci1988.0011183X002800050013x
13. Association of Official Analytical Chemists,Gaithersburg, MD, USA.Official Methods of Analysis. 17th ed;2000.
14. Humphries EC. Mineral components and ash analysis.In:Paech K, Tracey MV, editors. Moderne Methoden der Pflanzenanalyse/ Modern Methods of Plant Analysis. Springer, Berlin, Heidelberg;1956.p.468-502. https://doi.org/10.1007/978-3-642-80530-1_17.
15. Jackson ML. Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India; 1973.
16. Subbiah, BV and Asija, GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:259-60.
17. Olsen SR. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. US Department of Agriculture; 1954.
18. Stanford G and English L. Use of the flame photometer in rapid soil tests for K and Ca. Agron J. 1949;41:446-47. https://doi.org/10.2134/agronj1949.00021962004100090012x
19. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John New York: Wiley and Sons; 1984.
20. Ramesh T, Madhushree S, Rathika S, Meena S, Raja K. Drone based herbicide application in greengram (*Vigna radiata*). Indian J Agric Sci. 2024;94(3):329-332. https://doi.org/10.56093/ijas.v94i3.144541
21. Chen Y, Qi H, Li G, Lan Y. Weed control effect of unmanned aerial vehicle (UAV) application in wheat field. International Journal of Precision Agricultural Aviation. 2019 ;2(2):25-31. http://dx.doi.org/10.33440/j.ijpaa.20190202.45
22. Madhusree S, Ramesh T, Rathika S, Meena S, Raja K. Effect of drone application of pendimethalin on microbial population, nodulation, weed control and yield of green gram (*Vigna radiata* L.). Int J Plant Soil Sci. 2023;35(22):157-164. https://doi.org/10.9734/ijpss/2023/v35i224121
23. Shivanna KR, Ram HM. Pollination biology: contributions to fundamental and applied aspects. Curr Sci. 1993;65(3)226-33.https://www.jstor.org/stable/24095121
24. Tomar SK, Tomar TS. Effect of herbicides and their tank mixture on weed dynamics and yield of zero tilled wheat (*Triticum aestivum*) under rice (*Oryza sativa*)-wheat cropping system of eastern Uttar Pradesh. Indian J Agron. 2014;59(4):624-28.
25. Sravani P, Subramanyam D, Nagavani AV, Umamahesh V, Sagar GK. Weed management effect on weed growth and yield of foxtail millet (*Setaria italica* (L.) Beauv). Indian Journal of Weed Science. 2021;53(4):430-2. https://doi.org/10.5958/0974-8164.2021.00079.4
26. Kumar A, Paliwal A, Rawat L, Kumar P, Paliwal A, Chaudhary S. Barnyard millet (*Echinochloa frumentacea*) productivity enhancement through establishment methods and weed management practices under hilly rain fed conditions. Int J Chem Stud. 2019;7(2):1360-2.
27. Shanmugapriya P, Rathika S, Ramesh T, Janaki P. Evaluation of weed management practices on weed control and yield of transplanted finger millet. Pharma Innovation. 2019;8(5):276-278.
28. Shanmugapriya P, Rathika S, Ramesh T, Janaki P. Response of transplanted finger millet to weed management practices under sodic soil condition. J Appl Nat Sci. 2022;14 (SI); 263-268. https://doi.org/10.31018/jans.v14iSI.3711
29. Prakash R, Vanniarajan C. Genetic variability for panicle characters in indigenous and exotic barnyard millet (*Echinochloa frumentacea* (Roxb.) Link) germplasm over environment. Vegetos . 2013;26(2):297- 306. https://doi.org/10.5958/j.2229-4473.26.2.088
30. Ugare R, Chimmad B, Naik R, Bharati P, Itagi S. Glycemic index and significance of barnyard millet (*Echinochloa frumentacae*) in type II diabetics. J Food Sci Technol. 2014; 51:392-5. https://doi.org/10.1007/s13197-011-0516-8
31. Liakos KG, Busato P, Moshou D, Pearson S, Bochtis D. Machine

learning in agriculture: A review. Sensors. 2018;18(8):2674

32. Shanmugapriya P, Rathika S, Ramesh T, Janaki P. Influence of weed management practices on nutrient removal and performance of transplanted finger millet (*Eleusine coracana* L.). Indian J Agric Res. 2023;57(3):324-329. https://doi.org/10.18805/IJARe.A-5589

33. Rana SS, Angiras NN, Sharma GD. Effect of herbicides and interculture on nutrient uptake by puddle seeded rice and associated weeds. Indian Journal of Weed Science. 2000;32(1&2):70-3.

34. Pavithra K, Janaki P, Gomadhi G, Rathika S, Ejilane J. Effect of nitrogen levels and herbicides on major nutrients uptake and recovery by finger millet in sodic soil. J Pharmacogn Phytochem. 2019;8(4):200-206.

35. Vinothini G, Murali Arthanari P. Nutrient removal by weeds as influenced by the integrated weed management practices in irrigated kodo millet (*Paspalum scrobiculatum* L.). Pharma Innovation. 2021;10(5):408-411

36. Reddy MSSK, Ameena M. Influence of weed management practices on weed flora, crop yield and nutrient uptake in direct seeded rainfed lowland rice. J Crop Weed. 2021;17(2):206-210