OPTIMIZATION OF HERBICIDE DOSE AND SPRAY FLUID FOR DRONE-BASED WEED MANAGEMENT IN IRRIGATED BARNYARD MILLET

SANGEETHA JEBALIN, V. V.[1] – RATHIKA, S.[2*] – RAGAVAN, T.[1] – BASKAR, M.[2] – JEYAPRAKASH, P.[2] – RAMESH, T.[2] – VALLAL KANNAN, S.[3]

[1]*Agricultural College and Research Institute (AC&RI), Tamil Nadu Agricultural University (TNAU), Madurai - 625 104, India*

[2]*Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), TNAU, Tiruchirapalli - 620 027, India*

[3]*Coastal Saline Reseacrh Center (TNAU), Ramanathapuram -623 536, India*

[*]*Corresponding author*
e-mail: rathikas@tnau.ac.in; phone: +91-979-121-6356

(Received 27th Jul 2024; accepted 18th Oct 2024)

Abstract. Yield potential of millets is not fully achieved due to several factors. Crop-weed competition is the major factor in declining the yield of nutri-cereals. The research was conducted to optimize the herbicide dose and spray fluid for two methods of spray to achieve higher weed control efficiency and to exploit the full yield potential of barnyard millet during *Rabi*, 2023-24 at ADAC&RI, TNAU, Tiruchirappalli, Tamil Nadu, India in Randomized Block Design (RBD) with three replications. The treatment consists of chemical weed management practices with two quantities of herbicide pretilachlor @375 g/ha and 500 g/ha, three levels of spray fluid with two methods of application for drone (40, 50 and 60 l/ha) and for manual spray (500 l/ha). The major weed flora, weed density, weed dry matter production, weed control efficiency and economics were observed and calculated. The results revealed that the application of pre-emergence herbicide pretilachlor @500 g/ha with the spray fluid of 40 l/ha by drone method of spray is considered as optimum dose of herbicide and spray fluid. It achieved higher weed control efficiency of 91.9% at 15DAT (days after transplanting) and 89.2 at 30 DAT of critical period and supported for higher grain yield (2195 kg/ha). Also obtained higher net income (Rs. 27441 /ha) when compared to unweeded control. The same treatment achieved the highest output energy (79160 MJ/ha), energy use efficiency (15.11) and energy productivity (0.42 kg/MJ).
Keywords: *economics, energy use efficiency, pretilachlor, spray methods, weed control efficiency, yield*

Introduction

Barnyard millet (*Echinochloa frumentacea*), a highly significant nutricereal by drought-resistant nature with a short growth cycle of 95-100 days, which makes it ideal for rain-fed agriculture. It has been recognized as an appropriate option for climate-resilient farming. Millets are characterized by their rapid growth, short duration (95-100 days) and making them resilient to adverse conditions (Raundal et al., 2017). Currently, there is a growing demand for barnyard millet owing to its exceptional nutritional value and versatility. It serves as a nutrient powerhouse and is a staple nutricereal in numerous regions. Barnyard millet offers a comprehensive nutritional profile by containing approximately 8.7% moisture, 10.1% protein, 6.7% crude fiber, 2.0% total fat, 3.9% fat, 68.8% carbohydrates, providing an energy value of 398 kcal in 100 g of barnyard millet (Kumari et al., 2021). 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) (Kaur et al., 2020).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Barnyard millet is primarily cultivated by broadcasting under rain-fed conditions. The productivity is quite low due to poor germination and establishment when using the broadcast sowing method, and non adoptation of other agronomic practices among other factors (Parihar et al., 2021). The higher yield can be achieved by cultivating the crop under irrigated condition either by direct sown or transplanting method with recommended agronomic practices. Transplanting is also commonly practiced under irrigated conditions, offering benefits such as improved seed germination in nurseries, the ability to maintain the desired population in the main field, better establishment, enhanced growth and yield factors, and increased grain and straw yield (Priyanga et al., 2019). Better crop establishment minimizes the need for gap filling and thinning to maintain an optimal population (Dileep et al., 2018). Weed is a major menace for reduction in yield under irrigated condition. As reported in 2021, weeds caused a 63.5% reduction in barnyard millet yield (ICARDWR). Weed management adds higher production cost and reduce the benefit. Effective weed management is important to achieve higher yield and net income. Farmers are increasingly using herbicides for weed management due to labour shortages and the high cost of manual weeding. The unscientific or poor skill spray man leads to uneven management of weeds and affects environmental hazards in addition to crop-weed competition and low weed control efficiency. Drone method of spray plays a major role in precise application with in short period of time and supports to reduce the crop weed competition and enhance higher weed control efficiency and higher yield (Ramesh et al., 2024). The drone is having several positive features however it can be effectively utilized by optimizing the chemical concentrations and required spray volume to cover the entire field with uniform application and helps to achieve nigher weed control efficiency and economic benefits. With this background this study was conducted to optimize the herbicide dose and spray fluid for drone based chemical weed management under irrigated condition.

Materials and Methods

Experimental site

The field experiment was conducted during *Rabi*, 2023-24 at ADAC & RI, TNAU, Tiruchirappalli, Tamil Nadu by using barnyard millet variety MDU 1 (*Figure 1*). The soil of the experimental field was sandy clay loam in texture, moderately drained with pH of 8.6 (sodic soil) classified as *Vetric Ustropept*. The objective of study is to find out the optimum herbicide dosage for weed management in barnyard millet through drone application and to optimize the spray fluid requirement for spraying herbicide using drone for effective weed control in barnyard millet.

Experimental design, treatment and spray equipment

The experiment was conducted in Randomized Block Design (RBD) with three replications. The treatment consist of chemical weed management practices with two quantity of herbicide (375 g/ha and 500 g/ha) and different levels of spray fluid for drone (40, 50, 60 l/ha) and manual spray (500 l/ha).

The literature available on quantity of herbicide recommended for irrigated cultivation of barnyard millet is limited. The quantity of herbicide was decided for research based on the phytotoxicity effect on crop at the higher level (500 g/ha) and possibilities for reduction of herbicide (375 g/ha) by precise application through drone. Pre-emergence

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

pretilachlor at 500 g/ha showed no phytotoxicity (Sravani et al., 2021). The herbicide available in the market in the name of Rifit 50% EC.

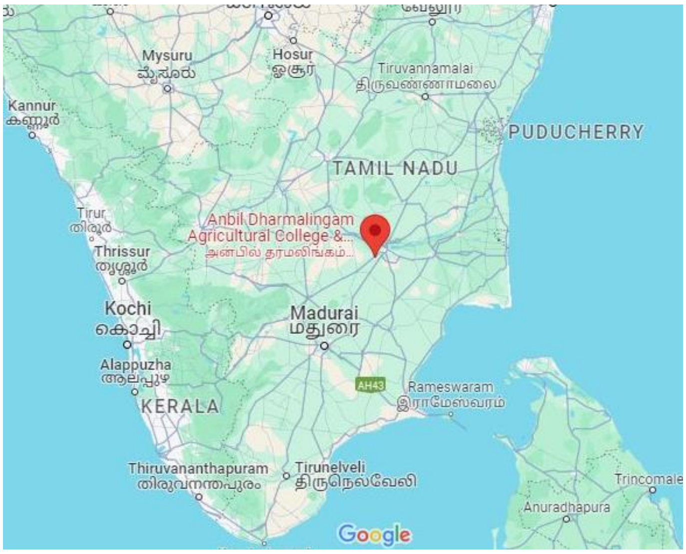

Figure 1. *Location of the experimental site – ADAC & RI, Tamil Nadu, India*

Among two method of spray, in drone EFT E610p 10 litre Agricultural drone was used and knapsack sprayer was used for manual spray for the application of pre emergence herbicide. The drone flight 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 litre with cone shape nozzle. The drone's flying height was kept at one metre above the crop. The spray fluid was adjusted by pulse width modulation signal's duty cycle in drone spray based on the treatment schedule. Flat fan type of nozzle was used in knapsack sprayer.

Crop production

The nursery was raised by adopting recommended agronomic practices given in the TNAU crop production guide 2020 and the seedlings were maintained upto 18 days. The main field was ploughed by using a cultivator and secondary tillage was done by using rotovator and obtained pulverized soil with fine tilth. The layouts were formed by levelling the fields and plots were formed with the size of 20 x 5 m for each treatment and buffer channel were established at 2 m around each plots to prevent the spray drift during drone spraying between adjacent plots. The blanket recommended fertilizer doses of 40:30:50 of N, P_2O_5, and K_2O kg/ha were applied in the form of urea, Single Super Posphate, and Murate Of Potash respectively. Full dose of P_2O5, and K_2O along with 50% of N was applied as basal, remaining 50% of N was applied at 30DAT.

Eighteen-day-old seedlings were transplanted in the main field at the spacing of 25 × 10 cm with one seedling per hill. The treatment for weed management were imposed by the application of pre-emergence herbicide on 3 DAT and followed other agronomic practices.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Data collection

Weed density

The density of dominant weed groups, viz., grasses, sedges, and broad- leaved weeds (BLW) was observed by using 1m X 1m quadrant at 15, 30, 45 days after transplanting (DAT). The total weed density per plot was recorded and expressed as the number/ m^2.

Weed dry weight

Grasses, sedges, and BLW were collected from quadrates at two location in each plot at 15, 30, and 45 DAT and sun dried, and oven dried at 80 ± 5°C for 72 hours. Weight of each class of weed was added to the group to arrive at total weed dry weight. The dry weight of the weed was expressed in g m^{-2}.

Weed control efficiency

Weed control efficiency was determined at 15, 30, and 45 DAS using the following formula (Mani et al., 1973).

$$WCE\ (\%) = \frac{W_{pc} - W_{pt}}{W_{pc}} \times 100 \quad \text{(Eq.1)}$$

where,

Wpc = Weed density in the control plot

Wpt = Weed density in the treated plot

Weed Index

The Weed Index (WI) was calculated using the formula (Gill, 1969). It indicates the percentage of yield loss due to weeds and is given by

$$WI = \frac{X - Y}{X} \times 100 \quad \text{(Eq.2)}$$

where,

X = Yield from weed-free plot

Y = Yield from weeded plot

Yield parameters and yield

The yield attributes were recorded at harvest stage. The standard procedure was followed for estimating the productive tillers by counting the earhead bearing tillers at five random places in each plot and expressed as productive tillers /m2. Earhead length and earhead weight was measured from the tagged plants in every plot, the mean value was computed and expressed in cm/earhead and in g/earhead, respectively. The test weight was measured at 12 % moisture and expressed in g/1000 grains. Grain and straw yields were determined by harvesting earheads from the net plot area, which were then threshed, cleaned, and dried to 12% moisture content. Grain yield was calculated and expressed in kg/ha. The dry weight of the stalks was recorded after three days of sun drying at 12% moisture and reported as kg/ha.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Economics

The economics was computed based on the expenditure on input costs, wage of labours and revenue through market price of the final farm produce. The gross return, net return and cost benefit ratio were calculated for all the treatments by employing the formulae furnished below.

Gross return (Rs. /ha) = Economic yield (kg/ha) x Market value of the produce (Rs. /kg)

Net return (Rs. /ha) = Gross return (Rs./ha) – Cost of cultivation (Rs. /ha)

$$BCR = \frac{Gross\ return}{Cost\ of\ cultivation} \tag{Eq.3}$$

Energy

Energy use efficiency and energy productivity was calculated by using the formula suggested by Devasenapathy et al. (2009). The energy values for all inputs and outputs were derived using published energy conversion coefficients. To determine the energy output from produce (grain and straw), the production quantity was multiplied by its energy equivalent. Energy efficiency percentage was calculated by dividing the output energy by the input energy. Energy productivity was used to find the ratio between yield and energy.

Statistical analysis

The data on various characters were statistically analysed as suggested by Gomez and Gomez (1984). The collected data were compiled, tabulated, and subjected to statistical analysis. One-way ANOVA using AGRES software was employed to assess the treatment effect and statistical significance was observed at critical difference (CD) at the rate of p=0.05% level of probability was worked out for comparison of mean data. Non-significant comparisons were denoted as 'NS'.

Results and Discussion

The results of weed density (No. /m^2), weed dry weight (g/m^2) and weed control efficiency (%) at different stages of 15 DAT, 30 DAT, 45 DAT is presented in *Table 1*, yield attributes in *Table 2*. Weed density is depicted in *Fig. 2*, weed dry weight in *Fig. 3* and weed control efficiency in *Fig. 4* at different stages (15, 30, 45 DAT). Grain and straw yield at harvest is given in *Fig. 5*. Correlation between weed indices and grain yield is indicated in *Fig. 6*, energy use efficiency and energy productivity is depicted in *Fig. 7*., and economics is given in *Fig. 8*

Weed flora

The major grasses identified in the experimental plots were *Brachiaria ramosa* (Brown top millet), *Echinochloa colonum* (Jungle rice), *Enchinochloa crus-galli* (Viper grass), *Digitaria sanguinalis* (Crab grass), (Sawan), *Chloris barbata* (Peacock plume grass) *Dactyloctenium aegypticum* (makra/Crowfoot grass), *Eleusine indica* (Goose grass), *Cynodon dactylon* (Doob/Bermuda grass) and *Setaria glauca* (bajra/Yellow foxtail). The major broad-leaved weeds were *Acanthospermum hispidum* (Bristly starbur),

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Convolvulus arvensis (Field bind weed), *Celosia argentia* (chilimil/ White cock's comb), *Boerhaavia erecta*, *Phylanthus madraspatensis*, *Commelina benghalensis* (kankoua/ Tropical spider wort), *Cleome viscosa* (Cleome), *Corchorus fasicularis* and *Trianthema portulacastrum* (Horse purslane). The major Sedges observed in the experimental fields were *Cyperus compressus*, *Cyperusiria* (Rice flat sedge / Umbrella sedge) and *Cyperus rotundus* (Purple nut sedge).

The predominant weed flora identified in the weedy check in irrigated barnyard millet were, *Echinochloa colona*, *Cynodan dactylon*, *Dactyloctenium aegyptium*, under grasses, *Cyperus rotundus* L. under sedges and, *Digera arvensis*, *Trianthema portulacastrum*, *Convolvulus arvensis Portulacaoleracea*, *Eclipta alba and Ammannia baccifera*, under broad leaved weeds (Priyanga et al., 2019). The important weeds observed in barnyard millet were *Echinochloa colona* (grass), *Cyperus rotundus* (sedge) and *Amaranthus viridis*, *Boerhaavia diffusa*, *Cleome viscosa*, *Phyllanthus niruri*, *Commelina benghalensis* (broad-leaved weeds) (Shamina et al., 2019).

Weed density

The lowest weed density (16.24 /m^2, 24.29 /m^2 and 37.41 /m^2) was observed in the application of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 40 l/ha by drone spray at 15, 30 and 45 DAT respectively whereas the highest weed density of 72.80 /m^2, 111.98 /m^2 and 159.91 /m^2 was recorded in unweeded control (*Figure 2, Table 1*).

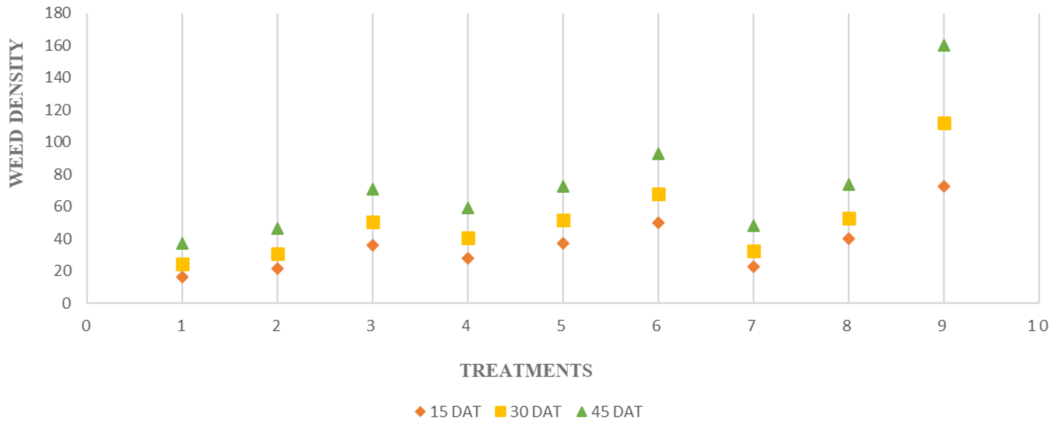

Figure 2. *Effect of weed management practices on weed density at 15, 30, 45 DAT. (Treatment details are given under Table 1)*

Whereas in manual spray of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 500 l/ha using manual spray at 15, 30 and 45 DAT the weed density was (21.49 /m^2, 31.02 /m^2 and 46.78 /m^2) were recorded. The pre-emergence application of herbicide reduced weed density and dry biomass. This effect is likely due to the decreased germination of weeds during the early stages of crop growth by the influence of pre-emergence spray (Kumar et al., 2019). Chemical weed control methods are most effective than mechanical methods on reduction of weed densities and biomass (Hasan et al., 2021).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Table 1. *Effect of herbicide quantity, spray fluid and method of spray on weed density (Numbers/m^2) dry weight (g/m^2) and weed control efficiency (%) in irrigated barnyard millet*

Treatments		15 DAT			30 DAT			45 DAT		
		Weed density (No./m^2)	Weed dry weight (g/m^2)	WCE (%)	Weed density (No./m^2)	Weed dry weight (g/m^2)	WCE (%)	Weed density (No./m^2)	Weed dry weight (g/m^2)	WCE (%)
T_1	DS PE Pretilachlor 500 g /ha+ SF 40 litres /ha	4.09 (16.24)	2.91 (7.98)	91.9	4.98 (24.29)	3.80 (13.99)	89.2	6.15 (37.41)	5.78 (33.03)	82.8
T_2	DS PE Pretilachlor 500 g /ha+ SF 50 litres /ha	4.69 (21.49)	3.30 (10.39)	89.4	5.61 (31.02)	4.28 (17.91)	86.1	6.87 (46.78)	6.49 (41.66)	78.3
T_3	DS PE Pretilachlor 500 g /ha+ SF 60 litres /ha	6.07 (36.38)	4.53 (20.13)	79.5	7.15 (50.58)	5.57 (30.51)	76.4	8.46 (71.06)	7.94 (62.49)	67.4
T_4	DS PE Pretilachlor 375 g /ha+ SF 40 litres /ha	5.34 (28.09)	3.86 (14.39)	85.4	6.40 (40.46)	4.96 (24.18)	81.3	7.73 (59.23)	7.23 (51.76)	73.0
T_5	DS PE Pretilachlor375 g /ha+ SF 50 litres /ha	6.12 (37.03)	4.65 (21.11)	78.5	7.22 (51.61)	5.79 (33.03)	74.4	8.56 (72.85)	8.03 (64.00)	66.6
T_6	DS PE Pretilachlor 375 g /ha+ SF 60 litres /ha	7.09 (49.83)	5.42 (28.89)	70.6	8.28 (68.18)	6.88 (46.91)	63.7	9.67 (93.12)	9.74 (94.47)	50.8
T_7	MS PE Pretilachlor 500 g /ha+ SF 500 litres /ha	4.81 (22.66)	3.44 (11.40)	88.4	5.73 (32.34)	4.34 (18.38)	85.8	7.00 (48.50)	6.53 (42.09)	78.1
T_8	MS PE Pretilachlor 375 g /ha+ SF 500 litres /ha	6.36 (39.98)	4.71 (21.71)	77.9	7.32 (53.07)	5.92 (34.64)	73.2	8.61 (73.66)	8.44 (70.78)	63.1
T_9	Un weeded Control (No weed management)	8.56 (72.80)	9.94 (98.27)		10.61 (111.98)	11.39 (129.14)		12.66 (159.91)	13.85 (191.86)	
SEd		0.18	0.18		0.14	0.22		0.22	0.31	
CD (P=0.05)		0.39	0.38		0.30	0.48		0.47	0.66	

DS – Drone spray, PE – Pre emergence, SF – Spray fluid, MS – Manual spray (Data within parentheses are original values)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Weed dry weight

The lowest weed density of 7.98 g/m^2, 13.99 g/m^2 and 33.03 g/m^2 were observed in the application of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 40 l/ha by drone at 15, 30 and 45 DAT respectively. Manual spray of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 500 l/ha 15, 30 and 45 DAT was 10.39 g/m^2, 17.91 g/m^2 and 41.66 g/m^2. The highest weed dry weight of 98.27, 129.14 and 191.86 g/m^2 was observed in unweeded control. Broad leaved weed density contributed higher on weed dry weight. This result might be due to the sufficient concentration of herbicides reached the weeds, influence on reduction in the number of weeds and suppression on growth of weeds. Broadleaf weeds constituted the highest percentage of the total weed density (Kumar et al., 2019) (*Figure 3, Table 1*).

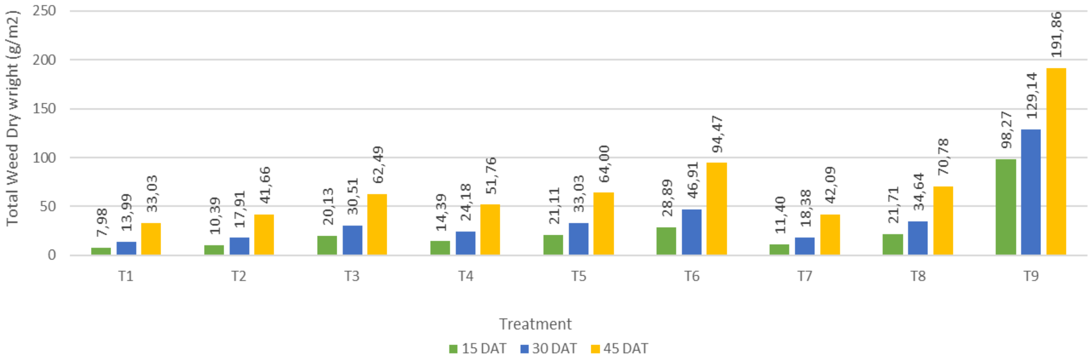

Figure 3. *Effect of weed management practices on weed dry weight (kg/ha) at 15, 30, 45 DAT. (Treatment details are given under Table 1)*

Weed control efficiency

The highest weed control efficiency of 91.9%, 89.2% and 82.8% was observed in the application of pre-emergence herbicide of Pretilachlor @500 g/ha with the spray fluid of 40 l/ha by drone at 15, 30 and 45 DAT, respectively. This could be a result of uniform distribution and greater benefit of herbicides (*Table 1*, *Figure 4*).

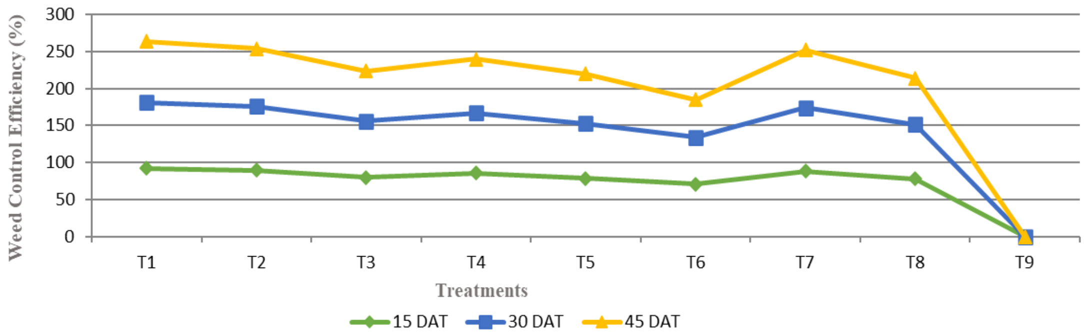

Figure 4. *Effect of weed management practices on Weed Control Efficiency at 15, 30, 45 DAT. (Treatment details are given under Table 1)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Using drones for spraying is more adaptable and consistent, with a spraying efficiency of 60 times greater than that of a knapsack sprayer (Chen et al., 2019). Compared the conventional spraying equipment with unmanned aerial machinery, it has the benefits of more uniform liquid distribution and greater penetration, enabling the construction of uniform application technology (Zhang et al., 2020). Unmanned aerial vehicle achieved greater efficiency than knapsack manual sprayer (Hussain et al., 2022). Weed control efficiency of 88.4%, 85.8% and 78.1% was observed in manual spray of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 500 l/ha 15, 30 and 45 DAT.

Yield attributes and yield

The highest grain yield of 2195 kg /ha was recorded by the support of higher number of producive tillers (180 /m^2), number of grains (1642 /earhead) and earhead weight 8.9 g in the application of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 40 l/ha using drone. This might be due to the reduction in crop – weed competition at early stage of the crop and supported for enhances growth and yield parameters. Grain yield of 2021 kg /ha was recorded by the support of higher number of producive tillers (165 /m^2), number of grains (1530 /earhead) and earhead weight 7.9 g in the application of pre-emergence herbicide of pretilachlor @500 g/ha with the spray fluid of 500 l/ha in manual spray. The lowest grain yield of 884 kg/ha, number of productive tillers (99 /m^2), number of grains 1059 /earhead and earhead weight 5.1 was recorded in unweeded control plot. Kumar et al. (2015) reported that weed competition led to a reduction in the grain yield of barnyard millet (*Table 2, Figure 5*).

Table 2. *Effect of weed management practices on yield attributes and yield parameters in irrigated barnyard millet*

Treatments		**Productive Tillers/m^2**	**No. of grains / earhead**	**Earhead length (cm)**	**Earhead weight (g)**	**Test weight (g)**
T_1	DS of PE Pretilachlor @500 g /ha with SF of 40 l /ha	180	1642	21.9	8.9	3.6
T_2	DS of PE Pretilachlor @500 g /ha with SF of 50 l /ha	168	1533	21.1	8.1	3.6
T_3	DS of PE Pretilachlor @500 g /ha with SF of 60 l /ha	135	1302	17.1	6.6	3.5
T_4	DS of PE Pretilachlor @375 g /ha with SF of 40 l /ha	151	1412	18.7	7.3	3.5
T_5	DS of PE Pretilachlor @375 g /ha with SF of 50 l /ha	133	1291	17.0	6.6	3.5
T_6	DS of PE Pretilachlor @375 g /ha with SF of 60 l /ha	117	1167	15.0	5.8	3.4
T_7	MS of PE Pretilachlor @ 500 g /ha with SF of 500 l /ha	165	1530	20.7	7.9	3.6
T_8	MS of PE Pretilachlor @ 375 g /ha with SF of 500 l /ha	132	1278	17.0	6.5	3.5
T_9	Unweeded Control	99	1059	13.1	5.1	3.4
SEd		5	51	0.7	0.3	0.1
CD (P=0.05)		11	108	1.5	0.6	NS

DS – Drone spray, PE – Pre emergence, SF – Spray fluid, MS – Manual spray (Data within parentheses are original values)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

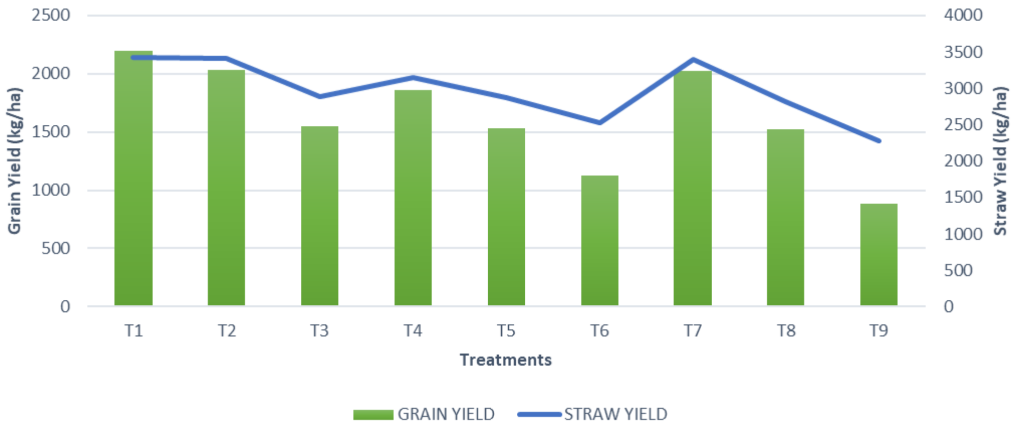

Figure 5. *Effect of herbicide application on Grain and Straw yield. (Treatment details are given under Table 1)*

Effective weed management practices with right herbicide with correct quantity along with correct spray fluid and correct method of spray supported to enhance the yield of 54% when compared to the unweeded control. The unweeded control showed a loss of due to a 43.5% decrease in grain yield and a 27.0% decrease in straw yield compared to plots where one inter cultivation was done at 20 days after sowing (DAS) and one hand weeding at 40 DAS (Kumar et al., 2019). Yield reduction reached as high as 84 percent in the unweeded plot (Ramamoorthy et al., 2002). Uncontrolled weeds reduced the grain and straw yield of ragi by 72 percent compared to yields from two hoeing done at 20 and 40 DAS, this decrease was due to the high weed density and biomass present in the weedy check throughout the crop growth period (Kujur et al., 2019).

Correlation between weed indices and yield

The correlation revealed that increase in weed density resulted to higher weed dry weight and negatively correlated with yields, whereas weed control efficiency and grain yields are positively correlated (*Figure 6*). Weed dry weight and grain yield was negatively correlated. A positive association between rice yield and weed control efficiency (WCE) against various weed types, such as grasses, sedges, and broadleaf weeds (Singh et al., 2007). Strong negative linear correlation was found between weed dry weight and grain yield (Ansari et al., 2017). There is a positive correlation between weed control efficiency (WCE) and grain yield (Yusuf et al., 2021). Weed dry weight had strong relationship with grain yield than weed density (Paul et al., 2023).

Energy

The knapsack sprayer required more input energy compared to the drone application. Among the weed management treatments, the highest output energy (79160 MJ/ha), energy use efficiency (15.11), and energy productivity (0.42 kg/MJ) were observed with drone application of pretilachlor at 500g/ha using 40 l/ha of spray fluid. This is because drone application of herbicides effectively reduces excess energy inputs, such as water and labour, compared to knapsack methods. Likewise energetic benefits of drone in herbicide application were reported by Paul et al., 2023 in rice and Ramesh et al. (2024) in green gram. Farmers obtained benefit from both energy and water savings, promoting resource efficient practices (Sahni et al., 2024) (*Figure 7*).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Figure 6. *Correlation between weed indices and grain yield*

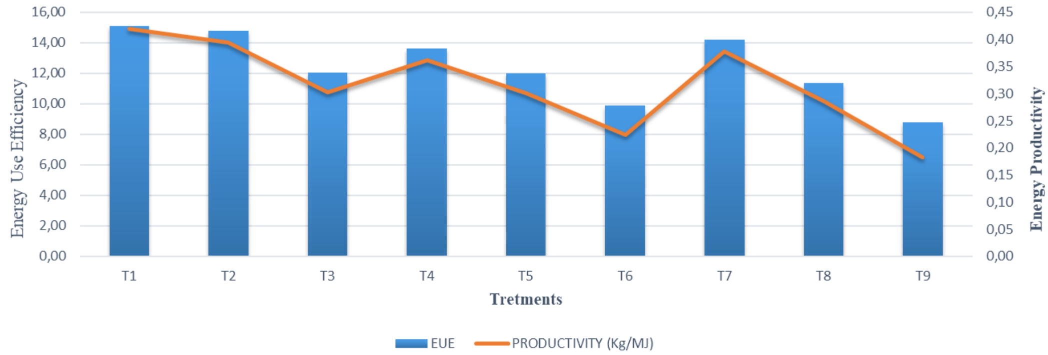

Figure 7. *Effect of herbicide quantity and spray volume on energy use efficiency and energy productivity. (Treatment details are given under Table 1)*

Economics

Additional cost involved in management of weeds added additional revenue when compared to unweeded control. The application of herbicide through drone spray of pretilachlor @ 500g/ha with 40 l/ha of spray fluid resulted on net income Rs. 27441 and BCR 2.0 when compared to unweeded control. The application of herbicide through manual spray of pretilachlor @500 g/ha with 500 l/ha of spray fluid obtained net income Rs. 22971 and BCR 1.8 when compared to unweeded control (*Figure 8*).

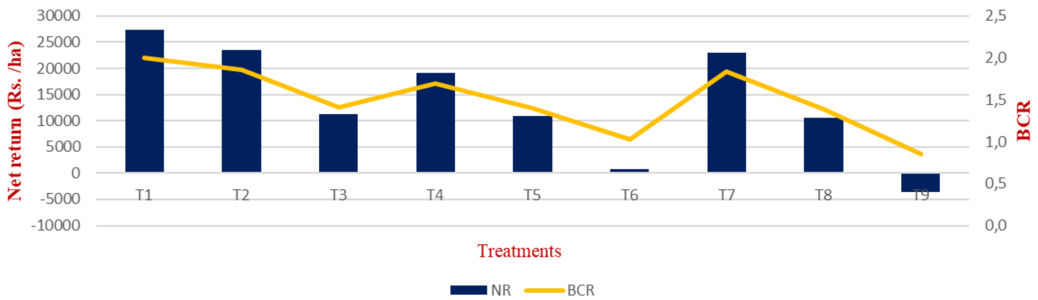

Figure 8. *Effect of quantity and methods of spray on economics. (Treatment details are given under Table 1)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

Drone based application technique for agrochemicals is considered as a low-cost alternative to the conventional manned aerial application and a high efficiency replacement for manual spray operations (He et al., 2017). Rapid technological innovations in the areas of AI, improved weed–management approaches which are highly efficient and environmentally safe to control the weed populations (Esposito et al., 2021). The recent technologies help to reduce the herbicide dose and decrease environmental contamination as well as increase profitability (Manisankar et al., 2022).

Drones can significantly reduce labour costs associated with manual spraying. Traditional methods, such as manual and ground-based spraying, involve higher labour costs and are time-consuming, especially in large fields. Drone technology allows for faster coverage and precise application, which can lead to overall cost savings (Takekawa et al., 2023). Compared to traditional methods drones significantly expedite the process of allowing farmers to allocate their time more effectively. Efficient drone-based herbicide application contributes to sustainable agriculture by minimizing the environmental impact associated with energy-intensive operations (Sahni et al., 2024).

Conclusion

Pre emergence application of pretilachlor @500 g/ha with 40 l/ha of spray fluid using drone at 3 DAT achieved higher reduction of weed density (16.24 /m^2), weed dry weight (7.98 g/m^2) and enhanced the weed control efficiency (91.9) at 15DAT. This led to grain yield (2195 kg/ha), net income (Rs. 27441 /ha) and BCR (2.0) and achieved highest output energy (79160 MJ/ha), energy use efficiency (15.11) and energy productivity (0.42 kg/MJ). The weed density, weed dry matter production were negatively correlated with yield and weed control efficiency at 15 DAT were positively correlated with grain yield.

The results conclude that the application of pretilachlor @500 g/ha with spray fluid of 40 l/ha by drone at 3 DAT is important along with other agronomic practices for enhance the weed control efficiency and yield and reduction in cost of cultivation and increase in net income and BCR.

REFERENCES

[1] Ansari, M. H., Yadav, R. A., Siddiqui, M. Z., Ansari, M. A., Khan, N., Mishra, D., Husain, K. (2017): Efficacy of crop establishment techniques and weed control measures on weed dynamics, weed control efficiency and productivity in rice (*Oryza sativa*). – Indian Journal of Agricultural Sciences 87(8): 1084-88.

[2] Chen, Y., Qi, H. L., Li, G. Z., Lan, Y. B. (2019): Weed control effect of unmanned aerial vehicle (UAV) application in wheat field. – International Journal of Precision Agricultural Aviation 2(2).

[3] Devasenapathy, P., Senthilkumar, G., Shanmugam, P. M. (2009): Energy management in crop production. – Indian Journal of Agronomy 54(1): 80-90.

[4] Dileep, K., Pasupalak, S., Baliarsingh, A. (2018): Effect of establishment methods and sowing time on growth and yield of rice varieties (*Oryza sativa* L.). – The Pharma Innovation Journal 7(4): 904-907.

[5] Esposito, M., Crimaldi, M., Cirillo, V., Sarghini, F., Maggio, A. (2021): Drone and sensor technology for sustainable weed management: A review. – Chemical and Biological Technologies in Agriculture 8: 18.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

[6] Gill, H. S. (1969): Weed index-a new method for reporting weed control trials. – Indian Journal Agronomy 14: 96-98.
[7] Gomez, K. A. (1984): Statistical procedures for agricultural research. – Wiley and Sons, John NewYork.
[8] Hasan, M., Ahmad-Hamdani, M. S., Mustafa Rosli, A., Hamdan, H. (2021): Bioherbicides: An eco-friendly tool for sustainable weed management. – Plants 10(6): 1212.
[9] He, X., Bonds, J., Herbst, A., Langenakens, J. (2017): Recent development of unmanned aerial vehicle for plant protection in East Asia. – International Journal of Agricultural and Biological Engineering 10(3): 18-30.
[10] Hussain, M., Wang, Z., Huang, G. M., Mo, Y., Kaousar, R., Duan, L. S., Tan, W. M. (2022): Comparison of droplet deposition, 28-homobrassinolide dosage efficacy and working efficiency of the unmanned aerial vehicle and knapsack manual sprayer in the maize field. – Agronomy 12(2): 385.
[11] ICAR-DWR. (2021): Annual Report. – ICAR–Directorate of Weed Research (DWR), Jabalpur. p 118.
[12] Kaur, H., Sharma, S. (2020): An overview of Barnyard millet (*Echinochloa frumentacea*). – Journal of Pharmacognosy and Phytochemistry 9(4): 819-822.
[13] Kujur, S., Singh, V. K., Gupta, D. K., Kumar, S., Das, D., Jena, J. (2019): Integration of different weed management practices for increasing yield of finger millet (*Eleusine coracana* L. Gaertn). – Journal of Pharmacognosy and Phytochemistry 8(2): 614-617.
[14] Kumar, A., Paliwal, A., Rawat, L., Kumar, P., Paliwal, A., Chaudhary, S. (2019): Barnyard millet (*Echinochloa frumentacea*) productivity enhancement through establishment methods and weed management practices under hilly rain fed conditions. – International Journal of Chemical Studies 7(2): 1360-1362.
[15] Kumari, P., Kajla, P., Kaushik, D. (2021): Barnyard Millet-Composition, Properties, Health Benefits, and Food Applications. – In Handbook of Cereals, Pulses, Roots, and Tubers, CRC Press, pp. 149-156.
[16] Mani, V. S., Malla, M. L., Gautam, K. C., Bhagwandas, B. (1973): Weed-killing chemicals in potato cultivation. – Indian Farming 23(8): 17-18.
[17] Manisankar, G., Ghosh, P., Malik, G. C., Banerjee, M. (2022): Recent trends in chemical weed management: A review. – The Pharma Innovation 11(4): 745-753.
[18] Parihar, M., Kumar, A., Bisht, J. K., Bhinda, M. S., Meena, R. P., Mondal, T., Joshi, D. C., Bijarniya, H., Singh, S., Kant, L. (2021): Reviving the forgotten food network of potential crops to strengthen nutritional and livelihood security in Northwestern Himalayas. – Indian Journal of Agronomy 66: 44-59.
[19] Paul, R. A. I., Murali Arthanari, P., Pazhanivelan, S., Kavitha, R., Djanaguiraman, M. (2023): Drone-based herbicide application for energy saving, higher weed control and economics in direct-seeded rice (*Oryza sativa*). – Indian Journal of Agricultural Sciences 93(7): 704-709.
[20] Prashanth, K. M. K., Shekara, B. G., Yamuna, B. G., Sunil, C. M. (2015): Crop weed competition for nutrients by weeds and drill sown finger millet [*Eleusine coracana* (L.)]. – International Journal of Tropical Agriculture 33(3): 2049-2053.
[21] Priyanga, M., Ragavan, T., Durai Singh, R., Prabhaharan, J. (2019): Effect of establishment methods and weed management practices on weed control in barnyard millet under irrigated condition. – International Journal of Chemical Studies 7: 3201-3204.
[22] Ramamoorthy, K., Christopher Louurduraj, A., Prem Sekhar, M. (2002): Weed management studies with pre-emergence Isoproturon in rainfed direct sown finger millet (*Eleusine coracana Gaertn*.). – Madras Agricultural Journal 89(1-3): 30-32.
[23] Ramesh, T., Madhusree, S., Rathika, S., Meena, S., Raja, K. (2024): Drone based herbicide application in greengram (Vigna *radiata*). – The Indian Journal of Agricultural Sciences 94(3): 329-332.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186

[24] Raundal, P. U., Pawar, P. P., Musamade, A. M., Mahajan, M. S., Desale, S. B. (2017): Response of little millet varieties to different levels of fertilizers under rainfed condition. – A peer-Reviewed Multi-Disciplinary International Journal.
[25] Sahni, R. K., Kumar, S. P., Thorat, D., Rajwade, Y., Jyoti, B., Ranjan, J., Anand, R. (2024): Drone Spraying System for Efficient Agrochemical Application in Precision Agriculture. – In Applications of Computer Vision and Drone Technology in Agriculture 4.0, Singapore: Springer Nature, Singapore, pp. 225-244.
[26] Shamina, C., Annadurai, K., Hemalatha, M., Suresh S. (2019): Effect of spacing and weed management practices on barnyard millet (*Echinochloa frumentaceae*) under rainfed condition. – International Journal of Current Microbiology and Applied Sciences 8(6): 330-337.
[27] Singh, S., Ladha, J. K., Gupta, R. K., Bhushan, L., Rao, A. N., Sivaprasad, B., Singh, P. P. (2007): Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). – Crop Protection 26(4): 518-524.
[28] Sravani, P., Subramanyam, D., Nagavani, A. V., Umamahesh, V., Karuna Sagar, G. (2021): Weed management effect on weed growth and yield of foxtail millet [*Setaria italica* (L.) Beauv]. – Indian Journal of Weed Science 53(4): 430-432.
[29] Takekawa, J. Y., Hagani, J. S., Edmunds, T. J., Collins, J. M., Chappell, S. C., Reynolds, W. H. (2023): The Sky is Not the Limit: Use of a Spray Drone for the Precise Application of Herbicide and Control of an Invasive Plant in Managed Wetlands. – Remote Sensing 15(15): 3845.
[30] Yusuf, Y. M., Abubakar, H., Dominic, O. (2021): Effects of Weed Control on Growth and Yield of Pearl Millet (*Pennisetum glaucum* L.) in the Sudan Savanna, Sokoto State, Nigeria. – Journal of Current Opinion in Crop Science 2(2): 155-164.
[31] Zhang, X. Q., Song, X. P., Liang, Y. J., Qin, Z. Q., Zhang, B. Q., Wei, J. J., Li, Y. R., Wu, J. M. (2020): Effects of spray parameters of drone on the droplet deposition in sugarcane canopy. – Sugar Tech 22: 583-588.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ●ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_61736186