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RESEARCH ARTICLE

Synergizing weed - nitrogen management and optimizing productivity and profitability of rainfed baby corn (*Zea mays* L.)

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Abstract

Baby corn is a high nitrogen (N) demanding exhaustive crop. Weed infestation causes 39 % loss in yield under rainfed condition. An experiment comprising four weed management practices *viz*., W_1: Atrazine 1.0 kg ha^{-1} (pre-emergence), W_2: Tembotrione 90 g ha^{-1} + 2,4-D 400 g ha^{-1} (post-emergence), W_3 : W_1 + manual weeding at 21 days after sowing (DAS), W_4: Hoeing and weeding at 21 DAS allocated to main plots and five N management practices *i.e.* N_1:100 % soil test-based N from chemical source ($C_{100\%STN}$), N_2: $C_{75\%STN}$ + farmyard manure (FYM) $_{25\%STN}$, N_3: $C_{75\%STN}$ + vermicompost (VC)$_{25\%STN}$, N_4: $C_{75\%STN}$ + FYM$_{12.5\%STN}$ + vermicompost$_{12.5\%STN}$ and N_5: $C_{50\%STN}$ + FYM$_{25\%STN}$ + vermicompost$_{25\%STN}$ allocated to sub plots were tried in split plot design with three replications at Bhubaneswar, India during *kharif* 2022 and 2023. The treatment combination W_3N_1 produced the maximum dehusked baby cob (2.38 t ha^{-1}), keeping W_3N_3 and W_3N_4 at par whereas, W_3N_3 produced the maximum green fodder yield (27.48 t ha^{-1}), keeping W_3N_1 and W_1N_3 at par. The treatment combination W_3N_1 recorded the maximum net return of 225.10 × 10^3 ₹ ha^{-1} and return per rupee investment of 3.89 as against 188.11 × 10^3 ₹ ha^{-1} and 3.20 with W_3 and 189.74 × 10^3 ₹ ha^{-1} and 3.43, respectively with N_1. Both baby cob and green fodder yield exhibited significant negative correlation with weed density and biomass. The treatment W_3N_1 gave the maximum productivity and profitability, but W_3N_3 with similar yield is recommended considering productivity and long-term sustainability.

Keywords: dehusked baby cob; green fodder; leaf area index; net return; return per rupee investment; SPAD

Introduction

Baby corn, developed as a commercial crop in late 1970s, is becoming popular as a source of food for man and feed for cattle (1). It is a remunerative crop and farmers can fetch net return of ₹146013 ha^{-1} and return per rupee invested of 2.28 with cost of cultivation of ₹ 114268 ha^{-1} (2). The crop plays an important role in spread of income and employment opportunities round the year in India due to its short life-span and adaptation to diverse weather conditions. A farmer can raise four crops of baby corn annually due to short life-span and adaptation to diverse weather conditions.

Baby corn grown in *kharif* season (June to September) is subjected to keen competition from a broad-spectrum weed flora for resources like nutrient, moisture, light and space. Crop weed competition becomes acute due to wider inter-row space and higher weed density than that of the crop. Growth of crop and weed exhibit inverse relationships. Season-long weed infestation reduces baby corn yield by 44.0 % (3). The yield loss due to weeds in rainy season baby corn is 39 % as against 40-50 % in summer (4, 5). Several options (herbicidal, cultural, manual, mechanical or combinations) are available for weed management in baby corn. Atrazine is a popular herbicide in maize with high selectivity. It provides early season broad-spectrum weed control in maize. Additional manual weeding takes care of subsequent flushes of weeds. Better performance of atrazine + one hand weeding over atrazine alone has been reported earlier (6). Pendimethalin + manual weeding gives better weed control over pendimethalin alone (7). Application of post-emergence herbicide is required when a farmer fails to apply pre-emergence herbicide due to erratic weather conditions. Tembotrione is as an efficient post-emergence herbicide for maize considering its effects on control of grassy and non-grassy weeds and productivity (8). Tembotrione provides effective control of *Echinochloa colona* and *Commelina benghalensis* and *Ageratum* spp. in maize (9). Tembotrione 100 mL ha^{-1} provides satisfactory weed control in baby corn (10). A single herbicide does not control all species of weeds (5). Herbicide combinations (Tank-mix or ready-mix) with different mode of action are better than application of a single herbicide to check development of herbicide resistance. Some researchers have reported the maximum net profit and B:C ratio with hoeing and weeding at 30 and 45 DAS, while others achieved the maximum yield of baby corn by manual weeding twice at 20 and 40 DAS (4, 7).

Baby corn is a high nitrogen demanding crop. Baby corn responds upto 180-200 kg N ha^{-1} (11-13). Many researchers reported the maximum yield of baby cob with application of 100 % N from chemical source. Application of 100 % recommended nitrogen through chemical fertilizer produced higher baby cob and green fodder yield than all other combinations of chemical nitrogen and vermicompost (14). Continuous application of higher dose of chemical fertilizer has adverse effects on soil health. Substitution of full or part of chemical nitrogen with organic manures may sustain soil health. Application of vermicompost has positive effects on yield and yield attributes of baby corn (15). Vermicompost, equivalent to 120 kg N ha^{-1} is the best organic source for yield attributes and yield of baby corn (16). Vermicompost reduces the requirement of chemical fertilizer and increases yield of baby corn (17). Humic acid and Plant Growth-Promoting Rhizobacteria (PGPR) present in vermicompost promotes crop growth (18). Application of 75 % N through vermicompost or FYM + 25 % through chemical fertilizer gave the maximum values of yield attributes and yield of baby corn in Nepal (19). Application of recommended fertilizer dose (RDF) (150:60:40 kg NPK ha^{-1}) produced similar baby cob and green fodder yield as application of vermicompost @ 5 t ha^{-1} (20). Integrated nutrient management is required to minimize dependence on chemical fertilizers, maintain or improve soil health and impart sustainability to baby corn production (21). Hence, there is a need to compare relative performance of baby corn under integrated nitrogen management practices against chemical source alone.

While extensive studies have been conducted on individual aspects of weed and nitrogen management in baby corn, limited research has explored their combined or interactive effects, particularly under rainfed conditions. Moreover, there is a lack of comprehensive studies comparing integrated weed and nitrogen management strategies with a single method of weed control or chemical source of nitrogen. Both weed and nitrogen management practices act synergistically to improve performance of a crop. Weeds deplete a lion's share from nitrogen applied to a crop. Effective weed management practices decrease competitive ability of weeds against crop, minimize nitrogen removal by weed and facilitate uptake by crop. Under these circumstances, the present experiment was designed with hypothesis that appropriate weed management and nitrogen sources would exhibit complementarity to check weed density and biomass, promote crop growth and yield attributes, maximize productivity and profitability of baby corn under rainfed conditions.

Materials and Methods

Experimental site

A field-based experiment was conducted at Agricultural Research Station, Faculty of Agricultural Sciences (IAS), Siksha 'O' Anusandhan Deemed to be University, Bhubaneswar, Chhatabar, Odisha, India, during *kharif* (June-September) season of 2022 and 2023. The farm is situated at 20° 25' N latitude, 85° 67 'E longitude and 51 m above the mean sea level in East and South-Eastern Coastal Plain Agro-climatic Zone of Odisha, India. The soil of the experimental site was acidic (pH - 5.23) sandy loam (Sand- 67.6 %, silt- 20.8 % and cay-11.6 %) in texture with normal electrical conductivity (0.31d Sm^{-1} at 25 °C), low organic carbon (0.28 %), low available N (187.57 kg ha^{-1}), low available P (4.80 kg ha^{-1}) and low available K (79.80 kg ha^{-1}).

Treatment details

The experiment comprising four weed management and five nitrogen management practices was tried in a split-plot design with three replications. The weed management practices *viz.*, W_1: Atrazine 1.0 kg ha^{-1} (pre-emergence spray), W_2: Tembotrione 90g ha^{-1} + 2,4-D 400g ha^{-1} (post-emergence spray, tank-mix), W_3: W_1 + manual weeding at 21 days after sowing (DAS), W_4: Hoeing and weeding at 21 DAS, were allocated to main plots. The soil-test-based nitrogen dose (150 kg ha^{-1}) for the crop was computed by adding 25 % extra N over the recommended dose (120 kg N ha^{-1}) for baby corn in the state of Odisha, India, as the soil was rated low in available N by the alkaline permanganate method (22). The N requirement was met with varying percentages from chemical source (urea), FYM and vermicompost under different treatments. The N management practices, *viz.* N_1: 100 % Soil Test Based Nitrogen from chemical source ($C_{100\%STN}$), N_2: 75 % STN from chemical source + 25 % N as Farm yard manure ($C_{75\%STN}$ + $FYM_{25\%STN}$), N_3: 75 % STN from chemical source + 25 % N as vermicompost ($C_{75\%STN}$ + $VC_{25\%STN}$), N_4: 75 % STN from chemical source + 12.5 % N as FYM + 12.5 % N as VC ($C_{75\%STN}$ + $FYM_{12.5\%STN}$ + $VC_{12.5\%STN}$) and N_5: 50 % STN from chemical source + 25 % STN as FYM + 25 % N as VC ($C_{50\%STN}$ + $FYM_{25\%STN}$ + $VC_{25\%STN}$) were allocated to sub plots.

Crop management

Baby corn crop variety 'Syngenta G-54 (duration 50-55 days) 14' marketed and supplied by Syngenta India Pvt. ltd was used in the experiment. The colour of the baby cob in this cultivar was light yellow. In this cultivar, silking preceded tasseling, which minimized the chances of pollination. The crop was sown on 7 July 2022 (27^{th} standard mereological week (SMW) and 13 July 2023 (28^{th} SMW) during the first and the second year, respectively, with a spacing of 40 cm × 30 cm. The plot size was 4.8 m × 4.0 m. Being a high rainfall area, the broad bed and furrow (BBF) method was adapted to facilitate drainage of excess rainwater from the field during intense rain. Each plot had 4 beds with height of 15 cm and bed width of 90 cm and furrow width of 30 cm between broad beds (Fig. 1). To maintain recommended plant population per hectare, three rows of baby corn were accommodated per bed with row-to-row distance of 30 cm. Atrazine 1.0 kg ha^{-1} was applied as preemergence spray using water at 1000 L ha^{-1}, whereas tembotrione + 2,4-D 90 + 400 g ha^{-1} was applied as post emergence tank-mix spray using water at 500 L ha^{-1}. Fall armyworm attack was checked by spraying Emamectin benzoate 5 SG at 0.4 g/L water. Tender baby cobs were harvested after 2-3 days of silking. The cobs were harvested during 24^{th} to 29^{th} August (34^{th}-35^{th} SMW) and 2^{nd} to 6^{th} September (35^{th}-36^{th} SMW) in 2022 and 2023, respectively.

Crop weather relationship

The crop received 708.7 mm rainfall in 34 rainy days in 2022 (27-35 SMW) as against 892.8 mm in 29 rainy days in 2023 (28-36 SMW). The rainfall quantity was adequate and the distribution was congenial for crop growth and development during both years (Fig. 2). The Broad Bed and Furrow (BBF) method was adopted to facilitate drainage of excess rainwater from the field during intense rain (23). The maximum and the minimum temperature ranged between 31.1-34.9 °C and 25.9-27.2 ^{0}C in 2022, as against 31.2-34.5 °C and 25.3-26.6 °C in 2023, respectively (Fig. 3). The thermal regime was congenial during the lifespan of the crop.

Sampling and data recording

Weed count and dry weight of weeds were recorded at 30 days after planting from two quadrates, each of size 0.5 m × 0.5 m, per plot. The average value of the weed population was taken

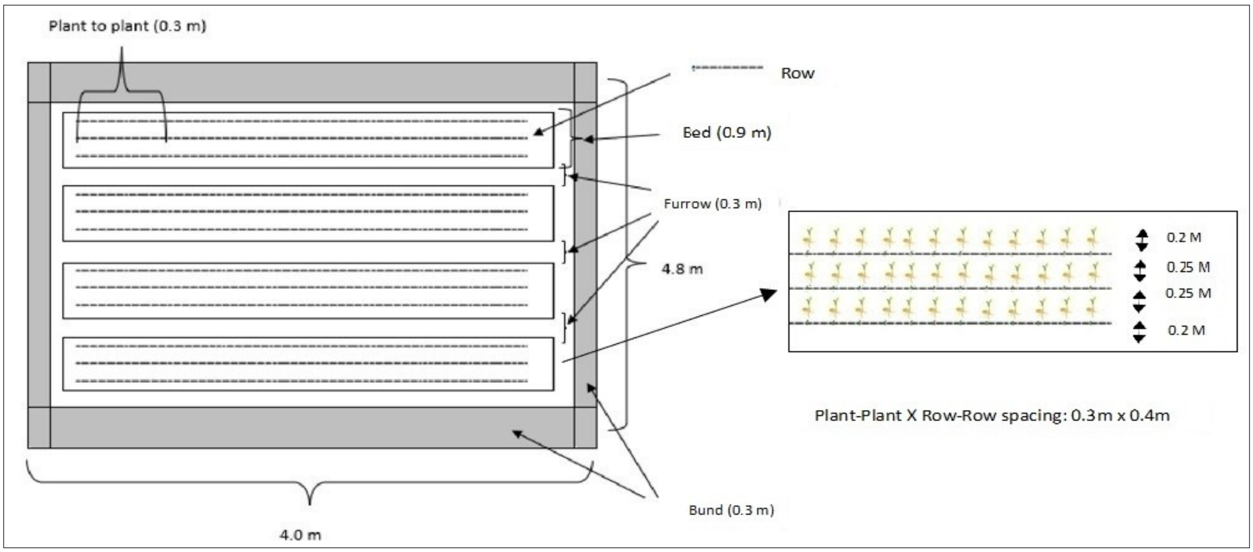

Fig. 1. Schematic representation of planting rainfed baby corn by broad bed and furrow (BBF) method.

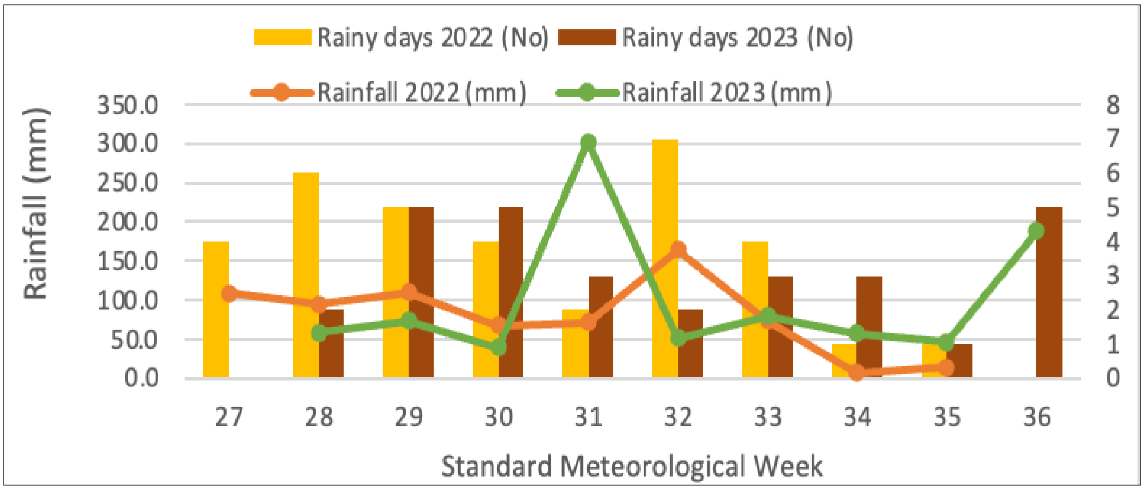

Fig. 2. Standard meteorological week–wise rainfall and rainy days during the growth period of baby corn.

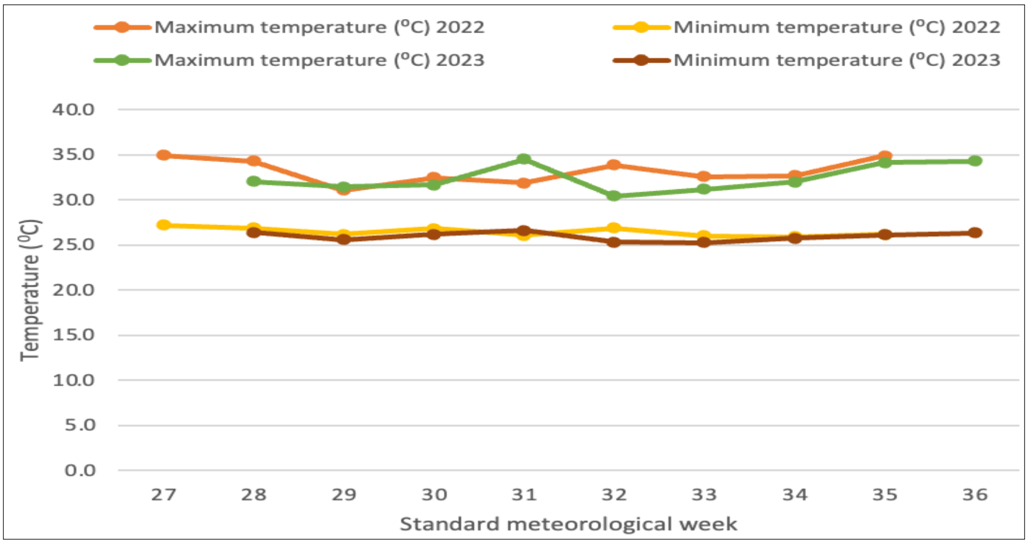

Fig. 3. Standard meteorological week–wise maximum and minimum temperature (°C) during growth period of baby corn.

and expressed as no quadrate^{-1}. For determining biomass, the samples were taken for sun drying followed by oven drying at 70 °C for 24 hr and dry matter was expressed as g quadrate^{-1} (quadrates of size 50 cm × 50 cm). The height of ten tagged sample plants was measured with the help of a meter scale from the base of the plant to the base of the fully opened top leaf until tasseling, after which plant height was measured from the base of the plant to the base of the tassel. The average plant height was found out and the values were expressed in centimeter. Leaf area per plant was determined by using leaf area meter. Leaf area index (LAI) was worked out by using equation 1 (24).

$$\text{LAI} = \frac{\text{Leaf}(cm^2)}{\text{Ground}(cm^2)} = \frac{\text{Leaf area per plant}(cm^2)}{\text{Land area occupied by the plant}(cm^2)} \quad \text{(Eqn. 1)}$$

The Soil Plant Analysis Development (SPAD) readings, indicative of chlorophyll content of leaf were recorded using a chlorophyll meter (SPAD-502 plus) at the midpoint of the youngest fully expanded leaf. The mean of 10 readings per plot was considered as the measured SPAD value (25). Length of the cob was measured from the base to the tip of the baby cob and expressed in centimeter. The circumference was measured at the center of the cob using a thread. This was taken as the girth of the cob, then converted to diameter and expressed in centimetres. Husked baby cobs and fodder were harvested from net plot area and converted to t ha^{-1}. Husk and silk were separated from husked baby cob to record the weight of the dehusked baby cob t ha^{-1}. Gross return from baby cob and fodder were computed by multiplying the price of baby cob (₹110000 t^{-1}) and fodder (₹1500 t^{-1}) with respective yields (t ha^{-1}). Net return was computed by deducting cost of cultivation from gross return. Return per rupee investment was found out by dividing gross return by cost of cultivation.

Statistical analysis

The data on different parameters were subjected to statistical analysis by adopting an appropriate procedure for split plot design (26). The data were analyzed by using the SPSS software. Bartlett Test indicated homogeneity of error variances of both years for different parameters. Hence, the data from both years were subjected to pooled analysis.

Results

Weed growth

Nine weed species, *viz*., large crab grass (*Digitaria sanguinalis* L.), flat sedge (*Cyperus difformis* L.), globe fingerush [*Fimbristylis miliacea* (L.) *Vahl*.], creeping water primrose (*Ludwigia perennis* L.), touch-me-not (*Mimosa pudica* L.), sickle pod (*Cassia tora* L.), cyanotis [*Cyanotis cucullata* (Roth) *Kunth*], West African mallow (*Corchorus aestuans*) and pigweed (*Amaranthus viridis* L.) were found in the experimental site. Weed density and biomass were recorded at 30 days after planting practices (Table 1). Among weed management practices, application of atrazine @1.0 kg ha^{-1} as pre-emergence spray followed by one manual weeding at 21 days after sowing was the most efficient with the minimum weed density (4.97 $quadrate^{-1}$) and the minimum weed biomass (3.96 $quadrate^{-1}$) and proved to be superior to all other weed management practices. Atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS decreased weed density by 35, 56 and 60 % and biomass by 31, 37 and 70 % compared to atrazine 1.0 kg ha^{-1} alone, tembotrione + 2,4-D @ 90 + 400 g ha^{-1} and hoeing and weeding at 21 days after sowing. Among nitrogen management practices, 100 % soil test-based nitrogen as chemical fertilizer (urea) recorded the minimum weed population (6.62 $quadrate^{-1}$) and biomass (6.14 g $quadrate^{-1}$), being superior to all other weed management practices for weed density and at par with $C_{75\%STN}$ + $FYM_{25\%STN}$ and $C_{75\%STN}$ + $VC_{25\%STN}$ for weed biomass.

Crop growth

Plant height increased continuously from 30 DAS to till harvest. The SPAD readings exhibited an increasing trend between 30 to 45 DAS and declined thereafter till the minimum value at harvest (Table 2). Weed management practices differed significantly at 45 DAS for plant height, when application of atrazine 1.0 kg ha^{-1} followed by manual weeding at 21 DAS recorded the maximum value of 120.8 cm, being at par with atrazine 1.0 kg $ha^{-1}$and tembotrione + 2,4-D 90 + 400 g $ha^{-1}$and significantly superior to hoeing and weeding at 21 DAS. Among nitrogen management practices, application of 100 % soil test-based nitrogen through chemical fertilizer (N_1) recorded the maximum plant height of 73.8, 117.8 and 178.3 cm at 30 and 45 DAS and at harvest, respectively, keeping N_4 at 30 DAS and N_3at 45 DAS at par. Among weed management practices, application of atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS recorded the maximum LAI of 1.17, 2.49 and 5.05 at 30 and 45 DAS and harvest, respectively, but the differences among weed management practices were not statistically significant. Among nitrogen management practices, application of 100 % soil test-based nitrogen from chemical source (N_1) recorded the maximum LAI of 1.26, 2.85 and 5.80 at 30 and 45 DAS and harvest, respectively, keeping $C_{75\%STN}$ + $VC_{25\%STN}$ (N_3) at par. Among the weed management practices, atrazine 1.0 kg ha^{-1} recorded the maximum SPAD value of 36.36, 44.28 and 42.53 at 30 and 45 DAS and harvest, respectively, keeping W_1 at par at 30 DAS and harvest and W_1 and W_2 at 45 DAS. Nitrogen management practices differed significantly for SPAD readings at 30 DAS and harvest. Application of 100 % soil test-based nitrogen from chemical source recorded the maximum SPAD value of 36.53 and 42.29 at 30 DAS and harvest, respectively, keeping N_3 at par.

Table 1. Effect of fertilizer and weed management on biomass and weed density 30 days after planting in rainfed baby corn

Treatment	Weed density (No $quadrate^{-1}$)	Weed biomass (g $quadrate^{-1}$)
Weed management		
W_1 - Atrazine 1.0 kg ha^{-1}	2.83 (7.59) *	2.5(5.75)
W_2 - Tembotrione + 2,4-D 90 + 400 g ha^{-1}	3.41(11.24)	2.6(6.29)
W_3 - W_1 + Manual weeding at 21 DAS	2.34(4.97)	2.12(3.96)
W4- Hoeing and weeding at 21 DAS	3.58(12.43)	3.67(13.31)
Sem ±	0.12	0.08
CD (P=0.05)	0.35	0.27
Nitrogen management (Source wise % STN)		
N_1-$C_{100\ \%STN}$	2.66(6.62)	2.58(6.14)
N_2- $C_{75\ \%STN}$ + $FYM_{25\ \%STN}$	3.08(9.07)	2.66(6.6)
N_3- $C_{75\ \%STN}$ + $VC_{25\ \%STN}$	2.87(7.81)	2.65(6.55)
N_4- $C_{75\ \%STN}$ + $FYM_{12.5\ \%STN}$ + $VC_{12.5\ \%STN}$	2.995(8.51)	2.67(6.65)
N_5- $C_{50\ \%STN}$ + $FYM_{25\ \%STN}$ + $VC_{25\ \%STN}$)	3.5(11.80)	3.06(8.88)
SEm±	0.1	0.08
CD (P=0.05)	0.29	0.25

*Original values in parentheses are $\sqrt{(x + 0.5)}$ transformed values before parentheses. DAS: Days after sowing, quadrate – each quadrate of size 50 cm x 50 cm; MW: Manual weeding; HW – hoeing and weeding, SEm± - Standard error of mean, CD – Critical difference, STN – Soil test-based nitrogen dose, C – Chemical, FYM – Farm Yard Manure, VC – Vermicompost

Table 2. Effect of weed and nitrogen management on growth parameters of baby corn

Treatment	Plant height (cm)			Leaf area index			SPAD value		
	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest
Weed management									
W_1	67.8	120.3	169.5	1.10	2.48	4.99	35.76	44.24	42.19
W_2	69.0	120.3	168.7	1.14	2.48	4.69	35.22	42.91	40.99
W_3	70.7	120.8	169.1	1.17	2.49	5.05	36.36	44.28	42.53
W_4	66.8	91.8	162.5	1.09	2.34	4.57	33.82	41.21	39.26
SEm±	0.9	1.76	3.46	0.03	0.05	0.15	0.35	0.62	0.38
CD (P=0.05)	NS	5.4	NS	NS	NS	NS	1.07	1.93	1.18
Nitrogen management									
N_1	73.8	117.8	178.3	1.26	2.85	5.8	36.53	43.99	42.29
N_2	66.2	112.6	161.6	1.12	2.31	4.09	34.59	43.41	41.29
N_3	67.9	114.6	165.9	1.20	2.79	5.62	35.91	43.65	41.75
N_4	72.5	111.2	169.1	1.19	2.66	5.11	35.39	43.07	41.16
N_5	62.5	110.4	162.3	0.83	1.62	3.46	34.03	41.68	39.74
SEm±	0.7	1.3	2.4	0.025	0.03	0.137	0.34	0.59	0.35
CD (P=0.05)	2.4	3.7	6.7	0.07	0.10	0.386	0.95	NS	0.98

DAS - Days after sowing, SEm± - Standard error of mean, CD - Critical difference, SPAD - Soil Plant Analysis Development, W – Weed management, N – Nitrogen management

Yield attributes

Among weed management practices application of atrazine 1.0 kg ha^{-1} followed by manual weeding at 21 DAS was the best with the maximum of 2.38 cob $plant^{-1}$, the longest cob (8.3 cm), the thickest cob 1.46 cm thick, the heaviest dehusked cob (54.7 g cob^{-1}) and heaviest dehusked cob (11.9 g ha^{-1}), keeping atrazine 1.0 kg ha^{-1} at par for cobs $plant^{-1}$, dehusked cob length and dehusked cob diameter (Table 3). Atrazine 1.0 kg ha^{-1} followed by manual weeding at 21 DAS recorded significantly higher husked and dehusked cob weight than all other weed management practices. Among nitrogen management practices, application of 100 % soil test-based nitrogen from chemical fertilizer (N_1) produced the maximum cobs $plant^{-1}$, the longest and the thickest dehusked cob and the heaviest husked and dehusked cob, keeping N_3 at par for cobs $plant^{-1}$ and N_3 and N_4 for husked cob weight.

Dehusked cob and fodder yield

Among weed management practices, application of atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS (2.17 t ha^{-1}) produced the maximum dehusked cob yield, registering 10, 18 and 39 % higher production than atrazine 1.0 kg ha^{-1} alone, tembotrione + 2,4-D and hoeing and weeding at 21 DAS, respectively (Table 4). Among nitrogen management practices, 100 % soil test-based nitrogen from chemical fertilizer produced the maximum dehusked cob yield of 2.10 t ha^{-1}, keeping N_3 at par. The interaction effect of weed and nitrogen management practices was significant on dehusked cob yield. Baby corn with application of atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS and 100 % soil test-based nitrogen from chemical fertilizer (W_3N_1) produced the maximum dehusked cob yield of 2.38 t ha^{-1}, keeping W_3N_3 and W_3N_4 at par. All other treatment combinations produced significantly less dehusked cob yield than 100 % STN from the chemical source. Within each weed management practice, N_1 produced the maximum baby cob yield and N_3 and N_4 under W_1, W_3 and W_4 and N_2 and N_3 under W_2 produced statistically similar dehusked cob yield. Among weed management practices, W_3 (23.78 t ha^{-1}) produced the maximum green fodder yield, keeping W_1 at par and registering 5 and 17 % higher green fodder yield than W_2 and W_4, respectively. Among nitrogen management practices, N_1 (25.21 t ha^{-1}) produced the maximum green fodder yield, keeping N_3 at par. Other N management practices produced significantly less green fodder than N_1. The interaction effect of weed and nitrogen management practices was found to be significant on green fodder yield of baby corn. The treatment combination W_3N_1 (27.46 t ha^{-1}) produced the maximum green fodder yield, keeping W_3N_3 and W_1N_3 at par.

Economics

Among weed management practices, application of atrazine @ 1kg ha^{-1} + manual weeding at 21 DAS accrued the maximum gross return (₹ 274.55 × 10^3 ha^{-1}) and proved superior to other weed

Table 3. Effect of weed management and nitrogen management on yield attributes of baby corn

Treatment	Cobs $plant^{-1}$	Dehusked cob length (cm)	Dehusked cob diameter (cm)	Husked cob weight (g)	Dehusked cob weight (g)
Weed management					
W_1	2.32	7.9	1.45	51.6	10.9
W_2	2.26	7.6	1.34	49.8	10.6
W_3	2.38	8.3	1.46	54.7	11.9
W_4	1.95	6.4	1.28	40.9	9.0
SEm±	0.02	0.1	0.013	0.7	0.1
CD (P=0.05)	0.06	0.4	0.04	2.3	0.4
Nitrogen management					
N_1	2.41	8.6	1.54	52.1	11.7
N_2	2.19	6.7	1.32	43.5	9.5
N_3	2.39	8.1	1.47	51.7	11.0
N_4	2.34	8.0	1.35	51.7	10.7
N_5	1.81	6.4	1.24	47.3	10.1
SEm±	0.020	0.1	0.021	0.6	0.2
CD (P=0.05)	0.06	0.3	0.06	1.7	0.4

SEm± - Standard error of mean, CD – Critical difference, W – Weed management, N – Nitrogen management, WN – Weed management in the same or different level of nitrogen management, NW – Nitrogen management in the same level of weed management

Table 4. Interactive effect of weed and nitrogen management on the yield of dehusked cob and fodder in baby corn

Treatments	N_1	N_2	N_3	N_4	N_5	Mean
			Dehusked cob yield (t ha^{-1})			
W_1	2.20	1.73	2.17	2.10	1.64	1.97
W_2	2.02	1.92	2.07	1.60	1.60	1.84
W_3	2.38	2.07	2.28	2.26	1.87	2.17
W_4	1.79	1.33	1.69	1.69	1.31	1.56
Mean	2.10	1.76	2.05	1.91	1.60	
SEm±	W-0.027	N-0.027	WN-0.054	NW-0.053		
CD (P=0.05)	W-0.08	N-0.08	WN-0.12	NW-0.15		
			Green fodder yield (t ha^{-1})			
W_1	24.88	20.27	26.22	23.85	19.71	22.99
W_2	25.93	22.10	21.01	23.41	20.48	22.59
W_3	27.46	21.92	27.48	22.08	19.94	23.78
W_4	22.56	19.09	22.64	22.62	14.43	20.27
Mean	25.21	20.84	24.34	22.99	18.64	
SEm±	W-0.338	N-0.314	WN-0.655	NW-0.628		
CD (P=0.05)	W-1.04	N-0.887	WN-1.36	NW-1.77		

SEm± - Standard error of mean, CD - Critical difference, W - Weed management, N - Nitrogen management, WN - Weed management in the same or different level of nitrogen management, NW - Nitrogen management in the same level of weed management

management practices (Table 5). Atrazine 1.0 kg ha^{-1}, tembotrione + 2,4-D and hoeing and weeding at 21 DAS recorded 8.5, 13.8 and 26.4 % less gross returns than atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS. Among nitrogen management practices, application of 100 % STN from a chemical source gave the maximum gross return (₹ 268.63 × 10^3 ha^{-1}), keeping N_3 at par. The interaction effects of weed and nitrogen management practices were significant on system gross return. The treatment combination W_3N_1 (₹ 302.99 × 10^3 ha^{-1}) accrued the maximum gross return, keeping W_3N_3 (₹ 292.20 × 10^3 ha^{-1}) at par and other treatment combinations below it. The accrued gross returns with W_3N_1 and W_3N_3 were derived as sum of gross return from dehusked baby cob and green fodder *i.e.* 261.8 + 41.19 and 250.98 + 41.22 (Fig. 4). Among weed management practices, W_3 gave the maximum net return (₹ 188.11 × 10^3 ha^{-1}), registering 11.9, 25.0 and 74.2 % higher values than W_1, W_2 and W_4, respectively. Among nitrogen management practices, N_1 (₹ 189.74 × 10^3 ha^{-1}) gave the maximum net return, registering 32.2, 12.2, 20.5 and 74.9 % higher values than W_2, W_3, W_4 and W_5, respectively. The interaction effect of weed and nitrogen management was significant on net return for baby corn. The treatment combination W_3N_1 (₹ 225.10 × 10^3 ha^{-1}) recorded the maximum net return, being superior to all other treatment combinations. Among weed management practices, W_3 (3.20) recorded the maximum return per rupee investment. Among nitrogen management treatments, N_1 (3.43) recorded the maximum return per rupee investment. The treatment combination W_3N_1 (3.89) recorded the maximum return per rupee investment, keeping W_1N_1 (3.76) at par and all other treatment combinations recorded significantly lower values.

Correlation

Both baby cob (dehusked) and green fodder yield exhibited significant positive correlation with plant height at harvest (0.630, 0.676), LAI at harvest (0.767, 0.853), SPAD reading at harvest (0.891, 0.734), baby cobs plant^{-1}(0.822, 0.782), dehusked cob length (0.877, 0.835), dehusked cob diameter (0.717, 0.739), husked cob weight (0.796, 0.630), dehusked cob weight (0.822, 0.684) and significant negative correlation with weed density at 30 DAS (-0.866, -0.688) and weed biomass at 30 DAS (-0.728, -0.467) (Fig. 5). All growth parameters, yield attributes, dehusked

Table 5. Interactive Effect of weed management and nitrogen management on economic indices of babycorn

Treatment	N_1	N_2	N_3	N_4	N_5	Mean
			Gross return (× 10^3 ₹/ha)			
W_1	279.69	221.07	277.85	266.59	210.15	251.07
W_2	261.28	244.71	259.04	211.48	206.53	236.61
W_3	302.99	260.21	292.20	282.09	235.24	274.55
W_4	230.55	175.12	220.04	219.65	165.37	202.15
Mean	268.63	225.28	262.28	244.95	204.32	0.00
SEm±	W-2.99	N-2.90	WN-5.99	NW-5.80		
CD (P=0.05)	W-9.21	N-8.20	WN-12.71	NW- 6.40		
			Net return (x10^3 ₹/ha)			
W_1	205.32	143.81	189.19	183.62	118.80	168.15
W_2	183.62	164.16	167.09	125.23	111.90	150.40
W_3	225.10	179.43	200.02	195.61	140.38	188.11
W_4	144.93	86.61	120.13	125.43	62.78	107.98
Mean	189.74	143.50	169.11	157.48	108.46	0.00
SEm±	W-2.99	N-2.90	WN-5.99	NW-5.80		
CD (P=0.05)	W-9.21	N-8.20	WN-12.71	NW- 6.40		
			Return per rupee investment			
W_1	3.76	2.86	3.13	3.21	2.30	3.05
W_2	3.36	3.04	2.82	2.45	2.18	2.77
W_3	3.89	3.22	3.17	3.26	2.48	3.20
W_4	2.69	1.98	2.20	2.33	1.61	2.16
Mean	3.43	2.77	2.83	2.81	2.14	
SEm±	W-0.04	N-0.034	WN-0.070	NW- .067		
CD (P=0.05)	W-0.11	N-0.10	WN-0.15	NW- .190		

SEm± - Standard error of mean, CD – Critical difference, W – Weed management, N - Nitrogen management, WN – Weed management in same or different level of nitrogen management, NW – Nitrogen management in same level of weed management

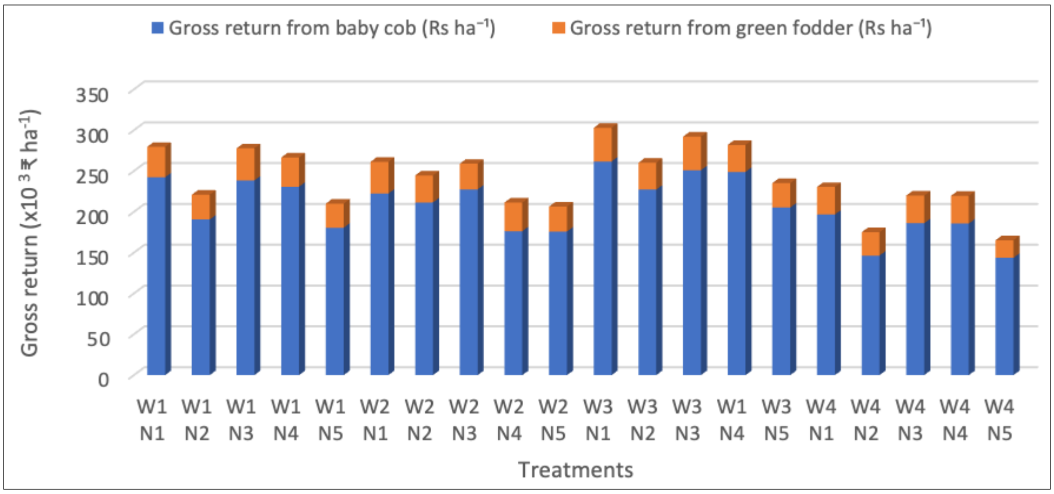

Fig. 4. Interactive effects of weed and nitrogen management on gross returns from baby cob and green fodder. W : Weed management, N : Nitrogen management.

Traits	*BCY*	*GFY*	*WD*	*WB*	*PH*	*LAI*	*SPAD-H*	*BCP*	*DCL*	*DCD*	*HCW*	*DCW*
BCY	1.000											
GFY	0.775	1.000										
WD	-0.866	-0.688	1.000									
WB	-0.728	-0.467	0.729	1.000								
PH	0.630	0.676	-0.532	-0.428	1.000							
LAI	0.767	0.852	-0.620	-0.232	0.664	1.000						
SPAD-H	0.891	0.734	-0.868	-0.781	0.605	0.672	1.000					
BCP	0.822	0.787	-0.752	-0.608	0.666	0.794	0.854	1.000				
DCL	0.877	0.835	-0.794	-0.646	0.798	0.842	0.847	0.917	1.000			
DCD	0.717	0.739	-0.736	-0.426	0.605	0.760	0.722	0.699	0.777	1.000		
HCW	0.796	0.630	-0.718	-0.812	0.618	0.563	0.740	0.736	0.880	0.599	1.000	
DCW	0.822	0.684	-0.795	-0.742	0.631	0.593	0.743	0.713	0.856	0.656	0.909	1.000

0 – 1 (+ve)

-1 – 0 (-ve)

N = 20

r 5 % at 18 d.f. = 0.444

r 1 % at 18 d.f. = 0.561

Fig. 5. Correlogram showing correlation among yield, growth parameters and yield attributes of rainfed baby corn. BCY - Baby cob (Dehusked) yield (t ha^{-1}), GFY - Green fodder yield (t ha^{-1}), WD - Weed density at 30 DAS (Numbers quadrate^{-1}), WB - Weed biomass at 30 DAS (g quadrate^{-1}), PH - Plant height at harvest (cm), LAI - LAI at harvest, SPAD - H - SPAD reading at harvest, CP - Baby cobs plant^{-1}, DCL - Dehusked cob length (cm), DCD - Dehusked cob diameter (cm), HCW - Husked cob weight (g), DCW - Dehusked cob weight (g), d.f.- degree of freedom.

baby cob yield and green fodder yield exhibited mutual positive correlation with each other, whereas, weed density and biomass exhibited significant negative correlation with all characters denoting growth, yield and yield attributes.

Discussion

Weedflora, density and biomass

Integrated weed management comprising atrazine @ 1.0 kg ha^{-1} on the pre-emergence spray followed by one manual weeding at 21 DAS excelled over other weed management practices (Table 1). Atrazine, a symmetrical triazine, is used as a pre-emergence and early post-emergence spray for selective control of both grassy and broad-leaf weeds. It inhibits photosynthetic electron transport in photosystem-II by interacting with a polypeptide in the chloroplast membrane, leading to the formation of singlet oxygen ($^1O_2$), a highly damaging form of oxygen that interacts with cellular lipids, proteins, nucleic acids and other molecules, induces cellular disorganization and causes plant death. Thus, atrazine provided early and broad-spectrum weed control. Further supplementation of manual weeding at 21 DAS could tackle leftover weeds and a new flush of weeds effectively. Both tank-mix post-emergence spray of tembotrione + 2,4-D (W_2) and hoeing and weeding at 21 DAS (W_4) were less efficient than atrazine @1.0 kg ha^{-1} on the pre-emergence spray followed by one manual weeding at 21 DAS (W_3) in the present experiment. Hoeing and weeding at 21 DAS (W_4), a traditional method of weed management by farmers, was not effective due to the dominance of a perennial grassy weed *Digitaria sanguinalis* L., which could not be managed by this method due to a lack of early weed control. The lower efficacy of the tank-mix post-emergence spray of tembotrione + 2,4-D was due to the failure of the treatment to provide early weed control and the temporary phytotoxicity of tembotrione to baby corn. Better weed control with atrazine 1.0 kg ha^{-1} + intercultivation at 30 days after sowing has earlier been reported (27). The efficacy of 100 % soil test-based nitrogen as chemical fertilizer ($C_{100\%STN}$) in reducing weed density and $C_{100\%STN}$, $C_{75\%STN}$ + $FYM_{25\%STN}$ and $C_{75\%STN}$ + $VC_{25\%STN}$ in reducing weed biomass was due to better crop growth and the smothering effect of crop canopy on weeds under these treatments. The treatments with a higher proportion of chemical N ensured a ready and adequate supply of N to baby corn, a quick-growing and high nitrogen-demanding crop.

Best practices for baby cob and green fodder productivity

The superiority of atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS over other weed management practices may be attributed to early and effective weed control by atrazine and tackling of escaped and new flush of weed by manual weeding, The lower degree of weed control by atrazine alone (W_1), tembotrione + 2,4-D (W_2) and hoeing and weeding (W_4) could be due to appearance of new flush of weed in case of the 1st, lack of early weed control in case of the 2nd and non-control of perennial grassy weeds in case of the 3rd. The maximum baby cob and green fodder yield with atrazine 1.0 kg ha^{-1} + intercultivation at 30 days after sowing has been reported earlier (28). The superiority of $C_{100\%STN}$ (N_1) and $C_{75\%STN}$ + $VC_{25\%STN}$ over other N management practices for dehusked baby cob and green fodder yield (Table 4) was due to ready availability of adequate N from chemical source in the first case and ready supply from chemical source and steady supply from vermicompost source in the second case to fulfill phase-wise N demand of baby corn, a fast growing and nitrogen demanding crop and 25 % of N need of the crop was fulfilled by vermicompost without loss in yield. Application of 100 % recommended nitrogen through chemical fertilizer produced higher baby cob and green fodder yield than all other combinations of chemical nitrogen and vermicompost (14). The maximum dehusked baby cob yield in summer and winter (1.72 and 2.13 t ha^{-1}, respectively) with full N from inorganic source (150 kg N ha^{-1}), being at par with 120 kg N from inorganic source + cow dung 5 t ha^{-1} has been reported earlier (29). Application of recommended dose of NPK (150:60:40 kg ha^{-1}) and vermicompost @ 5t ha^{-1} produced statistically similar baby cob and green fodder yield and proved superior to FYM @ 12.5 t ha^{-1} and farm compost @12.5 t ha^{-1}(20). Higher dehusked baby cob and green fodder yields were recorded under $C_{75\%STN}$ + $VC_{25\%STN}$ compared to $C_{75\%STN}$ + $FYM_{25\%STN}$, indicating the superiority of vermicompost over FYM. Vermicompost proved to be a better manure source than FYM in baby corn (30).

Economics - a decisive factor for the choice of weed and nitrogen management

The maximum gross return, net return and return per investment from the crop with atrazine 1.0 kg ha^{-1} + manual weeding at 21 DAS among weed management practices (₹ 274.55 × 10^3 ha^{-1}, ₹ 188.11 × 10^3 ha^{-1} and 3.20, respectively) and 100 % soil test-based nitrogen from chemical fertilizer among nitrogen management practices (₹ 268.63 × 10^3 ha^{-1}, ₹ 189.74 × 10^3 ha^{-1} and 3.43, respectively) indicated distinct economic advantages these two practices over the rest. The profitability of baby corn is correlated with baby cob and green fodder yield (31). The maximum net return and benefit cost ratio with atrazine 1.0 kg ha^{-1} + intercultivation at 30 days after sowing has been reported earlier (31). Though N_1 and N_3 were at par for dehusked baby cob and green fodder yield, N_1 was superior to N_3 for net return due to the high cost of the organic component (25 % N equivalent) in N_3. However, the combination of these two (W_3N_1) increased gross return, net return and return per investment to ₹ 302.99 × 10^3 ha^{-1}, ₹ 225.10 × 10^3 ha^{-1} and 3.89, respectively, indicated a high degree of synergy, early weed control, broad-spectrum and season-span weed control and adequate and ready availability of nitrogen.

Negative relationships between crop and weed growth

Significant negative correlation between weed density and biomass with baby corn growth parameters, yield attributes and yield established the importance of weed management in enhancing the productivity of baby corn under rainfed conditions. Weeds pose serious competition with the crop for nutrients, light, moisture and space and reduce crop growth. A better crop can be achieved by appropriate weed management (32).

Conclusion

Weed infestation and inadequate and improper nitrogen management pull down the productivity and profitability of rainfed baby corn. We experimented to explore synergy between weed and nitrogen management for developing a strategy to solve the problem. It is concluded that weed management by pre-emergence application of atrazine 1.0 kg ha^{-1} followed by manual weeding at 21 days after sowing along with application of 100 % soil -test based nitrogen (150 kg ha^{-1}) from chemical source (urea) and weed management by pre-emergence application of atrazine 1.0 kg ha^{-1} followed by manual weeding at 21 days after sowing along with 75 % soil - test based nitrogen (112.5 kg ha^{-1}) from urea + 25 % nitrogen as vermicompost can maximize productivity of dehusked baby cob and green fodder. The former was the best, considering both productivity and profitability, while the latter is recommended for sustainability in productivity and soil health. The research findings have several implications for the future in addressing challenges of climate change, the problem of soil degradation and instability in the ecosystem. These offer a practical and eco-friendly solution to common challenges to the production of baby corn under rainfed conditions. Easy, effective and economic weed management along with nitrogen supply through judicious combination of inorganic and organic sources can not only tackle the weed menace, but also ensure a steady and ready supply of nitrogen for the sustainable production of the crop. These practices can help farmers reduce unnecessary input costs and make better use of their land, resulting in the built-up of healthy soils over time. The present findings uncover some new scientific questions *viz.* impact of weed and nitrogen management practices on baby cob, silk and fodder quality, impact of legume/pulse crop inclusion on nitrogen enrichment of soil in baby corn based cropping system, affordability of organic sources of nitrogen, impact of treatments on energetics, carbon efficiency indices, climate change mitigation and adaptation for exploration by scientists in future.

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Authors' contributions

AM carried out the field experiment, recorded data and helped in manuscript preparation. BB conceptualized the experiment, monitored the experiment and reviewed the manuscript. AKP helped in the preparation of figures. SDB helped in statistical analysis, MP and AKB helped in manuscript finalization. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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