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Research Paper

Enhancing hybrid maize (*Zea mays*) productivity, profitability and energetics through tillage and weed-management practices in Eastern India

ANSHUMAN NAYAK[1], C.M. KHANDA[2], S. DAS[3], S.K. MOHANTY[4], B.B. SAHOO[5] AND B.S. NAYAK[6]

Regional Research and Technology Transfer Station, Odisha University of Agriculture and Technology, Bhawanipatna, Kalahandi, Odisha 766 001

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 at Regional Research and Technology Transfer Station, Bhawanipatna of the Odisha University of Agriculture and Technology, Odisha, to study the effect of tillage and weed-management practices (WMPs) on weed-control efficiency (WCE), yield attributes, yield, economics and energetics of hybrid maize (*Zea mays* L.). The results revealed the minimum weed dry-matter production (4.9 g/m^2) in conventional tillage (CT) followed by 5.5 g/m^2 dry-matter in minimum tillage (MT) and 5.9 g/m^2 in zero tillage (ZT) at 60 days after sowing (DAS). Among the WMPs, hand-weeding (HW) at 20 and 40 DAS and application of atrazine 1.0 kg a.i./ha followed by HW at 40 DAS resulted in significantly less weed dry weight with higher weed-control efficiency (WCE) at all the stages of growth. The CT recorded higher seed yield (4.78 t/ha), followed by MT and ZT. However, HW at 20 and 40 DAS resulted higher seed yield (5.76 t/ha) which was at par with application of atrazine 1.0 kg a.i./ha followed by (fb) HW at 40 DAS (5.07 t/ha). The seed yield in HW and atrazine-applied plots was 146 and 117% higher than the weedy check. Higher energy-use efficiency (EUE) and energy productivity with less specific energy and energy intensiveness were recorded in MT (7.40, 0.50 kg/MJ, 2.24 MJ/kg and 0.300 MJ/₹) indicating, efficient energy utilization by MT than ZT and CT. Among WMPs, application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS recorded EUE of 9.56, energy productivity of 0.65 kg/MJ, specific energy of 1.56 MJ/kg and energy intensiveness of 0.294 MJ/₹.

***Key words*:** Energetics, Hybrid maize, Productivity, Profitability, Tillage, Weed management

Maize (*Zea mays* L.) is the third important cereal crop after rice and wheat, popularly called as the queen of cereals, grown in diverse climatic conditions in India. Though rainy (*kharif*) season maize accounts for 83% of the total maize-growing areas in India, the productivity is very low (2,706 kg/ha) in comparison to the winter (*rabi*) maize productivity of 4,436 kg/ha (iimr.icar.gov.in/india-maize scenario/December, 2021). This low productivity of rainy season maize is due to the different biotic and abiotic stresses. Among the different biotic and abiotic factors responsible for yield reduction in rainy season maize, weeds play a significant role competing for water, nutrients, sunlight and space. In maize, heavy weed infestation results in yield loss to the tune of 60–83% (Ehsas *et al*., 2016). Timely control of weeds faces the problem of labour scarcity and too low or high soil moisture, which hinders the interculture operations (Choudhary *et al*., 2021). The land-preparation methods also affect the weed flora composition and density in the system. Conventional tillage requires more fuel energy than minimum and zero tillage (Kumar *et al*., 2021; Harish *et al*., 2022). Energy is used in every aspect of agricultural production system in terms of inputs, labour, machineries etc. Though energy input in modern agriculture system is very high, increased energy input may not bring maximum profit due to the ever-increasing cost of inputs. Judicious use of input can reduce the energy use and optimize the productivity and profitability (Singh *et al*., 2020). The present study was carried out to study the effect of different tillage and weed-management practices on weed biomass, weed-control efficiency, yield attributes, yield, economics and energetics of hybrid maize production during the rainy seasons.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 at Regional Research and

[2]**Corresponding author's Email:** cmkhandaouat@gmail.com
[1,3,4,5,6]Scientist, Regional Research and Technology Transfer Station, Odisha University of Agriculture and Technology, Bhawanipatna, Kalahandi, Odisha, 766001; [2]Associate Director of Research, Regional Research and Technology Transfer Station, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, 751 003

Technology Transfer Station of the Odisha University of Agriculture and Technology Bhawanipatna, Kalahandi, to evaluate the performance of different tillage and weed-management practices on hybrid maize. The soil was black cotton type, having medium soil organic carbon content (0.68%), low in available N (205 kg/ha), medium in available P (23 kg/ha) and high in available K (295 kg/ha). The experiment was laid out in split-plot design, taking 3 tillage methods, i.e. conventional tillage (CT), minimum tillage (MT) and zero-tillage (ZT) in main-plots, and 5 weed-management practices, i.e. 2 hand-weedings (HW)–20 and 40 days after sowing (DAS), pre-emergence application of atrazine 1.0 kg a.i./ha at 1–2 days after sowing (DAS), followed by (fb) 1 HW at 40 DAS, mulching with straw @ 6.0 t/ha at 15 DAS, intercropping of maize with cowpea [*Vigna unguiculata* (L.) Walp.] in 1:1 ratio + pre-emergence application of pendimethalin 1.0 kg a.i./ha at 1 to 2 DAS and weedy check. The hybrid maize 'DKC 9126' was sown on 30 July during both the years at a spacing of 60 cm × 30 cm with fertilizer dose of 120 : 60 : 60 kg N : P_2O_5 : K_2O/ha, where 25% N, 100% P_2O_5 and 50% K_2O were applied basal, 50% N at knee-high stage (22 days after sowing) and 25% N along with 50% K_2O at pre-tasselling stage. Seed was sown by tractor-drawn seed drill. The herbicides atrazine @ 1.0 kg a.i./ha and pendimethalin @ 1.0 kg a.i./ha was sprayed 1 day after sowing. Straw @ 6 t/ha was used for mulching 15 DAS. Observations on yield attributes were taken from 5 random plants before harvesting and averaged to obtain mean. The yield from the plots was recorded leaving the border rows which were converted into kg/ha. Cost of cultivation was calculated taking the prevailing market price of the inputs and gross return was calculated taking into account the seed yield and minimum support price of maize during 2017 (13.25/kg) and 2018 (17.0/kg). Paddy straw used for mulching was excluded from cost and energy calculation, whereas only the labour engaged for this purpose was included in these calculations. For recording weed dry-matter accumulation (DMA) all the species of different weeds were cut at ground level from 2 random spots in the quadrate of 50 cm × 50 cm time to time and then dried in hot-air oven at 60±2°C till the constant weight was obtained. Weed-control efficiency (WCE) was calculated as:

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

Energy input was calculated from sowing to harvesting pertaining to each treatment by multiplying the quantity of inputs with their respective energy equivalents (Table 1) as suggested by Singh and Mittal (1992) and expressed in Mega Joule (MJ)/ha. In the energy output, only maize grain was taken for calculation and biomass residues were excluded. Energy-use efficiency (EUE), specific energy, energy productivity and energy intensiveness were calculated using the following formula suggested by Mittal and Dhawan (1988) and Rajpoot *et al*. (2021).

Table 1. Standard values for calculation of energy relationship for different inputs and output

Input/output form	Unit	Energy coefficient (MJ)
Labour (adult man)	Hour	1.96
Diesel	Litre	56.31
Farm machineries including self-propelled machines	Hour	62.70
Chemical fertilizers		
N	Kg	60.60
P_2O_5	Kg	11.10
K_2O	Kg	6.70
Agrochemicals (Herbicides, insecticides etc.)	Kg	120.00
Maize seed	Kg	14.70
Cowpea seed	Kg	14.70

Source: Singh and Mittal (1992)

The data were subjected to statistical analysis as prescribed by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed dry matter and weed-control efficiency

The tillage methods had significant effect on dry-matter accumulation of weed at 60 and 90 DAS, whereas it had no significant influence at 30 DAS of weed. In general, there was progressive increase in dry weight of weeds with time and lesser weed dry matter was recorded in conventional tillage (CT), followed by minimum tillage (MT) and zero tillage (ZT) practice at all the stages. Upasani *et al.* (2017) also reported non-significant effect of tillage methods in maize - wheat system on dry-matter accumulation of weeds. The total dry-matter of weeds in maize crop was higher in ZT plots than MT and CT practices (Kumar and Angadi, 2014). Weed-management practices significantly influenced the weed dry weight at 30, 60 and 90 DAS (Table 2). Pre-emergence application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS and (maize + cowpea) intercropping along with pre-emergence application of pendimethalin 1.0 kg a.i./ha recorded lesser weed dry-matter, followed by the treatment hand-weeding (HW) at 20 and 40 DAS, straw mulching and the maximum in weedy check at 30 DAS. However, dry-matter accumulation of weed at 60 and 90 DAS was found to be less in HW at 20 and 40 DAS which was at par with application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS and (maize + cowpea) intercropping along with pre-emergence application of pendimethalin 1.0 kg a.i./ha and significantly differed from straw mulching @ 6 t/ha and weedy check (Table 2). The WCE was found to be non-significant at 30, 60 and 90 DAS due to tillage methods. However, WCE significantly differed by WMPs at 30, 60 and 90 DAS. At 30 DAS, application of atrazine 1.0 kg a.i./ha followed by HW at 40 DAS recorded higher WCE, followed by (maize + cowpea) intercropping along with pre-emergence application of pendimethalin 1.0 kg a.i./ha and HW at 20 and 40 DAS which were at par with each other and significantly different from straw mulching @ 6.0 t/ha (Table 2). At 60 DAS, HW at 20 and 40 DAS showed higher WCE, being at par with (maize + cowpea) intercropping along with pre-emergence application of pendimethalin 1.0 kg a.i./ha and application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS and differed significantly from straw mulching @ 6.0 t/ha. The WCE was higher in HW at 20 and 40 DAS being statistically at par with application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS and significantly different from (maize + cowpea) intercropping along with pre-emergence application of pendimethalin 1.0 kg a.i./ha and straw mulching @ 6.0 t/ha at 90 DAS (Table 2). Better WCE was achieved owing to better weed control by pre-emergence herbicides and hand-weeding, resulting in reduced weed biomass production during the first 60 DAS. Madhavi *et al.* (2013) also reported similar findings.

Yield attributes and yield

The number of rows/cob, 100-seed weight and straw yield were significantly influenced by different tillage practices, whereas number of seeds/row and seed yield of maize remained non-significant. The number of rows/cob, number of seeds/rows, 100-seed wight, seed yield and stover yield were higher in conventional tillage, followed by minimum tillage and zero tillage (Table 3). The seed yield in conventional and minimum tillage was 27.3 and 14.6 % higher than ZT, respectively. This was owing to efficient utilization of available soil moisture, nutrients and solar energy at all the stages of crop growth and lower weed infestation as also reported by Choudhary *et al*., (2021). These results are in close conformity with the findings of Kumar and Angadi (2014). The different WMPs significantly affected the yield attributes and yield. The HW at 20 and 40 DAS resulted higher number of rows/cob, number of seeds/row, 100-seed wight, seed yield and stover yield, followed by application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS, maize + cowpea intercropping + pendimethalin 1.0 kg a.i./ha, straw mulching @ 6.0 t/ha and weedy check. The seed yield in HW at 20 and 40 DAS and application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS which were at par with each other, was found to be 146 and 117% more than weedy check and significantly differed from the other treatments. The better yield and yield attributes were mainly because of minimum crop-weed competition during the critical period of crop growth, which enabled the crop for maximum utilization of nutrients, moisture, light and space which in turn influenced the yield and yield components (Rajpoot *et al*., 2021; Choudhary *et al.,* 2021). Singh *et al*. (2007) also reported higher values of growth parameters of maize with pre-emergence application of atrazine (1.0 kg/ha) and manual weeding at 30 DAS.

Economics and energetics

Tillage methods significantly influenced the cost of pro-

Table 2. Effect of tillage and weed-management practices on weed dry-matter and weed-control efficiency in hybrid maize (pooled over 2 years)

Treatment	Dry weight of weeds (g/m^2)			WCE (%)		
	at 30 DAS	at 60 DAS	at 90 DAS	at 30 DAS	at 60 DAS	at 90 DAS
Tillage methods						
Conventional tillage	2.5(8.0)	3.9(21.5)	4.9(29.0)	53.3	54.4	45.4
Minimum tillage	2.8(11.1)	4.7(28.7)	5.5(37.1)	58.4	53.9	48.5
Zero tillage	3.2(14.9)	4.8(35.5)	5.9(44.3)	57.3	59.7	49.6
SEm±	0.1	0.1	0.2	1.4	1.9	2.4
CD (P=0.05)	NS	0.3	0.7	NS	NS	NS
Weed-management practices						
HW at 20 and 40 DAS	1.7(2.7)	2.3(5.1)	3.4(11.8)	72.8	76.8	67.1
Atrazine 1.0 kg a.i./ha fb HW at 40 DAS	1.5(2.0)	2.7(6.6)	3.6(13.2)	76.7	72.7	65.0
Straw mulching @ 6.0t/ha	2.8(7.5)	4.3(18.7)	5.4(29.3)	56.6	57.0	48.1
Maize + cowpea intercropping + Pendimethalin 1.0 kg a.i./ha	1.5(1.6)	2.6(4.4)	4.2(16.7)	75.5	73.6	59.0
Weedy check	7.0(42.9)	10.3(108)	10.6(113)	-	-	-
SEm±	0.1	0.2	0.2	1.7	1.4	1.5
CD (P=0.05)	0.3	0.5	0.5	5.0	4.1	4.3

Figures were subjected to square-root transformation $\sqrt{(x+0.5)}$; original values are in parentheses
WCE, Weed-control efficiency; DAS, days after sowing; fb, followed by; HW, hand-weeding

Table 3. Influence of tillage and weed-management practices on yield attributes and yield of hybrid maize (pooled over 2 years)

Treatment	Rows/cob	Seeds/row	100-seed weight (g)	Seed yield (t/ha)	Straw yield (t/ha)
Tillage methods					
Conventional tillage	13.2	28.8	29.7	4.78	8.81
Minimum tillage	12.8	26.9	28.9	4.30	8.62
Zero tillage	12.2	25.3	27.7	3.75	6.64
SEm±	0.2	1.2	0.4	0.19	0.21
CD (P=0.05)	0.7	NS	1.3	NS	0.63
Weed-management practices					
HW at 20 and 40 DAS	14.6	29.4	31.4	5.76	9.54
Atrazine 1.0 kg a.i./ha fb. HW at 40 DAS	13.8	28.8	29.6	5.08	9.08
Straw mulching @ 6.0 t/ha	11.8	26.5	28.3	3.93	8.33
Maize + cowpea intercropping + Pendimethalin 1.0 kg a.i./ha	13.2	28.0	28.7	4.30	7.70
Weedy check	10	22	26	2.34	3.92
SEm±	0.2	0.8	0.6	0.27	0.57
CD (P=0.05)	0.6	2.4	1.6	0.77	1.70

DAS, days after sowing; fb, followed by; HW, hand-weeding

duction and gross returns of maize. Higher cost of production (₹ 30,273/ha), gross (₹ 70,587/ha) and net returns (₹ 40,314/ha) were found in CT practice due to the cost involved in repeated tillage than MT and ZT practice. However, higher returns/rupee invested were achieved in ZT (2.33), followed by CT (2.30) and MT (2.27). The WMPs significantly affected the cost of production, gross returns, net returns and returns/rupee invested. Higher cost of cultivation (₹ 32,422/ha) and gross returns (₹ 88,090/ha) were found in HW at 20 and 40 DAS, followed by atrazine 1.0 kg/ha fb HW at 40 DAS, maize + cowpea intercropping + pendimethalin 1.0 kg a.i./ha, straw mulching @ 6 t/ha and weedy check. However, net returns and returns/rupee invested were the maximum owing to application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS (₹ 56,498/ha and 2.87), followed by HW at 20 and 40 DAS (₹ 55,668/ha, 2.72) which were at par with each other and differed significantly from other treatments (Table 4). Kamble *et al.* (2005) reported the maximum returns with application of pre-emergence herbicide atrazine fb hoeing and 1 HW at 20 DAS. Swetha *et al.* (2015) also recorded higher benefit : cost (B : C) ratio with application of atrazine 1.0 kg/ha fb inter-cultivation at 30 DAS (3.11) than HW at 20 and 40 DAS (2.72) and intercropping of maize with cowpea + pre-

Table 4. Effect of tillage methods and weed management practices on economics and energetics of hybrid maize production (pooled over two years)

Treatment	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Returns/ rupee invested	Energy input (MJ/ha)	Energy output (MJ/ha)	Energy-use efficiency	Energy productivity (kg/MJ)	Specific energy (MJ/kg)	Energy intensiveness (MJ/₹)
Tillage methods										
Conventional tillage	30,273	70,587	40,314	2.30	9,750	69,426	7.17	0.49	2.30	0.320
Minimum tillage	28,927	66,741	37,814	2.27	8,743	64,116	7.40	0.50	2.24	0.300
Zero tillage	26,189	62,350	36,161	2.33	8,349	61,200	7.41	0.50	2.35	0.317
SEm±	129	1,972	1,972	0.08	–	2,464	0.30	0.02	0.11	–
CD (P=0.05)	506	6,421	NS	NS	–	NS	NS	NS	NS	–
Weed-management practices										
HW at 20 and 40 DAS	32,422	88,090	55,668	2.72	9,114	86,324	9.60	0.65	1.55	0.278
Atrazine 1.0 kg a.i./ha fb. HW at 40DAS	30,486	86,984	56,498	2.87	9,056	85,258	9.56	0.65	1.56	0.294
Straw mulching @ 6.0t/ha	26293	56,212	29,919	2.13	8,657	55,263	6.52	0.44	2.40	0.322
(Maize + cowpea) intercropping + Pendimethalin 1.0 kg a.i./ha	28,354	66,662	38,308	2.35	9,290	63,601	6.96	0.47	2.21	0.323
Weedy check	24,761	34,849	10,088	1.41	8,602	34,123	4.01	0.27	3.77	0.344
SEm±	167	2,224	2,224	0.08	–	2,214	0.26	0.02	0.11	–
CD (P=0.05)	487	6,324	6,324	0.24	–	6,295	0.75	0.05	0.30	–

HW, hand-weeding; fb, followed by

emergence application of pendimethalin 1.0 kg/ha (2.55) and weedy check (1.6).

Among the tillage methods, the energy input for hybrid maize production was less in ZT (8349 MJ/ha) which was succeeded by MT and CT (Table 4). The higher energy input in MT and CT was due to more use of diesel and tractor for ploughing as compared to CT. Among WMPs, weedy check consumed lesser energy (8,602 MJ/ha) as diesel and tractor were not used for ploughing succeeded by straw mulching @ 6.0 t/ha, application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS, HW at 20 and 40 DAS and maximum energy was used in maize + cowpea intercropping + pendimethalin 1.0 kg a.i./ha (Table 4). Sharma and Thakur (1989) also reported higher energy input due to seedbed preparation, sowing and weed-control practice for cultivation. The energy output followed the same trend as that of maize seed yield. Higher energy output was in CT (69,426 MJ/ha), followed by MT (64,116 MJ/ha). The WMPs had significant effect on energy output where HW at 20 and 40 DAS registered higher energy (86,324 MJ/ha) being at par with application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS (85,258 MJ/ha) and lesser energy output in weedy check (34,123 MJ/ha). The energy-use efficiency (EUE) which is the ratio of energy output to energy input was maximum in zero tillage (7.41), followed by MT and CT and were at par with each other. Among the different WMPs, HW at 20 and 40 DAS showed maximum EUE (9.60), being at par with application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS (9.56) and significantly different from all other WMPs with lesser EUE in weedy check (4.01). Energy productivity showed the quantity of seed produced per unit energy used. Among the tillage methods, ZT and MT exhibited more energy productivity (0.50 kg/MJ) than CT (0.49 kg/MJ). The HW at 20 and 40 DAS and application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS recorded higher energy productivity of 0.65 kg/MJ each and significantly differed from maize + cowpea intercropping + pendimethalin 1.0 kg a.i./ha (0.47 kg/MJ), straw mulching @ 6.0 t/ha (0.44 kg/MJ) and weedy check (0.27 kg/MJ). Specific energy is the energy used for production of one unit seed. Specific energy remained non-significant due to the tillage practices where lesser energy was used in MT (2.24 MJ/kg), followed by CT and ZT to produce 1 kg of seed. Among the WMPs, specific energy was less in HW at 20 and 40 DAS (1.55 MJ/kg) which was at par with application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS (1.56 MJ/kg) and significantly different from other practices being maximum in weedy check (3.77 MJ/kg). Energy intensiveness was less in MT (0.300 MJ/₹) and succeeded by ZT (0.317 MJ/₹) and CT (0.320 MJ/₹), which showed CT is investment intensive as compared to ZT and MT. Hand-weeding at 20 and 40 DAS recorded lesser energy intensiveness (0.278 MJ/₹) succeeded by application of atrazine 1.0 kg a.i./ha fb HW at 40 DAS (0.294 MJ/₹), straw mulching @ 6.0 t/ha (0.322 MJ/₹), maize + cowpea intercropping + pendimethalin 1.0 kg a.i./ha (0.323 MJ/₹) and maximum in weedy check (0.344 MJ/₹).

From the above study, it was concluded that sowing hybrid maize by minimum tillage and weed control by pre-emergence application of atrazine at 1 day after sowing, followed by 1 hand-weeding at 40 DAS could fetch better yield and higher returns with optimum energy utilization in rainfed uplands of Eastern India.

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