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Effect of Weed Management Practices on Growth, Yield, and Profitability of Hybrid Maize at Dang, Nepal

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ABSTRACT

Weeds pose a major challenge in maize cultivation, resulting in financial losses for farmers and becoming a major burden. To achieve financial sustainability for hybrid maize growers, understanding the effect of weeds on growth, yield, and profitability is important. We examined the effect of various weed management practices on the growth, yield, weed dynamics, and profitability of hybrid maize in Dang, Nepal. Organized in a Randomized Complete Block Design (RCBD) with four replications, our experiment included five treatments: atrazine at the rate of 1 kg a.i. ha^{-1}, two-hand weeding at the rate of 20 and 40 DAS, black on silver plastic mulching, power weeder at the rate of 20 and 40 DAS, and a weedy check. The results revealed that treatment black-on-silver plastic mulching led to the highest grain yield (9.91 t ha^{-1}), significantly outperforming the atrazine treatment, two-hand weeding, power weeder, and weedy check treatments. We found 15 different weed species across six plant families, with broadleaf and grassy weeds predominating over sedge weeds during the initial stages of crop growth. Total weed density and dry weight were lowest with the black-on-silver plastic mulching compared to other treatments. Additionally, black-on-silver plastic mulching resulted in superior weed control efficiency, achieving rates of 96.31%, 95.86%, and 96.20% at 30, 45, and 90 days after sowing (DAS), respectively. Atrazine application proved to be the most profitable, resulting in the highest net return and benefit-cost ratio. The results showed that while black-on-silver plastic mulching significantly enhances the grain yield of hybrid maize by effectively suppressing weed growth, atrazine application emerges as the most economically viable weed management practice.

Keywords: Atrazine efficiency, Benefit-cost ratio, Hybrid maize yield, Mulching

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INTRODUCTION

Maize (*Zea mays)* is one of the major cereal crops of Nepal, playing an important role in addressing food security and sustaining the livelihoods of a substantial portion of the population. Maize had the largest population, nearly 1.2 billion tons, and the fastest growth since 2000, with a 97 percent increase compared to other major cereals (FAO 2022). Hill farmers in Nepal have embraced maize as a fundamental aspect of their lifestyle, as it serves as a source of sustenance, animal feed, and fodder (Sapkota and Pokhrel 2013). In the mid-hills and high hills, more than two-thirds of maize production is consumed directly by humans on the farms, while in the terai, less than half of maize is consumed by humans, with a significant portion being sold in the market (Paudyal et al 2001). In 2021/2022, maize was cultivated in an area of 985,565 ha with a total production of 3,106,397 Mt in Nepal (FAO, 2022). The maize demand has been constantly growing in the country by about 5% annually over the last decade (Sapkota and Pokhrel 2013). As the feed demand is also increasing at 11% per annum, the demand for maize is shifting from food to feed for livestock and poultry (KC et al 2015).

Although the production and productivity of maize in Nepal have been gradually increasing, the national productivity is lower than both attainable and global average productivity (FAO 2022, MOALD 2023). Its yield is hindered by multiple factors, including weed infestation, soil fertility issues, inadequate nutrient management practices, and a lack of advanced technologies. Among several constraints to maize production, weed infestation emerges as the primary constraint in maize production (Shrestha et al 2019). Weeds have a great potential to cause up to 60% yield loss in crops, depending on the environment (Yaduraju and Adusumilli 2013). In addition, among various production limitations in maize, weed infestation is identified as a primary concern, as grain yield losses range from 35 to 83% (Usman et al 2001). Similarly, weed infestation reduces the yield of spring maize by 37.17% (Shrivastav et al 2015). Weed infestation has a detrimental impact on the quality of the crop, as it competes with the main crop plant for essential resources such as light, water, and nutrients, further reducing crop yield. Weeds release harmful chemicals that negatively affect the associated crop, causing a significant economic challenge in maize cultivation (Sharma and Rayamajhi 2022). Crop-weed competition for water reduces water availability and leads to crop water stress (Zimdahl 2018). In terms of nutrient competition, the nutrient uptake by the weeds was at least 5 times higher than that of maize after one month of sowing maize (Lehoczky and Reisinger 2003). Due to these weed crop competitions, we must follow weed management practices for maize yield improvement.

To minimize yield loss caused by weed competition, it is crucial to implement scientific and prudent weed management practices starting from the early stages of crop growth. Manual weeding is the most dominant weed management practice in Nepal; however, many farmers still do not follow any specific weed control method. Given the array of weed control methods available, each one is more suitable for use in specific crops, at times, and in specific locations. In the terai condition of Nepal, the use of black polythene mulch and silver-black mulch was found to be more efficient in reducing overall weed density and dry weight throughout the crop season, with the highest yield on silver-black mulch (Timsina et al 2019). Similarly, the highest grain yield of maize and the lowest weed density and weed dry weight were found on black plastic mulching (Gurung et al 2019). Numerous research studies on weed management practices in maize have been conducted; however, there is room for research comparing the growth, yield, and profitability of power tiller, black on silver plastic mulching, to that of atrazine application and hand weeding. Thus, this study was carried out to evaluate the effect of different weed management practices on the growth, yield, and profitability of hybrid maize production.

MATERIALS AND METHODS

The experiment was carried out in Narayanpur, Lamahi Municipality-3, Dang, Nepal, as in Figure 1, during the spring season (Feb-July) of 2021. The experimental site's geographical location was 27°52'37.73''N (latitude) and 82°34'21.65''E (longitude). The soil pH of the experimental plot was neutral (6.6) with a sandy loam texture. The nitrogen and potassium levels were medium, and the level of phosphorus was low. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 5 treatments and 4 replications. The details of the treatments are shown in Table 1, and the layout of the field is shown in Figure 2.

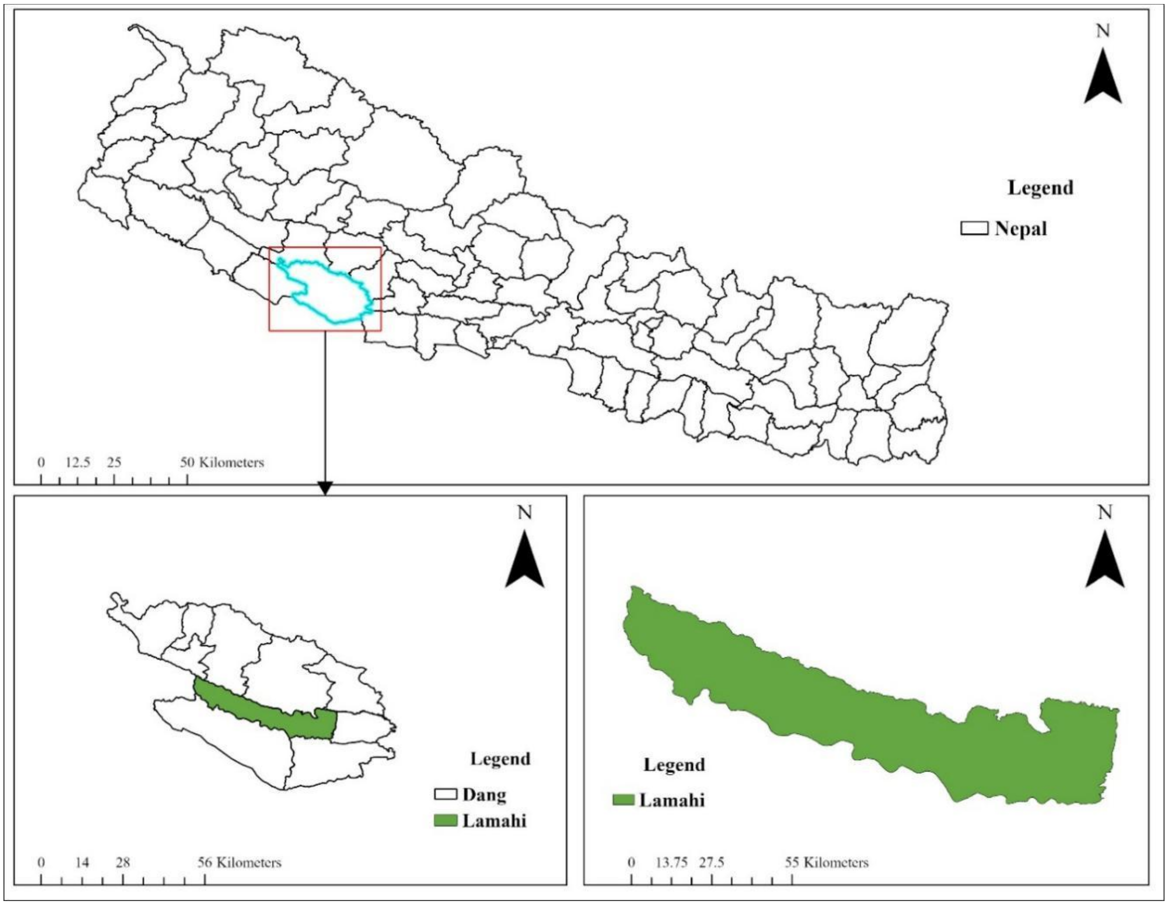

Figure 1. Research site at Lamahi municipality in Dang district of Nepal

Atrazine was applied 2 days after sowing (DAS). Black-on-silver plastic mulching was kept after the completion of field preparation, and the weedy check plot was left without weeding throughout the growing period. The individual plot size was made 4.8m x 3m (14.4m^2) with 8 rows per plot and 15 plants per row. Seeds of Rampur hybrid-10 variety of maize were sown using Jap planter, keeping rows 60cm apart and plant to plant 20cm apart on 4th March 2021.

Table 1. Details of treatment used for the field experiment, 2021

Treatment Number	Treatment details
T1	Atrazine 50wp as pre-emergence (PE) @1.0 kg a.i ha^{-1}
T2	2 Hand weeding @ 20 and 40 DAS
T3	Black-on-silver plastic mulching
T4	Power weeder @ 20 and 40 DAS
T5	Weedy check

The recommended dose of fertilizer N: P_2O_5: K_2O @ 180:60:40 kg/ha was applied in each plot in the form of urea, DAP, and Muriate of Potash (MOP). Phosphorus and potassium were fully applied as a basal dose, and nitrogen was applied equally in three splits during the sowing, knee-high, and tasseling stages. Thinning was conducted at 20 DAS to keep a single plant per hill by removing weaker and extra plants. Earthing was done at 60 DAS, and the crop was irrigated twice at the early knee-high stage and tasseling stage through a surface irrigation system.

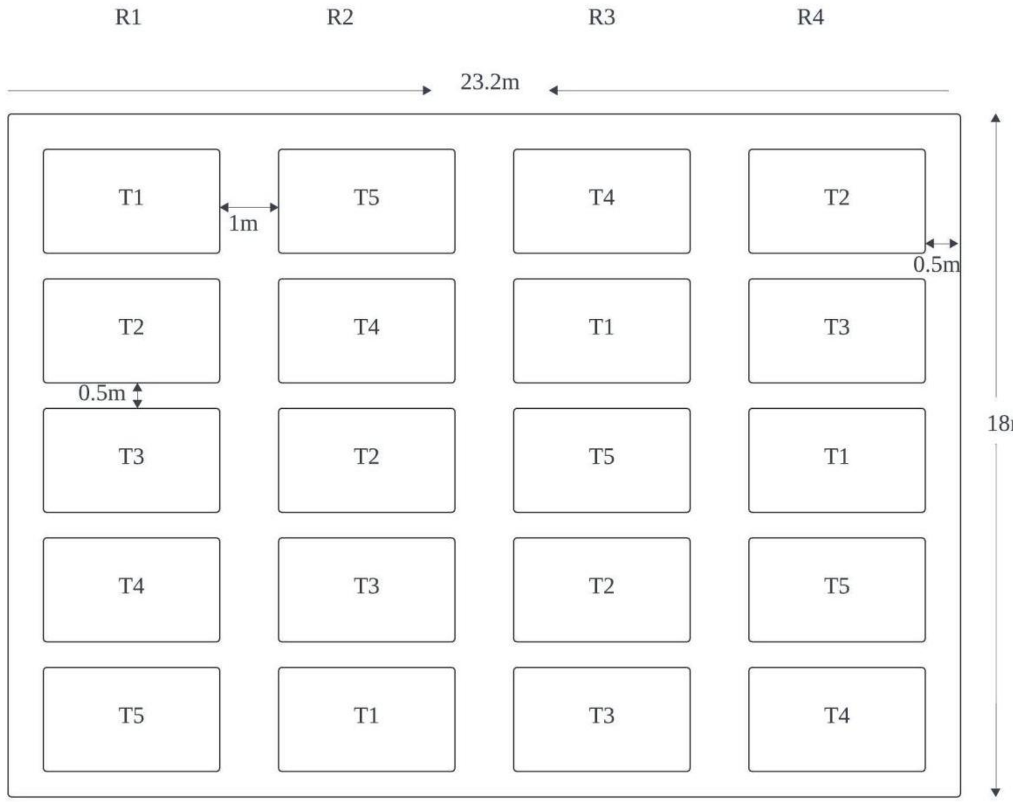

Figure 2. Field layout and randomization of the treatment at Lamahi, Dang, Nepal, 2021

Weed sampling was conducted using a 60cm x 60cm wooden quadrate at 30, 45, and 90 DAS to identify weeds and assess weed density and dry weight. Weed Control Efficiency (WCE) and Weed Control Index (WCI) were calculated according to the formulas established by Mani et al. (1973) and Mishra and Tosh (1979), respectively. All agronomic and economic data were collected and calculated using standard techniques to ensure accuracy. We transformed the weed data using a square root transformation to make the data normal before analysis. ANOVA was computed for statistical evaluation, and significant differences were analyzed using DMRT for mean comparison following the methods outlined by Gomez and Gomez (1984).

RESULTS

Weed flora

In the experimental field, a total of fifteen different weed species belonging to 6 different families were identified (Table 2). *Cynodon dactylon, Cyperus rotundus, Amaranthus viridis, Chenopodium album, Parthenium hysterophorous, Bidens pilosa, and Digitaria ciliaris* were the major weed species identified in the research field.

Table 2. Weed species identified in the experimental field at Lamahi in 2021

S.N.	Common name	Scientific name	Weed Category	Family
1.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	GW	Poaceae
2.	Barnyard grass	*Echinochola cruss-galli* (L.) P. Beauv.	GW	Poaceae
3.	Cogon grass	*Imperata cylindrica* (L.) P. Beauv.	GW	Poaceae
4.	Smooth Crabgrass	*Digitaria ciliaris* (Retz.) Kohler	GW	Poaceae
5.	Purple nut sedge	*Cyperus rotundus* (L.)	SW	Cyperaceae
6.	Rice flat sedge	*Cyperus iria* (L.)	SW	Cyperaceae
7.	Grass-like fimbria	*Fimbristylis miliaceae* (Vahl)	SW	Cyperaceae
8.	Lamb's quarters	*Chenopodium album* (L.)	BLW	Amaranthaceae
9.	Pigweed	*Amaranthus viridis* (L.)	BLW	Amaranthaceae
10.	Goat weed	*Ageratum conyzoides* (L.)	BLW	Asteraceae

S.N.	Common name	Scientific name	Weed Category	Family
11.	Beggar ticks	*Bidens pilosa* (L.)	BLW	Asteraceae
12.	Common Groundsel	*Senecio vulgaris* (L.)	BLW	Asteraceae
13.	Black nightshade	*Solanum nigrum* (L.)	BLW	Solanaceae
14.	Common chickweed	*Stellaria media* (L.) Vill.	BLW	Caryophyllaceae
15.	Carrot weed	*Parthenium hysterophorus*(L.)	BLW	Asteraceae

Plant height

The maximum plant height was recorded in black-on-silver plastic mulching at 30DAS and showed a significant difference compared to the rest of the treatment, but at par with atrazine (Table 3). At 60 DAS, maximum plant height was recorded in black on silver plastic mulching and showed a significant difference compared to the rest of the treatments. At 90 DAS, the maximum plant height (246.05 cm) was obtained in black on silver plastic mulching and showed a significant difference from atrazine, 2-hand weeding, power weeder, and weedy check. The maximum crop height could be due to excellent weed control, high water use efficiency, and early and vigorous growth of plants. The minimum plant height was recorded in the weedy check plot. The average crop height had increased from 34.82 cm at 30 DAS to 134.15 cm at 45 DAS and to 223.27 cm at 90 DAS.

Table 3. Plant height(cm) and leaf area index of maize as influenced by weed management practices at Lamahi in 2021

Weed Management Practices	Plant height (cm)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Black-on Silver Plastic Mulching	39.32^{a}	157.33^{a}	246.05^{a}	0.47^{a}	4.13^{a}	4.31^{a}
Atrazine (1kg a.i. ha^{-1})	37.34^{ab}	141.50^{b}	230.65^{b}	0.35^{b}	3.58^{b}	3.90^{ab}
2 Hand Weeding	33.84^{b}	130.65^{bc}	222.80^{bc}	0.32^{b}	3.10^{c}	3.61^{b}
Power Weeder	31.95^{b}	126.90^{c}	218.80^{c}	0.30^{b}	2.82^{c}	3.48^{b}
Weedy Check	31.64^{b}	114.35^{d}	198.05^{d}	0.19^{c}	2.25^{d}	2.64^{c}
F-test	*	***	***	***	***	***
LSD (0.05)	5.74	11.59	9.08	0.09	0.42	0.45
Sem (±)	1.86	3.76	2.95	0.03	0.14	0.14
CV%	10.70	5.60	2.64	18.40	8.60	9.74
Grand Mean	34.82	134.15	223.27	0.33	3.18	3.59

Note: DAS = Days after sowing, Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level.

Leaf area index

Weed management practices significantly influenced LAI throughout all dates of observation in the experiment (Table 3). The maximum LAI was recorded in black on silver plastic mulching at 30 DAS (0.47) and 60 DAS (4.13) and showed a significant difference from the rest of the treatments. Similarly, maximum LAI was recorded in black on silver plastic mulching at 90 DAS and showed a significant difference from the rest of the treatments, but at par with atrazine. At all the dates of observation, the minimum LAI was recorded in the weedy check.

Weed density

The results indicated significant maximum weed density in the weedy check plot, while the minimum weed density was observed in plots having black-on-silver plastic mulching (Table 4). The average grass and broad-leaf weed density was higher than that of sedge weeds. Total weed density was significantly affected by weed management practices, with lower values under black-on-silver plastic mulching and higher values under the weedy check at all observations. The total weed density recorded in black-on-silver plastic mulching (10.43/m^2) was significantly lower than all other plots at 30 DAS. The sedge weed density at 90 DAS was found to be non-significant.

Weed dry weight

Significantly higher and lower grass weed dry weights were observed in the weedy check and black on silver plastic mulching, respectively (Table 5). The average dry weight of grass weeds was greater than that of broad leaf and sedge weeds at 30 DAS. However, at 45 DAS and 90 DAS, the average dry weight of broad-leaf weeds exceeded that of grass and sedge weeds. Total weed dry weight was significantly affected by weed management practices and recorded a minimum in black on silver plastic mulching and a maximum in weedy check at all dates of observation. After black-on-silver plastic mulching, the total dry weight was recorded as a minimum under the application of atrazine 1kg a.i./ha at all dates of observation.

Weed control efficiency

Data (Table 6) indicated that at 30 DAS, the highest WCE (96.31%) was observed in black on silver plastic mulching, which was at par with atrazine, while the lowest WCE was observed in the power weeder. At 45 DAS and 90 DAS, maximum WCE was recorded in black on silver plastic mulching and showed a significant difference with the rest of the treatments, and minimum WCE was recorded in power weeder.

Weed control index

The weed management practices significantly influenced the weed control index (Table 6). The maximum and minimum WCIs were recorded in black on silver plastic mulching and power weeder at all dates of observation. At 30 DAS, the maximum WCI was recorded in black on silver plastic mulching (97.68%), and at par with atrazine (87.63%), and the minimum was recorded in power weeder (56.33%). At 90 DAS, the maximum WCI was recorded in black-on-silver plastic mulching and showed a significant difference with the rest of the treatment and the minimum WCI was recorded in the power weeder. The average WCI of the experiment was increased from 30 to 45 DAS and then decreased to 90 DAS.

Table 4. Weed density as influenced by weed management practices in hybrid maize at Lamahi in 2021

Weed Management Practices	Weed density (no./m^2)											
	30 DAS				45 DAS				90 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Black-on Silver Plastic Mulching	3.17^{d} (9.73)	0.70^{c} (0.00)	0.975^{d} (0.70)	3.25^{e} (10.43)	3.08^{d} (9.00)	1.99^{cd} (4.17)	0.98^{d} (0.70)	3.74^{e} (13.89)	3.47^{c} (11.80)	2.13 (4.20)	1.42^{d} (2.10)	4.23^{d} (18.06)
Atrazine (1kg a.i. ha^{-1})	5.78^{c} (33.33)	0.70^{c} (0.00)	3.05^{c} (9.05)	6.50^{d} (42.38)	5.79^{c} (33.35)	2.95^{bc} (8.33)	3.84^{c} (14.58)	7.51^{d} (56.25)	8.27^{b} (68.75)	3.15 (9.70)	7.74^{c} (61.13)	11.75^{c} (139.58)
2 Hand Weeding	9.43^{b} (88.88)	1.43^{bc} (2.10)	5.15^{b} (27.77)	10.85^{c} (118.80)	5.35^{c} (28.47)	1.27^{d} (1.40)	8.12^{b} (65.98)	9.76^{c} (95.83)	9.85^{b} (98.60)	2.52 (7.65)	10.40^{b} (108.30)	14.60^{b} (214.58)
Power Weeder	10.28^{b} (107.65)	1.88^{b} (3.50)	7.43^{a} (57.65)	12.88^{b} (168.75)	7.65^{b} (58.32)	3.06^{b} (9.03)	8.85^{b} (81.95)	12.00^{b} (145.83)	10.35^{b} (111.80)	3.69 (13.90)	9.76^{b} (95.18)	14.8^{b} (220.80)
Weedy check	15.10^{a} (228.48)	3.95^{a} (15.30)	7.53^{a} (54.88)	17.25^{a} (298.60)	9.60^{a} (92.37)	4.10^{a} (16.65)	14.95^{a} (223.17)	18.49^{a} (341.67)	13.57^{a} (184.02)	3.30 (10.40)	16.69^{a} (278.48)	21.76^{a} (473.15)
F-test	***	***	***	***	***	***	***	***	***	ns	***	***
LSD (0.05)	1.57	0.94	1.47	1.90	0.72	0.97	1.78	1.33	2.43	1.48	1.24	2.10
Sem (±)	0.51	0.30	0.47	0.63	0.23	0.32	0.57	0.43	0.79	0.48	0.40	0.68
CV%	11.70	35.40	19.77	12.33	7.40	23.56	15.67	8.37	17.32	32.40	8.74	10.18
Grand Mean	8.75	1.73	4.82	10.15	6.30	2.68	7.35	10.30	9.10	2.96	9.20	13.43

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level. GW=grass weeds, SW= Sedge weeds, BLW= Broad leaf weeds; Data are subjected to square root transformation ($\sqrt{(x+0.5)}$), and data in parentheses are original values.

Table 5. Weed dry weight as influenced by weed management practices in hybrid maize at Lamahi in 2021

Weed Management Practices	Weed dry weight (g/m²)											
	30 DAS				45 DAS				90 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Black-on Silver Plastic Mulching	0.98^{d} (0.45)	0.71^{c} (0.00)	0.74^{d} (0.05)	1.00^{e} (0.50)	1.45^{c} (1.65)	0.98^{bc} (0.53)	0.74^{d} (0.05)	1.64^{e} (2.23)	2.32^{c} (4.97)	1.43 (1.65)	1.38^{d} (1.88)	2.90^{d} (8.50)
Atrazine (1kg a.i. ha^{-1})	1.59^{c} (2.09)	0.71^{c} (0.00)	1.01^{c} (0.54)	1.75^{d} (2.64)	2.62^{b} (6.44)	1.43^{ab} (1.57)	2.01^{c} (3.60)	3.47^{d} (11.62)	7.00^{b} (48.57)	2.47 (5.80)	6.50^{c} (41.63)	9.80^{c} (96.00)
2 Hand Weeding	2.39^{b} (5.23)	0.78^{bc} (0.10)	1.30^{b} (1.23)	2.65^{c} (6.56)	2.55^{b} (6.03)	0.83^{c} (0.20)	3.53^{b} (12.00)	4.30^{c} (18.23)	7.20^{b} (52.65)	1.84 (3.59)	8.30^{b} (69.34)	11.20^{b} (125.60)
Power Weeder	2.77^{b} (7.38)	0.82^{b} (0.17)	1.60^{a} (2.12)	3.16^{b} (9.68)	3.15^{b} (9.80)	1.21^{bc} (0.98)	3.68^{b} (13.28)	4.90^{b} (24.07)	7.98^{ab} (64.62)	2.42 (5.90)	7.73^{b} (59.48)	11.40^{b} (130.00)
Weedy check	4.37^{a} (18.63)	0.96^{a} (0.43)	1.85^{a} (2.97)	4.74^{a} (22.02)	4.97^{a} (24.35)	1.96^{a} (3.68)	8.95^{a} (79.80)	10.40^{a} (107.83)	9.39^{a} (87.78)	2.31 (4.88)	11.02^{a} (121.73)	14.65^{a} (214.40)
F-test	***	***	***	***	***	**	***	***	***	*ns*	***	***
LSD (0.05)	0.44	0.085	0.25	0.45	0.61	0.54	0.52	0.55	1.48	1.03	1.14	1.22
SEm(±)	0.14	0.03	0.08	0.15	0.19	0.18	0.17	0.18	0.48	0.34	0.37	0.39
CV%	11.69	6.97	12.40	11.05	13.3	27.44	8.90	7.30	14.20	32.20	10.60	7.90
Grand Mean	2.42	0.79	1.30	2.66	2.95	1.28	3.78	4.95	6.78	2.09	6.99	9.99

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level. GW=grass weeds, SW= Sedge weeds, BLW= Broad leaf weeds; Data are subjected to square root transformation ($\sqrt{(x+0.5)}$) and data in parentheses are original values.

Table 6. Weed control efficiency and weed control index as influenced by weed management practices in hybrid maize at Lamahi in 2021

Weed Management Practices	Weed Control Efficiency (WCE)			Weed Control Index (WCI)		
	30 DAS	45 DAS	90 DAS	30 DAS	45 DAS	90 DAS
Black on Silver Plastic Mulching	9.84^{a} (96.31)	9.82^{a} (95.86)	9.83^{a} (96.20)	9.91^{a} (97.68)	9.90^{a} (97.90)	9.83^{a} (96.00)
Atrazine (1kg a.i. ha^{-1})	9.27^{a} (85.58)	9.16^{b} (83.49)	8.42^{b} (70.59)	9.38^{a} (87.63)	9.47^{b} (89.16)	7.47^{b} (55.34)
2 Hand Weeding	7.79^{b} (60.32)	8.48^{c} (71.64)	7.41^{c} (54.72)	8.36^{b} (69.64)	9.13^{c} (82.86)	6.46^{bc} (41.46)
Power Weeder	6.41^{c} (42.34)	7.55^{d} (57.09)	7.30^{c} (53.24)	7.50^{c} (56.33)	8.80^{d} (77.45)	6.23^{c} (38.97)
F-test	***	***	***	***	***	***
LSD (0.05)	1.20	0.56	0.91	0.69	0.22	1.05
Sem (±)	0.35	0.16	0.26	0.2	0.06	0.31
CV%	9.38	4.13	7.18	5.17	1.50	9.08
Grand Mean	8.33	8.75	8.24	8.79	9.33	7.49

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level. GW=grass weeds, SW= Sedge weeds, BLW= Broad leaf weeds; Data are subjected to square root transformation ($\sqrt{(x+0.5)}$) and data in parentheses are original values.

Yield attributing characters

Weed management practices had a significant impact on the yield-attributing characters of maize (Table 7). The number of kernels per ear (426.7), cob length (20.33cm), and thousand-grain weight (345.75g) were found significantly higher in black-on-silver plastic mulching. Whereas the lowest values of these yield-attributing characters were recorded in weedy check plots. The maximum shelling percentage (table 6) was recorded on black-on-silver plastic mulching (77.80%), which showed a significant difference from 2-hand weeding, power weeder, and weedy check but at par with atrazine (73.90%). The minimum sterility percentage was observed in black-on-silver plastic mulching (7.50%), a figure that was statistically similar to atrazine (8.90%) and 2-hand weeding (11.23%).

Table 7. Yield attributing characters as influenced by weed management practices in hybrid maize at Lamahi in 2021

Weed Management Practices	Number of kernels per ear	Cob length (cm)	Cob girth (cm)	Shelling (%)	Sterility (%)	Thousand Grain Weight(g)
Black-on Silver Plastic Mulching	426.70^{a}	20.33^{a}	5.32^{a}	77.80^{a}	7.50^{a}	345.75^{a}
Atrazine (1kg a.i. ha^{-1})	394.95^{ab}	18.35^{b}	5.09^{ab}	73.90^{ab}	8.90^{ab}	328.75^{b}
2 Hand weeding	379.10^{b}	18.05^{b}	4.54^{bc}	72.29^{b}	11.23^{ab}	322.50^{b}
Power Weeder	377.60^{b}	17.87^{b}	4.43^{c}	71.88^{b}	11.77^{b}	316.75^{b}
Weedy Check	326.00^{c}	15.88^{c}	4.06^{c}	66.67^{c}	16.15^{c}	300.63^{c}
F-test	**	**	**	**	**	***
LSD (0.05)	41.10	1.69	0.62	4.40	3.75	12.80
SEm (±)	13.33	0.55	0.20	1.40	1.22	4.16
CV %	7.00	6.10	8.61	3.94	21.92	2.58
Grand Mean	380.87	18.10	4.69	72.50	11.11	322.88

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level.

Grain yield

Grain yield was significantly affected by different weed management methods. All the treatments proved significantly superior to the weedy check with respect to grain yield. The average grain yield of the experiment was found to be 7.35 t ha^{-1} (Table 8). The highest grain yield was obtained in black on silver plastic mulching (9.91 t ha^{-1}), which was significantly superior to atrazine, 2-hand weeding, power weeder, and weedy check.

Harvest index

The harvest index of maize was significantly affected by different weed management methods. The highest harvest index was obtained in black-on-silver plastic mulching (0.39) and was significantly superior to other treatments but at par with atrazine (0.35). The lowest harvest index was recorded in the weedy check (0.28). The average harvest index of the experiment was found to be 0.34.

Table 8. Grain yield, fodder yield, and harvest index as influenced by weed management practices of hybrid maize at Lamahi in 2021

Weed Management Practices	Grain Yield (t ha^{-1})	Fodder yield (t ha^{-1})	Harvest Index (HI)
Black-on Silver Plastic Mulching	9.91^{a}	13.57^{a}	0.39^{a}
Atrazine (1kg a.i. ha^{-1})	8.13^{b}	13.28^{ab}	0.35^{ab}
2 Hand weeding	7.08^{b}	12.03^{bc}	0.34^{b}
Power Weeder	7.02^{b}	11.76^{c}	0.34^{b}
Weedy Check	4.63^{c}	10.40^{d}	0.28^{c}
F-test	***	**	**
LSD (0.05)	1.41	1.28	0.045
SEm (±)	0.46	0.41	0.02
CV %	12.40	6.78	8.8
Grand Mean	7.35	12.2	0.34

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level

Economic analysis

Economic analysis of different weed management practices (Table 9) showed that a significant maximum gross return was obtained in black-on-silver plastic mulching (NPR 237.84 thousand/ha). The weedy check resulted in the significantly lowest gross return (NPR 132.42 thousand/ha), followed by the power weeder. However, the data analyzed indicated that the application of atrazine resulted in the highest net return, which was statistically similar to black on silver plastic mulching and power weeding. A weedy check plot resulted in the lowest net return (18.50 thousand/ha), followed by 2 hand weeding. Regarding the benefit-cost ratio (B: C), the atrazine @ 1 kg a.i. ha^{-1} recorded the highest benefit-cost ratio as it gave NPR 1.98 by costing only one rupee, which shows a significant difference from black on silver plastic mulching, 2-hand weeding, power weeder, and weedy check.

Table 9. Economics of maize production as influenced by weed management practices at Lamahi in 2021

Weed Management Practices	The total cost of cultivation (NRs)	Gross return (NRs)	Net return (NRs)	B: C ratio
Black-on Silver Plastic Mulching	147500	237840^{a}	90340^{ab}	1.61^{b}
Atrazine (1kg a.i. ha^{-1})	98100	195060^{b}	96960^{a}	1.98^{a}
2 Hand weeding	110000	169920^{b}	59920^{b}	1.54^{b}
Power Weeder	102270	168420^{b}	66150^{ab}	1.65^{b}
Weedy Check	92500	132420^{c}	18500^{c}	1.20^{c}
F-test	-	***	**	**
LSD (0.05)	-	35181.90	33807	0.31
SEm (±)	-	11417.80	10971.7	0.10
CV %	-	12.60	33	12.5
Grand Mean	110074	180732	66374	1.60

Note: Means followed by the same letter(s) in a column are not significantly different by DMRT at a 5% level of significance. ns= Nonsignificant, *=significant at 5% probability level, **= significant at 1% probability level, ***=significant at 0.1% probability level, (135NRs~$1USD)

DISCUSSION

Many weed species found in the experimental area play a crucial role in Nepalese agriculture, particularly in maize production. For instance, *Cyperus rotundus, Cyperus iria,* etc., are the major weeds of maize in Nepal (Marahatta 2018). Shrestha et al (2021) reported 16 major species of weeds, including *Cynodon dactylon, Cyperus rotundus, Imperata cylindrica, Digitaria ciliaris, Chenopodium album,* etc., in the spring maize at Dhading, Nepal. Weed species possess huge adaptability to their surroundings and employ a wide array of strategies to enhance their success and gain a competitive advantage over other crop species. The weed species compete with crops for soil moisture, causing water stress, and altering nutrient uptake in maize, i.e., both the available N pool in the soil and dry matter allocation within the plant, and affecting the photosynthesis rates (Rajcan and Swanton 2001). Our study supports the hypothesis that applying different weed management methods can suppress weed infestation and reduce its impact in maize fields. Weed density, weed dry mass, and weed growth differed significantly between weed control methods applied in the study. Among the treatments used in the study as options for weed management, black-on-silver plastic mulch yielded significant results in terms of controlling weed growth and enhancing maize production compared to other treatments employed. Conversely, the weedy check plot recorded the highest weed flora, weed density, weed dry matter, and the lowest yield (Tables 3, 4 and 7). Asif et al (2020) reported maximum plant height and minimum dry weight of weed seed on plastic mulching, which aligns with our experiment results. Likewise, Gurung et al (2019) reported a higher grain yield of maize, and high weed control efficiency, while Timsina et al (2019) noted a higher weed control index and recorded the lowest sterility percentage on black polythene mulch, consistent with the findings of our study. The better inhibition of weed growth by the application of plastic mulch is due to the creation of a protective barrier on the soil surface, which inhibits light penetration, restricts the photosynthetic ability of weed seeds, and increases soil temperature, which reduces seed viability for germination (Egley 1983, Hussain et al 2022). Plastic mulching improved plant traits and the yield of the maize plant. This can be accounted for with better weed control by plastic mulch. When the weeds are suppressed, maize plants gain an advantage in space and nutrition that may result in enhanced plant traits such as plant height and plant leaf area index, followed by increased plant yield. Further, most studies have shown a positive link between plant height and dry matter and the yield of maize plants (Freeman et al 2007, Sharma et al 2016). The height of maize plants is a significant morphological characteristic; it is closely associated with both aboveground dry matter (DM) and grain yield in maize, making it a valuable indicator of vegetative growth and potential yield (Sharma et al 2016). Similarly, in any plant, Leaf Area Index (LAI) serves as a significant factor influencing net primary production, water and nutrient utilization, and carbon balance in all plants. A higher leaf area index indicates increased photosynthetic activity by plants and optimized utilization of solar energy for carbon assimilation (Bréda 2008). A study by Hussain et al (2022) claimed that elevated LAI results in more area for photosynthesis, leading to higher Crop Growth Rate (CGR) and subsequent increases in dry matter yield, plant height, grain/cob, achenes/head, and 1000-grain/achenes weight, ultimately enhancing maize yields.

After black on silver plastic mulch, our study showed that atrazine was efficient in weed suppression in maize fields, a finding supported by Olabode and Sangodele (2015), whereas Khan et al (2020) observed that all significant yield-attributing characteristics of the crop, including grain yield and harvest index, were comparable between atrazine application and hand weeding. However, our study yielded differing results from Khan et al (2020) regarding weed control efficiency, weed control index, and weed dry matter. These parameters differed significantly between atrazine application, hand weeding, and power weeding, while the results for the latter two methods were comparable. Kumaresan et al (2023) explored nonchemical weed management in the maize field, and they found better weed control efficiency when hand weeding was employed at 20 and 40 DAS compared to power weeder application; consistent with our results. This might be due to the fact that the use of a power weeder doesn't remove the weeds within crop rows, and these weeds still compete with the maize plant for light, space, and nutrients. Additionally, Chicouene (2007) emphasized that the mechanical weeding method required precise crop arrangement and the allocation of suitable inter-row spacing in the field according to the type and size of the instrument used, which makes this method of weed management inconvenient among farmers, prompting a shift towards more eco-friendly and safer weed control methods, such as hand weeding. From an economic perspective, the application of atrazine emerged as a more cost-effective option compared to the plastic mulch utilized in the study. When comparing the economics of weed management in the cowpea field, Osipitan et al (2018) found that the single use of pre-emergence herbicide was more economical than the single input of hand weeding for weed control. The increase in several hand weeding incurred higher variable costs, outweighing the benefit derived from the crop production. (Khan et al 2020) also found atrazine application to be the most economical method for weed control in maize fields. Shrestha et al (2021) compared the B: C ratio associated with different herbicide use and hand weeding. They found a higher B: C ratio (2.58) in atrazine @ 1 kg a.i. ha^{-1} treated plot. The lowest benefit ratio was recorded in the weedy check (1.20). This might be due to low production resulting from maximum weed infestation. The B: C ratio of black on silver plastic mulching is lower than that of atrazine application could be due to the higher cost of plastic at the initial stage. Despite comparable results and economic benefits, the adverse effects on the environment, soil productivity, chemical residue in the soil, and herbicide resistance development in weeds are the main concerns with the use of atrazine. Singh et al (2015) mention the necessity of choosing an appropriate herbicide based on the existing weed flora in the field and following precise dosage, application methods, timing, soil moisture levels, and application techniques. Moreover, there is potential for additional research into the reuse of black plastic for subsequent maize cultivation seasons, offering potential cost reductions and increased profitability compared to herbicide application, while also benefiting both economic and environmental aspects.

CONCLUSION

The implementation of different weed management techniques significantly affected the plant growth parameters and weed growth in the maize field. Notably, the use of black-on-silver plastic mulching enhanced crop growth and lowered weed dry weight and weed density in the maize field. Weed control efficiency and weed control index were also found to be higher with the use of black on silver plastic mulch. Following the application of black on silver plastic mulch, atrazine consistently reduced the weed growth throughout the crop production period, with grain yield comparable to that achieved through 2 hand weeding and use of power weeder methods. However, in terms of net return and BC ratio, our study highlighted that the application of atrazine 1.0 kg a.i. ha^{-1} as pre-emergence was more profitable than black-on-silver plastic mulching, hand weeding, power weeder, and weedy check. Nevertheless, the potential negative impacts associated with herbicides call for attention to the sole dependence upon atrazine for weed control. Further, while our study presented the higher benefits of using plastic mulch, it didn't consider the potential solarization effect or evaluate its profitability for the long term, suggesting scope for further research in this area. Moreover, integrated weed management, which was not evaluated in this study, can be an alternative approach, particularly in fields with diverse weed flora and where one method of weed management may prove costly to adapt at the farm level.

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AUTHORS' CONTRIBUTION

Santosh Paudel: Writing - original draft, Writing - review and editing, Conceptualization, Methodology development, Formal analysis, Data curation, and Visualization
Madhav Prasad Neupane: Writing - review and editing, Validation, Supervision
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CONFLICTS OF INTERESTS

The authors declare that they don't have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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