Effect of weed management practices on weed dynamics, yield and economics of spring maize at Dhading Besi, Nepal

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Abstract

Weeds have been a major constraint in maize cultivation resulting in huge economic loss to farmers. A field experiment was conducted at Dhading Besi, Nepal to evaluate the effect of different weed management practices on weed dynamics, yield and economics of spring maize in 2020. The experiment was laid out in Randomized Complete Block Design (RCBD) comprising of eight treatments with three replications. Rajkumar hybrid maize variety was used in the experiment. The treatments consisted of weedy check, weed free, atrazine as PE @1.0 kg a.i./ha, pendimethalin as PE @1.0 kg a.i./ha, atrazine @ 1.0 kg a.i./ha as PE followed by (*fb*) 2,4-D EE @0.5 kg a.i./ha as PoE, pendimethalin @ 1.0 kg a.i./ha as PE *fb* 2,4-D EE @ 0.5 kg a.i./ha as PoE, 2 hand weeding @ 20 and 40 DAS and Farmer's practice. The experiment result revealed that sequential application of atrazine *fb* 2,4-D EE treatment resulted in highest grain yield (11.37 t/ha) which was statistically similar with weed free (11.24 t/ha) and followed by the treatment atrazine (10.36 t/ha). 16 weed species belonging to 6 different families were identified. The broad leaf weeds and grassy weeds were more prominent than sedges. The total density and dry weight of weeds were found significantly lower in sequential application of atrazine *fb* 2,4-D EE than other treatments. Similarly, application of atrazine *fb* 2,4-D EE resulted in maximum weed control efficiency of 87.59 %, 95.91 % and 92.17% at 30, 45 and 60 DAS respectively. The lowest weed index (-1.27%) was also obtained in the application of atrazine *fb* 2,4-D EE. Yield loss due to weed in the weedy check treatment was found to be 50.99% followed by farmer's practice (43.17%). The benefit cost ratio and increment in benefit over weedy check were highest in atrazine *fb* 2,4-D EE followed by atrazine and significantly better than other weed management treatments. The sequential application of atrazine *fb* 2,4-D EE was found to be the most effective in controlling weeds, high yielding and economical among the different weed control treatments. The application of atrazine one time as PE was found to be next better option for weed control in spring maize.

Keywords: Spring maize, weed dynamics, weed management, yield

Introduction

Maize (*Zea mays* L.) also known as "Queen of Cereals" is the most important cereal crop grown in the world. Among cereals, it has the highest production volume of over 1.14 billion metric tons cultivated in 193.74 million ha area worldwide (FAO, 2018). In Nepal, maize is the second most important cereal crop after rice. It is a traditional crop cultivated as a way of life for food, feed and fodder (Paudyal *et al*., 2001). As the feed demand is increasing at the rate of 11% per annum, the demand for maize is shifting from food to feed for livestock and poultry (KC *et al*., 2015). The national production of maize in the fiscal year 2075/76 is 2713.63 thousand tons cultivated in 956.44 thousand ha (MoALD, 2018/19). The global average productivity of maize is about 5.9 t/ha with highest productivity of 11.8 t/ha in USA (FAO, 2018), whereas in Nepal the productivity of maize is only 2.8 t/ha (MoALD, 2018/19). According to MoALD (2018/19), Province no.1 and Bagmati Province have the highest share of 30.6% and 22.0% of total maize production in the country respectively with highest productivity of 3.14 t/ha in Province 2 and the lowest productivity of 2.25 t/ha in Sudurpaschim province. In Dhading district, area under maize cultivation is 20,678 ha with annual production of 58,601 Mt and productivity of 2.83 t/ha (MoALD, 2018/19). Behind this lower productivity of maize in the country, there are many production constraints.

Among them, weed infestation has been a serious problem limiting the maize production. Weeds compete with crops for nutrients, moisture, light and space and also possess allelopathic effects on crops (Walia and Walia, 2015). As farmers are practicing maize cultivation along with applying high inputs for higher production, that has enhanced the weed infestation. The extensive use of chemical fertilizers, repeated irrigation and wide spacing between maize rows provide suitable environment for weed growth and establishment enhancing the yield loss (Fanadzo *et al.*, 2007; Bajwa , *et al*.,2014).

Maize plants are more sensitive to the competition by neighboring weedy plants during critical period of weed control (CPWC) (Cerrudo *et al.*, 2012). The CPWC in maize varies from 2 to 7 weeks after sowing, with the most critical competition between 4-7 weeks after sowing (Shrestha *et al.*, 2019). As the early stages of maize are highly susceptible to weed competition, effective weed control at pre and early post emergence stages is necessary (Shrestha *et al.*, 2018). Conventional method of manual weed control requires large number of laborers (Shrestha *et al*., 2019), which are being scarce because of migration to foreign countries as well as in urban areas in non-agriculture sector and also costly because of increased wages of laborers (Jaquet *et al.*, 2019). Various chemical and mechanical methods of weed management have been used all over the world. However, the effective and economic control of weeds in maize cultivation can be achieved through the efficient and right use of pre and post emergence herbicides (Hossain *et al*., 2019). Marahatta (2018) also reported the application of suitable pre-emergence followed by post-emergence herbicides for effective control of weeds in maize, which is beneficial even than the manual weeding.

Materials and Methods

The experiment was conducted at Kudule, Dhading Besi, Nilkantha Municipality-12, Dhading, Nepal during spring season (Feb-June) of 2020. The geographical location of experimental site was 27°54’46.73’’N (latitude), 84°54’17.86’’E (longitude) and 612m (altitude). Soil of experimental plot was neutral (6.6) with sandy loam texture. The total rainfall received, average relative humidity, average maximum and minimum temperature during crop season were 727.34 mm, 61.27%, 24.82^{0}C and 15.12^{0}C respectively. The experiment was laid out in Randomized Complete Block Design (RCBD) comprising of 8 treatments and 3 replications:

1. Weed free
2. Atrazine as pre-emergence (PE) @1.0 kg a.i./ha
3. Pendimethalin as PE @1.0 kg a.i./ha
4. Atrazine @ 1.0 kg a.i./ha as PE followed by (*fb*) 2,4- D Ethyl Ester (EE) @0.5 kg a.i./ha as post-emergence (PoE)
5. Pendimethalin @ 1.0 kg a.i./ha as PE *fb* 2,4-D EE @ 0.5 kg a.i./ha as PoE
6. 2 Hand weeding @ 20 and 40 DAS
7. Farmer’s practice
8. Weedy check

Atrazine and pendimethalin were applied at 3 days after sowing (DAS) and 2,4- D EE was applied at 35 DAS. Farmer’s practice included the manual weeding at 35 DAS, hand weeding at 7 days’ interval up to 8 weeks after sowing was done in weed free plots and weedy check plot was left without weeding throughout the growing period. The individual plot size was made 3m* 2.5m (7.5 m^2) with 5 rows per plot and 10 plants per row. Seeds of Rajkumar hybrid maize were sown on 14th February 2020 at 60*25 cm spacing. The recommended dose of fertilizer N: P_2O_5:K_2O @160:60:40 kg/ha was applied in each plot in the form of urea, DAP and Muriate of Potash (MOP). Full dose of phosphorus and potassium were applied as basal dose and nitrogen was applied in three equal splits at the time of sowing, knee high stage and tasseling stage of the crop. Thinning was done at 20 DAS. Earthing up was done at 60 DAS. Weed sampling was done to identify weeds, to determine weed density and dry weight at 30, 45 and 60 DAS. Weed control Efficiency (WCE), Weed Control Index (WCI) and Weed index (WI) were calculated using the formula given by Mani *et al.*, (1973), Mishra and Tosh (1979) and, Gill and Vijay Kumar (1969) respectively. All the agronomic data and economics were taken and calculated using standard technique. The Data on weeds were transformed by square root transformation. ANOVA was computed and significant data were subjected to DMRT for mean comparison (Gomez and Gomez, 1984).

Results and Discussions

Weed flora

Sixteen different weed species belonging to 6 different families were identified in the experimental field (Table 1). *Chenopodium album*, *Oryza sativa*, *Ageratum conyzoides*, *Cynodon dactylon*, *Cyperus rotundus, Stellaria media, Digitaria* spp., *Fimbristylis* spp. were the major weed species identified in the research field. Dahal and Karki (2014) also reported 12 major species of weed including *Cynodon dactylon*, *Digitaria ciliaris, Cyperus rotundus, Ageratum conyzoides* etc. in spring maize in Rampur, Chitwan.

Table 1. Weeds observed in spring maize at Dhading Besi, Nepal in 2020

Common name	Scientific name	Family
Grasses		
Rice	*Oryza sativa* (L.) subsp. *Indica*	Poaceace
Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceace
Cogon grass	*Imperata cylindrica* (L.) P. Beauv.	Poaceace
Smooth Crab grass	*Digitaria ciliaris* (Retz.) Koeler	Poaceace
Hairy crab grass	*D. sanguinalis* (L.) Scop.	Poaceace
Sedges		
Purple nut sedge	*Cyperus rotundus* (L.)	Cyperaceae
Rice flat sedge	*Cyperus iria* (L.)	Cyperaceae
Fringe rush	*Fimbristylis* spp. (Vahl)	Cyperaceae
Broad leaf weed		
Lamb's quarters	*Chenopodium album* (L.)	Amaranthaceae
Pigweed	*Amaranthus viridis* (L.)	Amaranthaceae
Goat weed	*Ageratum conyzoides* (L.)	Asteraceae
Beggar ticks	*Bidens pilosa* (L.)	Asteraceae
Common Groundsel	*Senecio vulgaris* (L.)	Asteraceae
Heart leaf Drymarry	*Dymaria cordata* (L.)	Caryophyllaceae
Common chickweed	*Stellaria media* (L.) Vill.	Caryophyllaceae
Wood sorrel	*Oxalis* spp. (L.)	Oxalidaceae

Plant height

Significantly taller plant height was recorded in weed free plots at 30 and 60 DAS which was statistically similar with atrazine *fb* 2,4-D EE and atrazine only plots at 60 DAS (table 2). This could be due to regular removal of weeds that facilitated optimum utilization of soil nutrients and moisture by crop and hence lead to optimum growth of the plants. At 90 DAS, the maximum plant height (277.26 cm) was obtained in sequential application of atrazine *fb* 2,4-D EE. This could be due to better controlled of weeds by the application of herbicides which allow plants to grow freely without competition with weeds. As no weed control measures were applied, weedy check resulted in lower plant height at various dates of observation. The results are in accordance with Nandaji (2019) that the sequential application of atrazine *fb* 2,4- D resulted higher plant height. This was statistically at par with atrazine only and both were superior to sole application of pendimethalin.

Table 2. Plant height (cm) and leaf area index of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	Plant height (cm)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	45 DAS	60 DAS
Weed free	16.57[a]	119.1[a]	275.93[a]	0.14[a]	0.86[a]	3.80[a]
Atrazine as PE	15.24[ab]	113.73[a]	272.47[a]	0.12[a]	0.59[b]	3.58[ab]
Pendimethalin as PE	14.38[ab]	97.87[b]	256.93[b]	0.09[b]	0.50[bc]	2.50[d]
Atrazine as PE *fb* 2,4-D EE	15.27[ab]	118.9[a]	277.26[a]	0.11[a]	0.79[a]	3.84[a]
Pendimethalin as PE *fb* 2,4-D EE	13.49[ab]	107.2[ab]	260.07[b]	0.09[b]	0.56[bc]	3.16[bc]
2 Hand weeding	13.98[b]	110.13[ab]	275.8[a]	0.09[b]	0.85[a]	2.97[cd]
Farmer's practice	11.52[c]	79.93[c]	236.87[c]	0.06[c]	0.43[c]	1.59[e]
Weedy check	11.49[c]	68.73[c]	222.13[d]	0.05[c]	0.27[d]	0.87[f]
F-test	*	**	**	*	**	**
LSD (P<0.05)	2.28	14.3	12.0	0.02	0.15	0.58
SEm(±)	0.75	4.70	3.94	0.01	0.05	0.19
CV %	9.32	7.99	2.63	14.21	13.69	11.79
Grand Mean	13.99	101.95	259.68	0.09	0.61	2.79

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

Leaf area index

The LAI in the experiment was significantly influenced by weed management practices at all dates of observation (Table 2). It was generally higher in weed free plots and statistically similar with atrazine *fb* 2,4-D EE applied plots and significantly lower in weedy check treatment. The lower LAI in weedy check was because of limited supply of nutrients like nitrogen to the crop due to higher crop-weed competition that reduced plant growth and chlorophyll content of plants thereby influencing leaf area and photosynthetic efficiency. Imoloame and Omolaiye (2016) also reported lower leaf area index in all plots of maize that was left weedy for 6, 9 and 12 weeks after sowing.

Weed density

The result showed significant reduction of broad leaf weed density in the application of atrazine *fb* 2,4-D EE (table 3). Similar result was reported by Gaur *et al*., (1991) that sequential application of atrazine *fb* 2,4- D significantly reduced all of the broadleaf weeds but not all of grassy weeds. The average grass and broad leaf weed density were found to be greater than that of sedge weeds. Total weed density was significantly affected by weed management practices and found significantly lower under weed free plots and higher under weedy check at all observations. After weed free, the minimum total weed density was recorded in atrazine only (44.44/m^2) at 30 DAS and in atrazine *fb* 2,4-D EE at 45 DAS (24.44/m^2) and 60 DAS (26.66/m^2). Verma and Maurya (2018) also reported low weed density in Kharif maize with the sequential application of atrazine *fb* 2,4-D.

Weed dry weight

Significantly highest and lowest grass weed dry weights were observed in weedy check and weed free respectively (Table 4). But at 45 DAS, highest grass weed dry weight (36.16 g/m^2) was recorded in pendimethalin only treated plots. Whereas the minimum broad leaf weed dry weight was recorded in atrazine *fb* 2,4- D EE at 30 and 45 DAS. The average dry weight of broad leaf weeds was greater than that of grassy and sedge weeds respectively. Total weed dry weight was significantly affected by weed management practices and recorded minimum in weed free and maximum in weedy check at all dates of observation. After weed free, the total weed dry weight was recorded minimum under application of atrazine *fb* 2,4-D EE at all dates of observation.

Weed control efficiency

Data showed that (Table 5) at all dates of observation, significantly highest and lowest WCE were observed in weed free and farmer's practice respectively. But at 45 DAS, the lowest WCE was recorded in pendimethalin only (68.43%). After weed free, the highest WCE was recorded in sequential application of atrazine *fb* 2,4-D EE at 30 DAS (87.59%), 45 DAS (95.91%) and 60 DAS (92.17%) which was statistically at par with atrazine only at 30 DAS and with 2 hand weeding at 30 and 45 DAS. Nandaji (2019) also found higher weed control efficiencies in atrazine *fb* 2,4-D treated plots than other treatments at 40, 60 and 80 DAS.

Weed control index

Weed control index (WCI) was significantly influenced by weed management practices (table 5). The highest and lowest WCI were recorded in weed free and farmer's practice treatments at all dates of observation except at 45 DAS. At 45 DAS, WCI was recorded lowest in pendimethalin only (76.21%). After weed free, the highest WCI was recorded in atrazine *fb* 2,4-D EE treatment which was statistically at par with both atrazine only and 2 hand weeding treatment at 30 and 45 DAS. The data are in accordance with the findings of Nandaji (2019).

Table 3. Weed density as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Density (no./m^2)											
	30 DAS				45 DAS				60 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Weed free	1.99^{a}	0.71	1.96^{ab}	2.70^{a}	1.13^{a}	0.71	2.68^{b}	2.92^{a}	1.54^{a}	0.71	1.54^{a}	2.20^{a}
	(3.44)	(0.00)	(3.33)	(6.77)	(1.11)	(0.00)	(7.77)	(8.89)	(2.22)	(0.00)	(2.22)	(4.44)
Atrazine as PE	6.43^{ab}	0.71	1.54^{ab}	6.62^{b}	5.28^{bc}	2.37	4.25^{bc}	7.24^{bc}	5.30^{bc}	2.43	2.83^{a}	6.67^{bc}
	(42.22)	(0.00)	(2.22)	(44.44)	(27.78)	(6.67)	(17.78)	(52.22)	(28.89)	(7.03)	(10.00)	(45.92)
Pendimethalin as PE	9.29^{b}	2.21	2.71^{ab}	10.06^{bc}	11.1^{bc}	1.85	7.1^{d}	13.34^{d}	7.55^{bc}	1.62	5.68^{b}	9.69^{de}
	(86.66)	(5.56)	(8.89)	(101.11)	(122.72)	(5.56)	(50.00)	(178.28)	(57.78)	(3.77)	(32.22)	(93.77)
Atrazine as PE *fb* 2,4-D EE	6.24^{ab}	1.55	0.71^{a}	6.56^{b}	4.90^{b}	0.71	0.71^{a}	4.90^{ab}	5.02^{b}	0.71	1.12^{a}	5.16^{b}
	(42.22)	(3.33)	(0.00)	(45.55)	(24.44)	(0.00)	(0.00)	(24.44)	(25.55)	(0.00)	(1.11)	(26.66)
Pendimethalin as PE *fb* 2,4-D EE	9.25^{b}	1.12	2.21^{ab}	9.71^{b}	7.63^{c}	0.71	4.01^{bc}	8.71^{c}	7.01^{bc}	0.71	2.21^{a}	7.45^{c}
	(92.22)	(1.11)	(5.56)	(98.89)	(58.89)	(0.00)	(16.67)	(75.56)	(51.11)	(0.00)	(5.56)	(56.67)
2 Hand weeding	5.26^{ab}	0.71	5.58^{b}	7.73^{b}	2.70^{bc}	0.71	4.87^{c}	5.66^{b}	4.49^{ab}	0.71	6.58^{b}	7.98^{cd}
	(27.78)	(0.00)	(32.22)	(60.00)	(8.89)	(0.00)	(23.33)	(32.22)	(21.11)	(0.00)	(44.44)	(65.56)
Farmer's practice	9.71^{b}	1.85	13.33^{c}	17.47^{c}	7.28^{d}	3.12	7.58^{d}	$11.05c^{d}$	7.64^{bc}	1.55	8.01^{b}	11.22^{e}
	(105.55)	(5.56)	(198.12)	(309.23)	(52.81)	(12.20)	(57.00)	(122.01)	(58.88)	(3.33)	(63.78)	(125.99)
Weedy check	8.46^{b}	1.54	16.98^{c}	19.27^{c}	11.6^{d}	2.41	20.73^{e}	24.04^{e}	8.46^{c}	1.37	15.88^{c}	18.27^{f}
	(80.00)	(2.22)	(294.45)	(376.67)	(138.89)	(11.11)	(432.22)	(582.22)	(77.78)	(2.22)	(254.44)	(334.44)
F-test	*	ns	*	**	*	ns	*	**	*	ns	*	**
LSD(0.05)	4.70	1.71	4.35	3.29	2.73	2.90	1.86	2.17	2.96	1.71	2.36	1.84
SEm(±)	1.55	0.56	1.43	1.08	0.89	0.95	0.61	0.71	0.97	0.56	0.78	0.61
CV %	37.94	75.03	44.09	18.75	24.2	105.0	16.36	13.20	28.75	79.69	24.59	12.24
Grand Mean	7.08	1.3	5.62	10.01	6.44	1.57	6.49	9.37	5.88	1.23	5.48	8.58

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

Table 4. Weed density as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Dry Weight (g/m^2)											
	30 DAS				45 DAS				60 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Weed free	0.76 (0.07)	0.71 (0.00)	0.78^{a} (0.12)	0.83^{a} (0.19)	1.04^{a} (0.61)	0.71 (0.00)	0.81^{ab} (0.16)	1.11^{a} (0.77)	0.71^{a} (0.00)	0.71 (0.00)	0.78^{a} (0.11)	0.78^{a} (0.11)
Atrazine as PE	1.24 (1.09)	0.79 (0.14)	0.73^{a} (0.03)	1.31^{a} (1.25)	2.55^{bc} (6.26)	1.12 (0.84)	1.62^{b} (2.14)	3.11^{bc} (9.24)	4.81^{bc} (24.60)	2.55 (8.78)	3.33^{ab} (14.15)	6.88^{bc} (47.52)
Pendimethalin as PE	2.14 (4.72)	0.88 (0.29)	0.93^{a} (0.38)	2.33^{c} (5.38)	5.97^{e} (36.16)	0.95 (0.51)	3.03^{c} (8.77)	6.75^{e} (45.43)	6.88^{cd} (47.61)	1.20 (1.43)	8.08^{cd} (66.45)	10.67^{d} (115.50)
Atrazine as PE *fb* 2,4-D EE	1.03 (0.61)	0.82 (0.19)	0.71^{a} (0.00)	1.13^{a} (0.80)	1.93^{ab} (3.48)	0.71 (0.00)	0.71^{a} (0.00)	1.93^{ab} (3.48)	5.72^{bcd} (32.77)	0.71 (0.00)	0.79^{a} (0.14)	5.72^{b} (32.91)
Pendimethalin as PE *fb* 2,4-D EE	2.29 (4.79)	0.81 (0.18)	1.09^{a} (0.89)	2.09^{bc} (3.85)	3.76^{cd} (13.65)	0.71 (0.00)	1.02^{ab} (10.72)	3.85^{c} (14.38)	7.11^{cd} (52.01)	0.71 (0.00)	3.19^{ab} (13.26)	8.09^{c} (65.27)
2 Hand weeding	1.10 (0.77)	0.71 (0.00)	1.21^{a} (1.03)	1.50^{ab} (1.80)	1.44^{ab} (1.69)	0.71 (0.00)	1.67^{b} (2.33)	2.09^{ab} (4.02)	3.40^{b} (11.60)	0.71 (0.00)	6.06^{bc} (38.73)	6.92^{bc} (50.33)
Farmer's practice	2.42 (6.82)	0.76 (0.09)	3.69^{b} (14.11)	4.61^{d} (21.02)	3.32^{c} (11.14)	2.29 (6.13)	3.71^{c} (8.77)	5.52^{d} (30.64)	5.72^{bcd} (32.37)	1.32 (1.98)	9.82^{d} (96.04)	11.44^{d} (130.38)
Weedy check	1.81 (2.92)	0.85 (0.24)	4.66^{b} (21.72)	5.00^{d} (24.88)	4.88^{de} (23.65)	1.81 (5.22)	12.70^{d} (161.42)	13.79^{f} (190.30)	7.91^{d} (66.86)	1.39 (2.33)	16.73^{e} (282.95)	18.75^{e} (352.14)
F-test	ns	ns	*	**	*	ns	*	**	*	ns	*	**
LSD(0.05)	1.24	0.22	1.07	0.73	1.28	1.62	0.83	1.16	2.45	1.64	2.91	1.75
SEm(±)	0.41	0.07	0.35	0.24	0.42	0.53	0.27	0.38	0.81	0.54	0.96	0.58
CV %	44.36	15.69	35.31	17.70	23.57	82.04	14.92	13.89	26.49	80.58	27.27	11.57
Grand Mean	1.60	0.79	1.72	2.35	3.11	1.13	3.16	4.77	5.28	1.16	6.10	8.66

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

Table 5: Weed control efficiency and weed control index as influenced by weed management practices of spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Control Efficiency (WCE)			Weed Control Index (WCI)		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
Weed free	9.93^{a} (98.08)	9.94^{a} (98.32)	9.96^{a} (98.69)	9.97^{a} (99.08)	10.01^{a} (99.57)	10.02^{a} (99.97)
Atrazine as PE	9.36^{ab} (87.13)	9.54^{bc} (90.58)	9.32^{bc} (86.40)	9.76^{ab} (94.70)	9.78^{ab} (95.12)	9.33^{b} (86.60)
Pendimethalin as PE	8.38^{b} (70.25)	8.29^{e} (68.43)	8.49^{d} (71.74)	8.87^{bc} (78.60)	8.76^{d} (76.21)	8.18^{c} (66.77)
Atrazine as PE *fb* 2,4-D EE	9.38^{ab} (87.59)	9.82^{ab} (95.91)	9.62^{ab} (92.17)	9.86^{ab} (96.77)	9.94^{ab} (98.23)	9.56^{a} (90.84)
Pendimethalin as PE *fb* 2,4-D EE	8.27^{b} (69.29)	9.35^{c} (86.84)	9.16^{bc} (83.48)	8.61^{c} (74.09)	9.63^{b} (92.32)	9.05^{b} (81.47)
2 Hand weeding	9.19^{ab} (83.88)	9.72^{ab} (94.05)	8.98^{c} (80.22)	9.60^{ab} (91.81)	9.92^{ab} (97.93)	9.31^{b} (86.20)
Farmer’s practice	4.16^{c} (17.47)	8.90^{d} (78.70)	7.93^{e} (62.35)	3.85^{d} (15.25)	9.14^{c} (83.15)	7.94^{c} (62.63)
F-test	**	**	**	**	**	**
LSD(0.05)	1.07	0.35	0.46	0.93	0.31	0.52
SEm(±)	0.35	0.11	0.15	0.30	0.10	0.17
CV %	8.25	2.41	3.28	6.91	2.06	3.69
Grand Mean	7.42	8.28	8.02	7.65	8.49	8.01

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

Yield attributing characters

Yield attributing characters of maize were significantly influenced by weed management practices (table 6). Plants per square meter (6.51), number of cobs harvested per m^2 (6.89), number of grains per cob (630.93) and thousand grain weight (331.71g) were found significantly higher in sequential application of atrazine *fb* 2,4-D EE. This could be due to the application of treatment which reduced the weed competition enhancing utilization of growth resources for better crop performance accompanied with better photosynthetic efficiency. Whereas, the lowest values of these yield attributing characters were recorded in weedy check plots.

Table 5. Yield attributing characters of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	No. of Plants/m^2	No. of cobs harvested/m^2	No. of kernels per cob	Thousand Grain Weight (g)
Weed free	6.51[a]	6.59[b]	599.33[ab]	318.05[a]
Atrazine as PE	6.22[b]	6.52[b]	581.20[ab]	325.59[a]
Pendimethalin as PE	5.48[c]	5.48[d]	491.20[cd]	292.49[b]
Atrazine as PE *fb* 2,4-D EE	6.51[a]	6.89[a]	630.93[a]	331.71[a]
Pendimethalin as PE *fb* 2,4-D EE	6.07[b]	6.15[c]	502.67[c]	290.92[b]
2 Hand weeding	6.22[b]	6.22[c]	548.67[bc]	297.87[b]
Farmer's practice	5.33[c]	5.33[d]	444.40[de]	276.72[c]
Weedy check	4.89[d]	4.89[e]	397.20[e]	268.31[c]
F-test	**	**	**	**
LSD(0.05)	0.26	0.29	54.9	13.5
SEm(±)	0.08	0.09	18.11	4.46
CV %	2.54	2.72	5.98	2.57
Grand Mean	5.91	6.01	524.45	300.21

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

Grain yield

Statistical analysis of data (Table 7) showed that the highest grain yield of 11.37 t/ha was obtained in atrazine *fb* 2,4-D EE which was statistically similar with weed free and followed by atrazine as PE (10.36 t/ha). Sharma *et al.*, (2018) also reported higher grain yield in application of atrazine *fb* 2,4-D among different herbicide treatments. The lowest grain yield (5.50 t/ha) was obtained in weedy check. The higher grain yield in atrazine *fb* 2,4-D EE could be due to its ability to reduce crop-weed competition resulting lower weed density and lower weed dry weight that provided better amounts of growth sources for increased plant height, LAI, number of cobs, number of grains per cob, thousand grain weight and in combined increased the grain yield.

Weed index

The data regarding weed index (Table 7) revealed that sequential application of atrazine *fb* 2,4-D EE resulted in significantly minimum value of weed index (-1.27%). Where, the negative sign indicated higher grain yield than in weed free plots. Similar result was reported by Shrestha *et al.*, (2018). Whereas, the weedy check plots recorded maximum yield loss of 50.99% which was followed by farmer's practice (43.17%). Gurung *et al.*, (2019) also reported highest weed index of 61.5 % in weedy check plots of winter maize.

Table 6. Grain yield, weed index and harvest index as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Grain yield (kg/ha)	Weed index (%)	Harvest index(HI)
Weed free	11247.76[a]	0.00[a]	0.49[a]
Atrazine as PE	10369.80[b]	7.74[b]	0.48[ab]
Pendimethalin as PE	8060.22[d]	28.18[d]	0.46[b]
Atrazine as PE *fb* 2,4-D EE	11372.46[a]	-1.27[a]	0.48[ab]
Pendimethalin as PE *fb* 2,4-D EE	9282.52[c]	17.36[c]	0.48[ab]
2 Hand weeding	9756.81[bc]	13.30[bc]	0.48[ab]
Farmer's practice	6379.99[e]	43.17[e]	0.43[c]
Weedy check	5507.33[f]	50.99[f]	0.42[c]
F-test	**	**	**
LSD (P<0.05)	730.00	6.35	0.02
SEm(±)	240.72	2.09	0.01
CV %	4.63	18.20	2.84
Grand Mean	8997.11	19.93	0.47

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

Economic analysis

The economic analysis of the data (Table 8) revealed that sequential application of atrazine *fb* 2,4-D EE resulted in the highest net return of 162.35 thousands/ha and B:C ratio of 2.70. Whereas atrazine only remained at second with net return of 144.15 thousands/ha and B:C ratio of 2.58. Similarly, weedy check plot resulted the lowest net return (42.42 thousands/ha) and B:C ratio (1.49) which were statistically similar with farmer's practice. Patel *et al*., (2018) also reported higher B:C ratio (2.98) for application of atrazine + pendimethalin as PE *fb* 2,4- D. The analyzed data also revealed that the application of atrazine *fb* 2,4-D EE resulted highest (73.83%) increment in benefit over weedy check which was statistically similar with atrazine only (70.57%).

Table 7. Economics of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	Total Cost of Cultivation (NRS)	Gross Return (NRS)	Net Return (NRS)	B:C Ratio	Increment in benefit over weedy check (%)
Weed free	142500	254313.0[a]	111813.03[c]	1.79[d]	61.89[b]
Atrazine as PE	91320	235472.9[b]	144152.90[b]	2.58[a]	70.57[a]
Pendimethalin as PE	94050	184559.0[d]	90508.96[d]	1.96[c]	52.81[c]
Atrazine as PE *fb* 2,4-D EE	95345	257702.0[a]	162357.04[a]	2.70[a]	73.83[a]
Pendimethalin as PE *fb* 2,4-D EE	98075	210492.5[c]	112417.48[c]	2.15[b]	62.12[b]
2 Hand weeding	114500	221712.3[bc]	107212.26[c]	1.94[c]	60.02[bc]
Farmer's practice	98000	148855.3[e]	50855.28[e]	1.52[e]	15.85[d]
Weedy check	86500	128927.4[f]	42427.43[e]	1.49[e]	-
F-test	-	**	**	**	**
LSD(0.05)	-	14627	14627	0.14	7.91

Weed Management Practices	Total Cost of Cultivation (NRS)	Gross Return (NRS)	Net Return (NRS)	B:C Ratio	Increment in benefit over weedy check (%)
SEm(±)	-	4822.42	4822.42	0.04	2.61
CV %	-	4.07	8.13	3.89	9.10
Grand Mean	102536.2	205254.3	102718	2.01	49.64

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns= Non-significant, *=significant at 5% probability level, **= significant at 1% probability level, NRS = Nepali Rupees The local market price of maize grain was NRS 20 per kg and market price of maize stover was assumed as NRS 2.5 per kg.*

Conclusion

The sequential application of herbicide atrazine @ 1.0 a.i. kg/ha as pre-emergence followed by 2,4-D EE @0.5 a.i. kg/ha as post-emergence herbicide was the most effective weed management treatment in Spring maize under Dhading Besi conditions of Nepal in controlling weeds, which also resulted in higher yield and economics. The next better option was pre emergence application of atrazine @ 1.0 a.i. kg/ha.

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Authors' Contributions

B. Shrestha, S.K. Sah and D. Marasini together planned and designed the experiment. B. Shrestha performed the experiment and analysis while S.K. Sah supervised throughout the experiment, result interpretation and manuscript development. KR Kafle and HB Bista contributed in facilitating and supervising the experiment.

Conflict of Interest

The authors declare no conflict of interest regarding publication of this manuscript.

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