Research Article

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Agronomic and economic performance of maize (*Zea mays* L.) as influenced by seed bed configuration and weed control treatments

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Abstract: Poor method of weed control and indiscriminate use of herbicides led to low yields, economic returns, and increasing environmental pollution in the southern Guinea savanna of Nigeria. These prompted the conduct of field trials in the 2018 and 2019 cropping seasons to determine the effects of seed bed configuration and weed control treatments on the agronomic and economic performance of maize. The treatments consisted of flat and ridge seed beds and six weed control treatments. The experimental design was a randomized complete block with split plot arrangement and replicated thrice. Results showed that seed bed configuration had significant ($p \leq 0.05$) effect on weed density, but not on maize grain yield. All the weed control treatments significantly ($p \leq 0.05$) reduced weed infestation and increased maize grain yields compared to the weedy check. Furthermore, Primextra at 1.5 kg active ingredient per hectare (kg a.i. ha^{-1}) + One supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1}, and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} applied on flat seed beds and two hoe weeding at 3 and 6 WAS + ridge produced higher yields, profit, and economic returns. Therefore, the above reduced herbicide rates applied on flat seed beds are recommended to farmers as alternatives to two hoe weeding at 3 and 6 WAS for profitable production of maize.

Keywords: flat seed bed, grain yield, reduced herbicide doses, ridge seed bed, weed management

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1 Introduction

Maize (*Zea mays* L.) is a major crop in Nigeria with an annual production of 10.16 million tonnes in 2018 [1]. The factors limiting the production of maize in the tropics include weed management, suboptimal planting densities, tillage, and low yielding varieties [2]. In West Africa, uncontrolled weed growth has been reported to cause 40–90% yield loss in cereals [3], 53–60% loss in legumes, 50–53% in oil seeds, and 65–91% loss in root and tuber crops [4].

A minimum of two well-timed hand weeding within the first six weeks after planting have been reported to provide effective weed control and minimized yield losses in maize [5]; however, the dwindling labour force, high cost of labour, and drudgery associated with hand weeding have made this method less feasible and the use of herbicides more attractive. Most farmers in Nigeria have embraced the use of herbicides for weed control, but the public is very much concerned about its effect on the environment and human health [6]. The two main effective ways to minimize the side effects of herbicides are either the application of lowest doses needed for effective weed control or integrated weed management system which involves the application of low dose of herbicides combined with other weed control methods which will give effective weed control, higher crop yield [7], and economic returns.

Seed bed configuration (flat and ridge) plays an important role in the conservation of soil water, weed management, and promotion of crop yields. It was reported that grain yield, weed density, and weed dry matter of flat seed bed exhibited non-significant difference from ridged method [8,9], while Nadeem et al. [10] and Prajapadi et al. [11] reported that ridge sowing was the better method in terms of effective weed control, promotion of yield, and economic returns in the production of cotton in Pakistan. In Nigeria, majority of farmers plant on flat or on ridges [12]; however, there is dearth of information on the agronomic and economic benefits of these seed bed configurations to guide farmer's decision in adopting the better method for maize production. Therefore, there is a need to determine the combination of weed control methods and seed bed configuration which will result in a safer, more effective weed control, higher yield, and economic returns in the production of maize in the southern Guinea savanna of Nigeria. The objectives of this study were (i) to determine more effective weed control method that provides higher yield, (ii) to determine seed bed configuration that provides better weed control and higher maize yield, and (iii) to determine the best combinations between weed control and seed bed configuration that provide higher grain yield and economic returns.

2 Materials and methods

2.1 Experimental site

The experiment was conducted during the 2018 and 2019 cropping seasons at the Teaching and Research Farm of the College of Agriculture, Kwara State University, Malete (latitude 08°71′N and longitude 04°44′E) in the southern Guinea savanna of Nigeria.

2.2 Treatment and experimental design

The experiment consisted of 12 treatments, namely, 2 seed bed types (flat and ridge) and 6 weed control methods: Primextra (metolachlor + atrazine) at 1.5 kg active ingredient per hectare (kg a.i. ha^{-1}) + One supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), Primextra + Aminicome (2,4-D) at 1.5 + 1.5 kg a.i. ha^{-1}, Primextra + Guard force (nicosulfuron) at 1.5 + 0.03 kg a.i. ha^{-1}, Primextra + Paraforce (paraquat) at 1.5 + 0.7 kg a.i. ha^{-1}, hoe weeding at 3 and 6 WAS, and a weedy check. These treatments were laid out in a randomized complete block design (RCBD) with a split plot arrangement and replicated three times. Seed bed type was allocated to the main plot, while the weed control treatments were in the subplots. Table 1 shows the manufacturers' recommended rates and percentage reduction of the herbicides used.

2.3 Cultural practices

After land preparation, the experimental area was marked into plots measuring 3 m × 3 m. The ridged seed beds were made with a hand hoe and spaced 60 cm apart. Planting was carried out on the 11th and 26th of July, 2018 and 2019, respectively and three treated maize (SUWAN var.) seeds were sown in a hole and the emerged seedlings were thinned to two plants per stand at 3 WAS. The plants were spaced 60 × 60 cm, giving rise to a plant population of 55,555 plants ha^{-1}. NPK 15:15:15 and urea fertilizers were applied to each plot to provide nutrient requirements of 120 kg N, 60 kg P_2O_5, and 60 kg K_2O ha^{-1}. Primextra herbicide was applied pre-emergence a day after planting, while all the post-emergence herbicides and SHW were applied at 6 WAS. Harvesting of the mature maize was done on the 8th and 17th of November, 2018 and 2019, respectively. The parameters measured were:

2.3.1 Weed density (No. m^{-2})

Weed density was obtained at 6 and 12 WAS by counting the total number of weed species within 1.0 m^2 quadrat placed randomly in three locations within each subplot.

Table 1: Manufacturers' recommendations and percentage reduction of herbicides

Herbicides used	Manufacturers' recommended rates (kg a.i. ha^{-1})	Reduced rates (kg a.i. ha^{-1})	Percentage reduction of doses (%)
Primextra (metolachlor – controls mainly narrow- and some broad-leaved weeds + atrazine – controls mainly broad-leaved and some grass weeds)	2–2.5	1.5	25–40
Paraforce (paraquat – controls both annual and perennial broad-leaved weeds)	1.0	0.7	30
Aminicome (2,4-D – controls mainly broad-leaved weeds)	2–3	1.5	25–50
Guard force (nicosulfuron – controls both broad- and narrow-leaved weeds)	0.04–0.6	0.03	25–95

2.3.2 Weed dry weight (g m^{-2})

Weed species in a 1.0 m^2 quadrat placed at random in three locations within each plot were uprooted at 6 and 12 WAS, gathered together, and oven-dried at 80°C for two days before weighing.

2.3.3 Weed cover score

Weed cover was visually assessed at 6 and 12 WAS, using a scale of 1 to 10, where 1 represents no weed cover and 10 complete weed cover.

2.3.4 Relative importance value (RIV%)

The RIV of each weed species at 6 and 12 WAS was computed as the mean of the percentage of relative frequency (RF) and relative density (RD) for each species as indicated in the formula below [13].

$$\text{RIV} = \frac{\text{RD} + \text{RF}}{2}$$

2.3.5 Plant height (cm)

The height of five randomly selected maize plants in a plot was measured from the soil level to the apex of the tassel at 6 and 12 WAS for flat seed bed, while on ridges, the measurement was from the crest of the ridge to apical bud of the maize and the average taken.

2.3.6 100 – seed weight (g)

One hundred seed weight was determined by weighing 100 grains of maize (at 13% moisture content) taken from the maize grains harvested from each subplot.

2.3.7 Grain yield (kg ha^{-1})

Grain yields of maize were weighed to obtain grain yield per net plot which were converted to grain yields per hectare.

2.4 Economic analysis

Economic performance of different treatment combinations of weed control treatments and seed bed configuration was determined by calculating the total cost of production, gross revenue, net revenue, and returns on United States (US) dollars ($) invested. Production cost (PC) was determined by adding the cost of inputs and farm operations used [14]. These included seeds, herbicides, insecticides, fertilizers, land preparation, labour for planting, herbicide and insecticide application, weeding, fertilizer application, harvest, and processing operations [14].

$$\text{PC} = \text{PC}_1 + \text{PC}_2 + \text{PC}_3 + \cdots \text{PC}_n$$

$$\text{Gross revenue (GR)} = \text{Crop yield } (Y) \times \text{Open market price } (P)$$

$$\text{Gross margin/Net revenue (NR)} = \text{Gross revenue (GR)} - \text{Production cost (PC)}$$

$$\text{Returns on US dollars invested} = \frac{\text{Gross revenue}}{\text{Production cost}}$$

2.5 Data analysis

All data were subjected to analysis of variance (ANOVA) using SAS statistical package. And where F test was significant at $p \le 0.05$, means were separated using least significant difference (LSD) at 5% level of probability. Similarly, maize yield values for different treatment combinations used for economic analysis were separated using Duncan's multiple range test at 5% level of probability.

3 Results and discussion

3.1 Effects of seed bed configuration and weed control treatments on weed infestation

The effects of seed bed configuration and weed control treatments on weed dry weight are presented in Table 2. There was no significant difference between the weed dry weight obtained from flat and ridged seed bed configurations at 6 and 12 WAS in both years. However, weed control treatments significantly ($p \le 0.05$) reduced weed dry weight compared to weedy check in both years at 6 WAS and in 2019 at 12 WAS. There was no significant interaction between weed control method and seed bed configuration.

Table 2: Effect of seed bed configuration and weed control method on weed dry matter, weed cover, and weed density

Treatment	Weed dry matter (g/m^2)				Weed cover score				Weed density			
	6 WAS		12 WAS		6 WAS		12 WAS		6 WAS		12 WAS	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Seed bed configuration (SBC)												
Flat	479.2a[1]	1362.9a	832.1a	1151.1a	3.6a	4.7a	4.5a	4.1a	8.1a	28.4a	11.3a	17.3b
Ridge	493.0a	1406.5a	862.1a	1807.4a	3.7a	4.7a	4.3a	3.9a	7.4a	21.9a	11.2a	31.9a
Weed control method (WCM)												
Primextra at 1.5 + One SHW at 6 WAS	371.2c	993.5bc	803.7a	431.1b	2.1c	4.0b	2.3c	1.9c	5.8b	18.3b	9.3b	14.5bc
Primextra + Aminicome at 1.5 + 1.5	411.7bc	748.6bc	943.1a	1624.5b	3.0b	3.3b	3.5bc	3.3bc	6.5b	24.7b	10.0b	26.8b
Primextra + Guard force at 1.5 + 0.03	406.5bc	1062.4bc	804.0a	1577.8b	2.2c	4.0b	2.8bc	3.6b	5.5b	19.3b	9.3b	19.2bc
Primextra + Paraforce at 1.5 + 0.7	425.9ab	330.6c	725.0a	933.3b	3.0b	3.9b	4.8b	2.3bc	6.0b	19.0b	11.8b	17.0bc
3 and 6 WAS	563.1b	455.1bc	796.2a	408.9b	2.0c	2.8b	2.7c	3.3bc	6.2b	17.7b	8.7b	10.3c
Weedy check	738.2a	3718.3a	1010.6a	3900.0a	10.0a	10.0a	10.0a	10.0a	16.5a	52.2a	18.3a	59.8a
Interaction												
SBC × WCM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ANOVA												
SBC	0.75	0.82	0.78	0.09	0.06	1.00	0.62	0.68	0.34	0.06	0.95	0.003
WCM	0.001	0.0001	0.66	0.0002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SBC × WCM	0.39	0.54	0.20	0.18	0.078	0.43	0.42	0.61	0.06	0.26	0.36	0.37

WAS = Weeks After Sowing, 1 = means in the same column followed by the same letters are not significantly different at 5% level of probability using LSD, NS = Not Significant.

Seed bed configuration had no significant effect on weed cover. Conversely, all the weed control treatments resulted in significantly ($p \leq 0.05$) lower weed cover compared to weedy check at 6 and 12 WAS in both years (Table 2). Weed density differed significantly ($p \leq 0.05$) between flat and ridged seed beds at 12 WAS in 2019 (Table 2), as flat seed beds significantly ($p \leq 0.05$) reduced weed density compared to the ridged beds, while weed control methods, Primextra at 1 5 kg a.i. ha^{-1} + One SHW at 6 WAS, Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1}, Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1}, Primextra + Aminicome at 1.5 + 1.5 kg a.i. ha^{-1}, and two hoe weeding at 3 and 6 WAS, resulted in significantly ($p \leq 0.05$) lower weed density compared to weedy check in both years. The interaction between weed control treatments and seed bed configuration was not significant. Neither flat nor ridged seed beds was superior to the other in the reduction of weed dry matter; however, flat seed beds resulted in limited control of weed density compared to the ridged beds, possibly because more buried weed seeds were brought up to the surface of the soil during the process of hoe weeding the ridges at 6 WAS. This contradicts the findings of Nadeem et al. [10] that ridge sowing is better method than flat seed bed in the control of weeds. All the weed control methods caused a significant reduction in weed infestation. This performance is a demonstration of their efficacy and ability to provide season-long weed control in maize production. Therefore, they constitute additional weed management options that can be used as an alternative to two hoe weeding which is associated with drudgery.

3.2 Effects of weed control treatments on the relative importance value of weed species

Tables 3 and 4 show the distribution of weed species and their relative importance values across treatment combinations at 6 and 12 WAS. A total of 13 weed species made up of 7 grass, 3 broad-leaved, and 3 sedge weeds were recorded across treatments at 6 WAS (Table 3). In comparison, a total of 14 weed species occurred at 12 WAS (Table 4). All the treatment combinations controlled all broad-leaved weeds and sedges effectively, but could not fully control the grass weeds, resulting in the predominance of weed species such as *Rottboellia cochinchinensis, Paspalum scrobiculatum, Brachiaria lata,* and

Table 3: Relative importance value (%) of weed species under different treatment combinations at 6 WAS, 2019

Weed species	**Form**	**P + One SHW + R**	**P + One SHW + F**	**P + Gf + R**	**P + Gf + F**	**P + A + R**	**P + A + F**	**P + Pf + R**	**P + Pf + F**	**3 and 6 WAS + R**	**3 and 6 WAS + F**	**Weedy + R**	**Weedy + F**	**Average (%)**
Rottboellia cochinchinensis	G	39.2	40.9	40.9	33.5	29.7	26.6	37	51.2	5.7	—	5.9	25.7	28
Digitaria horizontalis	G	8.9	15.4	—	8.7	8.8	5	—	7	20.2	19.8	50.7	20.4	13.7
Brachiaria lata	G	19.4	18.1	—	20.2	17.6	13.8	37	—	29.2	26.1	—	—	15.1
Setaria barbata	G	17.8	9.3	15.9	15.4	—	16.2	—	13.4	10.1	—	13.7	10.2	10.1
Paspalum scrobiculatum	G	8.9	13.1	19.7	11.2	43.8	27.9	25.9	20.7	10.1	32.3	17.9	—	19.3
Dactyloctenium aegyptium	G	—	—	5.3	—	—	—	—	—	—	—	—	9.3	1.9
Grasses (unidentified)	G	—	—	10.9	—	—	—	—	—	—	—	—	—	0.9
Hyptis suaveolens	BL	—	—	—	—	—	5.7	—	—	—	—	—	—	0.5
Commelina benghalensis	BL	5.9	—	7.6	—	—	—	—	—	—	—	—	9.3	1.9
Ageratum conyzoides	BL	—	—	—	—	5.6	—	—	—	—	—	—	—	0.5
Cyperus esculentus	S	—	5.9	—	5.2	—	5	—	7.8	—	—	—	3.5	1.9
Cyperus iria	S	—	—	—	—	—	—	—	—	6.8	—	—	—	0.6
Pycreus lanceolatus	S	—	—	—	—	—	—	—	—	18	21.9	11.8	9.8	5.1
Weed species richness		6	6	6	7	4	7	3	5	7	4	4	7	

P = Primextra, SHW = Supplementary hoe weeding at 6 WAS, F = Flat seed bed, R = Ridge seed bed, Gf = Guard force, A = Aminicome, Pf = Paraforce, G = Grasses, BL = Broad-leaved, S = Sedges.

Table 4: Relative importance value (%) of weed species under different treatment combinations at 12 WAS, 2019

Weed species	Form	P + One SHW + R	P + One SHW + F	P + Gf + R	P + Gf + F	P + A + R	P + A + F	P + Pf + R	P + Pf + F	3 and 6 WAS + R	3 and 6 WAS + F	Weedy + R	Weedy + F	Average (%)
Paspalum scrobiculatum	G	33.4	65.4	14.6	8.5	11.4	20.3	48.9	26.2	29.6	37.2	24.9	34.5	29.6
Brachiaria lata	G	29.4	—	—	19.3	26.8	29.5	—	6.7	7.6	24	9.8	—	12.8
Digitaria horizontalis	G	11.6	22.5	—	—	16.5	6.6	18.6	7.9	14.1	19.1	24.7	45.7	15.6
Setaria barbata	G	—	12.1	9.1	10.8	14.4	14.8	25.4	18.1	15.2	—	16	6.4	11.8
Rottboellia cochinchinensis	G	—	—	34.5	28.4	23.7	28.9	—	32.1	20.9	—	10.7	6	15.4
Dactyloctenium aegyptium	G	—	—	3.7	—	—	—	7.1	9.1	—	—	—	—	3.5
Grasses	G	—	—	—	8.5	—	—	—	—	—	—	—	—	0.71
Daniellia oliveri	BL	—	—	1.8	—	—	—	—	—	—	—	—	—	0.2
Hyptis suaveolens	BL	—	—	1.8	—	7.3	—	—	—	—	10.1	4.4	7.5	1.5
Vernonia galamensis	BL	—	—	—	—	—	—	—	—	—	—	3.2	—	0.3
Gomphrena celosioides	BL	—	—	—	—	—	—	—	—	—	—	3.2	—	0.3
Cyperus esculentus	S	—	—	—	8.5	—	—	—	—	—	9.1	—	—	1.5
Kyllinga squamulata	S	—	—	—	—	—	—	—	—	7.6	—	—	—	0.6
Pycreus lanceolatus	S	—	—	—	—	—	—	—	—	5.3	—	—	—	0.4
Weed species richness		3	3	7	6	6	5	4	6	7	9	9	5	

P = Primextra, SHW = Supplementary hoe weeding at 6 WAS, F = Flat seed bed, R = Ridge seed bed, Gf = Guard force, A = Aminicome, Pf = Paraforce, G = Grasses, BL = Broad-leaved, S = Sedges.

Table 5: Effect of seed bed configuration and weed control method on agronomic traits

Treatment	Plant height							
	6 WAS		12 WAS		100-seed weight		Grain yield (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019
Seed bed configuration (SBC)								
Flat	88.6a[1]	74.8a	162.6a	154.3a	20.6a	18.9a	2675.8a	1879.4a
Ridges	85.9a	76.9a	157.5a	155.4a	20.6a	20.3a	2000.1a	1978.7a
LSD (0.05)	10.85	5.03	8.86	11.7	1.49	2.49	1051.2	413.69
Weed control method (WCM)								
Primextra at 1.5 + One SHW at 6 WAS	86.8a	80.3a	161.8ab	162.4a	20.9a	20.6a	2650.9a	2523.4ab
Primextra + Aminicome at 1.5 + 1.5	83.2a	75.7a	150.5b	153.4a	22.0a	19.0a	2478.9a	1883.9b
Primextra + Guard force at 1.5 + 0.03	96.0a	77.3a	169.4a	153.5a	21.6a	21.5a	2201.2ab	1953.5ab
Primextra + Paraforce at 1.5 + 0.7	84.5a	80.8a	158.4ab	162.5a	21.9a	20.5a	2323.3ab	2208.7ab
3 and 6 WAS	87.8a	77.2a	165.6ab	165.8a	20.5a	21.4a	2352.2ab	2626.5a
Weedy check	85.5a	64.0b	154.6ab	131.7b	17.6b	14.6b	632.5b	378.7c
LSD (0.05)	18.7a	8.7	15.34	20.25	2.57	4.3	1820.8	716.53
Interaction								
SBC × WCM	NS	NS	NS	NS	NS	NS	NS	NS
ANOVA								
SBC	0.61	0.37	0.24	0.84	0.96	0.25	0.06	0.62
WCM	0.76	0.007	0.015	0.02	0.01	0.02	0.02	0.001
SBC × WCM	0.11	0.69	0.06	0.76	0.68	0.7	0.61	0.32

WAS = Weeks After Sowing, 1 = Means with the same letter(s) within a column are not significantly different at 5% probability according to least significant difference (LSD), NS = Not Significant.

Digitaria horizontalis in descending order of importance at 6 WAS (Table 3) and the predominance of *Paspalum scrobiculatum, Digitaria horizontalis, Rottboellia cochinchinensis, Brachiaria lata*, and *Setaria barbata* in descending order of importance at 12 WAS (Table 4). Gani et al. [15] reported that the predominance of weed species implies their high adaptive capacity which makes them to be more persistent and competitive with crops they associate with. However, specific treatment combinations which effectively controlled some of the above grass weed species in addition to broad-leaved weeds at 12 WAS (Table 4) include Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} + flat which controlled *Paspalum scrobiculatum* and *Digitaria horizontalis*, while Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} + ridge controlled *Digitaria horizontalis* and *Brachiaria lata*. Treatment combinations of Primextra + One SHW at 6 WAS + flat controlled *Rottboellia cochinchinensis*, *Digitaria horizontalis,* and *Brachiaria lata,* while Primextra + One SHW at 6 WAS + ridge controlled only *Rottboellia cochinchinensis*. Furthermore, Primextra + Paraforce + flat controlled *Digitaria horizontalis* and *Brachiaria lata,* while Primextra + Paraforce + ridge controlled *Rottboellia cochinchinensis* and *Brachiaria lata*. Treatment combination of two hoe weeding + flat controlled *Rottboellia cochinchinensis,* while two hoe weeding + ridge controlled *Brachiaria lata,* and Primextra + Aminicome + ridge controlled *Digitaria horizontalis*. These results provide information on the spectrum of weeds each of the treatment combinations can control. The above treatment combinations can also be applied in rotation to provide sustainable weed management and the prevention of herbicide resistant weeds and weed flora shift in maize.

3.3 Effect of weed control method and seed bed configuration on agronomic traits of maize

There was no significant difference between plant height of crops growing in the flat and ridged seed beds (Table 5). But weed control method affected plant height significantly at 6 WAS in 2019 and at 12 WAS in both years. Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} resulted in maize plants that were significantly ($p \leq 0.05$) taller than the weedy check, but were comparable with other weed control methods at 6 WAS in both years, while at 12 WAS, the same trend was recorded but Primextra + Aminicome at 1.5 + 1.5 kg a.i. ha^{-1} and weedy check produced significantly ($p \leq 0.05$) shorter plants in 2018 and in 2019, respectively. The interaction between weed control treatments and seed bed configuration was not significant. The ability of the weed control methods to significantly

Table 6: Economic assessment of seed bed configuration and weed control method in maize production

Treatment	Herbicide rates (kg a.i. ha^{-1})	Yield (kg ha^{-1})			Average cost of production ($)	Total revenue [R] ($)	Gross margin [GM] ($)	Return on investment [r]
		2018	2019	Mean				
P + One SHW + R	1.5	1326.7abc[1]	2585.3a	1955.9ab	469.62	604.4	134.8	1.287
P + One SHW + F	1.5	3975.2a	2461.5a	3218.5a	451.2	994.52	543.41	2.204
P + A + R	1.5 + 1.5	2469.0abc	1842.2abc	2155.6ab	459.63	666.1	206.54	1.449
P + A + F	1.5 + 1.5	2488.7abc	1925.6abc	2207.2ab	423.42	682.02	258.69	1.611
P + Gf + R	1.5 + 0.03	1833.8abc	1639.2abc	1736.5abc	447.57	536.58	89.08	1.2
P + Gf + F	1.5 + 0.03	2568.5abc	2267.8ab	2418.1a	426.8	747.2	320.52	1.751
P + Pf + R	1.5 + 0.7	1190.7abc	2448.8a	1819.8abc	456.89	562.32	105.5	1.231
P + Pf + F	1.5 + 0.7	3455.9ab	1968.7abc	2712.3a	432.54	838.1	405.56	1.938
3 and 6 WAS + R		2041.7abc	3085.8a	2563.7a	465.5	792.18	326.68	1.701
3 and 6 WAS + F		2662.6abc	2166.7ab	2414.7a	422.88	746.14	323.26	1.764
Weedy check + R		360.9c	271.2c	316.0c	376.42	97.64	−278.78	0.259
Weedy check + F		904.1bc	486.3bc	695.1bc	343.86	214.79	−129.07	0.601
ANOVA								
SBC × WCM		0.04	0.04	0.01				

1 = Means in the same column followed by the same letters are not significantly different at 5% level of probability according to Duncan's multiple range test, Price of maize in 2019/2020 = $0.309.00/1 kg of maize grain, P = Primextra, Gf = Guard force, Pf = Paraforce, A = Aminicome, F = Flat, WAS = Weeks after sowing, R = Ridge.

($p \leq 0.05$) reduce weed biomass, weed density, and weed cover minimized weed competition with the crops, thereby freeing enough growth factors of water, mineral nutrients, and sunlight for the production of more assimilates and taller plants. Similar result was reported by Khan et al. [16] that utmost maize plant height from herbicide treatments was due to availability of nutrients to maize plants in the absence of weeds.

One hundred seed weight from flat and ridged seed beds did not differ significantly, while all the weed control methods resulted in seeds that were significantly heavier than those from weedy check (Table 5). Grain yields from ridged and flat beds plots did not statistically differ ($p \leq 0.05$); however, Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS and Primextra + Aminicome at 1.5 + 1.5 kg a.i. ha^{-1} produced the highest grain yield which was comparable with the other treatments but was significantly greater ($p \leq 0.05$) than weedy check in 2018, while in 2019, plots treated with hoe weeding at 3 and 6 WAS had significantly ($p \leq 0.05$) higher grain yield which was on par with only Primextra at 1.5 at kg a.i. ha^{-1} + One SHW, Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1}, and Primextra + Paraforce at 1.5 + 0.07 kg a.i. ha^{-1}, but significantly higher than Primextra + Aminicome at 1.5 + 1.5 kg a.i. ha^{-1} which in turn produced yield that was significantly greater than the weedy check. The good yield performance of the weed control treatments, namely, application of reduced rate of herbicide plus one SHW at 6 WAS, pure herbicide combinations, and two hoe weeding at 3 and 6 WAS, was attributed to their ability to give better weed control of all the broad-leaved, sedge, and some grass weed species which minimized weed competition, thus making more growth factors available to crops for better growth, the production of heavier seeds, and higher grain yields. The above mentioned weed control methods can make the list of weed management options which could serve as alternatives to two hoe weeding at 3 and 6 WAS for safer and effective weed control in maize production. The low yield in the weedy check could be due to the intense weed competition with the maize plants. This is in line with the findings of Khan et al. [17] who reported low yield in weedy check.

3.4 Economic performance of seed bed configuration and weed control methods in the production of maize

Table 6 shows the economic benefits of seed bed configuration and methods of weed control. It shows that Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS and Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1} applied on flat seed beds resulted in maize yields (3975.2 and 3455.9 kg ha^{-1}, respectively), not statistically different from other weed control treatments, but were significantly ($p \leq 0.05$) greater than the weedy check applied on flat (904.1 kg ha^{-1}) or ridged seed beds (360.9 kg ha^{-1}) in 2018. In 2019, two hoe weeding at 3 and 6 WAS carried out on ridged seed bed, Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS applied on ridged or flat seed beds, and Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1} applied on ridged seed bed gave significantly higher grain yields (3085.8, 2585.3, 2461.5, and 2448.8 kg ha^{-1}, respectively), which were comparable with other weed control methods, but were significantly higher than the weedy check. The mean values of the two years showed that both Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS and Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1} applied on flat seed beds, two hoe weeding at 3 and 6 WAS + ridged or flat seed beds, and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} applied on flat seed bed resulted in maize yields (3218.4, 2712.3, 2563.7, 2414.7, and 2418.1 kg ha^{-1}) significantly ($p \leq 0.05$) higher than the weedy check, but comparable with other treatment combinations. The ability of the above treatment combinations to significantly reduce weed infestation throughout the season probably allowed the absorption of more growth resources by maize crop for better performance compared to the weedy check. The lowest average cost of crop production was incurred by the weedy check plus flat ($343.8) and ridged seed beds ($376.42), followed by weeding at 3 and 6 WAS plus flat ($422.88), while the highest cost of production was associated with treatment combinations of Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS and two hoe weeding at 3 and 6 WAS applied on ridged seed beds ($469.62 and $465.50, respectively). This could be due to the extra cost of making ridges and supports the findings of Dimri and Bankoti [9] that raised seed bed method of planting resulted in higher cost of cultivation over flat seed bed method of planting. The highest revenue came from the plots treated with Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS + flat seed bed ($994.52), followed by Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1} + flat ($838.10), two hoe weeding at 3 and 6 WAS + ridge ($792.18), and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} + flat ($747.20), while the lowest revenue was produced by the weedy check + ridged seed beds ($97.64). The treatment combinations with the highest gross margin (profit) and returns on investment were Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS + flat ($543.41 and 2.204), followed by Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1} + flat ($405.56 and 1.938), two hoe weeding at 3 and 6 WAS +

ridged seed bed ($326.68 and 1.701), two hoe weeding at 3 and 6 WAS + flat seed bed ($323.26 and 1.764), and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} + flat seed bed ($320.52 and 1.751). The application of reduced herbicide rates, namely, Primextra at 1.5 kg a.i. ha^{-1} + One SHW at 6 WAS, Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1}, and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} applied on flat seed beds resulted in better agronomic and economic performance compared to the other treatment combinations and are recommended to farmers as alternative to two hoe weeding at 3 and 6 WAS, which is associated with drudgery. This contradicts the findings of Nadeem et al. [10] that treatment combination of herbicide with ridge sowing resulted in higher economic returns than flat sowing.

4 Conclusion

From the findings of this study, it can be concluded that flat bed resulted in better control of weed density compared to ridged beds at the later part of the season. Similarly, there was no difference in the grain yield obtained from the flat and ridged seed beds. All the weed control methods including the combination of reduced herbicide rates and SHW at 6 WAS provided effective and season-long weed control and higher maize grain yield comparable with two hoe weeding at 3 and 6 WAS. All treatment combinations of Primextra at 1.5 kg a.i. ha^{-1} + One SHW, Primextra + Paraforce at 1.5 + 0.7 kg a.i. ha^{-1}, and Primextra + Guard force at 1.5 + 0.03 kg a.i. ha^{-1} applied on flat seed beds and two hoe weeding at 3 and 6 WAS applied on ridged seed beds resulted in better agronomic and economic performance compared with other treatments. Therefore, the combinations of these reduced herbicide rates applied on flat seed beds are recommended for rotational application and alternatives to two hoe weeding plus ridged seed beds for effective weed control, higher maize grain yield, economic returns, and minimization of herbicide residue in maize production.

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