Management approaches on maize (Zea Mays L.) Growth and yield using mesotrion and atrazine herbicides

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ABSTRACT

Maize (Zea mays L.) is a vital staple crop worldwide, but its productivity is often constrained by weed competition, particularly during early growth stages. This study evaluated the effectiveness of different weed management strategies using Mesotrione and Atrazine herbicides in combination with manual weeding across three maize varieties (MMRI Yellow, Pearl White, and Afghoiy). The experiment was conducted in summer 2019 under a Randomized Complete Block Design with three replications and five weed control treatments. Parameters recorded included weed density, biomass, plant height, ear height, stem diameter, leaf area, biological yield, and grain yield. Results indicated that both herbicide application and hand weeding significantly reduced weed density and biomass compared to untreated plots. The highest biological yield (18.28 t ha^{-1}) and grain yield (4.03 t ha^{-1}) were achieved with the recommended dose of Xiaowang (1X), which performed similarly to hand weeding. Moreover, a half dose of Xiaowang (½X) proved cost-effective while still delivering substantial weed suppression and yield improvements. These findings highlight the potential of integrated weed management strategies, where reduced herbicide doses combined with manual weeding can improve maize productivity while minimizing environmental and economic costs. The study suggests that herbicides, particularly at lower doses, can serve as an efficient and sustainable alternative to labor-intensive manual weeding in large-scale maize production systems.

Keywords: *Maize, Atrazine, Mesotrione, Manual weeding, Herbicides, Weed density, Weed biomass, Weed control efficiency, Grain yield.*
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Highlights of this paper

- Integrating Mesotrione and Atrazine herbicides with manual weeding effectively reduced weed pressure and enhanced maize growth and yield.
- Although hand weeding was most effective, Xiaowang at full and half doses offered a cost-efficient and scalable alternative for large-scale production.
- Integrated weed management combining cultural and chemical practices provides a sustainable approach to improve maize productivity while reducing environmental risks.

1. INTRODUCTION

Maize (Zea mays L.) is one of the most important cereal crops worldwide, ranking third after wheat and rice in terms of global production. It serves as a staple food, a major source of animal feed, and a raw material for various industrial products. Maize is rich in essential nutrients, including vitamins, minerals, starch, and proteins. On a dry weight basis, mature maize kernels contain approximately 71.7% starch, 9.5% protein, 4.3% oil, 1.4% ash, and 2.6% sugar per 100 grams [1]. This high nutritional value makes maize both economically and nutritionally significant, particularly in countries like Pakistan, where it is widely consumed as a staple food and utilized in diverse industrial applications.

In Pakistan, maize contributes about 2.6% to total agricultural production and 0.5% to the national GDP. The cultivated area expanded to 1.318 million hectares in 2018–2019, reflecting a 5.42% increase compared to the previous year. In 2017–2018, maize production reached a record 6.31 million tonnes, largely attributed to the adoption of improved varieties and the use of enhanced agricultural inputs inputs [2]. Despite this progress, the average yield remains below potential, primarily due to weed infestation. Weeds compete with maize for essential resources such as water, nutrients, sunlight, and space, leading to significant reductions in crop productivity.

Weeds, particularly during the early growth stages of maize, severely affect crop development by competing for essential resources and releasing allelochemicals that suppress maize growth, delay flowering, and reduce overall productivity. Previous studies have reported that weed competition can lower maize yields by up to 51%, with the extent of yield loss largely depending on the intensity of infestation and the timing of weed control practices [3, 4]. Therefore, the adoption of effective weed management strategies is crucial to achieving optimal maize production.

Managed weeds are beneficial to the growth and yield of maize. Manual weeding has been popular traditionally, but it is time-consuming and not economical when applied on mass farming. However, in recent years herbicides have taken over as the principal means of controlling weed because they are effective, convenient to use and cost effective. But there are environmental drawbacks to herbicides, which include herbicide resistance, soil erosion and threat of biodiversity. This has seen the emergence of integrated weed management (IWM) systems which combine the use of herbicides with other practices, such as manual weeding and crop rotation, to mitigate the adverse environmental effects of herbicides, as well as make them more sustainable [5, 6].

Effective weed management is essential for improving maize growth and yield. Traditionally, manual weeding has been widely practiced; however, it is labor-intensive, time-consuming, and uneconomical on a large scale. In recent years, herbicides have become the primary method of weed control due to their effectiveness, ease of application, and cost efficiency. Nevertheless, the intensive use of herbicides poses several environmental challenges, including the development of herbicide-resistant weed populations, soil degradation, and threats to biodiversity. To address these concerns, integrated weed management (IWM) systems have been introduced, which combine herbicide use with other practices such as manual weeding, crop rotation, and cultural techniques. These approaches aim to minimize the negative environmental impacts of herbicides while enhancing their long-term sustainability [5, 6].

Some of the best-performing maize herbicides can kill broadleaf and grassy weeds i.e. Atrazine and Mesotrion. Certain broad leaf weeds are controlled by Atrazine, whereas Mesotrion is an all round herbicide that in combination with Atrazine causes synergetic effects that help eliminate most weeds. Research findings also indicate that blending these two herbicides has better weed control effect as opposed to utilizing any of them independently [7-11]. As an example, as Chhokar, et al. [12] recently demonstrated, the combination of Atrazine and Mesotrione produced a strong effect in the weed control and crop safety increases. Likewise, Matte, et al. [6] have reported that Atrazine + Mesotrione reduced the number of various weeds and increased corn production. Bottcher, et al. [13] have shown that the combination of Atrazine + Mesotrione is effective even in Brazilian field conditions, which once again proves their universal value in terms of their uses. In addition to the issues regarding herbicide residues, Zhang, et al. [14] also reported that there are no safety issues traceable to the use of the herbicides when used at recommended dosage levels.

The results support a call to focus on integrated control over weed proliferation by maintaining the balance between the chemicals and manual methods of control of weeds on maize farms to maintain maize productivity and reduce environmental hazards. This paper assesses various strategies of weed management with emphasis on combination of Mesotrion and Atrazine herbicides with manual weeding. The experiment pertains to three varieties of maize and five weed management practices aimed at determining the most effective and sustainable relationship in managing weeds and leading to high productivity of the maize crop with minimal effect on the environment [15, 16]. The present study will bring new knowledge into reasonable and sustainable practices of maize weed control.

2. MATERIALS AND METHODS

2.1. Experimental Design

The experiment was conducted during the summer of 2016 at the research area of the Faculty of Agriculture, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. A Randomized Complete Block Design (RCBD) with a split-plot arrangement and three replications was employed. The main plots were assigned to three maize cultivars (MMRI Yellow, Pearl White, and Afghoiy), while the sub-plots consisted of five weed management treatments, including the application of different herbicides and manual weeding.

2.2. Weed Management Treatments

The following treatments were applied:

1. Control/Weedy Check: No weed management applied.
2. Hand Weeding: Manual removal of weeds 15 and 30 days after sowing (DAS).
3. Dafli Herbicide: Applied at 1250 g ha-1, containing 40% Atrazine and 10% Mesotrion.
4. Xiaowang (1X): Applied at 1250 ml ha-1, containing 44% Atrazine and 5% Mesotrion.
5. Xiaowang Reduced Dose (½ X): Applied at 625 ml ha-1.

Herbicides were applied 21 days after sowing using a hand pump with a flat jet nozzle in the afternoon.

2.3. Field Measurements

The following parameters were recorded:

- Weed Density (m^2): Weed density was recorded before and after herbicide application using a 1 m^2 quadrat.
- Fresh and Dry Weed Biomass (g m^2): Biomass was harvested from a 1 m^2 area before and after herbicide application.
- Plant Height (cm): Measured from the base of the plant to the initiation point of the tassel at maturity.
- Number of Ears (m^2): The number of ears collected at harvest.

- Biological Yield (kg ha^{-1}): Calculated based on the harvested area of each subplot.
- Grain Yield (kg ha^{-1}): Measured after drying the grains under sunlight for 5-8 days.

2.4. Statistical Analysis

Data was analyzed using Analysis of Variance (ANOVA), followed by Tukey's HSD Test for mean comparisons. The statistical analysis was performed using the Statistix computer software.

3. RESULTS

3.1. Effect of Weed Control Treatments on Crop Growth Parameters

3.1.1. Weed Density (m^2) Before and After Spray

The results of weed density before and after spraying are presented in Table 1. Significant differences were observed among the treatments. The weedy check recorded the highest weed density, with 144.33 m^2 before spraying and 157.33 m^2 after spraying. In contrast, hand weeding markedly reduced weed density to 151.00 m^2 before spraying and 144.67 m^2 after spraying. The Xiaowang (1X) treatment lowered weed density to 120.67 m^2 before spraying and 148.33 m^2 after spraying, while the reduced dose of Xiaowang (½X) showed a moderate effect, with values of 134.67 m^2 and 151.00 m^2 before and after spraying, respectively. Similarly, the Dafli treatment reduced weed density to 120.67 m^2 before spraying and 148.33 m^2 after spraying. Overall, hand weeding and Xiaowang (1X) were the most effective treatments in suppressing weed density, whereas the reduced dose of Xiaowang (½X) and Dafli were comparatively less effective but still superior to the untreated control.

3.1.2. Germination (%)

The results for germination percentage are presented in Table 2. The data showed that treatments had no significant effect on maize germination. At this stage, no chemical treatments had been applied, although pots had already been allocated to each treatment. Soil variation appeared to influence germination percentage. Among the treatments, the reduced dose of Xiaowang (½X) recorded the highest germination (95.83%), followed by Dafli (91.67%), whereas the weedy check showed the lowest (83.60%). Across varieties, Afghoiy exhibited the highest germination (95.62%), followed by MMRI Yellow (90.83%), while Pearl White recorded the lowest (83.93%). Treatment × variety interactions were statistically non-significant; however, the highest germination (100%) was observed in Hand Weeding × Afghoiy and Xiaowang (½X) × MMRI Yellow. These were followed by Dafli × MMRI Yellow and Xiaowang (1X) × MMRI Yellow, both recording 95.83%. The lowest germination (79.17%) occurred in the Weedy Check × MMRI Yellow interaction.

3.1.3. Days to 50% Tasseling and Silking (Days)

The results for days to 50% tasseling and silking are presented in Table 2. The weedy check recorded the longest duration to tasseling (79.17 days) and silking (81.67 days), indicating a significant delay in reproductive development. In contrast, hand weeding promoted the earliest tasseling (83.33 days) and silking (81.67 days), followed closely by Xiaowang (1X), which reached tasseling at 84.33 days and silking at 85.33 days. Dafli required 85.33 and 86.00 days for tasseling and silking, respectively, while the reduced dose of Xiaowang (½X) showed similar results (85.67 and 86.33 days). Overall, hand weeding and herbicide treatments accelerated tasseling and silking compared with the untreated control.

3.1.4. Ear Height at Maturity (cm)

Aspects about ear height at maturity mentioned in Table 2 indicated that Xiaowang reduced dose (2X) scored the highest with 68.67 cm, followed by Xiaowang (1X) 66.67 cm and hand weeding, 65.33 cm. The shortest ear length was 38.30 cm on the weedy check. This implies that the process of treating herbicide, especially herbicide Xiaowang 1X and reduced dose Xiaowang 2X, would encourage improved ear growth than the manual or untreated plots.

3.1.5. Stem Diameter (cm)

The results of stem diameter analysis at maturity, which are in Table 2 indicated that hand weeding produced the largest stem diameter (2.46 cm), while Xiaowang (1X)(1.90 cm) and Dafli (1.75 cm) recorded the second and third ranking respectively. The Xiaowang reduced dose (2X) produced the thickest diameter of the stem at 1.59 cm followed by the weedy check with the smallest stem diameter at 0.79 cm. These results indicate that hand weeding and Xiaowang (1X) enhance better stems which are vital in the growth and stability of the plant.

3.1.6. Leaf Area (cm^2)

The results on leaf area as indicated in Table 2 revealed that hand weeding produced largest leaf area (63.68 cm 2) followed by Dafli (69.39 cm 2) and Xiaowang (1X) (60.36 cm 2). Leaf area was also the least in the weedy check (37.98 cm 2). The findings indicate that effective weed control particularly hand weeding and Da fli would cause an increase in leaf area which is crucial in having maximum photography and all over plant growth.

3.1.7. Biological Yield (Ton/ha^{-1})

The results on biological yield were observed as in Table 2 Maximum biological yield was obtained in the hand weeding treatment 18.28 tons/ha, followed by Xiaowang (1X) (16.25 tons/ha) and Dafli (16.62 tons/ha). The weedy check gave the lowest biological yield (14.21 tons/ha). These results validate the argument that weed control measures would enhance significant increase in biomass and hand weeding was the most effective.

3.1.8. Grain Yield (Ton/ha^{-1})

The grain yield results are presented in Table 2. Hand weeding achieved the highest grain yield (4.03 tons/ha), followed by Dafli (3.83 tons/ha) and Xiaowang (1X) (3.65 tons/ha). The weedy check had the lowest grain yield (2.94 tons/ha). These results highlight the importance of efficient weed management in improving crop yield, with hand weeding proving to be the most effective.

Table 1. Suppressing effect of maize varieties and weed management on kind of weeds.

Weeds	Treatments	Varieties					
		Afghoiy		MMRI Yellow		Pearl White	
		Before	After	Before	After	Before	After
Deela (Cyprus rotundas)	Weedy check	37.3 ab	39.7 c	39.4 a	43.5 b	38.0 ab	55.6 a
	Hand weeding	28.5 e	1.5 g	32.6 c	8.9 e	30.9 d	10.12 d
	Dafli	29.0 d	8.5 a	33.2 c	10.3 de	35.4 b	12.5 e
	Xiaowang (1 X)	35.0 b	7.6 f	33.4 c	8.9 e	38.5 ab	9.12 e
	Xiaowang reduced dose (½ X)	36.0 b	8.7 e	34.4 b	11.2 d	39.5 a	13.5
	Means	**33.16 c**	**13.20 c**	**34.8 b**	**16.56 b**	**36.46 a**	**20.17 a**
Goose grass (Eleusine indica L.)	Weedy check	12.42 d	19.4 c	22.32 c	27.32 b	26.23 b	40.2 a
	Hand weeding	13.21 d	3.2 f	21.27 c	5.3 e	22.21 c	5.6 e
	Dafli	9.14 e	6.4 d	26.26 bc	6.7 d	23.26 c	6.7 d
	Xiaowang (1 X)	9.15 e	5.6 e	29.27 b	5.6 e	27.28 b	7.2 d
	Xiaowang reduced dose (½ X)	11.13 d	7.2 d	31.26 a	7.0 d	21.27 c	8.9 d
	Means	**11.01 c**	**8.36 c**	**25.67 a**	**10.38 b**	**24.07 b**	**13.72 a**
Bermuda grass (Cynon dactylon)	Weedy check	20.45 f	27.5 c	20.98 f	30.4 b	22.45 f	35.6
	Hand weeding	10.82 i	2.7 h	54.46 a	8.9 g	50.15 b	14.5
	Dafli	21.2 f	3.5 h	29.42 e	10.5 f	32.71 de	18.4
	Xiaowang (1 X)	19.15 g	6.2 g	39.46 c	12.6 e	34.78 d	12.8
	Xiaowang reduced dose (½ X)	14.42 h	8.2 g	37.60 cd	15.6 d	39.87 c	16.2
	Means	**17.21 b**	**9.62 c**	**36.38 a**	**15.60 b**	**35.99 a**	**19.50 a**
Horse purslane (Trianthema portula castrum L.)	Weedy check	38.5 d	40.6 c	39.6 d	56.7 b	37.7 d	62.2 a
	Hand weeding	20.2 f	3.7 g	27.4 e	9.5 f	56.5 a	12.3 e
	Dafli	24.4 f	4.2 g	55.6 a	12.5 e	47.4 c	21.5 d
	Xiaowang (1 X)	26.5 e	10.3 f	28.7 e	11.6 e	52.8 b	16.8 f
	Xiaowang reduced dose (½ X)	29.6 e	9.5 f	57.6 a	20.6 d	38.9 d	21.2 d
	Means	**27.84 c**	**13.66 c**	**41.78 b**	**22.18 b**	**46.66 a**	**26.84 a**
Field bind weed (Convolvulus arvensis)	Weedy check	31.92 c	3.6 c	20.98 f	39.2 b	34.21 b	42.3 a
	Hand weeding	27.92 de	2.5 h	25.72 e	7.6 f	24.31 e	7.9 f
	Dafli	26.91 e	5.3 g	27.82 de	5.8 g	35.21 b	5.9 g
	Xiaowang (1 X)	29.21 d	6.3 f	29.29 d	6.5 f	27.21 de	7.8 h
	Xiaowang reduced dose (½ X)	32.10 c	7.6 f	37.26 a	10.7 e	32.31 c	12.8 d
	Means	**29.61 b**	**11.54 c**	**28.21 b**	**13.96 a**	**30.65 a**	**15.34 a**
Miscellaneous	Weedy check	21.21	37.0 b	27.32	41.2 a	25.21	42.3 a
	Hand weeding	17.21	2.5 f	18.5	6.7 d	21.3	7.7 d
	Dafli	19.27	3.5 f	29.16	5.6 e	27.23	6.9 d
	Xiaowang (1 X)	15.67	7.2 d	21.21	8.6 d	23.24	12.3 c
	Xiaowang reduced dose (½ X)	15.59	8.6 cd	23.26	10.2 cd	26.27	9.6 cd
	Means	17.79 c	11.76 b	23.89 b	14.46 a	24.65 a	15.76 a

Note: Means within the same column followed by different letters (a, b, c, d, e, f, g, h) are significantly different from each other at P ≤ 0.05 according to the LSD test.

Table 2. Effect of weedicides on weed density, germination and tasseling, Days to 50% silking, Ear height (cm) at maturity, stem diameter (cm), leaf area (cm^{-2}), Biological yield (ton ha^{-1}) and Grain yield (ton ha^{-1}).

Treatments	**Weeds density (m^{-2}) before spray**			**Weeds density (m^{-2}) after spray**		
Varieties	**Afghoiy**	**MMRI Yellow**	**Pearl White**	**Afghoiy**	**MMRI Yellow**	**Pearl White**
Weedy check	144.33 NS	157.33	194.67	167.33 b	278.00 a	296.00 a
Hand weeding	151	144.67	190.33	24.00 e	42.67 e	66.33 d
Dafli	120.67	148.33	209.66	31.00 e	64.67 d	55.67 d
Xiaowang (1 X)	102.33	154.33	242.33	43.00 d	62.33 d	77.67 c
Xiaowang reduced dose (½ X)	134.67	151	186	44.67 d	84.67 c	85.33 c
Mean	130.06 c	151.13 b	204.59 a	62.00 c	106.48 b	116.02 a
	Germination%			**Days to 50% Tesseling**		
Weedy check	98.96 NS	79.17	81.67	60.67 a	61.33 a	62.67 a
Hand weeding	100	83.33	81.67	51.67 b	53.00 b	55.67 ab
Dafli	91.67	95.83	85	53.33 ab	55.33 ab	56.33 ab
Xiaowang (1 X)	91.67	95.83	84	55.33 ab	56.00 ab	59.33 ab
Xiaowang reduced dose (½ X)	95.83	100	87.5	57.33 ab	54.00 b	61.33 a
Mean	95.62 a	90.83 ab	83.9 b	55.66 a	55.93 a	59.00 a
	Days to 50% silking			**Ear height (cm) at maturity**		
Weedy check	68.67 a	70.33 a	71.67 a	38.30NS	40.63	43.92
Hand weeding	61.00 bc	62.33 b	65.00 b	28.07	41.12	50.46
Dafli	63.33 b	63.67 b	65.00 b	34.5	39.33	44.24
Xiaowang (1 X)	63.33 b	65.33 ab	66.67 ab	38.8	42.92	45.32
Xiaowang reduced dose (½ X)	65.00 b	66.00 ab	68.67 a	37.45	40.31	44.12
Mean	64.26 c	65.53 b	67.40 a	35.42 c	40.86 b	45.61 c
	Stem diameter (cm)			**Leaf area (cm^{-2})**		
Weedy check	0.91 c	0.87 c	0.79 c	57.98NS	57.38	43.47
Hand weeding	2.5 a	2 .46 a	1.72 b	63.68	57.04	45.8
Dafli	1.96 b	1.90 b	1.59 b	69.39	48.76	46.47
Xiaowang (1 X)	1.82 b	1.75 b	1.23 bc	60.36	41.58	58.12
Xiaowang reduced dose (½ X)	1.61 b	0.99 c	0.98 c	69.95	51.26	41.85
Mean	1.76 a	1.60 b	1.26 c	64.27 a	51.20 b	47.14 c
	Biological yield (ton ha^{-1})			**Grain yield (ton ha^{-1})**		
Weedy check	16.45 f	14.21 g	12.82 h	3.27 g	2.94 h	2.83 h
Hand weeding	19.92 a	18.28 a	17.37 b	4.70 a	4.35 b	4.03 c
Dafli	18.83 b	17.45 b	16.62 d	4.41 b	4.06 c	3.83 d
Xiaowang (1 X)	18.46 b	16.25 e	16.05 g	4.37 b	3.85 d	3.65 e
Xiaowang reduced dose (½ X)	18.43 b	15.54 f	14.04 h	3.55 ef	3.51 f	3.53 ef
Mean	18.41 a	16.34 b	15.38 c	4.06 a	3.74 b	3.58 c

Note: Means within the same column followed by different letters (a, b, c, d, e, f, g, h) are significantly different from each other at $P \leq 0.05$ according to the LSD test.

4. DISCUSSION

This study evaluated the effects of different weed management strategies, particularly the use of Mesotrione and Atrazine herbicides in combination with manual weeding, on maize growth and productivity. The results provide valuable insights into how these approaches influence key maize growth parameters, including weed density, biomass, plant height, ear height, stem diameter, leaf area, biological yield, and grain yield. Reducing weed density and biomass is critical for maximizing maize yield, and our findings show that both hand weeding and herbicide application significantly decreased these factors. Manual weeding was the most effective method, as it reduced weed biomass more than any herbicide treatment, highlighting its strong role in minimizing weed competition. However, herbicide application remains a more cost-effective and practical option for large-scale farming, as hand weeding is highly labor-intensive. These results are consistent with the findings of Ganie and Jhala [17], who reported that Mesotrione–Atrazine combinations enhance weed suppression efficacy in maize cropping systems.

Xiaowang (1X) herbicide was especially useful to reduce density of weeds similar to hand weeding in line with the results of Swetha, et al. [18] and Kakade, et al. [15] who indicated that herbicides such as Atrazine and Mesotrione effectively reduce biomass of weeds giving rise to better crop production. The Xiaowang reduced dose (1/2 X) also performed well in controlling weeds and this is cost effective as reported by Iqbal, et al. [5] and Abit, et al. [19] who posit that mesotrione-based program is not only effective but also safe in the growth of maize crops. It has been observed that in wheat farming, herbicide use may contribute to undesirable ecological outcomes that can include pollution and herbicide resistance [20]. This lends credence to our results that although herbicides are effective in curbing the population, the long run consequences on the environment must be taken into consideration. Consequently, the combination of the cultural crop production practices, e.g., hand weeding or cross-drilling, with herbicides can represent a more sustainable method of controlling weeds, particularly in reference to herbicide resistance stressed by Ramesh, et al. [21]. There was no significant difference in germination of treatments, but variety Afghoiy had the highest percentage of germination, as suggested elsewhere [15]. With regard to plant growth, the treatments had significant effects on the time of tasseling and silking. Hand weeding and herbicide application (specifically, Xiaowang) made the crop set out to tasseling and silking earlier than the weedy check, which serves as further evidence of the relevance of early suppression of weeds to ensure timely development of crops [5, 18]. As further demonstrated by Ul Haq, et al. [22] the importance of such a cultural control measure as a cross-drilling, to enhance crop establishment by minimizing early crop-weed competition and providing greater access to resources, which, conversely, help the development of the crop at an earlier stage, cannot be underestimated.

Ear height and stem diameter are some of the notable signs of total maize health and strength. It revealed by adding assimilation and photosynthetic efficiency to plant through developing increased girth and diameter of stem. In our study, herbicide treatment, especially Xiaowang (1X) and Xiaowang reduced dose (2X) stimulated better ear growth than manual weeding and the untreated plot. This was in line with the findings on Singh, et al. [23] where herbicide application proved more helpful in the development of the ears. Hand weeding produced the greatest average stem diameter and is important in plant stability validating the physical advantages of manual in weed control. The highest concentration of leaf area to support optimal photosynthesis and general growth of the plants was in the Dafli treatment (40% Atrazine and 10% Mesotrione), the hand weeding and the Xiaowang (1X). The trend is in the case of leaf areas being larger, better growth, and productivity is supported by Kakade, et al. [15]. As in the case of Hussain, et al. [20] cross-drilling cultural control was found to be effective optimal light interception, and photosynthesis by reducing weed competition and stimulating vegetative growth, such as larger leaf area.

The ultimate indicators of maize productivity are the biological and grain yield which yield economic returns. Our findings indicate that hand weeding exerted a substantial influence in enhancing biological yield (18.28 tons/ha) and grain yield (4.03 tons/ha), as adding evidence to the essentiality of efficient weed control in regard to optimal production of maize. This agrees with the results of Swetha, et al. [18] who found out that crop management improved greatly due to decreased management of weeds. Xiaowang (1X) and Dafli (40% Atrazine + 10% Mesotrione) were also very good with the treatments resulting in biological and grain yield of 16.25 tons/ha and 3.65 tons/ha respectively. Half dose of Xiaowang (1 2 X) was also effective and could become a sustainable alternative to large-scale farming with a massive reduction in weed biomass and even more significant increase in the yield. This adds to the results of Iqbal, et al. [5] on the cost-effectiveness and sustainability of low amounts of herbicide. In Ul Haq, et al. [22] cross-drilling and less use of herbicides led to increased grain yield because of the less weed competition just like we obtained in our study on the effectiveness of integrated weed management methods in enhancing the maize yield.

5. CONCLUSION

In summary, the integration of herbicide application, particularly Xiaowang (1X), with manual weeding significantly enhanced maize yield by effectively reducing weed pressure and improving crop growth. While hand weeding proved to be the most effective method for weed suppression and yield improvement, herbicide use especially at the recommended and reduced doses offers a practical, cost-effective, and scalable alternative for large scale farming systems. Future research should focus on identifying optimal herbicide concentrations, assessing their long-term impacts on soil health, and exploring environmentally friendly herbicide options to support sustainable maize production.

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