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Effects of Integrated Nitrogen Fertilization and Weed Management on Growth and Grain Yield of Sorghum Hybrid CS-200

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Abstract: A field experiment was carried out from May 2020 to August 2020 to investigate the impacts of nitrogen (N) fertilization and weed management on enhancing sorghum productivity in Afghanistan. The study included three different weed management practices: W_1 (Two hand weeding 25 and 45 days after sowing), W_2 (Atrazine + one hand weeding 45 days after sowing) and W_3 (Atrazine + Pendimethalin + one hand weeding 45 days after sowing) and four doses of N applications including: N_1 (no N application), N_2 (50 kg N ha^{-1}), N_3 (75 kg N ha^{-1}), and N_4 (100 kg N ha^{-1}). The experiment utilized a split plot design with three replications. The findings revealed that two hand weeding performed at 25 and 45 days after sowing (DAS) was the most effective method for managing weeds in sorghum. The N_4 treatment resulted in significantly improved growth parameters and yield characteristics, closely followed by N_3, with both treatments showing similar results in most observations. The highest seed and Stover yields were also associated with the N_4 treatment, followed by N_3. Thus, it can be concluded that applying 100 kg N per hectare, combined with weed management techniques either through two hand weeding at 25 and 45 DAS or through chemical management using atrazine and pendimethalin along with one hand weeding at 45 DAS enhances sorghum productivity in the agro-ecological conditions of Takhar province, Afghanistan.

Keywords: Sorghum, Yield, Atrazine, Nitrogen, Harvest index

INTRODUCTION

Grain sorghum is extensively cultivated in the semiarid regions of the world for purposes such as animal feed, human consumption, bioenergy, and feedstock. Its drought tolerance and ability to thrive in marginal environments make it a valuable crop for rainfed agricultural systems. Originating from the semiarid areas of Africa, sorghum possesses adaptive traits suited for stressful conditions and demonstrates significant genetic variability for characteristics like low nutrient tolerance and efficiency in water and nutrient utilization (George et al., 2014). Sorghum offers a decent nutritional profile, containing protein (7.5–10.8%), ash (1.2–1.8%), oil (3.4–3.5%), fiber (2.3–2.7%), and carbohydrates (71.4–80.7%), with dry matter percentages ranging from 89.2% to 95.3% (AbdelRahman et al., 2005). Additionally, it serves as a biofuel source through the use of starch, sugar, and other plant-based organic materials (Henzell, 2007).

Nitrogen (N) fertilizer is recognized for enhancing aboveground biomass yields (Anderson et al., 2013) and is crucial for cell division during plant growth (Stals and Inzé, 2001). Insufficient soil N results in reduced sorghum biomass due to decreases in leaf area, chlorophyll levels, and photosynthetic rates (Mahama et al., 2014). In irrigated regions, N fertilizer is essential and significantly impacts the dry matter and yield of sorghum varieties (Rahman et al., 2001). Ensuring proper and efficient use of applied N is vital for overall nutrient management, even more so than for other plant nutrients. Therefore, it is necessary to optimize N fertilizer levels to achieve satisfactory yields and high quality. The effectiveness of N application is a critical factor for its precise application, as it helps to evaluate the differences among cultivars for effective N usage, thereby minimizing contamination and reducing N fertilizer costs (Gardner et al., 1994).

A weed is defined as any plant that poses a threat, nuisance, or harm to humans, their animals, or the crops they desire. This definition highlights that virtually any plant can be considered a weed under specific conditions. Weeds can diminish yields, reduce crop quality, and hinder efficient harvesting.

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These negative impacts ultimately affect consumers, resulting in higher prices or low quality products. Certain weeds, like toxic ivy and oak, can cause significant discomfort for many individuals, while others, such as ragweed, can trigger hay fever, leading to discomfort and increased healthcare costs (Ferrell et al., 2006).

In Afghanistan, managing weeds in grain sorghum presents challenges due to the limited availability of herbicides for farmers. Combining herbicides with N fertilization may help achieve a weed-free crop, enhance N use efficiency, and thereby promote better crop growth and grain yields. Considering these factors, this field experiment aimed to evaluate the combined effects of N fertilization and weed management on the growth and grain yield of the Sorghum hybrid CS-200.

MATERIALS and METHODS

This study was conducted at the Bagh-e-Zakhera research station in the Department of Agriculture, Takhar province, Afghanistan, during the 2020 growing season. In Takhar, the temperature typically varies from 2°C to 37°C and is rarely below -4°C or above 40°C. The rainy period of the year lasts for 5.2 months (December 3 to May 10), with a sliding 31-day rainfall of at least 13 millimeters. The most rain falls during the 31 days centered around March 20, with an average total accumulation of 34 millimeters. The aim of this experiment was to investigate the impacts of various N fertilization levels and weed management practices on the growth and grain yield of sorghum. The experiment was structured as a split-plot design within a randomized complete block design, featuring three replications and twelve treatments. It included four different rates of N: N_1 (no N application), N_2 (50 kg N ha^{-1}), N_3 (75 kg N ha^{-1}), and N_4 (100 kg N ha^{-1}). The source of N was urea fertilizer. A common dose of 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} were applied. Weed management practices were consist of: W_1 (Two hand weeding 25 and 45 DAS), W_2 (Atrazine + one hand weeding 45 DAS) and W_3 (Atrazine + Pendimethalin + one hand weeding 45 DAS). Atrazine and Pendimethalin were applied as pre-emergence herbicides at the rate of 1.5 and 0.7 kg hac^{-1} respectively.

The full doses of phosphorus (P) and potassium (K), along with one-third of the N, were applied at the time of sowing. Each plot measured 5.0 m × 4.5 m (22.5 m^2), with a 1.0 m gap between adjacent plots and a 1.5 m space between blocks. The net plot size was 4.0 m × 3.6 m (14.4 m^2). During land preparation, a uniform application of 60 kg P_2O_5 per hectare and 40 kg K_2O per hectare was made. The land was prepared through two plowings followed by harrowing to achieve suitable tilth for sowing. The field was leveled with a small ladder and arranged for channels, bunds, and borders. The physical and chemical characteristic of soil is given in table 1.

***Table 1**. Chemical and physical characteristics of soil*

Physical characteristics			**Chemical properties**				
Texture class	Clay (%)	Sand	pH	EC (dS/m)	Potassium (ppm)	Phosphorus (ppm)	Nitrogen (%)
Silty loam	18	25	7.83	0.248	78.36	14.65	0.082

A high-yielding sorghum variety, CS-200, was imported from Pakistan for this study. This variety is known for its adaptability across a broad range of agro-ecological areas, thriving at altitudes between 1650 and 2800 meters above mean sea level (m.a.m.s.l.) and receiving annual precipitation ranging from 300 to 1500 mm. CS-200 was released in 2014, it is one of the most successful hybrid varieties. The seeds were manually sown to a depth of 5 cm in the first week of May 2020, with a row spacing of 45 cm and a plant spacing of 15 cm. The planting rows were aligned in a north-south direction to achieve a planting density of approximately 130,000 plants per hectare, with a maintained plant population of 187 plants per plot. All other agronomic practices were consistently applied across all treatments. The sorghum crop received around eight irrigations up to physiological maturity, with the first irrigation occurring at 12 days after sowing (DAS) and subsequent irrigations provided at 10-15 day intervals, depending on rainfall and temperature. The crop was harvested plot-wise at full maturity on August 5, 2020.

Sorghum plant height was measured from five randomly selected tagged plants. The height was measured from the soil surface to the apical branch of plant at 30, 60, 90 DAS and at harvest time. Sample plants were harvested from the area of 1 m^2 of each experimental plots to record biological yield, yield components and total grain yield. The seeds were sun-dried and thoroughly cleaned. Both seed and straw yields were recorded after cleaning the seeds, and the plot-wise seed and straw yields were converted to kg per hectare. For measuring the total weed density, the important weeds of the experimental plots during the period of experimentation were recorded and it was taken during growth period at 25, 45 DAS and at harvest. Number of panicle plant^{-1} was recorded from the count of thirteen randomly taken plants of the net plot area. Meanwhile, panicle weight (g) was measured from 13 plants per plot with the use of tailor tape and the values were recorded and averaged for each plot (Amini, 2022).

The weeds which were collected from each plots were used for recording total dry weed biomass at 3 different periods (25, 45 DAS and at harvest). The total dry weight of weeds was obtained after oven drying of weeds at 60-70 ^{0}C till a constant weight attained. The total dry weed biomass was expressed as g m^2 (Porwal, 2000). The harvest index (HI) was calculated using the appropriate formula.

$$HI = \frac{Grain\ yield}{Biological\ yield} x\ 100 \quad (1)$$

Statistical analysis

Statistical analyses of the data were conducted using a Completely Randomized Block Design along with a factorial approach and appropriate ANOVA. The significant differences between treatments were determined at a five percent significance level (Snedecor and Cochran, 1967).

RESULTS and DISCUSSION

Plant height

Data on sorghum plant height was measured at various growth stages (30, 60, and 90 DAS, as well as at harvest). The plant height increased with the progress in crop growth stage. Both weed management practices and N application significantly influenced the plant height (Table 2). While plant height was significantly affected by weed management practices at 90 DAS, other observations showed no significant differences among the treatments. The W_3 treatment resulted in the tallest plants at 90 DAS. Different N levels also significantly impacted plant height at all measurement times, with the N_4 treatment producing the tallest plants compared to the other N levels. The highest plant heights were observed with the N_4 treatment, whereas the lowest were recorded in the absolute N control treatment. All N levels significantly affected plant height compared to the absolute N control.

Interaction effects between weed management and N levels on sorghum plant height were not significant at 30 and 60 days after sowing, but were significant at 90 days after sowing and at harvest. The increase in plant height with higher N levels may be attributed to an increase in the number of nodes and internodal distance (Afzal et al., 2012). Noori (2020) found that the application of 100 kg N per hectare significantly enhances plant height, leaf number per plant, dry matter, and crop growth rate throughout the growing period. A similar findings were reported by Eltelib (2004).

Table 2. *Effect of N fertilization and weed management practices on plant height of sorghum*

Treatment	Plant height (cm) 30 DAS	60 DAS	90 DAS	At harvest
Weed management practices (WMP)				
W1: Two HW (25 and 45 DAS)	54.86a	182.67a	214.07b	270.25a
W2: Atrazine + one HW(45 DAS)	54.73a	177.00a	214.30b	269.08a
W3: Atrazine + Pendi + one HW (45 DAS)	56.43a	183.67a	220.81a	266.83a
SEm(±)	1.15	1.87	0.96	0.71
CD at 5%	NS	NS	3.85	NS
Levels of nitrogen				
N1: Absolute N control	43.29a	156.67a	182.74d	260.56b
N2: 50 kg N/ha	52.57a	180.56a	208.15c	269.33ab
N3: 75 kg N/ha	59.09a	186.11a	229.41b	262.56b
N4: 100 kg N/ha	66.42a	201.11a	245.27a	282.45a
SEm(±)	1.02	2.48	2.25	0.77
CD at (P= 5%)	3.05	7.42	6.75	2.30
Interaction (WMP × N levels)	NS	NS	S	S

DAS: days after sowing, HW: hand weeding, Pendi: pendimethalin, N: nitrogen, NS: not significant, S: significant, WMP: weed management practices. *Means followed by the same letters are not significantly different from each other at 5% probability level*.

Table 3. *Interaction effect of N fertilization and weed management on plant height (cm) of sorghum at 90 DAS*

Treatment	N1	N2	N3	N4	Mean
W1: Two HW (25 and 45 DAS)	190.80a	202.66b	220.33b	242.47	214.07b
W2: Atrazine + one HW(45 DAS)	169.00b	211.00a	233.76a	243.43	214.30b
W3: Atrazine + Pendi + one HW (45 DAS)	188.43ab	210.77a	234.13a	249.90	220.88a
Mean	182.74	208.14	229.41	245.26	216.39
				SE(m) ±	CD (P=5%)
Main effect of weed management				0.96	3.85
Main effect of nitrogen				2.25	6.75
Interaction (weed management × N application)				3.51	10.78

Table 4. *Interaction effect of N fertilization and weed management practices on plant height (cm) of sorghum at harvest*

Treatment	N1	N2	N3	N4	Mean
W1: Two HW (25 and 45 DAS)	261.0b	265.0b	270.0a	285.0a	270.2a
W2: Atrazine + one HW(45 DAS)	244.3c	278.6a	273.6a	279.6b	269.0a
W3: Atrazine + Pendi + one HW (45 DAS)	276.3a	264.3b	244.0b	282.6a	266.8b
Mean	260.5	269.3	262.5	282.4	
				SE(m) ±	CD (P=5%)
Main effect of weed management				1.4	4.3
Main effect of nitrogen				1.3	4.4
Interaction (weed management × N application)				1.35	4.43

Yield components

Weed Management practices did not significantly impact the number of panicles per square meter. Among the N fertilization treatments, the N_4 treatment produced the highest number of panicles compared to the absolute control. The interaction between weed management practices and N application was found to have no significant effect on the number of panicles per square meter. At the time of harvest, the number of seeds per panicle was significantly higher in the W_2 treatment compared to W_3 (Table 5). Among the N application treatments, the highest number of seeds per panicle was recorded with the N_4 treatment. Significant interaction effects were observed for seed weight per plant due to the combination of weed management practices and N application.

Weed management practices did not significantly influence panicle length. However, among the N fertilization treatments, the N_4 treatment had the longest panicles, followed by N_3. While weed management practices did not significantly affect panicle weight, among the N treatments, N_4 produced the heaviest panicles, followed by N_3 when compared to control. Interaction effects on panicle weight due to weed management practices and N application were also significant. Among the three weed management practices, W_1 resulted in a significantly higher weight of seeds per panicle (g) compared to W_3 at the harvest stage (Table 5). The weight of seeds per panicle was highest with the N_4 treatment. However, interaction effects on seeds per panicle weight due to weed management practices and N application were found to be non-significant.

Among the weed management practices, W_3 significantly increased the weight of 1,000 seeds compared to W_1 (Table 5). The N fertilization treatments significantly increased the weight of 1,000 seeds, with the N_4 treatment achieving a notably higher weight than the absolute control. The interaction between weed management practices and N application on the weight of 1,000 seeds was significant. Interaction effects on 1,000-seed weight resulting from weed management practices and N application were significant (Table 6).

Our findings align closely with those of Marsalis et al. (2009). Sifola et al. (2002) also noted that N application, particularly at 150 kg N per hectare, increased the number of grains in addition to facilitating dry matter accumulation during grain filling in the spike. A similar observation was made by Al Rawi (2005), who confirmed that the highest grain weight and grain yield were associated with higher rates of N fertilizer. These results are consistent with those reported by Wright and Catchpoole (1985), Al Salmani (2009), Conly et al. (2005), Buah and Winkar (2009), Gular (2008), and Yang et al. (2009).

Table 5. *Effect of N fertilization and weed management practices on yield attributes of sorghum*

Treatment	**Number of panicle/ m²**	**Number of seeds/ panicle**	**Length of panicle (cm)**	**Panicle weight (g)**	**Weight of seeds per panicle (g)**	**1000 grain weight (g)**
Weed management practices **(WMP)**						
W_1: Two HW (25 and 45 DAS)	12.91a	1354.92b	33.35a	38.72a	28.13a	17.55a
W_2: Atrazine + one HW(45 DAS)	12.83a	1521.33a	33.94a	36.82a	26.60b	14.41b
W_3: Atrazine + Pendi + one HW (45 DAS)	13.0a	1511.08a	34.24a	37.79a	27.83a	18.69a
SEm(±)	0.23	3.09	0.47	0.65	0.18	0.129
CD (P= 5%)	NS	12.46	NS	NS	0.73	0.380
Levels of nitrogen						
N_1: Absolute N control	12.55a	789.11d	27.38d	26.04c	14.31c	11.31c
N_2: 50 kg N/ha	12.77a	1202.77b	31.41c	33.38b	22.50b	13.65b
N_3: 75 kg N/ha	13.11a	1645.56c	35.69a	43.81ab	33.04ab	19.80ab
N_4: 100 kg N/ha	13.22a	2212.33a	40.91a	47.87a	40.22a	22.77a
SEm(±)	0.23	10.22	0.65	0.93	0.23	0.149
CD (P= 5%0	N/A	30.63	1.96	2.76	0.69	0.439
Interaction (WMP × N levels)	NS	S	S	S	S	S

DAS: days after sowing, HW: hand weeding, Pendi: pendimethalin, N: nitrogen, NS: not significant, S: significant, WMP: weed management practices. . *Means followed by the same letters are not significantly different from each other at 5% probability level*.

***Table** 6. Interaction Effect of N fertilization and weed management practices on number of seed per panicle of sorghum*

Treatment	N_1	N_2	N_3	N_4	Mean
W_1: Two HW (25 and 45 DAS)	695.33c	1263.33b	1386.67b	2074.33b	1354.91b
W_2: Atrazine + one HW(45 DAS)	777.33b	1178.33a	1757.00a	2372.67a	1521.33a
W_3: Atrazine + Pendi + one HW (45 DAS)	894.66a	1166.66a	1793.00a	2190.00ab	1511.08a
Mean	789.11	1202.77	1645.55	2212.33	
				SE(m) ±	CD (P=5%)
Main effect of weed management				3.0	12.4
Main effect of nitrogen				10.2	30.6
Interaction (weed management × N application)				15.6	47.4

***Table** 7. Interaction Effect of N fertilization and weed management practices on weight of seed per panicle (g) of sorghum*

Treatment	**N_1**	**N_2**	**N_3**	**N_4**	**Mean**
W_1: Two HW (25 and 45 DAS)	14.33a	22.83ab	34.00a	41.33a	28.13a
W_2: Atrazine + one HW(45 DAS)	13.93b	20.33b	33.80ab	38.33b	26.60b
W_3: Atrazine + Pendi + one HW (45 DAS)	14.67a	24.33a	31.33b	41.00a	27.83ab
Mean	14.31	22.50	33.04	40.22	
				SE(m) ±	CD (P=5%)
Main effect of weed management				0.1	0.7
Main effect of nitrogen				0.2	0.6
Interaction (weed management × N application)				0.3	1.2

***Table** 8. Interaction Effect of N fertilization and weed management practices on 1000 grain weight of sorghum*

Treatment	**N_1**	**N_2**	**N_3**	**N_4**	**Mean**
W_1: Two HW (25 and 45 DAS)	12.17a	15.37a	20.00b	22.67b	17.55b
W_2: Atrazine + one HW(45 DAS)	11.27ab	12.47c	15.67c	18.13c	14.41c
W_3: Atrazine + Pendi + one HW (45 DAS)	10.50b	13.13b	23.63a	27.50a	18.69a
Mean	11.31	13.66	19.80	22.77	
				SE(m) ±	CD (P=5%)
Main effect of weed management				0.3	0.8
Main effect of nitrogen				0.2	0.9
Interaction (weed management × N application)				0.2	0.9

Grain Yield Attributes

The grain yield of sorghum was significantly influenced by weed management. Among the three weed management practices, the highest grain yield was achieved with W_1, followed by W_3, while the W_2 treatment recorded the lowest grain yield (Table 9). The application of N fertilizer also had a significant effect on the grain yield of sorghum, with the N_4 treatment resulting in the highest yield, followed by N_3. In contrast, the lowest grain yield was associated with the N_1 treatment (control). Stover yield in sorghum was significantly affected by weed management as well. Among the three practices, W_1 and W_2 treatments resulted in a significantly higher stover yield compared to W_3 (Table 9). The impact of N fertilizer on stover yield was also significant, with the N_4 application producing more stover than the control (N_1).

The biological yield of sorghum was significantly influenced by weed management practices, with W_1 demonstrating a notably higher biological yield than W_3. Similarly, N application significantly affected the biological yield, with the highest yielding treatment being N_4, while the lowest was seen with N_1 (control). Increasing N doses contributed to an increase in biological yield. Additionally, the interaction between weed management practices and N fertilization had a significant impact on grain yield (Table 10). Weed management practices significantly affected the harvest index (HI) of sorghum. The highest HI was observed with W_3 followed by W_1, while the lowest was recoded with W_2 treatment. The HI was significantly influenced by different N fertilization levels. The highest HI was recorded with the N_1 treatment, followed by N_3, while the lowest HI was associated with N_4. Sifola et al. (2002) noted that N application enhances the number of grains and contributes to dry matter accumulation during grain filling in the spike. The efficiency of N application is crucial for accurately determining the variation among cultivars in terms of N utilization, which helps minimize contamination and reduce N fertilizer costs (Gardner et al., 1994). The application of N fertilizer improved both the growth and yield of sorghum compared to the control. Differences in growth and grain yield were also noted among the three weed management practices studied with the N application. Olugbemi and Ababyomi (2016) found that applying 120 kg N per hectare produced the best stover and grain yield responses in sweet sorghum. Similar findings regarding the positive effects of applying 100 kg N per hectare on yield were reported in earlier studies (Lehman et al., 1999; Conly et al., 2005; Buah and Mwinkaara, 2009).

***Table** 9. Effect of N fertilization and weed management practices on yields and harvest index of sorghum*

	Yield (kg ha^{-1})			
Treatment	Grain yield	Stover yield	Biological yield	Harvest index
Weed management practices (WMP)				
W_1: Two HW (25 and 45 DAS)	3310.83a	2116.50a	5427.333a	61.01b
W_2: Atrazine + one HW(45 DAS)	2546.08c	2111.16a	4657.250b	54.66c
W_3: Atrazine + Pendi + one HW (45 DAS)	3069.41b	1677.00b	4746.500b	64.66a
SEm(±)	27.85	7.75	29.95	0.23
CD at (P= 5%)	82.22	22.89	88.43	0.95
Levels of nitrogen				
N_1: Absolute N control	1352.33d	633.67d	1932.33d	69.98a
N_2: 50 kg N/ha	2279.00c	1691.22c	3832.33c	59.47c
N_3: 75 kg N/ha	3962.66b	2318.88b	5851.33b	62.59b
N_4: 100 kg N/ha	4307.78a	3229.22a	7370.00a	58.45c
SEm(±)	32.16	8.96	34.59	0.34
CD at (P=5%)	94.94	26.44	102.10	1.03
Interaction (WMP × N levels)	S	S	S	S

DAS: days after sowing, HW: hand weeding, Pendi: pendimethalin, N: nitrogen, NS: not significant, S: significant, WMP: weed management practices. . *Means followed by the same letters are not significantly different from each other at 5% probability level*.

***Table** 10. Interaction effect of N fertilization and weed management practices on grain yield (kg/ha) of sorghum*

Treatment	N_1	N_2	N_3	N_4	Mean
W_1: Two HW (25 and 45 DAS)	1926.67a	2346.66a	4423.33a	4546.66a	3310.83a
W_2: Atrazine + one HW(45 DAS)	867.00c	2156.66b	3437.33c	3723.33b	2546..08c
W_3: Atrazine + Pendi + one HW (45 DAS)	1263.33b	2333.66a	4027.33b	4653.33a	3069.41b
Mean	1352.333	2279.000	3962.667	4307.778	
				SE(m) ±	CD (P=5%)
Main effect of weed management				27.852	82.216
Main effect of nitrogen				32.161	94.935
Interaction (weed management × N application)				55.705	164.431

***Table** 11. Interaction effect of N fertilization and weed management practices on biological yield (kg/ha) of sorghum*

Treatment	N_1	N_2	N_3	N_4	Mean
W_1: Two HW (25 and 45 DAS)	2576.33a	4212.66a	6848.00a	8072.33a	5427.33c
W_2: Atrazine + one HW(45 DAS)	1449.33c	3865.66b	6145..33b	7168.66c	4657.25ab
W_3: Atrazine + Pendi + one HW (45 DAS)	1932.33b	3832.33b	5851.33c	7370.00b	4746..50a
Mean	1986.000	7358.16	6281.556	7537.000	
				SE(m) ±	CD (P=5%)
Main effect of weed management				29.955	88.423
Main effect of nitrogen				34.589	102.102
Interaction (weed management × N application)				59.911	84.726

***Table** 12. Interaction effect of N fertilization and weed management practices on Stover yield (kg/ha) of sorghum*

Treatment	N_1	N_2	N_3	N_4	Mean
W_1: Two HW (25 and 45 DAS)	649.67b	1866.00a	2424.66b	3525.67a	2116.500a
W_2: Atrazine + one HW(45 DAS)	582.33c	1709.00b	2708.00a	3445.33ab	2111.167a
W_3: Atrazine + Pendi + one HW (45 DAS)	669.00a	1498..66c	1824.00c	2716.67b	16777.08b
Mean	633.667	1691.222	2318.889	3229.222	
				SE(m) ±	CD (P=5%)
Main effect of weed management				7.756	22.895
Main effect of nitrogen				8.956	26.437
Interaction (weed management × N application)				15.512	45.790

Total weed density (m²) and total dry weed biomass

The total weed density in sorghum was significantly affected by weed management practices (Table 13). Among the weed control treatments, W_2 resulted in a higher total weed density at 25 and 45 DAS. However, both chemical weed management strategies demonstrated higher total weed density compared to W_1, although they were statistically similar at harvest. The N levels also significantly increased weed density compared to the control at, with the highest total weed density observed with the N_4 treatment on 25 and at harvest. No significant interaction effects between weed management practices and N application on weed density were observed (Table 14).

Data on total dry weed biomass (m^2) recorded at various growth stages (25, 45, and at harvest) showed a significant influence from N application and weed management practices on 45 DAS (Table 13). The highest weed biomass (m²) was observed with the W_2 followed by W_1 treatment at 45 DAS. Among the N treatments, the maximum dry weed biomass (m²) was recorded with the N_3 followed by

N_2 treatments on 45 DAS, which was significantly greater than the biomass in the N_1 (control). However, the N fertilization didn't affect weed biomass significantly on 25 DAS and at harvest. The interaction effects between weed management practices and N application were significant only for total dry weed biomass at 45 DAS.

Kolage et al. (2003) reported that pre-emergence application of atrazine at 1.0 kg per hectare significantly reduced weed intensity, resulting in a lower weed index and greater weed control efficiency compared to other herbicides. Porwal (2000) indicated that the highest grain and stover yields were achieved with the application of 1.0 kg of atrazine per hectare as a post-emergence treatment.

Table 13. *Effect of N fertilization and weed management practices on total weed density and dry weed biomass*

Treatment	Total weed density (m^{-2})			Total dry weed biomass ($g\ m^{-2}$)		
	25 DAS	45 DAS	At harvest	25 DAS	45 DAS	At harvest
Weed management practices (WMP)						
W_1: Two HW (25 and 45 DAS)	28.24b	1.598b	5.58b	2.258a	3.417a	1.858b
W_2: Atrazine + one HW (45 DAS)	61.33a	3.183a	9.50a	1.617a	3.500a	2.050a
W_3: Atrazine + Pendi + one HW (45 DAS)	11.68c	3.150a	9.58a	1.250a	2.542b	1.700b
SEm±	0.50	0.085	0.49	0.249	0.176	0.172
CD (P =0.05)	2.01	0.341	1.83	NS	0.709	NS
Levels of nitrogen						
N_1: Absolute N control	14.74d	2.72ab	5.56c	1.60b	1.77bc	0.68d
N_2: 50 kg N/ha	17.87c	3.00a	7.22b	2.05a	3.00b	1.14c
N_3: 75 kg N/ha	19.07b	2.42b	7.67b	1.63b	3.56a	2.21b
N_4: 100 kg N/ha	22.00a	2.43b	12.44a	1.54c	2.54b	3.44a
SEm±	0.473	0.215	0.52	0.162	0.17c	0.172
CD (P =0.05)	1.416	N/A	1.79	N/A	0.709	0.522
Interaction (WMP × N levels)	NS	NS	NS	NS	S	NS

DAS: days after sowing, HW: hand weeding, Pendi: pendimethalin, N: nitrogen, NS: not significant, S: significant, WMP: weed management practices. . *Means followed by the same letters are not significantly different from each other at 5% probability level*.

***Table** 14. Interaction effect of N fertilization and weed management practices on weed density (m^{-2}) of weed at 45 DAS*

Treatment	N_1	N_2	N_3	N_4	Mean
W_1: Two HW (25 and 45 DAS)	1.39b	1.97b	1.50c	1.53c	1.59b
W_2: Atrazine + one HW (45 DAS)	3.30ab	3.60a	3.17a	2.67b	3.18a
W_3: Atrazine + Pendi + one HW (45 DAS)	3.46a	3.17ab	2.60b	3.10a	3.15a
Mean	2.720	3.000	2.422	2.433	
				SEm±	CD (P =0.05)
Main effect of weed management				0.085	0.341
Main effect of nitrogen				0.215	NS
Interaction (weed management × N application)				0.334	NS

CONCLUSION

It was concluded from the results of this experiment that the weed management practice involving two hand weeding at 25 and 45 days after sowing (DAS) was more effective than the W_3 treatment (which included atrazine, pendimethalin, and one hand weeding at 25 and 45 DAS). The two hand weeding led to improved growth, yield attributes, seed yield, stover yield, and harvest index. Among the N application treatments, the N_4 treatment (100 kg N per hectare) proved to be the most effective for achieving the highest growth and grain yield in sorghum. Therefore, under the agro-ecological conditions of Takhar, Afghanistan, it is recommended to apply 100 kg of N per hectare and utilize two hand weeding at 25 and 45 DAS to enhance the growth and productivity of sorghum. Alternatively, if labor is scarce, applying the N_4 treatment combined with a weed control strategy using atrazine + pendimethalin + one hand weeding at 45 DAS could be considered. Generally, integrating nutrient management with weed control practices can significantly boost sorghum productivity. Further research might be necessary to pinpoint the best cultural practices for maximizing sorghum production across various agro-ecological zones in Afghanistan.

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AUTHOR CONTRIBUTIONS

The authors contributed equally to this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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