Response of chickpea to plant density and weed control methods under rainfed conditions in Duhok

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Abstract

A field experiment was carried out during winter season 2024–2025 winter season at Sumel and Zakho locations in Duhok Province, Iraq, to assess the effects of plant population density and weed control methods on weed infestation, growth, yield, and seed quality of chickpea (*Cicer arietinum* L.). The experiment was arranged in a factorial randomized complete block design with three replications, including three plant densities (26.66, 33.33, and 44.44 plants m^{-2}) and five weed control treatments (weedy check, Kordiclofen, Dimpex, Matador Pro, and hand hoeing). Moderate plant density (33.33 plants m^{-2}) significantly reduced narrow-leaf weed density to 35.2 and 9.33 weeds m^{-2} at Sumel and Zakho, respectively, compared with the lowest density. Selective herbicides Dimpex and Matador Pro achieved near-complete control of narrow-leaf weeds, reducing densities to ≤1.33 weeds m^{-2} and dry weights to as low as 0.52–5.63 g m^{-2}. Broad-leaf weed density was not significantly affected by plant density; however, Kordiclofen and hand hoeing reduced broad-leaf weed density to 4.22–7.33 weeds m^{-2} and dry weight to 10.09–21.29 g m^{-2} across locations. Seed yield was significantly influenced by both factors, with the highest mean yields recorded at 33.33 plants m^{-2} (358.089 kg ha^{-1} at Sumel and 362.29 kg ha^{-1} at Zakho). The maximum yields (469.28 and 478.23 kg ha^{-1} at Sumel and Zakho, respectively) were obtained from the combination of moderate density and hand hoeing. Biological yield peaked at 1415.77–1431.10 kg ha^{-1} under high density combined with effective herbicide control. Protein content was significantly improved by weed management, reaching up to 24.94% with hand hoeing, compared with about 20.5% in the weedy check.

Keywords: Chickpea, Plant Density, Herbicide, Weed Control.
(*Part of M.Sc thesis of the first author)

Introduction

Chickpea (*Cicer arietinum* L.) is considered to be one of the most important pulses in the world, ranking as the third-most produced pulse crop and member of the Fabaceae family [1]. Chickpea provides a rich source of dietary protein (21.1%), carbohydrates (61.5%), fat (4.5%), vitamins, and minerals, and beneficial phytochemicals while simultaneously contributing to agricultural sustainability through biological nitrogen fixation [2]. Iraq's contribution, while modest in global scale, represents a significant component of regional food systems and the livelihoods of farmers. According to the USDA [3], In Iraq, winter pulse cultivation, including chickpeas, is limited by irrigation and fluctuations in rainfall, resulting in yields of roughly 2.0 t ha^{-1} on rainfed smallholder farms in central and southern regions. According to the Kurdistan Region Statistical Office [4], cultivated area expanded dramatically from 30,699 dunams in 2012-2013 to 27,010 dunams in 2019-2020, alongside considerable growth in production (from 3,481 to 8,569 tons) and yield (from 113.4 to 317 kg $dunam^{-1}$). The Sulaymaniyah governorate emerged as the production center, representing 42.03% of cultivated area and 52.99% of regional production, with yields reaching 400 kg $dunam^{-1}$. Chickpea productivity, regardless of its agricultural importance, remains significantly constrained by biotic stresses, with weed competition being one of the most critical and economically damaging limitations [5]. Yield losses in chickpea systems are extensively reported and concerning. Studies consistently report reductions ranging from 24% to 63% under typical infestation levels, with losses potentially reaching 90% under totally uncontrolled conditions [6]. Chickpea, being a broadleaf crop, is susceptible to numerous broadleaf-specific herbicides, severely limiting chemical control options for the very weed group that frequently poses the most substantial competitive challenge [7]. Consequently, the traditional practice of manual hoeing continues to be effective and is still employed in numerous regions worldwide, with the potential to enhance grain yields by as much as 92% [8].

Plant population density promotes productivity of crops while equally inhibiting weed growth and development. Denser plant stands enhance light competition through earlier canopy closure, improve soil moisture utilization, and potentially alter microclimatic conditions that prevent weed establishment [9]. This approach requires highly precise adjustment, as excessively high densities may increase intraspecific competition, potentially reducing individual plant performance and yield components [10].The study aims to determine the impact of plant population densities and weed control methods on chickpea yield, yield component, and associated weeds at Duhok governorate.

Material and Methods

A field experiment was conducted during the winter season of 2024-2025 at two locations in Duhok Province, Iraq. The first location was the research farm of Field Crops Department, College of Agricultural Engineering Sciences, University of Duhok in Sumel. The second location was the agricultural research center in Zakho, located approximately 70 kilometers northwest of Duhok province. Table (1) displays the soil information for the studied locations. Also Table 2 represented meteorological Information's for both studied sites. The experiment was conducted in a factorial arrangement using a Randomized Complete Block Design (RCBD) with three replications. The first factor was plant density with three levels: D1 (26.66 plants/m²), D2 (33.33 plants/m²), and D3 (44.44 plants/m²). The second factor was weed control method, consisting of five treatments: T1 (weedy check), T2 (Kordiclofen [Aclonifen]), T3 (Dimpex [Clethodim 24%]), T4 (Matador Pro [Quizalofop-P-ethyl]), and T5 (Hand Hoeing). Chickpea seeds desi type (cultivar Flip 81) that obtained from the Research Center of Duhok were sown on November 15 in Sumel and November 17 in Zakho. Herbicides were applied at the recommended dose and suitable growth stages according to the herbicide label The herbicide information for the studied locations is shown in table (3). At maturation stage the number of narrow and broad-leaved weeds was recorded by using a quadrat (0.5 x 0.5 m²), which was randomly placed within each plot, and all narrow and broad-leaved weed individuals present within the quadrat were separated and counted manually to determine weed density, and then after air drying of samples the dry weight of narrow and broad-leaf weeds (g m^{-2}) was measured. Regarding plant growth measurements, at the maturation stage the data were collected and ten plants randomly selected to measure the: Plant height (cm), Seed Yield kg ha^{-1}, Biological weight, Protein percentage in seed (%). Analysis of variance (ANOVA) was used to evaluate treatment effects, and mean comparisons were conducted using Duncan's Multiple Range Test at $p \leq 0.05$.

Table (1): Physical and chemical characteristics of experimental soils at the Sumel and Zakho locations.

parameters / location	pH	EC ($dS.m^{-1}$)	Nitrogen (mg Kg^{-1})	Phosphorous (mg Kg^{-1})	Potassium (mg Kg^{-1})	Organic matter (%)	CEC (cmolc Kg^{-1})	Texture	Sand (%)	Silt (%)	Clay (%)
Sumel	7.75	0.31	74	4.43	15.66	1.48	27.94	Silty Clay	5.77	45.42	48.80
Zakho	7.87	0.21	83	5.87	17.82	1.92	26.88	Silty Clay Loam	18.41	48.75	32.84

Table (2): Meteorological conditions throughout the 2024-2025 growing season at Sumel and Zakho locations

Months	Relative humidity %		Rainfall (mm)		Temperature (°C)			
					Maximum		Minimum	
	Sumel	Zakho	Sumel	Zakho	Sumel	Zakho	Sumel	Zakho
November 2024	65	56	37.9	30.9	20.3	20.1	9.5	10.1
December 2024	60	56	11.3	19.8	15.9	15.9	5.2	5.4
January 2025	56	49	9.3	5.3	15.8	16.2	4.2	4.3
February 2025	56	44	45.9	52.6	12.4	12.7	2.6	2.8
March 2025	46	35	15.3	11.6	22.3	23.2	10.2	11.1
April 2025	45	44	57.7	38.4	25.5	25.6	14.9	15.0
May 2025	32	23	9.9	10.5	34.4	34.5	20.1	20.7
Total rainfall (mm)			187.3	169.1				

Table (3): Information regarding the studied herbicides at Sumel and Zakho locations:

Trade name	Active ingredient %	Formulation	Group	Recommended Dose ml/donum	Time of application	Target weeds
Dimpex	24% Clethodim	EC	Acyclic keto	75	2 to 3 leaf stage after weed emergence	Narrow leaf weeds
Kordiclofen	60% Aclonifen	SC	Monochloro benzenes	325	2 to 4 leaf stage of crop	Broad leaf weeds
Matador Pro	Quizalofop-ethyl 5%	EC	Aryloxyphenoxy-Propionates	300	3 to 5 leaf stage after weed emergence	Narrow leaf weeds

Table (4): Weed species in chickpea fields at the Sumel and Zakho sites during the growing seasons.

	Botanical name	English name	Family	Location
Narrow leaf weeds	*Avena fatua* L.	Common wild oat	Poaceae	Sumel & Zakho
	Lolium rigidum Gaudin	Rigid ryegrass	Poaceae	Sumel & Zakho
	Hordeum glaucum L.	Barley grass	Poaceae	Sumel & Zakho
	Phalaris minor Retz	Lesser Canarygrass	poaceae	Zakho
	Lomatium ambiguum (Nutt.) J.M.Coult. & Rose	Wyeth biscuitroot	Apiaceae	Sumel & Zakho
Broad leaf weeds	*Silybum marianum* L.	Milk thistle	Asteraceae	Sumel & Zakho
	Sinapis arvensis L.	wild mustard	Brassicaceae	Sumel & Zakho
	Lactuca serriola L.	prickly lettuce	Asteraceae	Sumel & Zakho
	Centaurea solstitialis L.	yellow star-thistle	Asteraceae	Zakho
	Galium aparine L.	Catchweed	Rubiaceae	Sumel & Zakho
	Medicago orbicularis (L.) Bartal.	blackdisk medick	Fabaceae	Zakho
	Fumaria parviflora Lam.	Fine leaf fumitory	Papaveraceae	Zakho
	Lathyrus sativus L.	grass pea	Fabaceae	Zakho
	Vicia sativa L.	common vetch	Fabaceae	Sumel & Zakho
	Astragalus hamosus L.	Hooked milk vetch	Fabaceae	Zakho
	Carthamus lanatus L.	Woolly distaff thistle	Asteraceae	Sumel
	Cichorium intybus L.	Common chicory	Asteraceae	Sumel
	Daucus carota L.	Bird’s nest	Apiaceae	Zakho

	Helminthotheca echioides (L.) Holub	Bristly oxtongue	Asteraceae	Zakho
	Gypsophila vaccaria L.	Cowcockle	caryophyllaceae	Zakho
	Polygonum aviculare L.	Common knotgrass	Polygonaceae	Sumel & Zakho

Results and Discussion

Data in Table 5 show that plant population density, weed control methods, and their interaction significantly affected narrow-leaf weed density at both Sumel and Zakho. At Sumel, the moderate density (D2: 33.33 plants m^{-2}) recorded the lowest weed number (35.2 weeds m^{-2}), indicating optimal canopy development and weed suppression, these results were in agreement with [11]. At Zakho, both D2 (9.33 weeds m^{-2}) and the high density D3 (11.06 weeds m^{-2}) were significantly more effective than the low density (D1: 17.33 weeds m^{-2}), reflecting site-specific crop–weed interactions and supporting by finding [12].

Chemical control was most effective against narrow-leaf weeds. Dimpex (T3) and Matador Pro (T4) achieved near-complete control, reducing weed numbers to 0.44–5.33 weeds m^{-2} at Sumel and 0.44–1.33 weeds m^{-2} at Zakho, consistent with [13 and 14]. Hand hoeing (T5) provided moderate control but was less effective than selective herbicides. These results was in line with [15]. Kordiclofen (T2) showed no significant effect on narrow-leaf weeds and was comparable to the weedy check at Sumel, confirming its limited activity on grassy species as reported by [16]. The weedy check (T1) recorded the highest infestations at both sites, which the data corroborating [17]. The density × weed control interaction indicated that selective herbicides (T3 and T4) consistently minimized narrow-leaf weeds across all densities, while the highest infestations occurred in the weedy check, particularly at low and high densities. This agrees with [12], who reported that combining moderate density with selective herbicides provides the most effective control of narrow-leaf weeds.

Table (5): Impact of Population Density and Weed Control Methods on the ***Number of narrow-leaf weeds*** per m^{-2} in the 2025 Growing Season at Sumel and Zakho Locations.

Treatments	**Sumel**				**Zakho**			
	Population Densities plants m^{-2}			Means of Weed Control Methods	**Population Densities plants m^{-2}**			Means of Weed Control Methods
Weed Control Methods	**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**		**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**	
T1 (Check)	90.0 b	64.0 cd	114.0 a	89.33 A	64.0 a	4.66 efg	24.0 b	30.88 a
T2 (Kordiclofen)	118.0 a	60.0 cd	77.33 bc	85.11 A	10.66 cdefg	22.66 bc	16.0 bcde	16.44 b
T3 (Dimpex)	1.33 f	0 F	0 f	0.44 C	1.33 fg	1.33 fg	1.33 fg	1.33 c
T4 (Matador Pro)	10.66 ef	2.66 F	2.66 f	5.33 c	1.33 fg	0 g	0 g	0.44 c
T5 (Hand hoeing)	26.0 e	49.33 D	70.0 c	48.44 b	9.33 defg	18.0 bcd	14.0 bcdef	13.77 b
Means of Population Densities	49.2 a	35.2 B	52.8 a		17.33 a	9.33 b	11.06 b	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Plant population density had no significant effect on broad-leaf weed density at either site (Table 6), or these observations consistent with [12 and 18]. Weed control effectiveness varied with herbicide mode of action and site conditions. At Sumel, Matador Pro (T4) was ineffective against broad-leaf weeds, recording the highest infestation (34.44 weeds m^{-2}), while Dimpex (T3) also showed poor control (16.44 weeds m^{-2}). In contrast, Dimpex provided better control at higher densities in Zakho, highlighting site-specific herbicide responses as noticed by [19]. Kordiclofen (T2) was consistently effective, producing low broad-leaf weed densities at Sumel (5.55 weeds m^{-2}), that was in agreement with [20]. Hand hoeing (T5) was the most reliable treatment across both sites, resulting in uniformly low weed counts (6.66 weeds m^{-2} at Sumel and 7.33 weeds m^{-2} at Zakho) which supported by [21]. The density × control interaction indicated that optimal broad-leaf weed suppression was achieved with hand hoeing at moderate plant densities, and these data consistent with [12].

Table (6): Impact of population density and weed control methods on the ***Number of broadleaf weeds*** per m^{-2} in the 2025 growing season at Sumel and Zakho locations.

Treatments	Sumel				Zakho			
	Population Densities plants m^{-2}			Means of Weed Control Methods	Population Densities plants m^{-2}			Means of Weed Control Methods
Weed Control Methods	D1 (26.6)	D2 (33.3)	D3 (44.4)		D1 (26.6)	D2 (33.3)	D3 (44.4)	
T1 (Check)	2.66 bc	4.0 bc	5.33 bc	4.0 c	6.0 bc	20.0 ab	20.0 ab	15.33 a
T2 (Kordiclofen)	2.66 bc	10.0 bc	4.0 c	5.55 c	18.66 abc	10.0 bc	13.33 bc	14.0 a
T3 (Dimpex)	16.0 bc	16.0 bc	17.33 b	16.44 b	30.0 a	8.0 c	4.0 bc	14.0 a
T4 (Matador Pro)	40.0 a	13.33 bc	50.0 a	34.44 a	13.33 bc	5.33 bc	12.0 bc	10.22 a
T5 (Hand hoeing)	8.0 bc	6.66 bc	5.33 cb	6.66 c	10.0 bc	4.0 c	8.0 bc	7.33 a
Means of Population Densities	13.86 a	10.0 a	16.4 a		15.6 a	9.46 a	11.46 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Population density significantly affected narrow-leaf weed dry weight at Sumel but not at Zakho (Table 7). At Sumel, the moderate density (D2: 33.33 plants m^{-2}) recorded the lowest weed biomass (46.16 g m^{-2}), representing reductions of 41.4% and 45.6% compared with low (D1: 78.77 g m^{-2}) and high (D3: 84.84 g m^{-2}) densities, respectively. This agrees with [11], who reported reduced weed biomass with narrower spacing, while the non-significant response at Zakho is consistent with [12]. Weed control methods showed marked differences. The selective grass herbicides Dimpex (T3) and Matador Pro (T4) were highly effective, reducing weed biomass to minimal levels at both sites (0.52–5.63 g m^{-2} at Sumel and 2.87–11.48 g m⁻² at Zakho), in line with [22]. Hand hoeing (T5) was less effective (56.03 g m^{-2} at Sumel and 52.51 g m^{-2} at Zakho). The pre-emergence herbicide Kordiclofen (T2) was ineffective against grassy weeds, showing biomass similar to the weedy check at Sumel (132.20 vs. 155.23 g m^{-2}). The density × control interaction confirmed the superiority of chemical control, as T3 and T4 reduced weed dry weight to near zero even at the highest density (D3) as corroborating by [15].

Table (7): Impact of population density and weed control methods on D*ry weight of narrow leaf weeds* (g) in the 2025 Growing Season at Sumel and Zakho Locations.

Treatments	Sumel				Zakho			
	Population Densities plants m^{-2}			Means of Weed Control Methods	Population Densities plants m^{-2}			Means of Weed Control Methods
Weed Control Methods	D1 (26.66)	D2 (33.33)	D3 (44.44)		D1 (26.66)	D2 (33.33)	D3 (44.44)	
T1 (Check)	120.95 c	68.13 d	276.62 a	155.23 a	166.2 a	98.68 abc	117.53 abc	127.47 A
T2 (Kordiclofen)	202.80 b	106.31 cd	87.5 cd	132.20 a	107.74 abc	148.22 ab	90.66 abc	115.54 A
T3 (Dimpex)	1.57 f	0 f	0 f	0.52 c	10.93 c	15.46 c	8.05 c	11.48 B
T4 (Matador Pro)	12.09 ef	1.41 f	3.38 f	5.63 c	0 c	8.61 c	0 c	2.87 C
T5 (Hand hoeing)	56.44 de	54.94 de	56.72 de	56.03 b	83.61 abc	32.02 bc	41.90 bc	52.51 B
Means of Population Densities	78.77 a	46.16 b	84.84 a		73.69 a	60.60 a	51.63 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Results in Table 8 indicate that broad-leaf weed biomass was mainly governed by herbicide selectivity, while plant population density had a secondary, site-dependent effect. At Sumel, moderate density (D2: 33.33 plants m^{-2}) significantly reduced broad-leaf weed dry weight (31.87 g m^{-2}), whereas density had no significant effect at Zakho. This agrees with [18 and 23], who reported limited influence of crop density on broad-leaf weeds. Weed control methods showed clear differences. Grass-specific post-emergence herbicides (Dimpex and Matador Pro) were ineffective against broad-leaf weeds, consistent with observations of [14 and

24]. However, at Zakho, T3 reduced dry weight to 36.42 g m^{-2} compared with the weedy check, highlighting environmental and flora effects as reported by [19 and 25]. The pre-emergence herbicide Kordiclofen (T2) effectively reduced biomass at Sumel (10.09 g m^{-2}) and Zakho (28.46 g m^{-2}), in line with [26]. Hand hoeing (T5) was the most effective and consistent treatment across locations, producing low dry weights at both Sumel (21.28 g m^{-2}) and Zakho (21.29 g m^{-2}), that was in agreement with finding [1 and 27]. The density × weed control interaction was significant, with hand hoeing giving the lowest broad-leaf weed dry weight at D2 in Sumel and D1 in Zakho, in agreement with [12].

Table (8): Impact of population density and weed control methods on *Dry weight of broad leaf weeds* (g) in the 2025 Growing Season at Sumel and Zakho Locations.

Treatments	**Sumel**				**Zakho**			
	Population Densities plants m^{-2}			Means of Weed Control Methods	**Population Densities plants m^{-2}**			Means of Weed Control Methods
Weed Control Methods	**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**		**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**	
T1 (Check)	2.76 b	9.7 b	82.71 ab	31.72 b	195.84 a	82.85 bc	84.93 bc	121.21 a
T2 (Kordiclofen)	5.02 b	17.36 b	7.9 b	10.09 b	25.05 bc	32.24 bc	28.10 bc	28.46 b
T3 (Dimpex)	164.36 a	73.18 b	73.86 b	103.80 a	26.76 bc	47.44 bc	35.07 bc	36.42 b
T4 (Matador Pro)	165.24 a	56.84 b	62.58 b	94.88 a	62.64 bc	87.02 bc	114.17 b	87.94 a
T5 (Hand hoeing)	19.66 b	2.26 b	41.93 b	21.28 b	8.98 c	28.06 bc	26.82 bc	21.29 b
Means of Population Densities	71.41 a	31.87 b	53.79 ab		63.856 a	55.52 a	57.82 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Plant population density significantly affected plant height only at Zakho, while weed control methods were significant at both locations (Table 9). At Sumel, plant height was statistically similar across densities, indicating no density effect on vegetative growth, in agreement with [28].In contrast, at Zakho, the lowest density (D1: 26.66 plants m^{-2}) produced the tallest plants (41.94 cm) that consistent with results of [29, 30 and 31] and explained by reduced interplant competition [32]. Weed control methods significantly influenced plant height at both sites. Herbicide treatments T3 (Dimpex) and T4 (Matador Pro) resulted in the tallest plants (30.91 and 30.50 cm at Sumel; 43.06 and 41.38 cm at Zakho), supporting findings by [13 and 22]. The weedy check (T1) produced the shortest plants (22.13 cm at Sumel and 34.16 cm at Zakho), confirming the suppressive effect of weed competition [33]. Hand hoeing (T5) performed comparably to herbicides, particularly at Zakho (43.13 cm) and these results were in line with [34, 35, 36 and 37]. A significant interaction was observed at Zakho, where the combination of the lowest density (D1) and hand hoeing produced the maximum plant height (53.25 cm) which consistent with finding of [38]. No significant interaction was detected at Sumel. Overall, plants at Zakho were taller than those at Sumel across treatments, indicating more favorable site-specific growth conditions.

Table (9): Impact of population density and weed control methods on ***Plant Height*** (cm) in the 2025 Growing Season at Sumel and Zakho Locations.

Treatments	**Sumel**				**Zakho**			
	Population Densities plants m^{-2}			Means of Weed Control Methods	**Population Densities plants m^{-2}**			Means of Weed Control Methods
Weed Control Methods	**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**		**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**	
T1 (Check)	21.5 ef	21.16 f	23.75 def	22.13 b	39.33 cdef	30.5 g	32.66 fg	34.16 b
T2 (Kordiclofen)	26.08 bcde	21.62 ef	25.33 cdef	24.34 b	33.75 defg	33.16 efg	33.5 defg	33.47 b
T3 (Dimpex)	27.41 bcd	30.16 bc	35.16 a	30.91 a	42.12 bc	37.83 cdefg	49.25 ab	43.06 a
T4 (Matador Pro)	30.91 ab	29.91 bc	30.66 ab	30.5 a	41.25 bcde	40.41 cdef	42.5 bc	41.38 a
T5 (Hand hoeing)	28.25 bcd	28.5 bcd	29.16 bc	28.63 a	53.25 a	41.66 bcd	34.5 cdefg	43.13 a

Means of Population Densities	26.83 a	26.27 a	28.81 a		41.94 a	36.71 b	38.48 b	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Results in Table 10 showed that plant population density significantly affected seed yield at both sites, with a significant density × weed control interaction. The moderate density (D2: 33.33 plants m^{-2}) produced the highest mean yields at Sumel (358.089 kg ha^{-1}) and Zakho (362.29 kg ha^{-1}), confirming the concept of optimum stand density and agreeing with [39]. Weed control had a strong influence on yield. Hand hoeing (T5) gave the highest yields at both sites (385.83 kg ha^{-1} at Sumel and 411.42 kg ha^{-1} at Zakho) that consistent with [40]. Among herbicides, Kordiclofen was highly effective and statistically comparable to hand hoeing at Sumel and these data was in line with [16]. Dimpex performed similarly to hand hoeing at Sumel but was less effective at Zakho, reflecting site-specific weed flora effects as reported by [22 and 25]. The highest yields at both locations resulted from combining moderate density (D2) with hand hoeing (T5), reaching 469.28 kg ha^{-1} at Sumel and 478.23 kg ha^{-1} at Zakho. This confirms previous findings that integrating optimal plant density with effective weed control maximizes chickpea yield [38 and 41].

Table (10): Impact of population density and weed control methods on *Seed Yield* (kg ha^{-1}) in the 2025 Growing Season at Sumel and Zakho Locations.

Treatments	**Sumel**				**Zakho**			
	Population Densities plants m^{-2}			Means of Weed Control Methods	**Population Densities plants m^{-2}**			Means of Weed Control Methods
Weed Control Methods	**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**		**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**	
T1 (Check)	121.04 g	238.47 ef	250.4 ef	203.30 c	141.44 g	255.17 e	260.10 e	218.90 D
T2 (Kordiclofen)	197.05 f	402.01 abc	373.66 bcd	324.24 b	249.97 e	377.73 cd	423.10 b	350.27 B
T3 (Dimpex)	413.96 ab	341.21 bcd	338.45 cd	364.54 ab	184.28 f	363.38 d	341.70 d	296.45 C
T4 (Matador Pro)	373.53 bcd	339.42 Cd	302.56 de	338.50 ab	273.65 e	336.92 d	333.70 d	314.76 C

T5 (Hand hoeing)	34.47 bcd	469.28 a	346.74 bcd	385.83 a	336.25 d	478.23 a	419.78 bc	411.42 A
Means of Population Densities	289.41 b	358.089 a	322.36 ab		237.12 b	362.29 a	355.68 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Plant population density and weed control methods significantly affected biological yield at both Sumel and Zakho, with a significant site-specific interaction (Table 11). At Sumel, biological yield increased gradually with increasing density, whereas at Zakho the response was more pronounced, with all density levels differing significantly. These results agree with [42], and reflect the influence of resource availability on biomass accumulation [43]. Weed control methods significantly influenced biological yield at both sites. Kordiclofen produced the highest yield at Sumel (1090.40 kg ha^{-1}) and the second highest at Zakho (1118.54 kg ha^{-1}), consistent with its strong control of broadleaf weeds [16]. At Zakho, hand hoeing resulted in the maximum biological yield (1120.37 kg ha^{-1}), in agreement with [34]. Dimpex gave a relatively high yield at Sumel (1076.36 kg ha^{-1}) but a lower yield at Zakho (923.13 kg ha^{-1}), indicating limited effectiveness where grasses were not dominant [13]. Matador Pro performed consistently across locations (980.29 kg ha^{-1} at Sumel and 1109.04 kg ha^{-1} at Zakho), supporting findings by [44]. A strong density × weed control interaction was observed. At Sumel, the highest biological yield (1415.77 kg ha^{-1}) was obtained from high density (D3) combined with Kordiclofen, confirming the synergistic effect of effective broadleaf control under resource-limited conditions [20]. At Zakho, high density combined with either Matador Pro or Kordiclofen produced similarly maximum yields (1420.12 and 1431.10 kg ha^{-1}), indicating an additive interaction. Overall, the benefit of increased plant density on biological yield depended on effective, site-specific weed management as mentioned by [19].

Table (11): Impact of population density and weed control methods on Biological Yield (kg ha^{-1}) in the 2025 Growing Season at Sumel and Zakho Locations

Treatments	**Sumel**				**Zakho**			
	Population Densities plants m^{-2}			Means of Weed Control Methods	**Population Densities plants m^{-2}**			Means of Weed Control Methods
Weed Control Methods	**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**		**D1 (26.66)**	**D2 (33.33)**	**D3 (44.44)**	

T1 (Check)	514.92 G	887.43 def	1016.44 bcde	806.26 b	525.70 g	886.05 ef	973.56 cdef	795.10 B
T2 (Kordiclofen)	692.82 Fg	1162.62 bc	1415.77 a	1090.40 a	750.99 fg	1173.54 bcd	1431.10 a	1118.54 A
T3 (Dimpex)	1149.80 Bcd	1105.93 bcd	973.36 bcde	1076.36 a	607.23 g	954.51 def	1207.64abc	923.13 B
T4 (Matador Pro)	1196.96 Ab	955.22 bcde	788.69 ef	980.29 ab	842.13 ef	1064.87 bcd	1420.12 a	1109.04 A
T5 (Hand hoeing)	920.10 Cdef	973.84 bcde	1044.09bcde	979.34 ab	959.24 def	1139.63 bcde	1262.23 ab	1120.37 A
Means of Population Densities	894.92 B	1017.01 ab	1047.67 a		737.06 c	1043.72 b	1258.93 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Results in Table 12 show that weed control methods significantly affected seed protein content, whereas plant population density and its interaction with weed control had no significant effect at either Sumel or Zakho, despite consistent numerical trends. This agrees with [45], who reported relative stability of chickpea protein content, although [46] observed reduced protein at higher densities due to nitrogen competition. Weed control had a clear influence on protein percentage. Hand hoeing produced the highest protein content at both sites (24.35% at Sumel and 24.18% at Zakho), significantly exceeding the weedy check, supporting [1]. Kordiclofen and Dimpex also improved protein content, giving values comparable to hand hoeing at Zakho and higher than the control at Sumel. In contrast, Matador Pro showed variable, site-dependent effects that consistent with [47], who reported reduced chickpea protein with quizalofop-p-ethyl. The weedy check consistently recorded the lowest protein content (20.47% at Sumel and 21.05% at Zakho). Although the density × weed control interaction did not identify a single optimal combination, the highest protein values were obtained with hand hoeing at the lowest density (D1), reaching 24.94% at Sumel and 24.50% at Zakho. These results supported by [48], who emphasized that lower plant density and effective weed control enhance seed protein content.

Table (12): Impact of population density and weed control methods on Protein Content % in the 2025 Growing Season at Sumel and Zakho Locations

Treatments	Sumel				Zakho			
	Population Densities plants m^{-2}			Means of Weed Control Methods	Population Densities plants m^{-2}			Means of Weed Control Methods
Weed Control Methods	D1 (26.66)	D2 (33.33)	D3 (44.44)		D1 (26.66)	D2 (33.33)	D3 (44.44)	
T1 (Check)	20.37 g	20.93 fg	20.11 g	20.47 c	20.48 e	21.61 cde	21.07 de	21.05 b
T2 (Kordiclofen)	24.34 abc	22.45 cdef	22.36 def	23.05 ab	24.01 ab	22.53 bcd	22.76 abcd	23.10 a
T3 (Dimpex)	23.07 abcde	21.94 defg	23.54 abcd	22.85 b	23.79 ab	22.58 abcd	22.32 bcd	22.9 a
T4 (Matador Pro)	22.95 bcde	21.44 efg	21.16 efg	21.85 b	22.51 bcd	23.13 abc	22.96 abcd	22.87 a
T5 (Hand hoeing)	24.94 a	24.65 ab	23.46 abcd	24.35 a	24.5 a	23.93 ab	24.11 ab	24.18 a
Means of Population Densities	23.13 a	22.28 a	22.13 a		23.06 a	22.75 a	22.64 a	

Values within each set of means followed by the same letter are not significantly different at p=0.05 according to Duncan's M.R.T., 1955.

Chickpea performance under rainfed conditions in Duhok was significantly influenced by plant density and weed control. A moderate density of 33.33 plants m^{-2} provided effective weed suppression and the highest seed yield at both locations. Selective herbicides (Dimpex and Matador Pro) efficiently controlled narrow-leaf weeds, whereas Kordiclofen and hand hoeing were more effective against broad-leaf weeds. The combination of moderate density with hand hoeing produced the maximum seed yield and protein content. Integrating optimal plant density with appropriate weed management is therefore essential for improving chickpea productivity and quality.

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