Herbicidal efficacy and selectivity of pendimethalin, oxadiazon and their tank mixtures to direct seeded onion

Nasr Eldin K. **Abdalla**[1], Abdel Gabbar T. **Babiker**[2,*]

1- Agricultural Research Corporation, Shendi Research Station, Shendi, Sudan.
*2- Department of Plant Protection, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum North, Sudan. * agbabiker@yahoo.com*

Abstract

Production of direct seeded onion is constrained by weeds and complete loss of crop yield is not uncommon. Field trials were undertaken to study the influence of sequential applications of the herbicides pendimethalin, oxadiazon and their tank mixtures on efficacy and selectivity to direct seeded onion. Experiments were undertaken at the Gezira and Shendi Research Stations. Onion (cv Saggai) seeds were planted on ridges. Grassy weeds were predominant at the Gezira Research Farm (62 and 69%), while at Shendi Research Farm broad-leaved weeds were the most common (71%). Pendimethalin at 1.19 and 1.79 kg a. i. ha^{-1}, applied at planting, effected excellent and persistent control (85-100%) of grassy weeds. The herbicide at the low rate displayed inconsistent performance on broad-leaved weeds across seasons and sites, while at the high rate it was toxic to the crop. Unrestricted weed growth reduced the onion bulb diameter by 55- 61% and bulb yield by 86-93%. Pendimethalin at 1.19 kg a. i. ha^{-1}, applied at planting, followed by oxadiazon and/or their tank mixtures 2 or 4 weeks after crop emergence provided adequate weed control and significantly increased bulb size and yield. The bulb diameter and yield, obtained, were often comparable to those of the weeded control.

Keywords: Direct seeded onion, weed, oxadiazon, pendimethalin, broad-leaved weeds, grasses

Introduction

Onion is a major vegetable crop in the Sudan grown for both nutritional and economical values [1]. The crop is planted mainly as transplants. However, direct seeding, limited at present to nurseries, is of vital importance in large scale plantations. The production of the crop is constrained by series of pests of which weeds and diseases are the most important [1]. Onion, in common with other Alliaceous crops, is characterized by small cylindrical and erect leaves, low growth rate and lack of canopy closure [2]. These characters make the crop vulnerable to weed competition, especially during the early growth stages. Weed competition adversely affects both total and marketable yields [3]. Losses in bulb yield in transplanted onion were reported to be more than 50% [3], whereas complete losses were often encountered in the direct seeded crop [4]. In Sudan hand-weeding is the main method of weed control in direct seeded onion. However, labour shortage, and mimicry between weeds and onion seedlings make timely removal of weeds, at the early stages of growth, difficult, expensive and virtually impossible. Several herbicides including pendimethalin, oxadiazon and oxyfluorfen have been

recommended for weed control in transplanted onions [5]. Experience has shown that direct seeded onion is more susceptible to herbicides than the transplanted crop. Pendimethalin, oxadiazon and oxyfluorfen at the rates recommended for transplanted onion are toxic to the direct seeded crop. The low margin of selectivity of most herbicides in direct seeded onions allows, only, the use of low rates and hence poor and non-persistent weed control is often achieved. Oxadiazon is one of the most commonly used post-emergence herbicide on onion [6]. Starting as early as the first true leaf stage, the chemical is applied at low rates (0.2 kg a.i. ha^{-1}), either alone or in combination with pendimethalin, without damage to the crop. At two fully developed leaves stage, higher rates up to 0.6 kg a.i ha^{-1} are applied with excellent selectivity [7]. Similarly, oxadiazon, applied at transplanting, or 7 to 14 days later, gave excellent and persistent control [5]. As a post-emergence treatment, oxadiazon has an excellent activity against existing weed seedlings, and also has soil activity, thus reducing further infestation by late germinating weeds. Pendimethalin is widely used in many countries, as a post-emergence herbicide [2]. It can be applied safely to the crop, at the first true leaf stage, or after transplanting [5]. Pendimethalin activity against grasses and broadleaved weeds, with more than two leaves, is improved when mixed with oxadiazon, oxyfluorfen or bentazon [2]. The present study was therefore undertaken to investigate possible provision of long season weed control through sequential application of herbicides. Treatments comprising of a low rate of pendimethalin applied at planting followed by oxadiazon alone and in tank mixtures with pendimethalin were evaluated, in field trials, for efficacy against weeds and for selectivity to onion.

Materials and methods

A field experiments was undertaken at the Gezira Research Station Farm (GRSF) Latitude 14° 23/ N, Longitude 33° 31/ E for two consecutive seasons (2003/04 and 2004/05) and at Shendi Research Station Farm (SRSF) Latitude 33° 26/ N, Longitude 16° 42/ E for one season (2005/06). The soil of the Gezira is vertisolic and is characterized by high clay content (54%), low nitrogen content (0.039%), low organic carbon (0.5%), alkaline reaction (pH=8.1), high cation exchange capacity (54 dS/m), and low electrical conductivity {>3.7 [cmol(+)/kg soil]} [8]. The soil of SRSF is a silty clay loam and silt loam textural classes. The clay, silt and sand content are 44, 41 and 15%, respectively. The soil is characterized by relatively high nitrogen content (474–740 ppm), low organic carbon (0.39–0.56%), slightly alkaline reaction (pH = 7.7–7.8), electrical conductivity of 0.39

[cmol(+)/kg soil], and cation exchangeable capacity of 55–57 dS/m [9]. The mean maximum temperatures at the GRSF in the specific growing seasons, 2003/04 and 2004/05, were 34.8–42.1 ^{0}C and 33.8–41.9 ^{0}C, respectively (Fig. 1). The corresponding mean minimum temperatures were 15.5–22.9 ^{0}C and 15.6–23.4 ^{0}C. At SRSF the mean maximum temperatures in season 2005/06 was 32–39.5 ^{0}C while the mean minimum temperatures was 15.7–25.3 ^{0}C (Fig. 1).

Onion cultivar Saggai, (5–8 seeds) were sown by hand in holes 2 cm deep on ridges 60 cm a part and at a within row spacing of 10 cm. The crop was sown on the third or last week of October on 3 rows per ridge. Four weeks after 50% onion emergence, the crop was thinned to one plant per hole. Pendimethalin, as Stomp, at 1.19 kg a.i. ha^{-1} was applied immediately after sowing as a basal treatment. Oxadiazon, as Ronstar, at 0.48, 0.71 or 0.95 kg a.i. ha^{-1} alone and in tank mixtures with pendimethalin at 1.19 kg a.i. ha^{-1} were applied 2 or 4 weeks after crop emergence (WACE) subsequent to the pendimethalin basal treatment. Herbicides were applied as aqueous sprays with a knapsack sprayer at a volume rate of 275–330 L ha^{-1}. Treatments were arranged in a randomized complete block design with 4 replicates. Treatments effects on weeds were assessed by counting total and individual weed species in 4 fixed quadrates (25 x 40 cm) at biweekly intervals. At harvest weed in 1 m^2, from each treatment, were cut, air-dried and weighed. Treatments effects on onion were assessed by determining number of leaves per plant, bulb diameter and bulb yield.

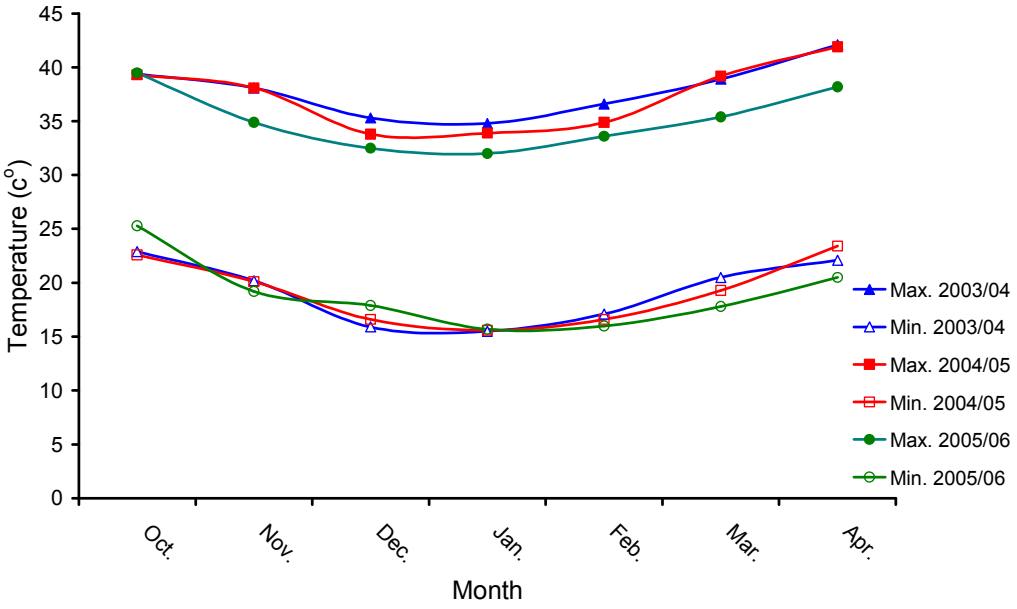

Figure 1. Monthly mean maximum and mean minimum temperatures at the Gezira (Seasons 2003/04 and 2004/05) and Shendi (Season 2005/06), October – April.

Results and discussion

Total number of weeds in the untreated plots were 110 and 138 m^{-2} at GRSF and 143 m^{-2} at SRSF. Of the total weeds 62 and 69 % and 29% were grasses at GRSF and SRSF, respectively. Predominant weeds at GRSF were *Brachiaria eruciformis* (Sm.) Griseb, *Seteria pallide-fusca* Stapt, *Ischaemum afrum* (J. F. Gmel.) Dandy, *Ipomoea cordofana* Choisy, *Corchorus* spp., *Ocimum basilicum* L, *Aristolochia bracteolata* Linn and *Phyllanthus niruri* L. However, predominant weeds in SRSF were *Amaranthus* spp., *Portulaca oleracea* L, *Convolvulus arvensis* L, *Chrozophora plicata* (Vahl) A. Juss. ex Spreng, *Ipomoea sinensis* (Desr.) Choisy *B. eruciformis* and *Echinochloa. Colona* (L.) Link. The data, clearly, showed variability in weed density and composition with season and site. At GRSF grassy weeds were predominant, while at SRSF broad-leaved ones were the most common. Variability in composition of the weed flora may play a crucial role in determining the success of chemical weed control and make herbicide mixtures more appropriate than single products for attainment of adequate and consistent weed control across sites and seasons.

Irrespective of seasons and sites, pendimethalin at 1.19 and 1.79 kg a.i. ha^{-1} effected and maintained excellent and persistent control (85-100%) of grassy weeds (Tables 1, 2 and 3). However, the activity of the product against broad-leaved weeds varied according to season and rate. In the first season pendimethalin, at the lower rate, effected moderate (55%) control of broad-leaved weeds at the GRSF (Table 1). However, a rapid decline in activity occurs at 4 WACE and the weed control dropped to 36%. In the second season however, the herbicide gave and maintained moderate control throughout the season (Table 2). At SRSF pendimethalin, at the low rate, gave excellent (75 and 87%) control of broad-leaved weeds early in the season, but only moderate control was maintained late in the season (Table 3). The observed variability in pendimethalin performance against broad-leaved weeds may be attributed to variations in composition of the weed flora and/or soil type. It has to be borne in mind that susceptibility of a weed to a herbicide, a part from intrinsic toxicity of the product, is influenced by environmental variables [10]. Furthermore pendimethalin, albeit effective on some broad-leaved weeds, it controls primarily grassy ones [11, 12].

Babiker and Ahmed [5], working on transplanted onion, reported that pendimethalin, oxadiazon and oxyfluorfen applied at transplanting or 7 days later resulted in excellent and persistent control of weed in onion. Pendimethalin and oxadiazon were effective in controlling weeds for 80–

90 days in garlic; however, weeds appeared in abundance late in the season [13].

Table 1. Influence of pendimethalin, oxadiazon and their tank-mixtures on grasses and broadleaved weeds in direct seeded onion at Gizera site (season 2003/04).

Treatment	Herbicide rate (kg a.i. ha^{-1})	% Weed control								Weed biomass (t. ha^{-1})
		Grasses				Broadleaved				
		2 †	4 †	6 †	8 †	2 †	4 †	6 †	8 †	
Pendimethalin	1.19	97	86	85	85	55	36	25	35	2.73
,,	1.79	96	97	92	96	74	84	58	60	2.03
Oxadiazon*	0.48	97	100	100	97	55	74	58	73	2.15
,, *	0.71	97	100	95	97	55	79	75	73	2.93
,, *	0.95	97	100	100	98	55	79	75	67	2.80
,, **	0.48	97	97	95	96	55	36	68	58	2.85
,, **	0.71	97	97	95	96	55	36	70	65	2.23
,, **	0.95	97	97	95	97	55	36	84	70	1.90
Oxadiazon + Pendimethalin*	0.48 + 1.19	97	100	100	100	55	79	75	85	2.65
,, + ,, *	0.71 + 1.19	97	100	100	100	55	89	83	87	1.83
,, + ,, *	0.95 + 1.19	97	100	100	96	55	89	83	85	1.95
,, + ,, **	0.48 + 1.19	97	97	100	100	55	36	67	85	2.53
,, + ,, **	0.71 + 1.19	97	97	100	100	55	36	83	85	1.53
,, + ,, **	0.95 + 1.19	97	97	100	100	55	36	75	85	3.13
Weeded control	–	100	100	100	100	100	100	100	100	0
Unweeded control	–	0	0	0	0	0	0	0	0	4.43
S.E.±	–	-	-	-	-	-	-	-	-	0.286
CV%	–	-	-	-	-	-	-	-	-	25

† = weeks after crop emergence, * and ** = applied 2 and 4 weeks after crop emergence, respectively.

Oxadiazon at 0.48 to 0.95 kg a.i. ha^{-1}, alone or in tank mixtures with pendimethalin, irrespective of season and application time, applied to plots previously treated with pendimethalin at 1.19 kg a. i. ha^{-1} resulted in moderate to excellent control of broadleaved weeds early in the season and showed extended activity on late season weeds (Tables 1, 2 and 3). Generally, the activity of the products increased with rate. These findings are consistent with a previous report that pendimethalin activity against grasses and broad-leaved weeds, with more than two leaves, is improved when applied in tank mixtures with oxadiazon, oxyfluorfen or bentazon [2]. It has been reported that oxadiazon at 1.0 – 1.5 kg a. i. ha^{-1} gave excellent control of both grasses and broadleaved weeds and resulted in high garlic bulb yield [14]. Oxadiazon is a contact herbicide with soil activity and its mode of action differs from that of

pendimethalin [11]. Application of oxadiazon in mixtures with pendimethalin ensured good control of existing weeds as well as those which germinate later.

All herbicide treatments except pendimethalin basal treatment in season 2004/05, reduced weed biomass significantly (Tables 1-3). In general, increasing the rate of oxadiazon from 0.48 to 0.95 kg a. i. ha^{-1} often resulted in decreased weed biomass. Moreover, oxadiazon at 0.48 to 0.95 kg a. i. ha^{-1} tank mixed with pendimethalin at 1.19 kg a. i. ha^{-1}, irrespective of application time, showed better suppression of weed biomass than oxadiazon alone.

Table 2. Influence of pendimethalin, oxadiazon and their tank-mixtures on grasses and broadleaved weeds in direct seeded onion.at Shendi site (season 2004/05).

Treatment	Herbicide rate (kg a.i. ha^{-1})	% Weed control								Weed biomass (t. ha^{-1})
		Grasses				Broadleaved				
		2 †	4 †	6 †	8 †	2 †	4 †	6 †	8 †	
Pendimethalin	1.19	100	100	100	100	51	75	67	50	2.75
„	1.79	100	100	100	100	63	68	70	67	1.25
Oxadiazon*	0.48	100	100	100	100	51	77	81	75	1.65
„ *	0.71	100	100	100	100	51	77	78	71	1.83
„ *	0.95	100	100	100	100	51	71	81	67	2.28
„ **	0.48	100	100	100	100	51	75	85	71	1.38
„ **	0.71	100	100	100	100	51	75	85	75	1.90
„ **	0.95	100	100	100	100	51	75	75	62	1.40
Oxadiazon + Pendimethalin*	0.48 + 1.19	100	100	100	100	51	74	71	67	1.85
„ + „ *	0.71 + 1.19	100	100	100	100	51	74	81	79	1.83
„ + „ *	0.95 + 1.19	100	100	100	100	51	81	85	75	1.38
„ + „ **	0.48 + 1.19	100	100	100	100	51	75	75	62	1.60
„ + „ **	0.71 + 1.19	100	100	100	100	51	75	74	71	1.98
„ + „ **	0.95 + 1.19	100	100	100	100	51	75	81	83	1.43
Weeded control	–	100	100	100	100	100	100	100	100	–
Unweeded control	–	0	0	0	0	0	0	0	0	3.60
S.E.±	–	-	-	-	-	-	-	-	-	0.614
CV%	–	-	-	-	-	-	-	-	-	53

† = weeks after crop emergence. * and ** = applied 2 and 4 weeks after crop emergence, respectively

Unrestricted weed growth, invariably, reduced number of leaves per plant significantly (Table 4). All herbicide treatments, except pendimethalin at 1.19 kg a. i. ha^{-1} in season 2003/04, resulted in leaves number comparable to the weeded control and differences between herbicide treatments were not significant. This finding can be attributed to maintenance of adequate weed control. Selectivity of the herbicides in onion when applied as post-emergence treatments may be attributed to low spray retention by the crop leaves. Onion leaves are erect and waxy and are expected not to

return much of the spray solution [2]. Weeds on the other hand, particularly broad-leaved ones, are expected to return most of the spray solution [15].

Table 3. Influence of pendimethalin, oxadiazon and their tank-mixtures on grasses and broadleaved weeds in direct seeded onion.at Shendi site (2005/06).

Treatment	Herbicide rate (kg a.i. ha^{-1})	% Weed control								Weed biomass (t. ha^{-1})
		Grasses				Broadleaved				
		2 †	4 †	6 †	8 †	2 †	4 †	6 †	8 †	
Pendimethalin	1.19	95	97	90	95	87	75	55	53	3.86b
„	1.79	95	99	100	98	87	78	40	44	1.75
Oxadiazon*	0.48	95	98	95	97	87	85	56	44	2.13
„ *	0.71	95	90	98	98	87	86	70	63	1.06
„ *	0.95	95	90	100	92	87	82	70	61	1.32
„ **	0.48	95	90	98	94	87	75	70	68	1.55
„ **	0.71	95	100	98	92	87	75	70	63	1.20
„ **	0.95	95	100	98	99	87	75	67	44	1.65
Oxadiazon +	0.48 + 1.19	95	95	90	98	87	86	70	46	1.91
„ + „	0.71 + 1.19	95	93	93	95	87	93	65	49	0.82
„ + „	0.95 + 1.19	95	100	95	96	87	85	53	47	1.16
„ + „	0.48 + 1.19	95	95	98	98	87	75	72	61	1.05
„ + „	0.71 + 1.19	95	100	98	90	87	75	80	64	1.41
„ + „	0.95 + 1.19	95	100	100	98	87	75	80	68	0.85
Weeded control	-	100	100	100	100	100	100	100	-	
Unweeded control	-	0	0	0	0	0	0	0	7.50	
S.E.±	-	-	-	-	-	-	-	-	0.282	
CV%	-	-	-	-	-	-	-	-	31	

† = weeks after crop emergence, * and ** = applied 2 and 4 weeks after crop emergence, respectively.

Bulb diameter was positively correlated with bulb yield (r = 0.87 – 0.91) (Table 5). The high positive correlation obtained is consistent with the role of bulb size as a yield determinant factor. Unrestricted weed growth reduced bulb diameter by 41-55% in comparison to the weeded control. Supplementation of pendimethalin basal treatment by oxadiazon alone or its tank mixtures with pendimethalin, irrespective of rate and application time, resulted in bulb diameter comparable to the weeded control. The observed increase in bulb size could attributed to maintenance of adequate weed control throughout the season (Tables 1, 2 and 3). The observed reduction in bulb diameter due to weeds interference is consistent with several reports [16, 17].

Unrestricted weed growth reduced onion bulb yield by over 80% (Table 5). All herbicides treatments out-yielded the unweeded control significantly. At GRSF pendimethalin at 1.19 kg a. i. ha^{-1}, applied as a pre-emergence treatment, increased bulb yield by about 4-6-fold (Tables 5). Increasing herbicide rate to 1.79 kg a. i. ha^{-1}

increased yield albeit not significantly. At SRSF the herbicide, at the low rate, increased onion yield by over 9-fold. However, at the high rate the increase in yield dropped to about 7-fold (Table 4). Lack of a significant increase in onion bulb yield at GRSF on increasing herbicide rate despite the improved weed control and the observed significant reduction in bulb yield at SRSF on increasing herbicide rate to 1.79 kg a. i. ha^{-1} (Tables 1, 2 and 5) may be attributed to phytotoxic effects. The high reduction in yield at SRSF compared to GRSF may be due to soil type. The lighter soil at SRSF may promote high uptake of the herbicide in comparison to the heavy clay soil at GRSF.

Table 4. Influence of pendimethalin, oxadiazon and their tank-mixtures on number of leaves per plant in direct seeded onion.

Treatment	Herbicide rate (kg a.i. ha^{-1})	Number of leaves per plant		
		Season		
		2003/04	2004/05	2005/06
Pendimethalin	1.19	9.3	10.0	10.5
,,	1.79	10.5	10.8	9.9
Oxadiazon*	0.48	10.3	11.3	10.4
,, *	0.71	10.3	10.5	10.5
,, *	0.95	9.8	10.0	10.6
,, **	0.48	9.8	10.5	12.0
,, **	0.71	10.0	11.3	10.9
,, **	0.95	10.5	10.0	11.8
Oxadiazon + Pendimethalin*	0.48 + 1.19	9.5	12.0	11.8
,, + ,, *	0.71 + 1.19	11.0	10.8	10.1
,, + ,, *	0.95 + 1.19	11.0	10.3	11.1
,, + ,, **	0.48 + 1.19	10.8	11.5	10.5
,, + ,, **	0.71 + 1.19	10.3	11.5	10.9
,, + ,, **	0.95 + 1.19	12.0	11.0	11.5
Weeded control	–	12.2	11.0	12.0
Unweeded control	–	7.2	8.5	7.0
S.E.±		0.51	0.46	1.13
CV%		10	8.7	22

* and ** = applied 2 and 4 weeks after crop emergence, respectively.

Pendimethalin alone is not reliable to be recommended for weed control in direct seeded onion. The low rate did not show reproducible performance across seasons and sites, while the high rate is somewhat toxic. Oxadiazon applied as a supplement to pendimethalin basal dose improved onion bulb yield. At GRSF in season 2003/04, oxadiazon alone at 0.48 and 0.95 kg a. i. ha^{-1} applied at 2 WACE and at 0.71 and 0.95 kg a. i. ha^{-1} applied 4 WACE resulted in bulb yield comparable to the weeded control. Oxadiazon in tank mixtures with pendimethalin, invariably, resulted in bulb yield comparable to the weeded control. In season 2004/05 oxadiazon alone and in tank

mixtures with pendimethalin, irrespective of rate or time of application, resulted in bulb yield comparable to the weeded control. However, in among all herbicides treatments oxadiazon at 0.48 and 0.71 kg a. i. ha^{-1} in tank mixtures with pendimethalin resulted in the highest bulb yield (Table 5). At SRSF oxidiazon at 0.71 and 0.95 kg a.i. ha^{-1} applied as a supplement to pendimethalin basal dose, 2 WACE, oxidiazon at 0.45 and 0.71 kg a.i. ha^{-1} applied 4 WACE, oxadiazon at 0.95 kg a .i. ha^{-1} tank mixed with pendimethalin applied 2 WACE and oxadiazon at 0.71 and 0.95 kg a .i. ha^{-1} tank mixed with pendimethalin applied 4 WACE, effected bulb yield comparable to the weeded control (Table 5). The increase in yield associated with oxadiazon and its tank mixtures with pendimethalin could be attributed to the good and/or excellent control of broad-leaved weeds including those escaping the pendimethalin treatment. Oxadiazon and its tank mixtures with pendimethalin were not toxic to onion. In general the activity, of the herbicide on broad-leaved weeds, increased with increasing rate. This could be attributed to size of the weeds leading to higher threshold levels resulting from a growth dilution effect. It has been reported that susceptibility of a weed to an herbicide may change with growth stage, mainly, due to a growth dilution effect in among other factors [2].

Table 5. Influence of pendimethalin, oxadiazon and their tank-mixtures on bulb diameter and yield of direct seeded onion.

Treatment	Herbicide rate (kg a.i. ha^{-1})	Bulb diameter (cm) Season			Yield (t. ha^{-1}) Season		
		2003/04	2004/05	2005/06	2003/04	2004/05	2005/06
Pendimethalin	1.19	3.9	4.2	4.8	9.5	6.7	28.1
„	1.79	5.4	4.1	4.9	12.6	6.9	19.0
Oxadiazon*	0.48	5.6	4.2	5.3	13.6	8.8	22.8
„ *	0.71	5.4	4.6	5.1	12.4	8.6	30.7
„ *	0.95	5.5	4.2	5.3	14.0	7.4	30.7
„ **	0.48	5.8	4.1	5.4	12.9	7.4	34.9
„ **	0.71	5.8	4.5	5.4	16.2	9.8	34.3
„ **	0.95	5.9	4.5	5.1	13.8	7.4	27.4
Oxadiazon + Pendimethalin*	0.48 + 1.19	5.4	5.2	5.0	15.0	9.8	25.2
„ + „ *	0.71 + 1.19	6.0	4.6	5.0	15.5	12.1	19.3
„ + „ *	0.95 + 1.19	6.2	4.6	5.2	15.2	8.6	30.9
„ + „ **	0.48 + 1.19	5.8	4.6	5.3	15.7	7.6	25.7
„ + „ **	0.71 + 1.19	6.1	4.5	5.5	16.2	7.4	36.7
„ + „ **	0.95 + 1.19	5.7	4.9	5.3	13.8	9.3	31.4
Weeded control	–	5.6	4.9	5.5	16.4	10.0	36.9
Unweeded control	–	3.3	2.9	2.5	1.4	1.4	2.6
S.E.±		0.31	0.03	0.57	1.72	0.81	1.13
CV%		11.0	11	19	15.0	20	16

* and ** = applied 2 and 4 weeks after crop emergence, respectively.

References

[1] Mohamed MB. 1997. The effect of cultural practices on vegetable pests and diseases. In: *Integrated Pest Management in Vegetables, Wheat and Cotton in the Sudan: A Participatory Approach,* (Z.T. Dabrowski ed.). pp. 80–89, ICIPE Science Press, Nairobi, Kenya.

[2] Rubin B. 1990. Weed competition and weed control in *Allium* crops. In: *Onions and Allied Crops, Vol. II, Agronomy, Biotic Interaction, Pathology, and Crop Protection.* (eds Rabinowitch, H.D. and Brewster, J.L.). pp. 64–81. CRC Press, Inc. Boca Raton, Florida.

[3] Abdalla NK, Babiker AGT. 2004. Efficacy of Pendikool 50EC (pendimethalin) and Eradikool 24EC (oxyfluorfen) as preemergence herbicides for weed control in transplanted onion. In: *Proceedings* 2004. The *70th – 71st Meeting of the Pests and Diseases Committee* (ed.. Mohmed GI) Agricultural Research Corporation, Crop Protection Centre, Wad Medani, Sudan, 164-167.

[4] Williams CF, Crabtree G, Mack HJ, Laws WD. 1973. Effect of spacing on weed competition in sweet corn, snap bean, and onions, *J Am Soc Hortic Sci* 98: 526 – 529.

[5] Babiker, AGT, Ahmed MK. 1986. Chemical weed control in transplanted onion (*Allium cepa* L.) in the Sudan Gezira. *Weed Res* 26: 133–137.

[6] Boshvitz Y. 1973. Lasting effect of oxadiazon in the soil and its influence on different crops in rotation. *Phytoparasitica* 1: 84.

[7] Eshel Y, Ohali I, Bandulah G. 1979. Selectivity of ethofumesate to onion, *Phytoparasitica* 7: 139–155.

[8] Idris MA.M. 1996. Agrotechnology transfer based on soil taxonomy Gezira benchmark soil, In: *Forschungen im Sudan Ergebnisse der interdisziplinaren Sudantagung in Februar 1996 in Erfurt* (ed. Pörtage kH) pp. 59–68. Institut fÜr Geographie Padägogische Hochshule.

[9] Ibrahim HS. 1983. The Sudanese environment. In: *Faba bean in the Nile Valley*. Report on the first phase of the ICARDA/IFAD Nile valley Project (M.C. Saxena and R.A. Steward eds.). pp. 16–21. ICARDA.

[10] Babiker, AGT. 1976. Behaviour and fate of pesticides in plant soil water system. Ph.D. Thesis, University of Glasgow, Glasgow, U.K.

[11] Ahrens WH. 1994. *Herbicide Handbook*, *Seventh edition*. West University Avenue Champaign, U.S.A.. pp.352.

[12] Thomson WT. 1987. Agricultural Chemicals, Book II Herbicides. Thomson, Fresno, Ca. pp.301. USA.

[13] Mohmood T, Hussain SI, Khokhar KM, Jeelani G, Hidayatullah. 2002. Weed control in garlic crop in relation to weedicides. *Asian Journal of Plant Sciences* 1: 412–413.

[14] Tunku P, Lagoke STO, Shaya DB. 2007. Evaluation of herbicides for weed control in irrigated garlic (*Allium sativum* L.) at Samaru, Nigeria. *Crop Protection* 26: 677–682.

[15] Verity J, Walker A, Drennan DSH. 1981. Aspect of the selective phytotoxicity of methazole. I. Measurements of species response spray retention and leaf surface characteristics. *Weed Res* 21: 243–253.

[16] Williams MM, Ranson, CV, Thompson WM. 2004. Effect of volunteer potato density on dry bulb onion yield and quality. *Weed Sci* 52: 754–758.

[17] Williams MM, Ranson CV, Thompson WM. 2007. Volunteer potato density influences critical time of weed removal in bulb onion. *Weed Technology* 21: 136–140.