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EVALUATING POSTEMERGENCE HERBICIDES FOR BROADLEAF WEED CONTROL IN IRRIGATED BREAD WHEAT (*Triticum aestivum* L.)

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ABSTRACT

The objective of this research was to study the effect of broadleaf herbicide treatments and grass + broadleaf herbicides on annual broadleaf weeds and bread wheat yield. Eight on-farm weed control trials were conducted in bread wheat from 2014-15 to 2016-17 in Tadla and Doukkala irrigated perimeters, Morocco: 3 trials using broadleaf herbicides and 5 trials using pre-mix or tank mix of grass and broadleaf herbicides. In 3 trials, 9 broadleaf herbicides (metsulfuron-methyl 6 g ha⁻¹, tribenuron-methyl 9.375 g ha⁻¹, amidosulfuron 15 g ha⁻¹ + iodosulfuron-methyl-sodium 3.75 g ha⁻¹, aminopyralid 9.9 g ha⁻¹ + florasulam 4.95 g ha⁻¹, dicamba 120 g ha⁻¹ + 2,4-D 344 g ha⁻¹, florasulam 3.75 g ha⁻¹ + 2,4-D 180 g ha⁻¹, flumetsulam 5 g ha⁻¹ + florasulam 3.75 g ha⁻¹, triasulfuron 6.15 g ha⁻¹ + dicamba 98.85 g ha⁻¹, and tribenuron-methyl 5 g ha⁻¹ + thifensulfuron-methyl 10 g ha⁻¹) caused no injury to bread wheat, reduced 80 to 100% density and shoot biomass of broadleaf weeds, and provided wheat grain yields up to 8.0 Tons ha⁻¹ compared to the untreated plots. In 5 trials, 12 pre-mix or tank mix of grass and broadleaf herbicides reduced shoot biomass of broadleaf weeds up to 100% and provided wheat grain yields up to 9.3 Tons ha⁻¹ compared to the untreated plots. Herbicide treatments containing pyroxulam or mesosulfuron-methyl + iodosulfuron-methyl-sodium caused crop injury, but wheat plants recovered and grain yield was not affected.

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Mesosulfuron-methyl + iodosulfuron-methyl-sodium and mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican were less effective on milk thistle (*Silybum marianum* (L.) Gaertn). Further research involving grass and broadleaf herbicides is needed to explore ways, including the use of adjuvants, to avoid wheat injury and optimize herbicide efficacy on noxious weeds such as milk thistle.

1 Introduction

Bread wheat (*Triticum aestivum* L.) is a major crop that is grown on 2 million hectares in Morocco (Rerhrhaye & Ait El Mekki, 2017). Out of this, about 200,000 hectares are cultivated under irrigation. Irrigated bread wheat is usually planted in November in rotation with several crops including sugarbeet (*Beta vulgaris* L.), corn (*Zea mays* L.), Egyptian clover (*Trifolium alexandrinum* L.) or alfalfa (*Medicago sativa* L.). In 2015-16, grain yield of irrigated bread wheat was estimated to 4 Tons ha⁻¹ (Rerhrhaye & Ait El Mekki, 2017), but area and yield increases over the past decades have been minimal. However, Jlibene & Chafai Elalaoui (2002) found that some bread wheat cultivars, when cultivated appropriately under irrigation, produced up to 7.8 Tons ha⁻¹.

More than 300 weed species have been identified in wheat fields (Taleb et al., 2000). Among them, major annual grass weeds are rigid brome (*Anisantha rigida* (Roth) Hyl.), sterile oat (*Avena sterilis* L.), canarygrass (*Phalaris brachystachys* Link, *P. minor* Retz., *P. paradoxa* L.), and rigid ryegrass (*Lolium rigidum* Gaud.) (Tanji, 2005). Major annual broadleaf weeds are common poppy (*Papaver rhoeas* L.), milk thistle (*Silybum marianum* (L.) Gaertn.), wild mustard (*Sinapis arvensis* L.), wild chicory (*Cichorium intybus* L.), spiny emex (*Emex spinosa* (L.) Campd.), and crown daisy (*Glebionis coronaria* (L.) Spach) (Tanji, 2005). All these weeds are fall and/or winter annuals, and the weed emergence pattern is a consequence of soil moisture (from rainfall and irrigation) and germination temperature requirements. In 23 weed control trials, Tanji (2002) found that weed densities in the untreated plots were up to 500 plants m², and grain yield losses of irrigated bread wheat due to weed competition were up to 80%.

Weed control with herbicides is the most common practice in irrigated wheat (Tanji, 2000). Furthermore, Tanji (2003) reported that tribenuron-methyl (9.375 g ha⁻¹), triasulfuron + terbutryne (10 + 150 g ha⁻¹), and 2,4-D + MCPA (330 + 341 g ha⁻¹) provided up to 96% control of annual broadleaf weeds. In general, the use of selective postemergence herbicides resulted in excellent weed control and increased bread wheat yield (Benahnia, 1985; Rafrafi, 1988; Errohi, 1995; Aitounejjar & Tanji, 1997; Benslimane, 2000; Tanji, 2002; Tanji, 2003; El Antri & Madkouri, 2005).

Since 2000, several postemergence herbicides (amidosulfuron, aminopyralid, flucarbazon, iodosulfuron-methyl-sodium, mesosulfuron-methyl, metsulfuron-methyl, pyroxulam, thifensulfuron-methyl, and many others) have been registered in Morocco for weed control in wheat. However, limited research has been conducted on weed control with these recently registered herbicides in irrigated wheat. Information on herbicide choice, effective herbicide application rates, and application timing is needed to provide producers with precise decision tools for managing weeds in wheat production systems. The objective of this study was to evaluate the response of annual broadleaf weeds and wheat production to 9 broadleaf herbicide treatments in 3 trials and 12 premix or tank mix of grass and broadleaf herbicide treatments in irrigated bread wheat in 5 trials.

2 Materials and Methods

2.1 Experiment site and design

A total of 8 bread wheat trials were conducted in farmers' fields from 2014-15 to 2016-17, in Doukkala and Tadla perimeters, Morocco: 3 trials using postemergence broadleaf herbicides (Tables 1 & 2) and 5 trials using premix or tank mix of postemergence grasses and broadleaf herbicides (Tables 1 & 3). The preceding crops were alfalfa, faba bean, sugar beet or bread wheat. Fields were plowed once with a deep plow and twice with a tandem disc. Each field measured 1 hectare that was drilled with "Amal" bread wheat at a seed rate of 200 kg ha⁻¹ in November 2014, 2015, and 2016. The N-P-K fertilizer used at planting was either diammonium phosphate (18-46-0) at the rate of 200 kg ha⁻¹ or 15-15-15 at the rate of 300 kg ha⁻¹. It was manually broadcast and incorporated with a tandem disc before planting. After crop emergence, ammonium nitrate 33% was broadcast 2 to 3 times during the growing season. Trials had access to irrigation to supplement rainfall (Table 1).

Trials were arranged as randomized complete blocks with 3 replications and individual plot size measured 10 m by 2 to 3 m. One nontreated control per replication was included for treatment comparisons. At the early wheat tillering stage, 9 broadleaf herbicide treatments (Table 2) and 12 premix or tank mix of grass and broadleaf herbicide treatments were applied (Table 3). The herbicides and their rates were

Table 1 Characteristics of the 8 on-farm trials conducted from 2014-15 to 2016-17 in the Tadla and Doukkala irrigated perimeters, Morocco

Management practices	3 trials with broadleaf herbicides			5 trials with premix or tank mix of grass and broadleaf herbicides				
	Tadla 2014-15 Trial 1	Tadla 2015-16 Trial 2	Doukkala 2015-16 Trial 3	Tadla 2014-15 Trial 1	Tadla 2015-16 Trial 2	Tadla 2016-17 Trial 3	Tadla 2016-17 Trial 4	Doukkala 2015-16 Trial 5
Preceding crop	sugarbeet	alfalfa	sugarbeet	sugarbeet	sugarbeet	sugarbeet	faba bean	sugarbeet
Tillage	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill	1 deep plowing + 2 tandem disc + planting with a drill
Date of planting	Nov 20, 2014	Nov 22, 2015	Nov 20, 2015	Nov 22, 2014	Nov 20, 2015	Nov 15, 2016	Nov 21, 2016	Nov 20, 2015
Date of crop emergence	Nov 29, 2014	Dec 1, 2015	Dec 1, 2015	Dec 1, 2014	Nov 29, 2015	Nov 21, 2016	Nov 28, 2016	Dec 1, 2015
Fertilizer at planting	200 kg ha ⁻¹ DAP 18-46-0	200 kg ha ⁻¹ DAP 18-46-0	300 kg ha ⁻¹ 15-15-15	200 kg ha ⁻¹ DAP 18-46-0	200 kg ha ⁻¹ DAP 18-46-0	200 kg ha ⁻¹ DAP 18-46-0	200 kg ha ⁻¹ DAP 18-46-0	300 kg ha ⁻¹ 15-15-15
Top dressing nitrogen	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	200 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 150 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	200 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 150 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage	100 kg ha ⁻¹ ammonium nitrate 33% at the tillering stage, 100 kg ha ⁻¹ ammonium nitrate 33% at the jointing stage
Foliar fungicide at the booting stage and repeated at heading	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	Spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹	spiroxamine 200 g ha ⁻¹ + tebuconazole 133.6 g ha ⁻¹ + triadimenol 34.4 g ha ⁻¹
Irrigation system	Flood irrigation	Flood irrigation	Flood irrigation	Flood irrigation	Flood irrigation	Flood irrigation	Flood irrigation	Flood irrigation
Date of spraying weed control trials	Dec 30, 2014 at the tillering stage	Jan 2, 2016 at the tillering stage	Jan 7, 2016 at the tillering stage	Jan 6, 2015 at the tillering stage	Jan 3, 2016 at the tillering stage	Jan 1, 2017 at the tillering stage	Jan 10, 2017 at the tillering stage	Jan 8, 2016 at the tillering stage

Table 2 Effect of broadleaf herbicides on the density and shoot dry weight (DW) of broadleaf weeds 2 months after treatment (2 MAT), and bread wheat grain yield in 3 on-farm weed control trials in 2014-15 and 2015-16 in the Tadla and Doukkala irrigated perimeters, Morocco

Herbicide (rate ha ⁻¹)		Tadla						Doukkala		
		Trial 1 2014-15			Trial 2 2015-16			Trial 3 2015-16		
		Weed density	Weed DW	Wheat yield	Weed density	Weed DW	Wheat yield	Weed density	Weed DW	Wheat yield
		pl m ⁻²	g m ⁻²	T ha ⁻¹	pl m ⁻²	g m ⁻²	T ha ⁻¹	pl m ⁻²	g m ⁻²	T ha ⁻¹
Amidosulfuron (15 g) + iodosulfuron-methyl- sodium (3.75 g)	SEKATOR (150 ml)	4	7	7.8	2	7	6.8	3	13	5.1
Aminopyralide (9.9 g) + florasulam (4.95 g)	LANCELOT (33 g)	4	9	7.8	4	7	6.7	1	7	5.3
Dicamba (120 g) + 2,4-D (344 g)	DIALEN SUPER (1 L)	1	3	7.9	2	3	6.8	3	13	5.1
Flumetsulam (5 g) + florasulam (3.75 g)	DERBY (50 ml)	2	5	7.8	2	6	6.9	1	13	5.2
Florasulam (3.75 g) + 2,4-D (180 g)	MUSTANG (600 ml)	4	9	7.8	3	7	6.6	0	0	5.6
Metsulfuron-methyl (6 g)	STARKEM (10 g)	3	7	8.0	1	4	6.8	1	7	5.7
Triasulfuron (6.15 g) + dicamba (98.85 g)	LINTUR (150 g)	3	7	7.8	3	7	6.7	12	20	5.8
Tribenuron-methyl (9.375 g)	GRANSTAR (12.5 g)	3	5	8.0	2	5	6.7	5	13	5.1
Tribenuron-methyl (5 g) + thifensulfuron-methyl (10 g)	HARMONY EXTRA (20 g)	2	4	8.0	2	3	6.6	3	13	5.3
Untreated check		29	75	7.2	26	60	6.1	57	1613	3.4
LSD (0.05)		5	5	NS	2	3	0.2	11	197	1.1

Table 3 Effect of premix or tank mix of grass and broadleaf herbicides on the density and shoot dry weight (DW) of broadleaf weeds 2 months after treatment (2 MAT) and wheat grain yield in 5 on-farm weed control trials from 2014-15 to 2016-17 in the Tadla and Doukkala irrigated perimeters, Morocco

Herbicide (rate ha ⁻¹)		Tadla								Doukkala	
		Trial 1 2014-15		Trial 2 2015-16		Trial 3 2016-17		Trial 4 2016-17		Trial 5 2015-16	
		Weed DW	Wheat yield	Weed DW	Wheat yield	Weed DW	Wheat yield	Weed DW	Wheat yield	Weed DW	Wheat yield
		g m ⁻²	T ha ⁻¹	g m ⁻²	T ha ⁻¹	g m ⁻²	T ha ⁻¹	g m ⁻²	T ha ⁻¹	g m ⁻²	T ha ⁻¹
Mesosulfuron-methyl (15 g) + iodosulfuron-methyl- sodium (3 g)	ATLANTIS (500 ml)	0	6.8	4	6.3	15	6.1	188	5.0	27	5.7
Mesosulfuron-methyl (7.5 g) + iodosulfuron-methyl-sodium (7.5 g)	COSSACK (1 L)	0	6.6	2	6.5	8	6.0	125	5.2	27	5.9
Flucarbazone (61.4 g) + amidosulfuron (15 g) + iodosulfuron-methyl-sodium (3.75 g)	EVEREST (43 g) + SEKATOR (150 ml)	1	6.7	3	6.5	3	6.3	4	8.8	13	4.4
Iodosulfuron-methyl-sodium (8 g) + fenoxaprop-p-ethyl (64 g)	HUSSAR (1 L)	3	6.6	5	6.4	10	6.2	15	7.8	0	4.5
Mesosulfuron-methyl (7.2 g) + iodosulfuron-methyl- sodium (6 g) + diflufenican (96 g)	KALENKO (800 ml)	3	6.7	5	6.5	4	6.1	99	6.1	13	4.5
Pinoxaden (45 g) + florasulam (5 g)	NAVIGATOR (1 L)	2	6.8	5	6.5	3	6.1	160	5.1	27	4.8
Mesosulfuron-methyl (7.5 g) + iodosulfuron-methyl sodium (2.5 g) + diflufenican (50 g)	OTHELLO (1 L)	3	6.8	5	6.4	0	6.4	25	8.8	13	5.6
Pinoxaden (30 g) + clodinafop (30 g) + florasulam (7.5 g)	SWIPE (1 L)	3	6.7	4	6.4	0	6.1	236	8.2	27	5.5
Pinoxaden (45 g) + amidosulfuron (15 g) + iodosulfuron-methyl-sodium (3.75 g)	AXIAL (1 L) + SEKATOR (150 ml)	3	6.5	4	6.4	0	6.5	5	9.0	13	5.4
Pyroxsulam (22.656 g) + florasulam (4.260 g)	FLORAMIX (320 g)	0	6.6	0	6.4	7	6.1	16	8.6	0	5.5
Clodinafop (60 g) + amidosulfuron (15 g) + iodosulfuron-methyl-sodium (3.75 g)	TOPIK (750 ml) + SEKATOR (150 ml)	3	6.5	4	6.2	0	6.2	0	9.2	13	5.1
Pinoxaden (22.5 g) + clodinafop (22.5 g) + amidosulfuron (15 g) + iodosulfuron-methyl- sodium (3.75 g)	TRAXOS (1 L) + SEKATOR (150 ml)	4	6.6	5	6.1	0	6.5	6	9.3	220	5.3
Untreated check		67	6.1	67	5.2	120	4.1	302	4.6	780	4.1
LSD (0.05)		5	NS	3	0.2	16	1.4	38	1.2	248	1.6

recommended field rates for weed control in wheat (Tables 2 and 3). In the 3 trials with broadleaf herbicides, major weed species infesting wheat included spiny emex (*E. spinosa*), common poppy (*Papaver rhoeas* L.), nettleleaf goosefoot (*Chenopodium murale*), wild mustard (*S. arvensis*), wild chicory (*C. intybus*), common sowthistle (*Sonchus oleraceus*), and henbit (*Lamium amplexicaule*). In the 5 trials with grass and broadleaf herbicides, major weed species infesting wheat were milk thistle (*S. marianum*), field marigold (*Calendula arvensis*), wild mustard (*S. arvensis*), wild chicory (*C. intybus*), and blue pimpernel (*Lysimachia arvensis*).

Herbicide application was done at the seedling or vegetative stage of broadleaf weeds. Foliar fungicides were sprayed at the boot stage and repeated at heading. Herbicide and fungicide treatments were applied with a backpack sprayer fitted with a spray boom with 4 flat fan 8002 nozzles calibrated to deliver 200 L ha⁻¹.

2.2 Measurements

Two months after treatments (2 MAT), weeds were collected from one 0.50 m x 0.50 m quadrat in each plot. Removed weeds were counted for density, and shoots were oven dried at 60°C to a constant weight and weighed. At full maturity, wheat was harvested at ground level in an area of 1 m² per plot. Wheat was threshed by a small combine and grain was cleaned and weighed. Wheat yield loss due to weed competition and yield increase due to herbicide use were calculated as follows:

$\% \text{yield loss} = \frac{\left(\begin{array}{l} \text{Grain yield in weed - free plots} \\ - \text{Grain yield in weedy plots} \end{array} \right)}{\text{Grain yield in weed - free plots}} \times 100$
$\% \text{yield increase} = \frac{\left(\begin{array}{l} \text{Grain yield in weed - free plots} \\ - \text{Grain yield in weedy plots} \end{array} \right)}{\text{Grain yield in weedy plots}} \times 100$

2.3 Statistical analyses

Measured variables (weed density, weed shoot dry weight, and wheat grain yield) varied across trials and cropping seasons, primarily due to differences in environmental conditions (irrigation, rainfall, soil type, crop rotation). Therefore, data analysis was performed for each trial to determine the significance of the herbicide treatments. Density and biomass of weeds and wheat grain yields were subjected to the ANOVA using SAS (SAS Institute, Cary, NC, USA). Means were compared using the Fisher's protected LSD at P = 0.05.

3 Results and Discussion

3.1 Weed control with broadleaf herbicides (3 trials)

Weed densities in untreated plots varied from 26 to 57 plants m⁻² (Table 2). Shoot dry weights varied between 60 and 1613 g m⁻². Five herbicide treatments viz. (i) metsulfuron-methyl 6 g ha⁻¹, (ii) tribenuron-methyl 9.375 g ha⁻¹, (iii) dicamba 120 g ha⁻¹ + 2,4-D 344 g ha⁻¹, (iv) flumetsulam 5 g ha⁻¹ + florasulam 3.75 g ha⁻¹, and (v) tribenuron-methyl 5 g ha⁻¹ + thifensulfuron-methyl 10 g ha⁻¹ provided consistently excellent weed control by reducing weed density and/or weed biomass by ≥90%. While the other herbicide treatments i.e. (i) amidosulfuron 15 g ha⁻¹ + iodosulfuron-methyl-sodium 3.75 g ha⁻¹, (ii) aminopyralid 9.9 g ha⁻¹ + florasulam 4.95 g ha⁻¹, (iii) florasulam 3.75 g ha⁻¹ + 2,4-D 180 g ha⁻¹, and (iv) triasulfuron 6.15 g ha⁻¹ + dicamba 98.85 g ha⁻¹ gave good to excellent control by reducing weed density and/or biomass by more than 80% (Table 2).

Such acceptable levels of weed control could be attributed to the herbicides reaching seedlings and small weed plants at the early wheat tillering stage, to the susceptibility of most annual broadleaf weeds to herbicides, and to better growth conditions of weeds under irrigation. Previous studies revealed that many annual broadleaf weeds were controlled by broadleaf herbicides in wheat (Benahnia, 1985; Rafrafi, 1988; Errohi, 1995; Diab, 1996; Aitounnejjar & Tanji, 1997; Benslimane, 2000; Tanji, 2002; Tanji 2003; El Antri & Madkouri, 2005). Further, Wu et al. (2010) reported in Australia that the efficacy of early postemergent applications of metsulfuron-methyl at 4.2 g ha⁻¹ on flaxleaf fleabane (*Erigeron bonariensis* L.) and it was effective up to 98%. In Egypt, Saad et al. (2011) reported that tribenuron-methyl (9.375 g ha⁻¹) and flumetsulam (5 g ha⁻¹) + florasulam (3.75 g ha⁻¹) reduced nettleleaf goosefoot (*Chenopodium murale* L.) density up to 91% 3 weeks after treatment.

Due to foliar or root absorption and possibly the activation by irrigation, broadleaf herbicide treatments containing residual herbicides such as aminopyralid, iodosulfuron-methyl-sodium, and triasulfuron have been effective in controlling initial weed infestations as well as multiple flushes of weeds, and provided season-long control of weeds. But, use of residual herbicides might restrict the choice of crops planted after wheat. In North Dakota, USA, Mikkelsen & Lym (2011) found that residues of aminopyralid applied at 120 g ha⁻¹ injured alfalfa, soybean, and sunflower planted 8 and 11 months after treatments (MAT). They found that corn was not affected by aminopyralid when seeded 8 or 11 MAT and appeared to be the best cropping option for land recently treated with aminopyralid.

3.2 Weed control with grass + broadleaf herbicides

Shoot weights of broadleaf weeds in untreated plots varied from 67 to 780 g m⁻² (Table 3). Major weed species found in the trials were milk thistle (*S. marianum*), field marigold (*C. arvensis*), wild mustard (*S. arvensis*), wild chicory (*C. intybus*), and blue pimpernel (*L. arvensis*).

Six herbicide treatments consistently provided excellent weed control by reducing weed biomass by 92-100% (Table 3). The other 6 treatments, including mesosulfuron-methyl + iodosulfuron-methyl-sodium, were excellent on many annual broadleaf weed species, but less effective against milk thistle (*S. marianum*), as indicated by higher weed biomass (Table 3). In Portugal, Barros et al. (2009) found that premix of mesosulfuron-methyl at 12 g ha⁻¹ + iodosulfuron-methyl-sodium at 2.4 g ha⁻¹ gave satisfactory control of rigid ryegrass (*Lolium rigidum*), but had limited ability to control some broadleaf weeds such as night catchfly (*Silene nocturna*), Moroccan chamomile (*Cladanthus mixtus*), prostrate knotweed (*Polygonum aviculare*), blue pimpernel (*Lysimachia arvensis*), glandular plantain (*Plantago afra*), and Queen Anne's lace (*Daucus carota*).

3.3 Grain yield after using broadleaf herbicides (3 trials)

None of the broadleaf herbicide treatments visibly injured wheat at any location. Injury was not expected since the herbicide treatments were applied under appropriate growth conditions and at the registered rates. Grain yields in sprayed plots ranged from 7.8 to 8.0 T ha⁻¹ in trial 1, 6.6 to 6.9 T ha⁻¹ in trial 2, and 5.1 to 5.8 T ha⁻¹ in trial 3 (Table 2). In these trials, no significant differences were observed between yields obtained in various treated plots. Yield variations between trials and years were probably due to different preceding crops and irregular durations between irrigations. Yield increases due to weed control were 11, 13, and 71% compared to the yields observed in nontreated plots in trials 1, 2, and 3, respectively. Increased grain yields recorded in all herbicide-treated plots in comparison with untreated plots could be attributed to the excellent weed control by all herbicide treatments used in this study. Weed control improved grain yields through better utilization of available resources like water, fertilizer, sunlight, and space. Other appropriate practices that could have increased grain yield were November planting, certified seeds, disease control with fungicides, and irrigation (Hamid, 1995; Ezzahiri et al., 1999; Bouhache et al., 2000; Mosseddaq et al., 2000; Zbair et al., 2000). In on-farm trials, bread wheat grain yields varied with cultivars and were up to 7.8 T ha⁻¹ when the best production practices were used (Jlibene & Chafai Elalaoui, 2002).

In untreated plots of all trials, grain yields were low compared to treated plots (Table 2). Yield losses due to weed competition

throughout the growing season were 10, 12, and 41% compared to the highest yields observed in treated plots in trials 1, 2, and 3, respectively. Broadleaf weeds left in the nontreated plots appeared to cause significant crop production losses; hence, herbicide selection should be based on knowledge of weed species present within the weed flora. This is consistent with previous research that has emphasized the potential for bread wheat yield loss due to weed competition (Tanji, 2002). Curran et al. (2015) found that bread wheat yields declined 0.55 to 1.2 kg ha⁻¹ per 1 kg ha⁻¹ increase in hairy vetch (*Vicia villosa* Roth) biomass.

3.4 Grain yield after using grass + broadleaf herbicides (5 trials)

Grain yields in sprayed plots ranged from 6.5 to 6.8 T ha⁻¹, 6.1 to 6.5 T ha⁻¹, 6.0 to 6.5 T ha⁻¹, 5.0 to 9.3 T ha⁻¹, and 4.4 to 5.9 T ha⁻¹ in trials 1 to 5, respectively (Table 3). The increased grain yields recorded in the herbicide treated plots in comparison with those of the untreated plots could be attributed to weed control, which resulted in reduced wheat competition from weeds. Using the highest yields obtained in treated plots, grain yield increases due to weed control were 11, 25, 59, 102, and 44% compared to the yields observed in nontreated plots in trials 1 to 5, respectively. Weed control with herbicides, as well as other appropriate practices, increased wheat grain yields (Ezzahiri et al., 1999; Bouhache et al., 2000; Mosseddaq et al., 2000; Zbair et al., 2000).

Grain yields were low in nontreated plots, as well as in treated plots where herbicide treatments failed to control milk thistle (trials 4 and 5, Table 3). Yield losses due to weed competition throughout the growing season were 10, 20, 37, 51, and 31% compared to the highest yields observed in treated plots in trials 1 to 5, respectively. High yield loss (51%) was due to milk thistle competition which drastically lowered grain yield in the untreated plots. Tanji (2002) reported that yield losses due to weed competition from the mixed populations of weeds were up to 80%.

Herbicide treatments containing (i) pyroxsulam, (ii) mesosulfuron-methyl + iodosulfuron-methyl-sodium and (iii) mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican, caused severe injury symptoms on wheat during almost 2 months after treatments (data not shown). They caused an overall stunting and crop height reduction. However, the crop recovered later in the season with no yield reduction. It is highly possible that wheat injury was due to both mesosulfuron and pyroxsulam. Pyroxsulam at 18 g ha⁻¹ caused 5 to 10% wheat injury 5 to 14 days after treatment, but wheat recovered completely (Geier et al., 2011). Mesosulfuron-methyl at 15 g ai ha⁻¹ with the crop safener at 30 g ai ha⁻¹ injured wheat 11 to 32%, but tiller number and height of treated wheat were, by 9 weeks after treatment, similar to those of nontreated wheat (Bailey et al.,

2004). Other studies revealed that wheat injury was often observed after application of mesosulfuron-methyl + iodosulfuron-methyl-sodium + safener, but injury did not reduce grain yield (Kirkland et al., 2001; Wiersma et al., 2003; Crooks et al., 2004a; Crooks et al., 2004b).

Conclusion

The results of this study indicate that very good control of most annual broadleaf weeds and high wheat yield can be achieved by the application of herbicide treatments containing 1 to 4 active ingredients at the early wheat tillering stage. Premix of grass and broadleaf herbicides were less effective on milk thistle (*S. marianum*). Herbicide treatments containing pyroxsulam or mesosulfuron-methyl + iodosulfuron-methyl-sodium caused crop injury, but wheat plants recovered and grain yield was not affected. Further research involving grass and broadleaf herbicides is needed to explore ways, including the use of adjuvants, to avoid wheat injury and optimize herbicide efficacy on noxious weeds such as milk thistle.

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Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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