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Antagonistic effect of 2,4-D plus MCPA and clodinafop propargyl on wheat (*Triticum aestivum*) field weeds in Iran

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ABSTRACT

A set of field and greenhouse experiments were conducted in 2004-2005 to study antagonistic effects of 2,4-D plus MCPA with clodinafop propargyl in wheat. The field experiments were conducted in Maybod and Oroumieh, where tank mixture of 2,4-D plus MCPA at 0, 975 and 1300 g ai ha^{-1}, with clodinafop propargyl at 0, 64, 80, 96 and 112 g ai ha^{-1} in factorial arrangement and four replications per treatment. Hoary cress (*Cardaria draba* (L.) Desv.), littleseed canarygrass (*Phalaris minor* Retz.), haresear mustard (*Conringia orientalis* (L.) Dumort.) and downy brome (*Bromus tectorum* L.) were the dominant weed species in the field experiments. Greenhouse experiments further evaluated the efficacy of these tank mixtures on prostrate knotweed (*Polygonum aviculare* L.), littleseed canarygrass and poison ryegrass (*Lolium temulentum* L.). In the field, herbicides were applied at wheat tillering while in the greenhouse the herbicides were applied at the beginning of tillering stage and at four-leaf stage of grass and broadleaf weeds, respectively. The most satisfactory tank mixture was 2,4-D plus MCPA at 975 and 1300 g ai ha^{-1} with clodinafop propargyl at 96 g ai

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ha^{-1}. Yield increased when tank mix of clodinafop propargyl with 2,4-D plus MCPA was applied on wheat. To prevent clodinafop propargyl efficacy reduction due to tank mixing with 2,4-D plus MCPA, the application dose (64 g ai ha^{-1}) should be increased to 96 g ai ha^{-1}.

Key words: herbicide; grain yield; antagonistic effect; Iran.

چکیده

بمنظور بررسی امکان کاربرد همزمان دو علف‌کش توفوردی‌ام‌سی‌پی و کلودینافوپ پروپارژیل دو آزمایش جداگانه گلخانه‌ای و مزرعه‌ای در طی سال‌های ۱۳۸۵ و ۱۳۸۶ انجام شد. در آزمایش‌های مزرعه‌ای که در میبد و ارومیه صورت گرفت علف‌کش توفوردی‌ام‌سی‌پی‌آ به میزان‌های ۹۷۵ و ۱۳۰۰ گرم به همراه کلودینافوپ پروپارژیل در مقادیر ۰، ۶۴، ۸۰، ۹۶ و ۱۱۲ گرم از ماده مؤثر در هکتار در قالب آزمایش فاکتوریل دو عاملی با طرح پایه بلوک‌های کامل تصادفی با چهار تکرار اجرا گردید. علف‌های هرز غالب در آزمایش مزرعه‌ای عبارت بودند: اُزمک (.*Cardaria draba* (L.) Desv)، خونی‌واش (.*Phalaris minor* Retz)، گوش خرگوش (.*Conringia orientalis* (L.) Dumort) و علف‌پشمکی (.*Bromus tectorum* L). در آزمایش گلخانه‌ای نیز اثرات مخلوط دو علف‌کش توفوردی‌ام‌سی‌پی‌آ و کلودینافوپ پروپارژیل بر علف‌های‌هرز هفت‌بند (.*Polygonum aviculare* L)، خونی‌واش و چچم (.*Lolium temulentum* L) مورد ارزیابی قرار گرفت. در آزمایش مزرعه‌ای علف‌کش‌ها در ابتدا مرحله پنجه‌زنی گندم و چهار برگی علف‌های‌هرز باریک‌برگ و پهن‌برگ بکار برده شد. نتایج نشان داد که بیشترین کارایی علف‌کش در کنترل علف‌های‌هرز باریک‌برگ و پهن‌برگ تیمار کاربرد مخلوط توفوردی‌ام‌سی‌پی‌آ به میزان ۹۷۵ تا ۱۳۰۰ گرم و کلودینافوپ‌پروپارژیل به میزان ۹۶ گرم از ماده مؤثر در هکتار بود. در این تیمارها بیشترین عملکرد دانه گندم نیز برداشت گردید. با توجه به این نتایج در صورت استفاده از مخلوط این دو علف‌کش بایستی مقدار مصرف کلودینافوپ پروپارژیل از ۶۴ گرم به ۹۶ گرم از ماده مؤثر در هکتار افزایش یابد*.

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واژه‌های کلیدی: علف‌کش، عملکرد دانه، کنترل علف‌های‌هرز، ایران.

Introduction

Weeds can cause dramatic yield loss in wheat if not being satisfactory controlled. Zand *et al.* (2007b) reported that weeds reduce wheat yield up to 30% throughout the country. At present, chemical control is the most widely applied method of weed control in Iran (Zand *et al*., 2007a, 2007b; Baghestani *et al*., 2007a, 2007b). Farmers traditionally use broadleaf herbicides tribenuron methyl and 2,4-D plus MCPA, and grass herbicides clodinafop propargyl and diclofop methyl (Zand *et al*., 2007a). The existing inadequate control of broadleaf weeds by tribenuron methyl could be blamed on the intensive application of this herbicide that has led to the occurrence of selection pressure toward tribenuron methyl-resistant weed biotypes (Nezamabadi *et al*., 2007) and also a change in weed flora. As a result, the application of 2,4-D plus MCPA has been on the increase. Clodinafop propargyl also faces similar scenario. Additionally, farmers generally prefer to use a tank mixture of tribenuron methyl or 2,4-D plus MCPA with a grass herbicide to reduce the cost of herbicide applications. However, little is known about the synergistic or antagonistic effects of these herbicides in a mixture (Baghestani *et al.*, 2007c, 2008).

Studies have indicated the antagonistic effects of auxin-type herbicides with ACCase inhibitor herbicides (Hall *et al*., 1999; Baghestani *et al.*, 2007c, 2008). Mueller *et al.* (1989) argued that tank mixture of 2,4-D or MCPA with fenoxaprop-p-ethyl could lower the efficacy of fenoxaprop-p-ethyl in control of Johnson grass (*Sorghum halepense* (L.) Pers.). Baghestani *et al.* (2008) reported that mixing bromoxynil plus MCPA with fenoxaprop-*p*-ethyl at 600+105 g ai ha^{-1} 2,4-D could significantly reduce sterile oat (*Avena ludoviciana* Dureiu) and littleseed canarygrass control efficacy. Chuah *et al*. (2006) found that tank mixing bensulfuron with 2,4-D at 1.25 + 36 g ai ha^{-1} was the most effective mixture for control of red sprangletop (*Leptochloa chinesis* (L.) Nees) and greater club-rush (*Scirpus grossus* (L.) f.). Olson & Nalewaja (1982) studied the effect of MCPA on ^{14}C-diclofop methyl uptake and translocation and found that antagonistic effect of MCPA reduced diclofop-methyl uptake, de-esterification and translocation. There are, however, other studies which indicated no antagonistic effects between these two herbicides (Hall *et al*., 1982; Kelly & Chapman, 1995).

Regarding the low efficiency of grass herbicides in mixture with auxin-type herbicides, an increase in grass herbicide dose could be investigated. The objectives of this study were (i) investigating the possibility of tank mixing 2,4-D plus MCPA with clodinafop propargyl, and

(ii) finding an effective mixture of both herbicides to improve the weed control programs.

Materials and methods

Field experiments: Experiments were conducted in 2004-2005 growing seasons in Maybod (54° 00´ N, 32° 12´ E; 1100m) and Oroumieh (37° 21´ N, 45° 14´ E; 1295m). The soil texture was clay loam and sandy loam in Oroumieh and Maybod, respectively. In Oroumieh, wheat (*T. aestivum* cv. Zarrin) was planted on 16 Oct 2004 at a density of 450 plants m^{-2} and in Maybod, wheat cv. Roshan was planted on 26 Sep 2004 at a density of 400 plants m^{-2}. Weed populations in Maybod included field bindweed (*Convolvulus arvensis* L.), hoary cress (*Cardaria draba* (L.) Desv.), fumitory (*Fumaria vaillantii* Loisel.), sterile oat (*Avena ludoviciana* Dureiu), and littleseed canarygrass (*Phalaris minor* Retz.). In Oroumieh, weed composition consisted of wild mustard (*Sinapis arvensis* L.), haresear mustard (*Conringia orientalis* (L.) Dumort.), flixweed (*Descurainia sophia* (L.) Webb.), hoary cress, cereal rye (*Secale cereale* L.), sterile oat and downy brome (*Bromus tectorum* L.).

Both experiments were conducted as a randomized complete block design with factorial arrangement of treatments and four replications. Factor one was 2,4-D plus MCPA SL 65% at 0, 975, and 1300 g ai ha^{-1}. Factor two was clodinafop propargyl 080 EC at 0, 64, 80, 96, and 112 g ai ha^{-1}. Herbicides were tank mixed and sprayed at the tillering stage of wheat. The plot size was 3m wide by 6m long at both locations. Herbicides were broadcast sprayed in water at 300 L ha^{-1} and 2.5 bar, using an Elegance 18 Knapsack sprayer equipped with flooding nozzle. Plots were 6 m × 3 m, with herbicides applied to one-half of each plot, and the other half was kept as its control (Zand *et al*., 2007b; Baghestani *et al*., 2007a).

The percentage of weed population reduction was measured separately for each weed species by counting the number of weeds prior to and 30 days after treatment (DAT) within a fixed $1m^2$ quadrat in the herbicide treated half of each plot. Weeds emerged between these two stages were hand hoed. The weed biomass reduction was measured at 30 DAT using $0.25m^2$ quadrats and dropped twice in the treated and untreated halves of each plot. All weeds were cut at the soil surface, separated by species, and oven dried at 75ºC for 72h. The difference between weed biomass in the treated and untreated halves was divided by the weed biomass in the untreated half and then multiplied by 100. The wheat grain yield was weighed at the 14% of relative humidity.

Greenhouse experiments: To evaluate the efficacy of tank mixtures of 2,4-D plus MCPA at 0, 975, and 1300 g ai ha^{-1} with clodinafop propargyl at 64, 80, 96, and 112 g ai ha^{-1}

greenhouse experiments were conducted in Tehran. Weeds included prostrate knotweed (*Polygonum aviculare* L.), littleseed canarygrass, and poison ryegrass (*Lolium temulentum* L.). Each species was studied separately. Seeds of littleseed canarygrass were also kept for 1 week in a germinator at the same condition. Weed seeds were then planted into 15cm diameter pots containing equal proportions of composted manure, sand and clay. No fertilizers were used and soil moisture was kept at or near field capacity. Plants were grown under the temperatures of 20± 5°C, with a day/night light regime of 16/8h, respectively. The plants were thinned to between 5 and 15, based on minimum number of plants observed in the replications of each experiment.

All experiments were conducted in a randomized complete block design with 14 treatments and four replications. The treatments consisted of different tank mix combinations of 2,4-D plus MCPA at 0, 975, and 1300 g ai ha^{-1} with clodinafop propargyl at 64, 80, 96, and 112 g ai ha^{-1}. In addition, tribenuron methyl DF 75% at 15 g ai ha^{-1} plus clodinafop propargyl 080 EC at 64 g ai ha^{-1} was used as a standard treatment and weedy pots as untreated controls. Grass and broadleaf weeds were treated at the beginning of their tillering stage and at four-leaf stage, respectively. Herbicides were sprayed in water at 300 L ha^{-1} and 2.5 bar, using a moving nozzle cabinet sprayer. Weed control was assessed visually at 30, 40, and 50 DAT on a scale of 1-9 based on the EWRC scale. A rating of 1 was defined as “complete control” and a rating of 9 was defined as “no control”. After the third visual assessment, all weeds were cut at the soil surface. The rate of weed population reduction was calculated by dividing weed population prior to herbicide applications by weed population after herbicide applications and multiplying by 100. All weeds were then oven dried at 70ºC for 48h and weighed.

Statistical analyses: The field and greenhouse data were statistically analyzed using GLM procedure in SAS software (SAS Institute 2000). The assumptions for variance analysis were tested by ensuring that the residuals had random, homogenous, and normal distribution about a mean of zero. If the assumptions for variance analysis were not adequately met, the rate of weed reduction would subject to an arcsine square root transformation. Weed biomass and wheat yield data were subject to a log(x+1) transformation when required. The Duncan multiple range test (DMRT) at 0.05 was used to determine the significance of the difference between treatment means. Since weather condition, soil texture, planting date and weed species differed at various field locations, the data for each location was analyzed separately.

Results and Discussion

Field experiments

Broadleaf weed populations: In Maybod, complete control of hoary cress was achieved with 2,4-D plus MCPA at both rates (Table 1). Baghestani *et al.* (2007c) found that fumitory was comletely controlled by 2,4-D plus MCPA at 975 and 1300 g ai ha^{-1} while field bindweed population was reduced by 96.2% and 96.9% from 975 and 1300 g ai ha^{-1}, respectively. In Oroumieh, the largest reductions in hoary cress (75.1%) and haresear mustard (85.2%) were achieved when this herbicide was applied at 1300 and 975 g ai ha^{-1}, respectively (Table 1). These findings indicated that 2,4-D plus MCPA at the 975 g ai ha^{-1} rate could be considered as an effective option in broadleaf weed control.

In Maybod, complete control of hoary cress was obtained whether 2,4-D plus MCPA was applied singly or tank mixed with clodinafop propargyl. Baghestani *et al.* (2007c) also came to the same conclusion in case of fumitory. However, the tank mix combination would help control grass weeds at the same time. Weed control was not successful in the untreated plots. In Oroumieh, a mixture of 2,4-D plus MCPA at 975 g ai ha^{-1} and clodinafop propargyl at 96 g ai ha^{-1} more effectively controlled haresear mustard than singly applied 2,4-D plus MCPA. Although tank mixed treatments were ineffective on hoary cress, 2,4-D plus MCPA and tank mixture of 2,4-D plus MCPA at 1300 g ai ha^{-1} with clodinafop propargyl at 112 g ai ha^{-1} were successfully tested for these weeds. In Maybod, no weed control was achieved in 2,4-D plus MCPA absent plots, so it appears that there is no additional benefit for the control of broadleaf weed populations by tank mixed herbicides. Baghestani *et al.* (2008) also reported that tank mixing bromoxynil plus MCPA with clodinafop propargyl/fenoxaprop-*p*-ethyl could not increase bromoxynil plus MCPA broad leaf weed control efficacy.

Grass weed populations: Clodinafop propargyl caused significant reductions in littleseed canarygrass population (Table 1). In Maybod, satisfactory control of littleseed canarygrass was obtained with almost all tank mixed treatments. In Oroumieh, this herbicide completely failed to control downy brome. Cereal rye and downy brome are known to be tolerant to this herbicide (Baghestani *et al.*, 2007b). Our results suggest that the recommended dose of this herbicide (64 g ai ha^{-1}) is sufficient to obtain an acceptable control of grass weeds. However, Baghestani *et al.* (2007c) found that satisfactory control of sterile oat could be achieved only if the recommended dose of this herbicide increases by 32 g ai ha^{-1}. Generally, since both weed species are among the dominant weeds in the wheat fields so an increase in the clodinafop propargyl application dose is necessary.

Most tank mixtures of 2,4-D plus MCPA with clodinafop propargyl controlled littleseed canarygrass between 90% and 100% in Maybod (Table 1). The recommended dose of this herbicide alone resulted in 93.25% reduction in the population of littleseed canarygrass at this location. The results were much worse in the case of downy brome as all treatments failed to control this weed. The lowest reduction (79.73%) in littleseed canarygrass population was obtained with the tank mix of 2,4-D plus MCPA at 1300 g ai ha^{-1} and clodinafop propargyl at 64 g ai ha^{-1}.

Broadleaf weed biomass: The 2,4-D plus MCPA treatments reduced haresear mustard and hoary cress biomass significantly in Oroumieh (Table 2). In Maybod, 2,4-D plus MCPA at both rates completely controlled hoary cress. Generally, it appeared that 2,4-D plus MCPA at 1300 g ai ha^{-1} was successful on aforementioned weeds at both locations. Baghestani *et al.* (2007c), however, reported 975 g ai ha^{-1} as the best dose of 2,4-D plus MCPA. The disagreement could be attributed to the difference in weed flora so that the presence of a perennial weed (hoary cress) in a wheat field requires higher doses of this herbicide to be applied.

The tank mixtures of 2,4-D plus MCPA at 1300 g ai ha^{-1} and 975 g ai ha^{-1} with clodinafop propargyl at 80 g ai ha^{-1}, and bromoxynil plus MCPA/dichloprop-p plus mecoprop-p plus MCPA/tribenuron methyl with clodinafop propargyl at 64 g ai ha^{-1} as the recommended dose reduced wild mustard biomass by 100% (Baghestani *et al.*, 2007c, 2008). In Oroumieh, haresear mustard biomass was mainly reduced by tank mixture of 2,4-D plus MCPA at 1300 g ai ha^{-1} with clodinafop propargyl at 64 and 112 g ai ha^{-1}. The combination of 2,4-D plus MCPA at 1300 g ai ha^{-1} with clodinafop propargyl at 112 g ai ha^{-1} provided the highest reduction in hoary cress biomass. Our results agrees with those of Baghestani *et al.* (2007c). In Maybod, the hoary cress was almost completely controlled by all tank mix combinations, indicating no necessity for including clodinafop propargyl.

Grass weed biomass: As expected, clodinafop propargyl applied alone did not result in satisfactory control of downy brome in Oroumieh (Table 2). This result was supported by Baghestani *et al.* (2007b) and Zand *et al.* (2007a). In Maybod, clodinafop propargyl at 96 g ai ha^{-1} reduced littleseed canarygrass biomass 97.6% (Table 2). As observed, a 32 g ai ha^{-1} increment in recommended herbicide rate resulted in the highest reduction in weed biomass.

In Oroumieh, none of herbicide treatments provided satisfactory control of downy brome (Table 2). This result is consistent with those obtained in the grass weed population reduction. In Maybod, however, the results were completely different. Littleseed canarygrass was almost satisfactorily controlled by either clodinafop propargyl alone or tank mixed at 96 g ai ha^{-1} with 2,4-D plus MCPA at 975 g ai ha^{-1}. But increasing the 2,4-D plus MCPA rate by 325 g ai ha^{-1} reduced the efficacy of clodinafop propargyl. It is recommended to use 2,4-D plus MCPA at 975 g ai ha^{-1} with clodinafop propargyl at 96 g ai ha^{-1} controlling both broadleaf and grass weeds. In another experiment conducted by the same author (Baghestani *et al.*, 2008), it was found that bromoxynil plus MCPA at 600 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1} could acceptably control littleseed canarygrass. So, where littleseed canarygrass is the dominant weed species of the wheat field, application of the latter herbicide is recommended instead of 2,4-D plus MCPA at 975 g ai ha^{-1} with clodinafop propargyl at 96 g ai ha^{-1}.

Wheat yield: None of the herbicide treatments resulted in significant increase in wheat yield in Maybod (Table 3). In Oroumieh, significant differences in wheat yield were observed between treatments. The higher rate of 2,4-D plus MCPA could nearly increase the garin yield by 2 t ha^{-1} in this location. Based on the results obtained for grain yield, the best treatment was clodinafop propargyl at the 64 g ai ha^{-1}. Further increase at the rate of this herbicide reduced grain yield, although the differences were still significant with the weed-free control. These results indicate that crop cultivar and environmental factors can greatly affect the efficacy a herbicide.

In Maybod, the highest grain yield was produced where wheat was sprayed with the mixture of 2,4-D plus MCPA at 975 g ai ha^{-1} and clodinafop propargyl at 96 g ai ha^{-1}, and singly applied clodinafop propargyl at 80 g ai ha^{-1}. The lowest grain yield caused by clodinafop propargyl at 96 g ai ha^{-1} treated plots. The addition of clodinafop propargyl to 2,4-D plus MCPA increased wheat grain yield compared with the plots treated by 2,4-D plus MCPA. In Oroumieh, differences in grain yield between different tank mixtures were greater than at Maybod. Clodinafop propargyl alone sprayed plots had significantly lower grain yield than all other treatments. In Maybod, the addition of clodinafop propargyl to 2,4-D plus MCPA significantly increased wheat grain yields. The mixtures containing the higher rate of 2,4-D plus MCPA produced slightly higher grain yields than those with the 975 g ai ha^{-1} rate. The grain yields in Oroumieh were higher than those recorded in Maybod which appears to contradict with the results obtained from weed population and biomass reductions. This indicates that higher grain yield in Oroumieh is related to greater yield potential of the wheat cultivar Roshan, its viability and better adaptability to the environmental conditions in Oroumieh.

Greenhouse experiment

Prostrate knotweed population reduced between 93.27% and 100% when treated by different herbicide treatments (Table 4). All 2,4-D plus MCPA included treatments reduced this weed population more than tribenuron methyl plus clodinafop propargyl treated pots. Baghestani *et al.* (2008) also found that tribenuron methyl at 15 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1} did not result in acceptable control of prostrate knotweed. However, these researchers reported excellent control of this weed with bromoxynil plus MCPA at 600 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1}, and dichloprop-p plus mecoprop-p plus MCPA at 1500 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1}. Visual weed control showed significant differences at 30, 40 and 50 DAT (Table 4). However, weed control was improved by the passage of time according to this criterion so that by 50 DAT all herbicide treatments had produced good results.

In case of littleseed canarygrass, the highest population reduction (90.60%) was achieved in pots treated by clodinafop propargyl at the highest dose (Table 5). However and by the addition of 2,4-D plus MCPA, the efficacy of this herbicide reduced almost dramatically indicating the antagonistic effects of these two herbicides. This result corresponds with the results of the field experiments in Maybod in which clodinafop propargyl at the recommended dose (64 g ai ha^{-1}) did not act well (Tables 1 and 2). The best and worst treatments in case of weed biomass reduction were 2,4-D plus MCPA at 1300 g ai ha^{-1} with clodinafop propargyl at 80 g ai ha^{-1}, and tribenuron methyl at 15 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1}, respectively (Table 5). Dichloprop-p plus mecoprop-p plus MCPA at 1500 g ai ha^{-1} with clodinafop propargyl at 64 g ai ha^{-1} reduced this weed population and biomass by 100% (Baghestani *et al*., 2008). Visual assessment of weed control showed lower efficacy of herbicide treatments than those for prostrate knotweed. On the other hand, judgement is better to be done from 40 DAT onward if visual rating is to be used as a control criterion.

Poison ryegrass was best controlled when it was treated by clodinafop propargyl at 112 g ai ha^{-1} (Table 6). Similar to littleseed canarygrass, percent weed population reduction was decreased by the addition of 2,4-D plus MCPA. Visual ratings also support these results.

Table 1- Mean percentage population reductions of some example broadleaf and grass weeds for the main effect of the herbicides and the interaction (tank mix combination) between 2,4-D + MCPA and clodinafop propargyl in Maybod and Oroumieh in 2004-2005.

Herbicide (g ai ha^{-1})	Location				
	Maybod Hoary cress	Littleseed canarygrass	Oroumieh Haresear mustard	Hoary cress	Downy brome
Main effect					
2,4-D plus MCPA (0)	2.20b*	-	1.11b	2.35b	-
2,4-D plus MCPA (975)	100a	-	85.20a	72.00a	-
2,4-D plus MCPA (1300)	100a	-	81.90a	75.10a	-
Clodinafop propargyl (0)	-	0.60c	-	-	0.8c
Clodinafop propargyl (64)	-	93.25b	-	-	6.40c
Clodinafop propargyl (80)	-	98.15ab	-	-	11.70ab
Clodinafop propargyl (96)	-	100a	-	-	19.20a
Clodinafop propargyl (112)	-	99.17a	-	-	21.40a
Interaction					
2,4-D plus MCPA (0) + clodinafop propargyl (0)	0b	0c	0d	0c	0a
2,4-D plus MCPA (0) + clodinafop propargyl (64)	0b	100a	0d	0c	0a
2,4-D plus MCPA (0) + clodinafop propargyl (80)	0b	100a	0d	0c	0c
2,4-D plus MCPA (0) + clodinafop propargyl (96)	0b	100a	0d	0c	10.00bc
2,4-D plus MCPA (0) + clodinafop propargyl (112)	0b	99.00a	0d	0c	19.20ab
2,4-D plus MCPA (975) + clodinafop propargyl (0)	100a	0c	81.60a	65.80a	0c
2,4-D plus MCPA (975) + clodinafop propargyl (64)	100a	100a	78.30a	70.00a	9.20bc
2,4-D plus MCPA (975) + clodinafop propargyl (80)	100a	100a	86.60a	78.70a	13.30ab
2,4-D plus MCPA (975) + clodinafop propargyl (96)	100a	100a	92.30a	70.00a	30.00a
2,4-D plus MCPA (975) + clodinafop propargyl (112)	100a	100a	88.80a	75.40a	19.20ab
2,4-D plus MCPA (1300) + clodinafop propargyl (0)	100a	0c	79.30a	77.50a	0c
2,4-D plus MCPA (1300) + clodinafop propargyl (64)	100a	79.73b	88.10a	79.20a	10.00bc
2,4-D plus MCPA (1300) + clodinafop propargyl (80)	100a	94.44a	75.70a	66.20a	21.70ab
2,4-D plus MCPA (1300) + clodinafop propargyl (96)	100a	100a	83.90a	67.50a	17.50ab
2,4-D plus MCPA (1300) + clodinafop propargyl (112)	100a	97.50a	82.50a	85.00a	25.80ab

* Means within each column followed by the same letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Table 2- Mean percentage biomass reductions of some example broadleaf and grass weeds for the main effect of the herbicides and the interaction (tank mix combination) between 2,4-D + MCPA and clodinafop propargyl in Maybod and Oroumieh in 2004-2005

Herbicide (g ai ha^{-1})	Location				
	Maybod Hoary cress	Littleseed canarygrass	Oroumieh Haresear mustard	Hoary cress	Downy brome
Main effect					
2,4-D plus MCPA (0)	1.48b*	-	2.24b	2.74b	-
2,4-D plus MCPA (975)	99.90a	-	77.48a	70.72a	-
2,4-D plus MCPA (1300)	100a	-	82.67a	72.04a	-
Clodinafop propargyl (0)	-	1.16c	-	-	1.17b
Clodinafop propargyl (64)	-	81.86a	-	-	12.47ab
Clodinafop propargyl (80)	-	86.05a	-	-	23.52a
Clodinafop propargyl (96)	-	97.60a	-	-	24.87a
Clodinafop propargyl (112)	-	77.94a	-	-	18.52a
Interaction					
2,4-D plus MCPA (0) + clodinafop propargyl (0)	0b	0c	0d	0e	0d
2,4-D plus MCPA (0) + clodinafop propargyl (64)	0b	100a	0d	0e	10.57cd
2,4-D plus MCPA (0) + clodinafop propargyl (80)	0b	100a	0d	0e	14.17cd
2,4-D plus MCPA (0) + clodinafop propargyl (96)	0b	100a	0d	0e	13.03cd
2,4-D plus MCPA (0) + clodinafop propargyl (112)	0b	98.49a	0d	0e	30.14abc
2,4-D plus MCPA (975) + clodinafop propargyl (0)	100a	0b	75.29abc	57.50d	0d
2,4-D plus MCPA (975) + clodinafop propargyl (64)	100a	64.40b	70.60bc	72.10abcd	8.71cd
2,4-D plus MCPA (975) + clodinafop propargyl (80)	100a	79.21b	87.89abc	85.80ab	20.56bcd
2,4-D plus MCPA (975) + clodinafop propargyl (96)	99.40a	100a	81.69abc	51.40d	46.47a
2,4-D plus MCPA (975) + clodinafop propargyl (112)	100a	100a	71.90bc	86.80ab	9.26cd
2,4-D plus MCPA (1300) + clodinafop propargyl (0)	100a	0b	63.05c	79.30abc	0d
2,4-D plus MCPA (1300) + clodinafop propargyl (64)	100a	81.20b	100a	59.70cd	18.13bcd
2,4-D plus MCPA (1300) + clodinafop propargyl (80)	100a	78.94b	79.19abc	66.40cd	39.94ab
2,4-D plus MCPA (1300) + clodinafop propargyl (96)	100a	92.80a	81.13abc	65.40bcd	22.96bcd
2,4-D plus MCPA (1300) + clodinafop propargyl (112)	100a	33.82bc	90.00ab	89.40a	12.28cd

* Means within each column followed by same the letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Table 3- Mean wheat yield for the main effects of the herbicides and the interaction (tank mix combination) between 2,4-D plus MCPA and clodinafop propargyl in Maybod and Oroumieh in 2004-2005.

Herbicide (g ai ha^{-1})	Grain yield (kg ha^{-1})	
	Maybod	**Oroumieh**
Main effect	3539a*	4373c
2,4-D plus MCPA (0)	3787a	5995b
2,4-D plus MCPA (975)	3718a	6109a
2,4-D plus MCPA (1300)		
Clodinafop propargyl (0)	3660a	4977b
Clodinafop propargyl (64)	3762a	5683a
Clodinafop propargyl (80)	3820a	5625a
Clodinafop propargyl (96)	3580a	5585a
Clodinafop propargyl (112)	3582a	5592a
Interaction		
2,4-D plus MCPA (0) + clodinafop propargyl (0)	3810a	4247e
2,4-D plus MCPA (0) + clodinafop propargyl (64)	3392ab	4337e
2,4-D plus MCPA (0) + clodinafop propargyl (80)	4172a	4382e
2,4-D plus MCPA (0) + clodinafop propargyl (96)	2682b	4430e
2,4-D plus MCPA (0) + clodinafop propargyl (112)	3637a	4467e
2,4-D plus MCPA (975) + clodinafop propargyl (0)	3687a	5350d
2,4-D plus MCPA (975) + clodinafop propargyl (64)	3847a	6280ab
2,4-D plus MCPA (975) + clodinafop propargyl (80)	3517ab	6240abc
2,4-D plus MCPA (975) + clodinafop propargyl (96)	4172a	6105bc
2,4-D plus MCPA (975) + clodinafop propargyl (112)	3710a	6002c
2,4-D plus MCPA (1300) + clodinafop propargyl (0)	3485ab	5335d
2,4-D plus MCPA (1300) + clodinafop propargyl (64)	4047a	6432a
2,4-D plus MCPA (1300) + clodinafop propargyl (80)	3770a	6252abc
2,4-D plus MCPA (1300) + clodinafop propargyl (96)	3887a	6220abc
2,4-D plus MCPA (1300) + clodinafop propargyl (112)	3400ab	6307ab

* Means within each column followed by the same letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Table 4- Mean population reduction, biomass, and visual weed control at 30, 40, and 50 days after treatment (DAT) for prostrate knotweed at different tank mixtures of 2,4-D + MCPA with clodinafop propargyl in the greenhouse experiment.

Herbicide	Dose (g ai ha^{-1})	Population reduction (%)	Biomass (g $plant^{-1}$)	Visual weed control (DAT)		
				30	40	50
Untreated control	-	0c*	8.15a	9a	9a	9a
2,4-D plus MCPA + clodinafop propargyl	975+ 0	98.42a	0.18c	3.25b	2.75bc	1.12c
2,4-D plus MCPA + clodinafop propargyl	1300+ 0	100a	0c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	975+ 64	99.14a	0.06c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	975+ 80	98.82a	0.20c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	975+ 96	99.18a	0.04c	3.25b	2.25d	1.12c
2,4-D plus MCPA + clodinafop propargyl	975+ 112	99.60a	0.03c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	1300+ 64	100a	0c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	1300+ 80	99.66a	0.19c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	1300+ 96	100a	0c	3.25b	2.25d	1c
2,4-D plus MCPA + clodinafop propargyl	1300+112	100a	0c	3.25b	2.25d	1c
Tribenuron methyl+ clodinafop propargyl	15+ 64	93.27b	1.22b	3.25b	3b	1.5b

* Means within each column followed by the same letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Table 5- Mean population reduction, biomass, and visual weed control at 30, 40, and 50 days after treatment (DAT) for littleseed canarygrass at different tank mixtures of 2,4-D plus MCPA with clodinafop propargyl in the greenhouse experiment.

Herbicide	Dose (g ai ha^{-1})	Population reduction (%)	Biomass (g $plant^{-1}$)	Visual weed control (DAT)		
				30	40	50
Untreated control	-	0f*	2.99a	9a	9a	9a
2,4-D plus MCPA + clodinafop propargyl	0+ 64	82.40ab	0.23bcd	6f	2.2cd	1.1f
2,4-D plus MCPA + clodinafop propargyl	0+ 80	89.70a	0.14cd	6.2ef	1.7d	1f
2,4-D plus MCPA + clodinafop propargyl	0+ 96	89.30a	0.47bcd	6.2ef	3.5c	1.6ef
2,4-D plus MCPA + clodinafop propargyl	0+ 112	90.60a	0.18cd	6.7cdef	3.5c	1.2f
2,4-D plus MCPA + clodinafop propargyl	975+ 64	62.10e	0.63b	7.7abc	6.7b	6b
2,4-D plus MCPA + clodinafop propargyl	975+ 80	64.00de	0.63b	8ab	6.9b	5.2b
2,4-D plus MCPA + clodinafop propargyl	975+ 96	76.30abcd	0.21bcd	7.2bcde	5.7b	2.7d
2,4-D plus MCPA + clodinafop propargyl	975+ 112	80.70abc	0.47bcd	7.7abc	5.2b	3cd
2,4-D plus MCPA + clodinafop propargyl	1300+ 64	73.00bcde	0.31bcd	7.7abc	5.7b	4c
2,4-D plus MCPA + clodinafop propargyl	1300+ 80	69.20bcde	0.74b	7.7abc	6.9b	3.5cd
2,4-D plus MCPA + clodinafop propargyl	1300+ 96	67.10cde	0.49bc	7.5abcd	6.1b	3.1cd
2,4-D plus MCPA + clodinafop propargyl	1300+112	82.20ab	0.48bcd	7.9ab	6.4b	3cd
Tribenuron methyl+ clodinafop propargyl	15+ 64	83.30ab	0.07d	8d	5.7b	2.5de

* Means within each column followed by the same letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Table 6- Mean population reduction, biomass, and visual weed control at 30, 40, and 50 days after treatment (DAT) for poison ryegrass at different tank mixtures of 2,4-D plus MCPA with clodinafop propargyl in the greenhouse experiment.

Herbicide	Dose (g ai ha^{-1})	Population reduction (%)	Biomass (g $plant^{-1}$)	Visual weed control (DAT)		
				30	40	50
Untreated control	-	0g	1.34a	9.00a	9.00a	9.00a
2,4-D plus MCPA + clodinafop propargyl	0+ 64	62.60cde	0.18defg	6.10bc	4.20d	1.90fg
2,4-D plus MCPA + clodinafop propargyl	0+ 80	82.40ab	0.02h	3.90d	2.90e	1.10g
2,4-D plus MCPA + clodinafop propargyl	0+ 96	90.40a	0.17efg	4.00d	2.90e	1.20g
2,4-D plus MCPA + clodinafop propargyl	0+ 112	91.90a	0.07gh	3.80d	2.70e	1.20g
2,4-D plus MCPA + clodinafop propargyl	975+ 64	48.00ef	0.37c	6.70bc	6.00bc	3.00cde
2,4-D plus MCPA + clodinafop propargyl	975+ 80	74.70abc	0.26de	5.60c	5.30cd	2.40def
2,4-D plus MCPA + clodinafop propargyl	975+ 96	58.80cde	0.24def	5.60c	5.20cd	2.00efg
2,4-D plus MCPA + clodinafop propargyl	975+ 112	71.40bcd	0.17efg	5.60c	5.30cd	3.00cde
2,4-D plus MCPA + clodinafop propargyl	1300+ 64	37.90f	0.52b	7.20b	7.20b	6.50b
2,4-D plus MCPA + clodinafop propargyl	1300+ 80	55.00de	0.30cd	7.10b	6.50bc	3.50c
2,4-D plus MCPA + clodinafop propargyl	1300+ 96	60.20cde	0.18defg	6.50bc	5.80c	3.10cd
2,4-D plus MCPA + clodinafop propargyl	1300+112	62.20cde	0.14efg	6.60bc	5.30cd	1.90fg
Tribenuron methyl+ clodinafop propargyl	15+ 64	70.60bcd	0.13fgh	6.00bc	5.20cd	2.10defg

* Means within each column followed by the same letter are not significantly different at 0.05 probability level according to Duncan's multiple range test.

Although most of herbicide treatments failed to control littleseed canarygrass (Table 5), the highest population reduction (90.6%) occurred when clodinafop propargyl was applied. However, combining it with 2,4-D plus MCPA reduced its efficacy both in terms of population and biomass reduction. The lowest biomass reduction was recorded when tribenuron methyl plus clodinafop propargyl was used for treating pots. Visual weed control showed that none of herbicide treatments had caused satisfactory damage at 30 DAT (Table 5), but using 50 DAT improved the results especially when clodinafop propargyl was applied alone.

Clodinafop propargyl at 112 and 96 g ai ha^{-1} caused the highest reductions in the population of poison ryegrass, although the addition of 2,4-D plus MCPA significantly reduced its efficacy (Table 6). Visual weed control at 30 DAT showed that most of herbicide treatments caused little damage (Table 6), however, at 40 and 50 DAT visual weed control by clodinafop propargyl improved considerably and resulted in better control of this weed.

Conclusion

The results of this study proved the antagonistic effects of clodinafop propargyl in mixture with 2,4-D plus MCPA for controlling broadleaf weeds. As a tank mixture, the highest weed control efficacy was observed through 2,4-D plus MCPA at 975 g ai ha^{-1} with clodinafop propargyl at 96 g ai ha^{-1}. Wheat grain yield was also increased by mixed application of clodinafop propargyl and 2,4-D plus MCPA. However, to overcome the clodinafop propargyl antagonistic effect with 2,4-D plus MCPA, its current application rate should be increased from 64 g ai ha^{-1} to 96 g ai ha^{-1}.

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