agriculture

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Efficacy of the Herbicide Lancelot 450 WG (Aminopyralid + Florasulam) on Broadleaf and Invasive Weeds and Effects on Yield and Quality Parameters of Maize

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Received: 22 August 2017; Accepted: 20 September 2017; Published: 24 September 2017

Abstract: Reduced efficacy of several herbicides on some important broadleaf weeds might be due to the extended use of the specific active ingredients. In our study, field experiments were carried out in Greece in 2014 and 2015 to study the efficacy of the herbicide Lancelot 450 WG (aminopyralid 300 g ai/kg + florasulam 150 g ai/kg) compared to other herbicides against broadleaf weeds in maize. Effects on crop yield and quality parameters (nitrogen, protein, and oil content) were also evaluated. Our results showed that the ready mixture of aminopyralid + florasulam at the recommended dose of 33 g/ha resulted in a very good control of *Xanthium strumarium*, *Amaranthus retroflexus*, *Cirsium arvense*, and *Solanum nigrum* even at 28 DAT, providing a long-term effect. Efficacy of the specific mixture was also very efficient against the invasive weed species *Physalis angulata* L. Moreover, there were not any significant differences between the two doses of Lancelot 450 WG (33 and 66 g/ha) and Callisto 10 SC at double the recommended dose (1500 mL/ha) regarding yield of maize, with untreated plots and treated with Callisto 10 SC at the recommended dose (750 mL/ha) showing significantly lower yields. It has to be noted that even double the recommended dose of Lancelot 450 WG (66 g/ha) was highly selective to the crop, without any adverse effects on yield and quality parameters. Conclusively, Lancelot 450 WG could be proposed as a very efficient herbicide for the control of the major broadleaf weeds and alien, invasive species in maize crop.

Keywords: aminopyralid; florasulam; broadleaf weeds; invasive species; maize

1. Introduction

Weeds are one of the most important reducing factors for crop yield reduction. Yield loss by weeds is reported to be higher than 30% in some cases depending on the different climatic conditions and management practices [1]. In particular, potential crop losses due to weeds are estimated to be 32% on average (range 26%–40%), exceeding potential losses due to pests (18%) and pathogens (15%) [2]. Globally, "more energy is expended for the weeding of man's crops than for any other single human task" [3].

Broadleaf weeds can be a serious problem for spring crops. Indeed, weeds such as *Solanum nigrum*, *Amaranthus* spp., *Xanthium strumarium*, *Abutilon theophrasti*, and others can often cause significant yield loss in several major crops, especially when found in high density and emerge very early during the crop life cycle. In parallel, in several European countries, the number of invasive plants has significantly increased [4,5]. However, continuous use of the same herbicides may result in the loss of their efficacy against some weeds [6,7]. Nowadays, there are many complaints by the farmers regarding the reduced efficacy of several ALS-inhibiting herbicides and especially sulfonylureas (rimsulfuron and nicosulfuron) against important broadleaf weeds such as *X. strumarium*, *A. retroflexus*, *Chenopodium album*, and *S. nigrum*. In many cases, broadleaf herbicides seem less effective in terms of weed control efficacy. This could be attributed to continuous applications of these herbicides and underlines necessity of introduction of new herbicide options [8].

Herbicide resistance has caused serious problems in weed control programs. Many researchers do not advise continuous applications of one herbicide or even a limited number of herbicides [9,10]. Therefore, control of weeds should be based on a combination of several agronomic and cultural practices along with chemical solutions. One of the best alternative tactics to inhibit evolution of herbicide-resistant weeds is the rotational application of herbicides with different modes of action and the use of herbicide mixtures [11,12].

It has also to been noted that several herbicides are out of registration and, consequently, the number of available tools on farmers' hands has been significantly reduced. Among the several herbicides that could be used in the maize crop are aminopyralid and florasulam. In particular, the selective herbicide aminopyralid is a pyridine carboxylic active ingredient with an auxinic mode of action that provides systemic control of target weeds in a post and pre-emergence level. Even if it is normally used for control of certain broadleaf species such as thistles, it also suppresses some annual grasses when applied pre- or early post-emergence [13]. Aminopyralid has potential utility for suppressing several weeds and reducing their seed bank, particularly in sites also infested with invasive members of the Asteraceae [14]. It has been reported that aminopyralid residues in soil affect crop rotation, with maize appearing to be the best option for land recently used with aminopyralid [15]. Moreover, after a relative application and based on the risk assessment results, the European Food Safety Authority (EFSA) modified the existing maximum residue level and concluded that the proposed uses of aminopyralid on maize will not result in a consumer exposure exceeding the toxicological reference [16]. Florasulam inhibits proto-porphyrinogen oxidase (PPO protox) and is used for broadleaf weed control [17]. Mesotrione, a member of the benzoylcyclohexanone-1,3-dione family, is a HPPD inhibitor already registered in maize. Taking into account that the use of two chemicals with different modes of action may enhance efficacy and increase the weed control spectrum, there is a clear need for evaluation of several new herbicide mixtures against serious weeds [18].

Western Greece is a typical maize productive area. Withdrawal of several herbicides, lack of integrated weed management systems based on a combination of several agronomic and cultural practices with chemical solutions, and reduced efficacy of some widely used herbicides made weed control really challenging in the wider area. The aim of the present study was to evaluate the new ready mixture of aminopyralid + florasulam in terms of its efficacy against weeds, maize yield, and quality.

2. Materials and Methods

2.1. Experimental Sites, Treatments, and Design

Two field experiments were carried out in Greece in 2014 and 2015 to study the efficacy of the new herbicide Lancelot 450 WG (aminopyralid 300 g ai/kg + florasulam 150 g ai/kg) compared to other herbicides (such as mesotrione) against broadleaf weeds in maize. Soil analysis of the experimental field is given in Table 1. Lancelot 450 WG was used at products doses of 33 and 66 g/ha (recommended and double the recommended dose, respectively). Callisto 10 SC (mesotrione 100 g ai/L) was also used at product doses of 750 and 1500 mL/ha (recommended and double the recommended dose, respectively), while some plots were left untreated as a control (Table 2). It has to be noted that herbicides' applications should be only with the registered doses. The only purpose of including double the recommended rates in the present study was to evaluate the selectivity and the potential negative effects on maize. Sowing was on 14 and 12 of May and spraying on 1 of June and 26 of May, for 2014 and 2015, respectively. Herbicide applications were performed with an air-pressurized hand-field plot sprayer, with a 1.6 m wide boom fitted with four flat fan nozzles, calibrated to deliver 400 L ha^{-1} of water at 250 kPa pressure. It has to be noted that the herbicide applications were performed at the 3–6 leaf growth stages (BBCH 13–16) of maize crop (Pioneer 1758 hybrid). Crop was planted in 75 cm rows at an approximate density of 70,000 to 80,000 seeds ha^{-1}. Mean monthly temperature and rainfall data recorded near the experimental area are given in Table 3.

Table 1. The physical and chemical properties of the soil in the experimental field.

Parameter	Agrinio 1
Sand (%)	27
Clay (%)	35
Silt (%)	38
Soil type	Clayloam
pH (1:2 H_2O)	7.4
Total $CaCO_3$ (%)	12.7
Organic matter (%)	3.4
Nitrogen (g kg^{-1})	0.13
Phosphorus (g kg^{-1})	0.45
Potassium (g kg^{-1})	3.05
Iron (g kg^{-1})	0.23
Electrical conductivity (mS cm^{-1})	3.01

Table 2. Treatments applied in the field experiments. Commercial names of the products, active ingredients, formulations and doses are given.

Treatment	Active Ingredients	Concentration	Formulation	Dose of the Product	Application Time
Lancelot 450 WG	aminopyralid florasulam	300 g ai/kg 150 g ai/kg	WG	33 g/ha	post emergence
Lancelot 450 WG	aminopyralid florasulam	300 g ai/kg 150 g ai/kg	WG	66 g/ha	post emergence
Callisto 10 SC	mesotrione	100 g ai/L	SC	750 mL/ha	post emergence
Callisto 10SC	mesotrione	100 g ai/L	SC	1500 mL/ha	post emergence
Untreated	-	-	-	-	-

Table 3. Mean monthly rainfall and temperatures (mean, maximum and minimum) at the field experiment site in 2014 and 2015.

		Rainfall	Temperature		
	Month		Mean	Maximum	Minimum
2014		mm		°C	
	May	39.8	17.9	28.7	9.6
	June	18.0	24.2	39.8	13.9
	July	11.8	26.0	35.3	18.1
	August	0	27.2	37.9	19.7
	September	41.0	22.6	31.7	13.4
	Total	110.6	-	-	-
2015		mm		°C	
	May	56.2	20.7	32.5	12.2
	June	37.0	23.4	34.0	16.0
	July	2.8	28.5	39.7	16.6
	August	36.2	27.5	38.9	19.3
	September	101.0	24.8	37.1	16.2
	Total	233.2	-	-	-

A completely randomized block design was employed with four replicates for each treatment. Plot size was 10 × 3 m. Rows were numbered 1 to 5 from right to left. Rows 1 and 5 were border rows. Yield data were collected from rows 3 and 4, while efficacy assessments were conducted by means of quadrats from the area between rows 2 and 4. Irrigation and other common cultural practices were conducted as needed during the growing season.

2.2. Assessments and Measurements

The efficacy of the treatments was based on measurements of weeds' densities and it was visually estimated at 14 and 28 days after spraying (crop growth stages BBCH 15–17 and 16–19, respectively) by means of a quadrat (50 × 50 cm) in each plot as described by Travlos et al. [18]. The efficacy assessment is presented as a percentage of weed reduction to the respective control treatments (scale 0–100%, 0: untreated, 100: no weeds at all). Phytotoxicity symptoms were evaluated (if any). At grain maturity (end of August for both fields), ears of the 20 maize plants (from rows 3 and 4 of each plot) were hand-harvested and dried at 80 °C until a constant weight was achieved. Grain moisture, thousand grain weight (TGW), and quality parameters (nitrogen, protein, and oil content) were also evaluated at harvest.

2.3. Statistical Analysis

Analysis of variance (ANOVA) was conducted for all data and differences between means were compared at the 5% level of significance using the Fisher's Protected LSD test. All statistical analyses were conducted using the Statsoft software package (Statsoft, Inc., 2300 East 14th Street, Tulsa, OK, USA).

3. Results and Discussion

In both the experimental years, the main weed species were *Xanthium strumarium*, *Amaranthus retroflexus*, *Cirsium arvense*, and *Solanum nigrum*, while there was also present the annual invasive species *Physalis angulata*. The results showed that Lancelot 450 WG at the recommended dose of 33 g/ha resulted to a satisfactory control of *X. strumarium*, *A. retroflexus*, *C. arvense*, and *S.nigrum* (Table 4). The efficacy of Callisto 10 SC at the dose of 750 mL/ha was up to 92.5% at 14 DAT. However, there was a significantly higher residual activity of Lancelot 450 WG compared to Callisto 10 SC and this was obvious at 28 DAT, whereas efficacy against *X. strumarium* was 95 and 85% for the higher doses of Lancelot 450 WG and Callisto 10 SC, respectively (Table 5). The above mentioned species were the dominant weeds in the specific field and consequently their long-term control is considered crucial for crop's performance. This residual efficacy of similar mixtures has been previously shown [16], while the need of herbicides with long-term activity against weeds was indicated [14,19]. The only case of higher efficacy of the high compared with the low dose of Lancelot 450 WG was against the noxious *C. arvense* at 28 DAT. It is generally considered that even low densities of some broadleaf weeds may produce sufficient seed to cause an economic problem for many years [20]. However, late weed emergence after an early post-emergence herbicide application often results in reduced fecundity and speculates little impact on the soil seed bank [21].

A similar trend was also recorded in terms of the efficacy against the invasive *P. angulata*. This species has been found and characterized as a new record for the weed flora of summer crops of Greece and a highly distributed invader in maize fields [22]. As shown in Tables 4 and 5, aminopyralid + florasulam at the recommended rate had an efficacy of 95% against *P. angulata* during the crucial period for the maize crop. In general, growth regulator herbicides are generally considered ineffective against invasive annual weeds. However, our results are in accordance with previous findings, showing that aminopyralid can be very effective against invasive weeds, while weed responses were highly variable beyond the seedling stage [23]. It has to be noted that this period of sufficient control of *P. angulata* provided especially by the mixture aminopyralid + florasulam (until 28 DAT) was larger than the crucial period for weed control in maize and consequently, after that, weed emergence would be of lower importance for crop productivity.

Table 4. Efficacy assessment (%) of the several treatments on broadleaf weeds at 14 DAT.

	Treatment	*X. strumarium*	*C. arvense*	*A. retroflexus*	*S. nigrum*	*P. angulata*
1	Lancelot 450 WG (33 g/ha)	90 ab	85 de	95 g	90 i	95 kl
2	Lancelot 450 WG (66 g/ha)	100 a	95 d	100 g	95 i	100 k
3	Callisto 10 SC (750 mL/ha)	83.75 b	80 e	92.5 g	90 i	85 l
4	Callisto 10 SC (1500 mL/ha)	95 a	90 de	100 g	90 i	95 kl
5	Untreated	0 c	0 f	0 h	0 j	0 m

Different letters within each column indicate significant differences between the treatments according to Fisher's LSD significance test ($p < 0.05$).

Table 5. Efficacy assessment (%) of the several treatments on broadleaf weeds at 28 DAT.

	Treatment	*X. strumarium*	*C. arvense*	*A. retroflexus*	*S. nigrum*	*P. angulata*
1	Lancelot 450 WG (33 g/ha)	90 ab	83.75 f	92.5 h	90 j	95 m
2	Lancelot 450 WG (66 g/ha)	95 a	95 e	95 h	90 j	100 m
3	Callisto 10 SC (750 mL/ha)	77.5c	77.5 f	87.5 h	80 k	80 n
4	Callisto 10 SC(1500 mL/ha)	85 bc	85 f	90 h	85 jk	90 mn
5	Untreated	0 d	0 g	0 i	0 l	0 o

Different letters within each column indicate significant differences between the treatments according to Fisher's LSD significance test ($p < 0.05$).

Moreover, our findings revealed that only few significant differences between the several herbicide treatments were obtained for yield and quality of maize (Tables 6 and 7). However, it has to be noted that all sprayed plots (with the exception of mesotrione at the recommended dose) resulted in significantly higher yields than the untreated control. In general, five percent has been suggested as the maximum tolerable yield loss in maize [24] and has been used in the literature as a hypothetical value for the action threshold for this crop [25]. In our case, yield loss in the untreated plots was up to 10% compared to the plots treated with the high dose of the mixture aminopyralid + florasulam (Table 6). Consequently, in our case, early emerging broadleaf weeds will certainly need to be controlled. Thousand grain weight (TGW) was not significantly affected by herbicide treatments and consequently the observed yield differences could be probably attributed to the different number of kernels. Previous studies have documented that grain yield is mainly determined by kernel number per unit land area [20,26]. In all cases, there were no permanent or serious phytotoxicity symptoms for the crop. Concerning some basic quality traits, there were only very few significant effects of the several treatments, while the recommended dose of Lancelot did not have any negative effect on the nitrogen, protein, and oil content of maize grains (Table 7).

Table 6. Effects of the several treatments on seed yield, thousand grain weight (TGW), and seed moisture.

	Treatment	Yield (t/ha)	TGW (kg)	Moisture (%)
1	Lancelot 450 WG (33 g/ha)	11.05 a	0.35 d	16 e
2	Lancelot 450 WG (66 g/ha)	11.13 a	0.35 d	16 e
3	Callisto 10 SC (750 mL/ha)	10.43 b	0.36 d	16 e
4	Callisto 10 SC (1500 mL/ha)	11.07 a	0.36 d	15 e
5	Untreated	10.06 b	0.36 d	15 e

Different letters within each column indicate significant differences between the treatments according to Fisher's LSD significance test ($p < 0.05$).

Table 7. Effects of the treatments on seed quality parameters.

	Treatment	Nitrogen (%)	Protein (%)	Oil (%)
1	Lancelot 450 WG (33 g/ha)	2.04 a	12.31 d	4.95 ef
2	Lancelot 450 WG (66 g/ha)	2.14 a	13.38 c	4.76 ef
3	Callisto 10 SC (750 mL/ha)	2.18 a	13.63 c	4.72 f
4	Callisto 10 SC (1500 mL/ha)	2.16 a	13.5 c	5.05 e
5	Untreated	2.06 a	12.88 cd	4.81 ef

Different letters within each column indicate significant differences between the treatments according to Fisher's LSD significance test ($p < 0.05$).

4. Conclusions

In the present study, the high and long-term efficacy of Lancelot 450 WG (aminopyralid + florasulam) at the recommended dose of 33 g/ha was demonstrated against broadleaf and invasive weeds in maize. Overall, Lancelot 450 WG can be a useful tool for the control of important broadleaf and weeds in maize, while some invasive species like *P. angulata* can be successfully controlled, too. The selectivity of the mixture was also satisfactory, without any adverse effects on maize crop, even when double the recommended dose was tested. The core of sustainable weed management is to use a range of tools in time and space. The EU's farmers have been obliged since 2014 to follow the principles of Integrated Pest Management (IPM) of Directive 2009/128/EC as a way to reduce risks of herbicides, fungicides, and other pesticides. Use of anti-resistant strategies is one of these principles and certainly, mixtures of herbicides can reduce the costs, lower the selection pressure, and prevent or delay herbicide-resistance issues especially when combined with several agronomic practices.

Acknowledgments: The authors wish to thank the Dow AgroSciences Export SAS for the financial support of the present study.

Author Contributions: Ilias Travlos and Vasilis Apostolidis conceived, performed, and analyzed the experiments. Ilias Travlos and Vasilis Apostolidis analyzed the data and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest. Vasilis Apostolidis is an employee of Dow AgroSciences.

References

1. Zand, E.; Baghestani, M.A.; Shimi, P. Weed control in wheat fields of Iran. In Proceedings of the First International Congress of Wheat, Tehran, Iran; 2003; pp. 419–450.
2. Royal Society. *Reaping the benefits: Science and the Sustainable Intensification of Global Agriculture*; Royal Society: London, UK, 2009; p. 76. ISBN 978-0-85403-784-1.
3. Holm, L. The role of weeds in human affairs. *Weed Sci.* **1971**, *19*, 485–490.
4. Almeida, J.; Freitas, H. Exotic flora of continental Portugal—A new assessment. *Bocconea* **2012**, *24*, 231–237.
5. Pyšek, P.; Chytry, M.; Pergl, J.; Sádlo, J.; Wild, J. Plant invasions in the Czech Republic: Current state, introduction dynamics: Invasive species and invaded habitats. *Preslia* **2012**, *84*, 575–629.
6. Owen, M.D.; Zelaya, I.A. Herbicide-resistant crops and weed resistance to herbicides. *Pest Manag. Sci.* **2005**, *61*, 301–311. [CrossRef] [PubMed]
7. Travlos, I.S.; Chachalis, D. Glyphosate-resistant hairy fleabane (*Conyza bonariensis*) is reported in Greece. *Weed Technol.* **2010**, *24*, 569–573. [CrossRef]
8. Baghestani, M.A.; Zand, E.; Soufizadeh, S.; Bagherani, N.; Deihimfard, R. Weed control and wheat (*Triticum aestivum* L.) yield under application of 2,4-D plus carfentrazone-ethyl and florasulam plus flumetsulam: Evaluation of the efficacy. *Crop Prot.* **2007**, *26*, 1759–1764. [CrossRef]
9. Beckie, H.J.; Heap, I.M.; Smeda, R.J.; Hall, L.M. Screening for herbicide resistance in weeds. *Weed Technol.* **2000**, *14*, 428–445. [CrossRef]
10. Travlos, I.S. Competition between ACC-inhibitor resistant and susceptible sterile wild oat (*Avena sterilis* L.) biotypes. *Weed Sci.* **2013**, *61*, 26–31. [CrossRef]

11. Till, D.C.; Lemerle, D. World wheat and herbicide resistance. In *Herbicide Resistance and World Grains*; Powles, S.B., Shaner, D.L., Eds.; CRC Press: Boca Raton, FL, USA, 2001; pp. 165–194.
12. Travlos, I.S.; Chachalis, D. Relative competitiveness of glyphosate-resistant and glyphosate-susceptible populations of hairy fleabane (*Conyza bonariensis* L.). *J. Pest Sci.* **2012**, *86*, 345–351. [CrossRef]
13. Rinella, M.J.; Masters, R.A.; Bellows, S.E. Growth regulator herbicides prevent invasive annual grass seed production under field conditions. *Rangel. Ecol. Manag.* **2010**, *63*, 478–490. [CrossRef]
14. Kyser, G.B.; Peterson, V.F.; Davy, J.S.; DiTomaso, J.M. Preemergent control of medusahead on California annual rangelands with aminopyralid. *Rangel. Ecol. Manag.* **2012**, *65*, 418–425. [CrossRef]
15. Mikkelso, J.R.; Lym, R.G. Aminopyralid soil residues affect crop rotation in North Dakota soils. *Weed Technol.* **2011**, *25*, 422–429. [CrossRef]
16. EFSA (European Food Safety Authority). Reasoned opinion on the modification of the existing maximum residue level for aminopyralid in maize. *EFSA J.* **2016**, *14*, 4497.
17. Krieger, M.S.; Pillar, F.; Ostrander, J.A. Effect of temperature and moisture on the degradation and sorption of florasulam and 5-hydroxyflorasulam in soil. *J. Agric. Food Chem.* **2000**, *48*, 4757–4766. [CrossRef] [PubMed]
18. Travlos, I.S.; Lysandrou, M.; Apostolidis, V. Efficacy of the herbicide GF-2581 (penoxsulam + florasulam) against broadleaf weeds in olives. *Plant Soil Environ.* **2014**, *12*, 574–579.
19. Smith, K.; Steckel, L.; Poston, D. Glyphosate-resistant horseweed and glyphosate-resistant cropping technologies. *Proc. South. Weed Sci. Soc. USA* **2005**, *58*, 231.
20. Travlos, I.S.; Kanatas, P.J.; Economou, G.; Kotoulas, V.E.; Chachalis, D.; Tsioros, S. Evaluation of velvetleaf interference with maize hybrids as influenced by relative time of emergence. *Experim. Agric.* **2011**, *48*, 127–137. [CrossRef]
21. Lindquist, J.L.; Mortensen, D.A.; Johnson, B.E. Mechanisms of corn tolerance and velvetleaf suppressive ability. *Agron. J.* **1998**, *90*, 787–792. [CrossRef]
22. Travlos, I.S. Invasiveness of cutleaf ground cherry *(Physalis angulata* L.) populations and impacts of water and nutrient availability of soil. *Chil. J. Agric. Res.* **2012**, *72*, 358–363. [CrossRef]
23. Rinella, M.J.; Bellows, S.E.; Roth, A.D. Aminopyralid constrains seed production of the invasive annual grasses medusahead and ventenata. *Rangel. Ecol. Manag.* **2014**, *67*, 406–411. [CrossRef]
24. Hall, M.R.; Swanton, C.J.; Anderson, G.W. The critical period of weed control in grain corn (*Zea mays*). *Weed Sci.* **1992**, *40*, 441–447.
25. Knezevic, S.Z.; Weise, S.F.; Swanton, C.J. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). *Weed Sci.* **1994**, *42*, 568–573.
26. Cirilo, A.G.; Andrade, F.H. Sowing date and maize productivity: II. Kernel number determination. *Crop Sci.* **1994**, *34*, 1044–1046. [CrossRef]