Efficacy of the herbicide GF-2581 (penoxsulam + florasulam) against broadleaf weeds in olives

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ABSTRACT

Effective weed control in perennial crops is a challenge due to the limited availability of registered herbicides and herbicide resistance. The objective of the study was to evaluate the efficacy of the herbicide GF-2581 (penoxsulam + florasulam) on broadleaf weeds in comparison with other commonly used herbicides. Field trials were conducted in olives, in Etoloakarnania (Agrinio region) for two years (2012 and 2013). Efficacy assessments were made at 30, 60, 90 and 120 days after treatment. The GF-2581 formulation provided excellent control of a broad spectrum of broadleaf weed species. The long-term control of *Sonchus oleraceous*, *Conyza canadensis* and *Stellaria media*, provided by GF-2581 during the growing season was significantly greater than that using flumioxazin. When combined with glyphosate or diquat, the level of control of these three weeds was improved. The GF-2581 agent applied pre-emergence followed 14 days later by application of glyphosate provided 100% control in 2012. Lower efficacy levels were observed in 2013 and may have been the result of higher rainfall when compared to 2012. GF-2581 is an effective herbicide product to control broadleaf weeds, as a part of integrated weed control management strategies in olives.

Keywords: weed control; long-term activity of herbicides; perennial crops

Effective weed control programs in perennial crops are constrained by limited availability of registered herbicides, and expanding populations of herbicide resistant weed biotypes (Heap 2012, Rojano-Delgado et al. 2012, Travlos and Chachalis 2013). Many herbicides with soil residual activity are no longer registered in the EU, which drastically limits potential weed control solutions for farmers. Moreover, the extended and frequent use of the same herbicide such as glyphosate, can greatly increase the risks of herbicide resistance that reduces control of several weeds (Dill 2005, Owen and Zelaya 2005, Rojano-Delgado et al. 2010). In Greece, there are many reports on reduced efficacy of glyphosate against weeds, such as *Sorghum halepense*, *Malva sylvestris*, *Lolium* spp. etc (Giannopolitis et al. 2008, Travlos et al. 2009). Moreover, there are many reports from Greek farmers that several weeds, such as *Conyza* spp., *Parietaria* spp. and other broadleaf weeds have become increasingly difficult to control, especially in no-tillage or minimum-tillage systems (Travlos and Chachalis 2010, 2012).

Effective herbicides with soil residual activity are often recommended for pre-plant and long-term weed control (Nandula et al. 2005, Davis et al. 2007). However, because of some inconsistencies in efficacy, further evaluation of the registered herbicides is required, while some new herbicides should be also studied (Norworthy et al. 2009). Penoxsulam and florasulam are two of them. Penoxsulam is the common name for (2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy-[1,2,4]-triazolo[1,5-c]pyrimidin-2-yl)-6-(trifluoromethyl) benzenesulfonamide. It is a systemic herbicide that is absorbed mainly by leaves and secondary by roots (Larelle et al. 2003). Florasulam is the common name for N-(2,6-difluorophenyl)-8-fluoro-5-methoxy[1,2,4]-triazolo[1,5-c]pyrimidine-2-sulfonamide. Their mode of action is the

inhibition of the acetolactate synthase enzyme (ALS), which inhibits the biosynthesis of the amino acids valine, leucine and isoleucine. Both of them seem to adequately control many broadleaf weeds in different crops. Their persistence in soils is related to clay and organic matter content, soil pH, rainfall, temperatures and other environmental factors (Krieger et al. 2000).

Some pre- and post-emergent herbicides, along with various integrated management strategies, may provide acceptable efficacy against noxious and problematic weed species. The objective of our study was to evaluate the efficacy of GF-2581 (penoxsulam + florasulam) and compare it with other commonly used herbicides.

MATERIAL AND METHODS

Field trials were conducted in Etoloakarnania, Greece (Agrinio region, 38°36'35.29''N, 21°25' 46.50'E) from March 22 to July 27, 2012 and from January 31 to June 2, 2013. The crop was olives (cv. Kalamon), the trees were 18 years old (at distances 6 and 4 m between rows and within each row, respectively). Soil physiochemical characteristics are given in Table 1.

Experiments were designed as a randomized block (eight treatments with three replications) with plot size 4 × 3 m. Herbicides GF-2581 225 SC [florasulam (75 g a.i./L) + penoxsulam (150 g a.i./L)] at 0.1 L/ha (Dow AgroSciences Export SAS, France), glyphosate (Dominator 360 SL® 360 g a.e./L, Dow AgroSciences Export SAS, France) at 72 g a.e./ha, diquat (Reglone 200 SL® 200 g a.i./L, Syngenta Ltd) at 660 g a.i./ha and flumioxazin (Pledge 50 WP® 50 g a.i./kg, Sumitomo Chemical Agro Europe SA) at 150 g a.i./ha were applied (Table 2). At the time of the first application (pre-emergence) there were few weeds present above the soil surface (only a small number of weeds were at 2 to 3 leaves). Second application (treatments 7 and 8) followed 14 days later. All treatments were applied with a field plot sprayer using a 1.6 m-wide boom fitted with four flat-fan nozzles and spray delivery volume of 300 L/ha at application pressure 250 kPa. The experiment was repeated the following year in a different part of the same orchard.

Table 1. Soil characteristics in the experimental field

Parameter	
Sand (%)	53
Clay (%)	16
Silt (%)	31
Characterization	sandy loam
pH (1:2 H_2O)	7.6
Total $CaCO_3$ (%)	0.8
Organic matter (%)	1.5
Nitrogen (g/kg)	0.36
Phosphorus (g/kg)	0.12
Potassium (g/kg)	1.8
Electrical conductivity (mS/cm)	0.51

The weed species composition on the research sites was dominated by broadleaf weeds including: *Sonchus oleraceus*, *Conyza canadensis*, *Plantago major*, *Scabiosa lucida*, *Stellaria media*, *Cardaria draba*, *Rumex* ssp., *Malva sylvestris*, *Mercurialis annua*, *Erodium* ssp. and *Vicia villosa*. Assessment of overall broadleaf weed control across species was determined by counting weed density (a wooden square quadrat of 60 × 60 cm was placed at random three times in each plot) and comparing the treated plots with adjacent untreated controls 30, 60, 90 and 120 days after first treatment (DAT).

Data obtained from the field trials were subjected to ANOVA. Year × treatment interactions were studied, while treatment means were separated using Fisher's protected *LSD* test at a significance level of $P = 0.05$ by means of Statistica 9.0 software package (StatSoft, Inc. 2300, Tulsa, USA).

RESULTS AND DISCUSSION

In our study, there was a significant year × treatment interaction and therefore results are separately shown for each year (Tables 3–5). At 30 DAT, plots where GF-2581 (penoxsulam + florasulam) was used provided excellent broadleaf weed control. Efficacy of glyphosate was significantly lower, probably because of the presence of a resistant biotype of *C. canadensis*, dominant weed in both years. Even when glyphosate was combined with flumioxazin, efficacy was relatively inadequate. Flumioxazin applied alone provided insufficient weed control. The addition of flumioxazin to tank mixtures provided a moderate residual control but did not increase control of *C. canadensis* seedlings; a finding similar to that was observed by Steckel et al. (2006). Differences in flumioxazin efficacy observed in 2012 and 2013; could

Table 2. The herbicide treatments tested in the experiments. Rates of the formulated products and application timing are also shown

Treatment	Herbicide (active ingredient)	Rate of product	Rate of active ingredients	Application timing
1	GF-2581 (penoxsulam + florasulam)	0.1 L/ha	7.5 g a.i./ha + 15 g a.i./ha	pre-emergence
2	Pledge 50 WP (flumioxazin)	0.3 kg/ha	0.15 g a.i./ha	pre-emergence
3	untreated control	–	–	–
4	GF-2581 (penoxsulam + florasulam) + Dominator 360 SL (glyphosate)	0.1 L/ha + 2 L/ha	7.5 g a.i./ha + 15 g a.i./ha + 72 g a.e./ha	pre-emergence
5	Pledge 50 WP (flumioxazin) + Dominator 360 SL (glyphosate)	0.3 kg/ha + 2 L/ha	0.15 g a.i./ha + 72 g a.e./ha	pre-emergence
6	GF-2581 (penoxsulam + florasulam) + Reglone 200 SL (diquat)	0.1 L/ha + 3.3 L/ha	7.5 g a.i./ha + 15 g a.i./ha + 660 g a.i./ha	pre-emergence
7	GF-2581 (penoxsulam + florasulam) + Dominator 360 SL (glyphosate)	0.1 L/ha + 2 L/ha	7.5 g a.i./ha + 15 g a.i./ha + 72 g a.e./ha	pre-emergence + 14 DAT
8	Dominator 360 SL (glyphosate) + GF-2581 (penoxsulam + florasulam)	2 L/ha + 0.1 L/ha	72 g a.e./ha + 7.5 g a.i./ha + 15 g a.i./ha	Pre-emergence + 14 DAT

DAT – days after pre-emergence treatment

be attributed to higher rainfall in 2013, 160 mm and 587 mm in 2012 and 2013, respectively (Table 6). Long-term efficacy of GF-2581, especially when combined with glyphosate (as a mixture or sequentially) was also recorded, resulting in 85% to 100% weed control. Our study also confirmed the very good knock-down effect of diquat, which was previously studied (Travlos and Chachalis 2010). However, the disadvantage of the absence of long-term efficacy makes diquat probably fitting better in a sequential application (e.g. after application of a residual herbicide).

The GF-2581 agent provided excellent broad spectrum broadleaf weed control. GF-2581 provided 86% and 88% control at 120 DAT in 2012 and 2013, respectively, which was the same level of control observed when GF-2581 was applied together with glyphosate at the first timing of application (Tables 3 and 4). In contrast, treatment where penoxsulam and florasulam were applied pre-emergent and glyphosate was applied 14 days later provided excellent activity at 60 DAT and reached 100% control in 2012 (Table 3). The slightly lower efficacy observed during 2013 may be attributed to greater precipitation in this year, which may have caused the GF-2581 to move deeper in the soil profile and out of the root zone of weeds. The other sequential treatment when glyphosate was applied first followed by GF-2581

Table 3. Total efficacy (%) of the tested treatments on broadleaf weeds at 30, 60, 90 and 120 days after treatment (DAT). Values represent means of the first year's experiment (2012)

Treatment	Day after treatment			
	30	60	90	120
Penoxsulam + florasulam	75^{ab}	78^{b}	84^{b}	86^{b}
Flumioxazin	45^{c}	49^{c}	42^{c}	40^{c}
Untreated control	0^{d}	0^{d}	0^{d}	0^{d}
(Penoxsulam + florasulam) + glyphosate	76^{ab}	80^{b}	85^{b}	86^{b}
Flumioxazin + glyphosate	64^{b}	66^{bc}	59^{c}	55^{c}
(Penoxsulam + florasulam) + diquat	81^{a}	84^{ab}	85^{b}	88^{ab}
(Penoxsulam + florasulam) + glyphosate (14 DAT)	82^{a}	94^{a}	97^{a}	100^{a}
Glyphosate + (penoxsulam + florasulam (14 DAT)	66^{b}	80^{b}	85^{b}	90^{ab}

Different letters in the same column present significant differences at 0.05 level according to Fischer's *LSD* test

Table 4. Total efficacy (%) of the tested treatments on broadleaf weeds at 30, 60, 90 and 120 days after treatment (DAT). Values represent means of the first year's experiment (2013)

Treatment	Day after treatment			
	30	60	90	120
Penoxsulam + florasulam	72^{ab}	76^{a}	82^{a}	85^{a}
Flumioxazin	28^{d}	30^{b}	23^{b}	25^{b}
Untreated control	0^{e}	0^{c}	0^{c}	0^{c}
(Penoxsulam + florasulam) + glyphosate	74^{ab}	80^{a}	86^{a}	88^{a}
Flumioxazin + glyphosate	47^{c}	49^{b}	45^{b}	41^{b}
(Penoxsulam + florasulam) + diquat	77^{a}	78^{a}	83^{a}	86^{a}
(Penoxsulam + florasulam) + glyphosate (14 DAT)	75^{a}	85^{a}	90^{a}	94^{a}
Glyphosate + (penoxsulam + florasulam (14 DAT)	62^{b}	76^{a}	80^{a}	85^{a}

Different letters in the same column present significant differences at 0.05 level according to Fischer's *LSD* test

(penoxsulam + florasulam) in most cases provided lower weed control. Perhaps, applying glyphosate after GF-2581 could provide some control of the emerging weeds followed by the residual benefit provided by GF-2581 (penoxsulam + florasulam). The efficacy of GF-2581 was significantly higher in both years and all assessments timings compared to flumioxazin treatment. The control of weeds such as *Sonchus* spp. and *Conyza* spp. is very important since they are prolific seed producers, with a single plant capable of producing thousands of non-dormant seeds (Weaver 2001, Travlos and Chachalis 2012), which can be widely dispersed by wind (Shields et al. 2006).

Efficacy data presented at 60 DAT for *S. oleraceous*, *C. canadensis* and *S. media* reveal that *S. media* was relatively easier to control with most herbicides (Table 5). On the contrary, for the most competitive species *S. oleraceus* and *C. canadensis* a mixture or sequential strategy is required in most cases. GF-2581 (penoxsulam + florasulam) compared with flumioxazin is significantly more effective; however, application of mixtures of penoxsulam and florasulam with glyphosate or diquat is recommended to optimize weed control.

Farmers prefer to include herbicides such as glyphosate in mixture with other herbicides that offer effective and economic solutions, despite the low efficacy of glyphosate in some weeds. The need of herbicides with long-term activity for weed control was documented (Mayhew et al. 2004, Nandula et al. 2005, Smith et al. 2005). Our

Table 5. Efficacy (%) of the tested treatments on the dominant broadleaf weeds of the experimental field at 60 days after treatment (DAT)

Treatment	*Sonchus oleraceus*		*Conyza canadensis*		*Stellaria media*	
	2012	2013	2012	2013	2012	2013
Penoxsulam + florasulam	82^{a}	78^{a}	60^{bc}	75^{b}	84^{ab}	82^{ab}
Flumioxazin)	54^{b}	48^{c}	7^{d}	13^{d}	74^{b}	68^{c}
Untreated control	0^{c}	0^{d}	0^{d}	0^{e}	0^{c}	0^{d}
(Penoxsulam + florasulam) + glyphosate	84^{a}	84^{a}	73^{ab}	90^{a}	85^{ab}	88^{a}
Flumioxazin + glyphosate	66^{b}	62^{b}	53^{c}	28^{c}	83^{ab}	77^{bc}
(Penoxsulam + florasulam) + diquat	88^{a}	85^{a}	80^{a}	84^{ab}	92^{a}	90^{a}
(Penoxsulam + florasulam) + glyphosate (14 DAT)	94^{a}	90^{a}	83^{a}	85^{ab}	92^{a}	90^{a}
Glyphosate + (penoxsulam + florasulam (14 DAT)	84^{a}	80^{a}	63^{b}	72^{b}	86^{ab}	85^{ab}

Different letters in the same column present significant differences at 0.05 level according to Fischer's *LSD* test

Table 6. Mean, maximum and minimum monthly temperature (°C) and monthly rainfall (mm) during the field experiments in 2012 and 2013

	2012				2013			
	rainfall	temperature			rainfall	temperature		
		mean	max	min		mean	max	min
January	–	–	–	–	210.8	9.5	13.6	5.9
February	–	–	–	–	167.2	10.4	14.1	7.1
March	39.4	12.6	25.7	1.5	93.0	12.8	17.3	8.9
April	47.2	16.1	30.3	6.3	47.8	17.2	23.2	11.6
May	73.6	19.7	31.1	11.3	68.6	21.6	27.6	16.5
June	0	26.7	37.5	15.1	–	–	–	–
July	0	29.7	39.9	20.2	–	–	–	–
Total	160.2	–	–	–	587.4	–	–	–

results confirm the potential of residual herbicides (such as GF-2581) in managing a wide range of weeds, including glyphosate resistant species. Additional assessments are needed to confirm that there is no antagonism between glyphosate and GF-2581 when applied together. Furthermore, the sequencing of the treatments to be proposed (first residual, secondly knock-down treatments) should be further evaluated to determine optimum timing and flexibility in timing of application while still achieving a desired level of control of a broad spectrum of weed species. This is aligned with farmers who want to see good efficacy on emerged plants coupled with long-term residual control.

At present, the opportunities to effectively control several broadleaf weeds by means of herbicides are reduced, and other non-chemical practices are often avoided because of cost and increased risk of soil erosion. New herbicides used in combination should be further studied. Conclusively, GF-2581 (penoxsulam + florasulam) is a promising new herbicide with soil residual activity, and in some cases significantly more effective even in high rainfall conditions than other residual herbicides that are currently registered. GF-2581 could provide satisfactory control of many broadleaf weeds especially when used as a component of integrated weed management programs.

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