CHAPTER 2

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Field assessment of crop residues for allelopathic effects on both crops and weeds

MI Ferreira[1] & CF Reinhardt[2]

[1]*Institute for Plant Production, Department of Agriculture Western Cape, Private Bag X1, Elsenburg, 7607, South Africa*
[2*]*Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002, South Africa*

mikefe@elsenburg.com

*Current address: *South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe, 4300*

INTRODUCTION

In South Africa's south western corner, the widespread use of herbicides on crop fields has led to new weed problems in the form of shifts in the dominance of species' in weed communities and the increased evolution of herbicide-resistant weeds. Most proven cases of herbicide resistance in South Africa occur in the orchards, vineyards, and wheat fields of the Western Cape Province (Pieterse & Cairns, 2009). The overuse of synthetic agrochemicals for pest and weed control has increased environmental pollution, unsafe agricultural products, and human health concerns (Khanh *et al.,* 2005). Therefore, system-oriented approaches to weed management that make better use of alternative weed management tactics are being promoted (Liebman and Davis, 2000; Barberi, 2002). Weeds are an important constraint in agricultural production systems (Oerke, 2006) because they act at the same trophic level as the crop, capturing part of the available resources that are essential for plant growth (Bastiaans, 2008). For these reasons, there is increasing interest in integrated weed management strategies based on a wide range of control options. One of these options is the inherent ability of many crops to suppress weeds through a combination of high early vigour (competition) and allelopathic activity to further reduce weed interference (Bertholdsson, 2005).

The International Allelopathy Society (IAS) has defined allelopathy as follows: 'allelopathy refers to any process involving secondary metabolites produced by plants, microorganisms and viruses that influence the growth and development of agricultural and biological systems' (Kruidhof, 2008). Belz (2007) reported that allelopathy can be an important component of crop/weed interference. The trend towards conservation tillage and widening range of crop rotation options and diverse production practices in the Western Cape Province has highlighted the potential exploitation of allelopathy to suppress weeds in cropping systems and is likely to be most beneficial where other options have become limiting due to herbicide resistance and high control costs (Jones *et al.,* 1999).

Crop allelopathy controls weeds by the release of allelochemicals from intact roots of living plants and/or through decomposition of phytotoxic plant residues (Qasem and Hill, 1989; Weston, 1996; Batish *et al.,* 2002; Belz, 2004; Khanh *et al.,* 2005). The incidence of growth inhibition of certain weeds and the induction of phytotoxic symptoms by plants and their residues is well documented for many crops, including all major grain crops such as rice (*Oryza sativa*), rye (*Secale cereale*), barley, sorghum (*Sorghum bicolor*), and wheat (*Triticum aestivum*) (Belz, 2004).

Crop residues can interfere with weed development and growth through alteration of soil physical, chemical, and biological characteristics. In the case of crop residues, there are two possible sources of allelochemicals; the compounds can be released directly from crop litter or they can be produced by microorganisms that use plant residues as a substrate (Kruidhof, 2008). Retention of crop residues in conservation tillage systems is recognised as also providing several other benefits including improved soil conservation and soil structure, as well as increased water infiltration and reduced costs for fuel and labour (Jones *et al.,* 1999).

Crop residues can also affect the physical properties of the soil. Residues conserve moisture (Liebl *et al.,* 1992; Teasdale & Mohler, 1993). Residues left on the soil surface can lead to decreased soil temperature fluctuations and reduced light penetration, which can both have an inhibitory effect on weed germination (Teasdale & Mohler, 1993). Furthermore, in some cases soil microbial populations, including soilborne pathogens, are stimulated after soil amendment with fresh plant material (Dabney *et al.,* 1996; Conklin *et al.,* 2002; Manici *et al.,* 2004).

Although residue management seems a key factor in residue-mediated weed suppression, very few studies have systematically compared the influence of different residue management methods on germination and establishment of crop and weed species (Kruidhof, 2008). Allelopathy is particularly relevant for weed management strategies applied in minimum and no-till cropping systems (Jones *et al.,* 1999), because weed control in such systems is particularly problematic and basically limited to the use of herbicides.

The inclusive definition for allelopathy mentioned above recognises that compounds are involved in the defense against multiple biological threats, including competition by other plants, herbivores and disease (Macias *et al.,* 2007). Manipulation of the allelopathic environment is mediated by several input production factors, and special adaptations might be needed for successful application of crop allelopathy (Belz, 2007). Duke *et al.* (2001) and Scheffler *et al.* (2001) proposed adaptations for successful application of allelopathy in terms of genetic approaches as it would enhance the weed-suppressing capacity of crop cultivars.

To achieve consistent results in the field from the use of crop residues, it is important to understand the mechanism of allelopathy (Diab & Sullivan, 2003). Field trials investigating crop allelopathy of rice cultivars showed that crop allelopathy does not kill weeds (Olofsdotter *et al.,* 1999; Olofsdotter, 2001), confirming that crop allelopathy may suppress but not eliminate weeds. Similar to many plant characteristics, allelopathy is influenced by environmental conditions (Olofsdotter, 2002; Weston & Duke, 2003). Thus, in a wide range of environments, the allelopathic potential of a certain cultivar may differ considerably. A clear understanding of such genotypeenvironmental interactions is required if allelopathy is to become a reliable option for weed management (Belz, 2004).

Furthermore, no information is available on the role of allelopathy in crop rotation systems in the Western Cape Province, where 750 000 ha are subjected to crop rotation. Of this area, more than 200 000 ha are under threat from invasive herbicide-resistant rye grass weed type. The objective of the present studies was to explore the possibility of using allelopathic properties of rotational crop residues for weed suppression (specifically suppression of herbicide-resistant rye grass weed type) to determine whether crop and weed residues left in the field release phytotoxins that affect the growth and yield of rotational crops and weeds.

MATERIALS AND METHODS

The study was conducted at the Tygerhoek Research Farm (19°54'E, 34°08'S) near Riviersonderend, South Africa. The main crop produced in this area is wheat in rotation with barley, canola, lupine, medic, and lucerne. The average annual rainfall at Tygerhoek is 443 mm (Appendix A, Table A1) and the long-term mean daily maximum and minimum temperatures are 22.4 °C and 10.2 °C, respectively. At this locality the stony loam soils are weakly developed residual (pH 5.1) of Mispah (Entisol) type (Soil Classification Working Group, 1991) containing 22 % clay and 1.6 % carbon. Total soil cations at this locality is 8.5 cmol(+) kg^{-1} and resistance of 370 Ohms. The research approach was similar in concept to that followed by Qasem and Hill (1989), Batish *et al.* (2002) and Bruce *et al.* (2005).

Experiment 1a-d

Dried plant material was collected following harvest in 2002 from the following crops: barley (*Hordeum vulgare* L. v. Clipper), canola (*Brassica napus* L. v. ATR Hyden), wheat (*Triticum aestivum* v. SST 88), lupine (*Lupinus angustifolius* L. v. Tanjil), lucerne (*Medicago sativa* L. v. SA standard), medic (*Medicago truncatula* Gaertn. v. Parabinga) and rye grass (*Lolium multiflorum* Lam. v. Energa). Stubble left on the soil surface after the harvesting process was collected manually and each stored separately for three months in a shed as plant residues for Exp 1a in 2003. Residues for use in Exp 1b, 1c and, 1d were produced in the years 2003, 2004 and 2005, respectively. Over this 4-yr period, each trial was planted in the same field, but each year on a different fallow site in close proximity to where the previous plantings were done. During the period that fallow sites were not in use, they were kept weed free, by rotating the use of herbicides glyphosate (Mamba™) and diquat/paraquat (Preeglone™), but plant material from weeds that did escape control was removed by hand from the trial site so as to leave a seedbed free of any plant residues for at least a year.

In each of the four years from 2003 to 2006 liming at a rate of 400 kg ha^{-1} was done six months before planting, based on soil analyses and aiming for a soil pH of 5.5. This was followed with chisel cultivation for incorporating the lime about 10 cm deep. Two months before planting the seedbed was prepared with a second chisel cultivation to leave a smooth seedbed, followed by uniform scattering of a quantity of plant residues equivalent to five tons per hectare, which is typically produced in the region under field conditions for barley and wheat and left on the field after harvesting. Residues were scattered per plot according to the lay-out in Table 1 (Appendix A, Figure A1). For experimental purposes, the same amount of plant residues was used for each treatment.

Table 1 Schematic representation of experimental design at Tygerhoek

		Plant residues (donors)							
Treatment number		Barley 1	Canola 2	Wheat 3	Lupine 4	Lucerne 5	Medic 6	Rye grass 7	Control 8
Plant species drilled	1 Barley	Barley	Barley	Barley	Barley	Barley	Barley	Barley	Barley
	2 Canola	Canola	Canola	Canola	Canola	Canola	Canola	Canola	Canola
	3 Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
	4 Lupine	Lupine	Lupine	Lupine	Lupine	Lupine	Lupine	Lupine	Lupine
	5 Lucerne	Lucerne	Lucerne	Lucerne	Lucerne	Lucerne	Lucerne	Lucerne	Lucerne
	6 Medic	Medic	Medic	Medic	Medic	Medic	Medic	Medic	Medic
	7 Rye grass	Rye grass	Rye grass	Rye grass	Rye grass	Rye grass	Rye grass	Rye grass	Rye grass

To prevent residues being blown away by wind, plots were covered with bird netting. The amount of residues applied in this way was 9 kg per plot (3 m x 6 m). Because plant residues were not incorporated into the soil it was assumed that possible confounding effects of a nitrogen-negative period could be avoided or at least restricted to negligible effect levels. Furthermore, fertilisation (in particular nitrogen) application was done in order to negate growth differences due to nutrients that might be released from the plant residues.

Plots were arranged in a randomised complete block design with three replicates, and were planted to barley, canola, wheat, lupines, lucerne, medic or rye grass (Table 1) in May each year from 2003 to 2006 as this is the growing season in the winter rainfall area for the southern hemisphere. Control plots received no plant residues before planting. Planting was done with a no-till ‘star wheel’ grain drill. Therefore, each crop was planted into seven different crop residues. Plots planted to lupine, lucerne, and medic received 10 kg P ha^{-1} at planting whereas 20 kg N ha^{-1} was applied to all other plots. Four weeks after planting, barley, wheat, canola, and rye grass plots received 30 kg N ha^{-1} and 15 kg S ha^{-1}. A further top dressing of 30 kg N ha^{-1} was applied to wheat, canola, and rye grass plots at 10 weeks after planting. Weeds were controlled with iodosulfuron at a rate of 200 g ai ha^{-1} in wheat and barley plots. In all other plots, grass weeds were controlled with cycloxydim at a rate of 300 ml ai ha^{-1} at six weeks after planting. Plant height of all the crops was measured with a stainless steel ruler of 1000 mm length, from the base of the crop stem at the soil surface to the highest growth point of five plants per plot at four weeks, eight weeks and at maturity. Plants per m^2 and the number of tillers were determined at harvest. For barley, seed plumpness and percentage seed nitrogen were measured; for wheat seed hectolitre mass and percentage seed protein were determined. Harvesting was done with a small plot combine. Grain mass per plot was determined and yield expressed on a per hectare basis.

Experiment 2

In the 2006 and 2007 winter rainfall seasons, in order to gather data that were more representative of local production practices, it was decided to plant all crops into plant residues left over from the 2005 and 2006 growing seasons (Exp 1c and 1d in 2005 and 2006), respectively. Apart from allelopathic effects, decomposing residues were expected to also release nutrients into the soil. Together with wheat and barley, it was decided that since lupine had suppressed grass weeds the most in Experiment 1, two cultivars should be evaluated as well as the weed type of *Lolium* spp, which was identified by the Compton Herbarium at Kirstenbosch Botanical Gardens as *L. multiflorum x perenne.* For commercial reasons, wheat v. SST 88 was replaced by v. SST 027 to ensure seed availability.

Crop planting in the 2006 and 2007 winter growing seasons was done at a 90º angle across the 2005 and 2006 plots of Experiment 1, respectively (Appendix A, Figure A2). Planting was done with a no-till 'star wheel' grain drill. Plots were 3 m x 3 m arranged in a randomised complete block design with three replicates and planted to barley, wheat, lupine v. Tanjil and v. Quilinock, rye grass, and rye grass weed type in May of each year. Plots were planted with row spacing of 17 cm and at seeding rates recommended for the area. All plant residues were manually removed from control plots. In terms of crop production practices, plots were handled in the same way as those in Experiment 1.

Prior to planting, counts of all weeds occurring on plots were done using a 0.25 m^2 steel grid at two positions spaced 1 m apart in the centre of each plot. In addition, weed population counts were done across all plots in June, August, and October to assess residue-mediated effects on weed seedling establishment for different residue treatments. Weed data expressed per m^2 were aggregated because non-destructive weed counts were done over the four sampling times. As density is a measure of weed severity, relative density values were calculated for each species. Relative density is the number of seedlings of a species expressed as percentage of total weed seedlings and was described by Cousens (1985) as a more appropriate representation of weed data than total weed counts.

Data Analyses

Data were subjected to ANOVA (SAS, 2000). Analyses of field data sets for Experiment 1 from 2003 until 2006 were done on data averaged over years, because the year by treatment interaction was not statistically significant, indicating that treatment effects were consistent over years, thus only the treatment main effect will be discussed. Analysis of variance was performed separately for the 2006 and 2007 experiments using the General Linear Model procedures of SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC, USA 2000). Results of the 2006 and 2007 experiments were also combined and investigated in a single analysis of variance (John and Quenouille, 1977) after testing that experiments are of comparable precision by means of Levene's test for homogeneity of variance (Levene, 1960). For crop stand the requirement of homogeneity of experiment variance was not met, therefore a weighted analysis was performed. The Shapiro-Wilk test was performed to test for normality (Shapiro, 1965). Data for crop stand was square root-transformed to improve assumptions of normality. Student's t-least significant difference was calculated at the 5% level to compare treatment means (Ott, 1998). A probability level of 5% was considered significant for all tests.

RESULTS

Experiment 1a-d

Both barley and rye grass residues reduced wheat grain yield (Table 2). Wheat residue significantly increased lupine yield above that attained with the no-residue control treatment. Treatment with wheat and rye grass plant residues increased rye grass yield significantly compared with the control.

Table 2 Effects of plant residues on yield for the various plant species in Exp 1

Plant residues	Barley yield (t ha^{-1})	Wheat yield (t ha^{-1})	Lupine yield (t ha^{-1})	Lucerne yield (t ha^{-1})	Medic yield (t ha^{-1})	Rye grass yield (t ha^{-1})
Barley	3.09a	2.94c	1.33ab	3.39ab	1.42bc	3.72c
Canola	3.14a	3.37b	1.27ab	3.28ab	1.68ab	3.73c
Wheat	3.35a	3.79ab	1.58a	3.62a	1.3bc	4.69ab
Lupine	3.1a	3.46b	1.02b	3.56ab	1.92a	3.59c
Lucerne	3.03a	3.98a	1.07b	3.51ab	1.32bc	4.03bc
Medic	3.11a	3.53b	1.13b	3.32ab	1.12c	3.78c
Rye grass	3.05a	2.84c	1.16b	2.74b	1.14c	4.98a
Control	3.19a	3.58ab	1.09b	3.3ab	1.56abc	3.68c
LSD ($P \leq 0.05$)	0.53	0.42	0.36	0.88	0.5	0.91

*Means followed by the same letter are not significantly different at the 0.05 probability level

Plant height of barley exposed to wheat or medic crop residues was significantly higher than the control. At harvest, plant residues from lucerne were associated with a significant increase in barley tillers above that attained in the control treatment. Barley plant residues caused a significant reduction in wheat seed hectolitre mass (data not presented).

Experiment 2

Barley

Compared with the control canola and lucerne residues had an inhibitory effect on the number of barley tillers (Table 3). This was also evident in barley yield, which was significantly reduced by canola and lucerne crop residues.

Table 3 Effects of retained plant residues in the 2006 and 2007 growing seasons on barley v. Clipper plant height, plant number, tillers, seed plumpness, percentage seed nitrogen and yield

Plant residues	Barley plant height (mm)	Barley plant number per m^2 at harvest	Barley tillers	Barley seed plumpness	Barley seed nitrogen (%N)	Barley yield (t ha^{-1})
Barley	761a*	69a	9.5ab	73.2a	2.33a	1.88bcd
Canola	805a	65a	7.3b	74.6a	2.34a	1.48cd
Wheat	805a	70a	10.8a	77.4a	2.32a	2.48a
Lupine	771a	75a	10.8a	80.1a	2.36a	2.42ab
Lucerne	760a	63a	7.3b	73.8a	2.44a	1.36d
Medic	782a	69a	8.8ab	79.7a	2.46a	2.30ab
Rye grass	784a	75a	8.8ab	80.9a	2.32a	2.00abc
Control	801a	72a	11a	79.8a	2.38a	2.21ab
LSD (P≤0.05)	67.4	10	2.4	10.6	0.14	0.56

*Means followed by the same letter are not significantly different at the 0.05 probability level

Wheat

No significant differences compared to the control were observed for wheat (Table 4).

Table 4 Effects of retained plant residues in the 2006 and 2007 growing seasons on wheat v. SST 027 plant height, plant number, tillers, seed hectolitre mass, percentage seed protein and yield

Plant residues	Wheat plant height in mm at 16 wks	Wheat plant number per m^2 at harvest	Wheat tillers	Wheat seed hectolitre mass	Wheat seed % protein	Wheat yield (t ha^{-1})
Barley	987ab*	72ab	5a	68.4a	11.7a	2.64ab
Canola	976abc	70ab	5a	68.8a	12.0a	2.40b
Wheat	961bc	77ab	5a	69.7a	11.8a	3.02ab
Lupine	977abc	79a	5a	70.2a	12.2a	3.32a
Lucerne	938c	66b	4a	68.8a	12.4a	2.27b
Medic	1007a	73ab	5a	69.3a	12.4a	2.89ab
Rye grass	956bc	70ab	5a	68.7a	11.5a	2.53ab
Control	973abc	71ab	5a	70.0a	12.2a	2.77ab
LSD (P≤0.05)	44	12	1	1.9	1.1	0.42

*Means followed by the same letter are not significantly different at the 0.05 probability level

Lupine v. Tanjil

Barley crop residues increased lupine (v. Tanjil) pod number per plant significantly above that attained with the control treatment (Table 5).

Table 5 Effects of plant residues in the 2006 and 2007 growing seasons on lupine v. Tanjil plant height, plant number, pod number per plant and yield

Plant residues	Lupine v. Tanjil plant height at 16 wks (mm)	Lupine v. Tanjil plant number per m^2 at harvest	Lupine v. Tanjil pod number per plant	Lupine v. Tanjil yield (t ha^{-1})
Barley	582a*	57a	7a	0.65ab
Canola	528a	46ab	6ab	0.71ab
Wheat	561a	45b	6ab	0.69ab
Lupine	509a	49ab	3cd	0.50bc
Lucerne	507a	48ab	2d	0.41c
Medic	514a	49ab	4cd	0.57bc
Rye grass	522a	44b	6ab	0.86a
Control	534a	52a	5bc	0.73ab
LSD (P≤0.05)	78	6	2	0.24

*Means followed by the same letter are not significantly different at the 0.05 probability level

Lupine v. Quilinock

Lucerne residue inhibited lupine (v. Quilinock) pod number significantly more than that attained with the control treatment (Table 6). Lupine crop residues, similar to canola, reduced lupine (v. Quilinock) pod number per plant, significantly more than with the control treatment. Lucerne crop residues, similar to canola and medic, also reduced lupine (v. Quilinock) yield significantly more than the control treatment.

Table 6 Effects of plant residues in the 2006 and 2007 growing seasons on lupine v. Quilinock plant height, plant number, pod number per plant and yield

Plant residues	Lupine v. Quilinock plant height at 16 wks (mm)	Lupine v. Quilinock plant number per m^2 at harvest	Lupine v. Quilinock pod number per plant	Lupine v. Quilinock yield (t ha^{-1})
Barley	596a*	52a	6a	0.65ab
Canola	544a	47a	4cd	0.71ab
Wheat	561a	48a	5ab	0.69ab
Lupine	532a	50a	3d	0.50bc
Lucerne	527a	48a	2e	0.41c
Medic	524a	46a	4bc	0.57bc
Rye grass	516a	46a	6a	0.86a
Control	538a	55a	5ab	0.73ab
LSD (P≤0.05)	85	10	1	0.24

*Means followed by the same letter are not significantly different at the 0.05 probability level

Rye grass

Medic, lucerne and canola crop residues inhibited rye grass significantly more than the control with regard to plant height at 16 weeks (Table 7).

Table 7 Effects of retained plant residues in the 2006 and 2007 growing seasons on rye grass v. Energa plant height, plant number, tillers and yield

Plant residues	Rye grass plant height at 16 wks (mm)	Rye grass plant number per m^2 at harvest	Rye grass tillers	Rye grass yield (t ha^{-1})
Barley	796abc*	80a	4ab	2.94a
Canola	698cd	76a	2b	2.97a
Wheat	773bcd	80a	5a	3.15a
Lupine	778bcd	76a	3ab	2.94a
Lucerne	699cd	78a	3ab	3.00a
Medic	690d	77a	3ab	2.76a
Rye grass	878a	84a	3ab	3.18a
Control	810ab	81a	4ab	3.24a
LSD (P≤0.05)	98	8	2	0.51

*Means followed by the same letter are not significantly different at the 0.05 probability level

Rye grass weed type

At 16 weeks after planting, crop residues of canola and medic had reduced rye grass weed type plant height significantly from that attained with the control treatment (Table 8). Medic and barley had reduced rye grass weed type plant number per m^2. This significant growth-inhibiting effect from barley crop residues on rye grass weed type was also evident in yield.

Table 8 Effects of retained plant residues in the 2006 and 2007 growing seasons on rye grass weed type plant height, plant number, tillers and yield

Plant residues	Rye grass weed type plant height at 16 wks (mm)	Rye grass weed type plant number per m^2 at harvest	Rye grass weed type tillers	Rye grass weed type yield (t ha^{-1})
Barley	646b*	74b	5a	2.61c

Canola	519c	84a	5a	3.09a
Wheat	645b	79ab	4a	2.79abc
Lupine	613bc	83a	4a	3.00abc
Lucerne	687ab	81ab	3a	2.91abc
Medic	546c	75b	5a	2.70bc
Rye grass	769a	80ab	3a	2.76abc
Control	693ab	84a	4a	3.03ab
LSD (P≤0.05)	96	7	2	0.39

*Means followed by the same letter are not significantly different at the 0.05 probability level

Relative Weed Density

A total of 39 weed species emerged across the trial area (Table 9). Control plots were dominated by broadleaf weeds (88.5 %) while grass weeds accounted for 11.5 % of weed seedlings. The number of weeds did not stay constant, but changed throughout the growing season as later emerging weeds appeared. The highest incidence of grass weeds occurred in barley and wheat plots at 25.7 % and 22.9 %, respectively. In contrast, plots planted to both lupines v. Tanjil and v. Quilinock, showed a reduction in grass weeds to 8.1 % and 10.1 %, respectively. The highest incidence of broadleaf weeds occurred in rye grass and rye grass weed type plots at 97.2 % and 95.9 %, respectively.

Table 9 Average relative weed density (%) at Tygerhoek for the 2006 and 2007 growing seasons, with totals for broadleaf and grass weeds indicated in the same row

	Barley v. Clipper	Wheat v. SST 027	Lupine v. Tanjil	Lupine v. Quilinock	Rye grass v. Energa	Rye grass weed type	Control
Broadleaf weeds - total %	74.3	77.3	92.2	90.2	97.2	95.9	88.5
Arctotheca calendula	1.4	0.3	0	0	0.6	0	0.4
Anagallis arvensis	3.2	3.4	0	0	0.7	0.7	0.5

Bidens pilosa	0	0.9	0.5	0.7	3	2.1	0.5
Capsella bursa-pastoris	3.2	2.1	1.1	0.5	0.3	0	0
Chenopodium album	0	0.1	0	0	0	0	5
Chenopodium carinatum	0	0.4	0	0	0	0	0.4
Chenopodium multifidium	0	0	0	0	0	0	0.3
Conyza albida	0	1.1	0.2	0.1	0.6	0.6	2.6
Coronopus didymus	0	0	0.4	0.5	0.7	0.6	0
Corrigiola litoralis	0	0	0	0.2	0	0	0
Cotula australis	2.1	1.8	0.4	0.5	5.7	2.3	2.3
Crassula thunbergiana	5.6	4.5	0.9	0.9	7.9	7.3	2.3
Daucus carota	1.3	1.9	1.1	0.8	0.4	0	0
Echium plantagineum	0	0.6	0	0	0	0	2
Emex australis	2	2.1	0	0	0.6	3.7	1.1
Erodium moschatum	3.1	3.5	0	1	1.7	2.8	8.6
Fumaria muralis	8.3	6	1.3	2.2	4	4.6	10.7
Gnaphalium subfalcatum	0	0	0.4	0.1	1.8	0	0.1
Lactuca serriola	0	1.1	1.1	1.3	0	0	0.7
Lepidium africanum	1.5	2.8	1	1.1	0.2	0.7	3
Linaria spuria	0	0.5	0.3	0.3	0.7	0	0.2
Lobelia erinus	0	0.9	0	0	0	0.5	0
Oenothera parodiana	3.4	1.6	0	0	2	2.7	0.2
Oxalis spp	1	1.8	0.4	1	2.7	2.1	4
Pichris echioides	0	0	1.2	0.9	0	0	0
Plantago lanceolata	0	1.4	37.6	27.5	0	0	7.6
Polycarpon tetraphyllum	8.6	6.4	19.5	18.3	5	11.2	7.2
Polygonum aviculare	0.4	5.6	17.3	23.4	24.1	18.5	14.2
Raphanus raphanistrum	4.9	3.8	0.9	1.5	1.9	0	0.6
Senecio pterophorus	0	0	0	0	0	0	0
Sonchus asper	1.2	2	5.3	4.2	1.1	0.5	2.1
Spergula arvensis	1.8	2	0	0	0	0	0.1
Stellaria media	21.3	18.7	1.3	3.2	31.5	35	11.8
Grass weeds – total %	25.7	22.9	8.1	10.1	3.2	4.1	11.5
Bromus diandrus	1.2	0.4	0	0	2.2	2.4	0.2
Digitaria sanguinalis	0	0.2	0	0	0	0.7	0.1
Isolepis antarctica	3.9	3.2	1.4	1.8	0	0	1
Juncus bufonius	1.2	1.1	0	0	0	0	0
Lolium multiflorum x perenne	7.8	8.7	3.9	4.5	0	0	8.2
Poa annua	11.6	9.3	2.8	3.8	1	1	2

Stellaria media had the highest relative density index and was the most prevalent emerging weed and hence, was the most important weed in terms of frequency in barley, wheat, rye grass, and rye grass weed type plots (Table 9). *Plantago lanceolata* had the highest relative density index and was the most important weed in terms of frequency in plots planted to both lupine varieties namely; v. Tanjil and v. Quilinock**.**

DISCUSSION

In Exp 1, the significant reduction in wheat hectolitre mass caused by barley residues and the significant reduction in wheat yield in the presence of residues of both barley and rye grass were probably due to allelopathic effects which are dependent on climatic and edaphic factors in the field and which should be replicated under controlled conditions for confirmation. Similarly, barley also reduced the yield of the rye grass in both Exp 1 and 2. Furthermore, plant height of this weed was reduced by canola and medic residues. In contrast, residues from the leguminous crops (lupine and medic) increased wheat growth with regard to plant number per m^2, yield, and plant height. Although allelopathic effects can be stimulatory (Belz, 2004) it must be considered that the N fixing ability of the leguminous crops could have had a subsequent beneficial effect on wheat.

The inhibitory effects of lucerne crop residues on the number of barley tillers and yield, and on plant height and yield of wheat is in accordance with those effects reported by Xuan and Tsuzuki (2002) and Xuan *et al.* (2005). Kruidhof (2008) also reported strong inhibitory effects by lucerne on seedling establishment. It was also reported by Kruidhof (2008) that lucerne plants contain water-soluble allelochemicals that are released into the soil environment from fresh leaf, stem, and crown tissues, as well as from dry hay, old roots and seeds.

A study in which sampling of lucerne plants as a mulch was spread over a long period showed that the immature lucerne residues contained more allelochemicals than older residues (Guenzi *et al.,* 1964). In the present study, effects of lucerne were probably more pronounced compared with other treatments of crop residues because although lucerne was dormant in the following winter growing season when Exp 2 was conducted, green plant material was still present as this perennial crop could not be controlled effectively in the field.

However, the results for barley from Exp 1 and 2 with regard to lucerne residues are contrasting as it increased barley tillers in Exp 1 while inhibiting it in Exp 2, but Xuan and Tsuzuki (2002) and Bertholdsson (2004) reported that between and within crop species there is large genetic variation in the allelochemical content of plant tissue. Also, various studies have shown that concentrations of allelochemicals in plants are not stable. The level of allelochemicals in a plant are influenced by abiotic and biotic stresses in combination with age or growth stage (Mwaja *et al.,* 1995; Reberg Horton *et al.,* 2005).

Kruidhof (2008) described a transition from inhibitory to stimulatory effects of crop residues over time. Low concentrations of allelochemicals can stimulate plant growth (Lovett *et al.,* 1989; Belz, 2004; Belz, 2007) and increased growth has also been associated with increased nitrate levels in residue-amended soil (Henson, 1970). Therefore, the increased growth observed in the present study may indicate that there was a positive nutrient effect in conjunction with growth-promoting allelopathic activity from the crop residues. This is congruent with most findings in allelopathy research that decomposing plant residues in soil exhibit the greatest inhibition at the early stages of decomposition and that phytotoxicity declines as decomposition proceeds (An *et al.,* 2001; Xuan *et al.,* 2005). The nature and strength of inhibitory allelopathic effects appear to be dependent on interactions between soil factors and crop residues and the allelochemicals they produce (Kumar *et al.,* 2009).

With respect to weeds, cover crop residues have been reported to negatively affect germination and establishment of weed seeds (Weston, 1996). Especially leguminous cover crops that contain high levels of allelochemicals seem well-suited for residue-mediated weed suppression. In combination with this, the physical effects (light interception) of the residue may also contribute to reduced weed emergence, as is conceivably the case in the field where an average of 5 t ha^{-1} crop residues from barley and wheat can be deposited on the soil surface. The possible positive effects of this organic mulch on soil moisture conservation must also be taken into consideration. In contrast, suppression of growth of Powell Amaranth (*Amaranthus powellii*) appears to be associated primarily with lower N availability in soils grown to certain crops (Kumar *et al.,* 2009). However, the impact of crop residues on weed management was not so much an absence of weeds, but rather delayed emergence and growth retardation, which could have been due to physical properties of the mulch, such as the prevention of light penetration, temperature changes and/or the physical obstruction of weed seedlings. Results from Exp 1 for medic on the suppression of rye grass weed type promise practical application under field conditions because of the crop’s spreading growth habit which could be effective for the establishment of effective organic mulches. According to results in Experiments 1 & 2, a mulch of this nature may suppress weeds without affecting wheat yield.

On plots planted to lupine (v. Quilinock) there was a reduction in total grass weeds to 8.1% and 10.1%, respectively (Table 8) when compared to control plots. As cycloxydim was applied across all lupine plots, including control plots, it should be taken into consideration that it is a more effective herbicide for grass control in lupine than iodosulfuron is in wheat. In the case of rye grass weed type, however, both lupine cultivars suppressed the weed to only 3.9% and 4.5%, respectively. Furthermore, a suppressive plant competition effect from broadleaf weeds on the grass weeds cannot be excluded. An early flush of emergence from a huge seed bank plus high growth rates probably benefited the dominance of broadleaved weeds. Lupine contain quinolizidine alkaloids that act as herbivore deterrents (Vilarino *et al.,* 2005), but these compounds have also been suggested to influence plant-plant interactions (Wink, 1983). In ascribing allelochemical-mediated effects under field conditions one has to be mindful of the fact that persistence of allelochemicals is largely influenced by soil type and weather conditions (Levitt *et al.,* 1984). Therefore any hypothesis based on crop residues imparting positive weed suppressive effects through the release of allelochemicals into the environment should be mindful of the fact that the practice is likely to be exposed to the vagaries of climatic (Bruce *et al.,* 2005) and edaphic factors, as well as likely being crop and weed-specific. Therefore, this field investigation warrants further investigation that ought to also involve work done under controlled conditions.

CONCLUSION

The optimal residue management strategy for weed suppression depends both on the nature (fine residues like those from medic are more effective as opposed to coarse residues of lupine) and amount (less residues leads to less weed control) of crop species' residues as well as on the target weed species. N-fixing leguminous crops such as medic and lupine had a stimulatory effect on wheat growth and yield and medic suppressed the important rye grass weed type. Lupine gave suppression of grass weeds, giving the mulches of both leguminous crops an added benefit and their inclusion and growing in crop rotation systems with wheat and barley as main crops, more importance. However, regarding weed suppression due to allelopathic effects from crop residues, the variability in effects ascribed to variable soil and climatic factors might argue against the practice being accepted as an effective stand-alone weed control option in the foreseeable future. Partial acceptance will likely be a compromise of combining the continued limited use of herbicides with leguminous crop residues for weed control.