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Competition and Control of Weeds in Kale Leaf Crop

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ABSTRACT

Weed population responsed to weed control practices was carried out to evaluate weed seed bank, weed populations, and the effects of the herbicides applied preemergence of cultivation on kale leaf control. The first experiment involved an evaluation of the site including soil type and previous types of management. The seed bank was then evaluated to estimate both the composition and populations of weeds present, which could, then, be compared to the weeds growing. There was a positive correlation between the weed seed bank and above ground weed communities. The second experiment involved testing the effects of the herbicides at their recommended rates on weed control and the phytotoxicity on a kale leaf. The crop was most significantly affected by atrazine followed by oxyfluorfen and then alachlor. Three main weed species dominated the weed growth in this experiment were smooth mimosa (*Mimosa invisa*), slender amaranth (*Amaranthus viridis*) and purple nutsedge (*Cyperus rotundus*). The third experiment involved a bioassay testing, again of phytotoxicity of the three herbicides on nine separate crops; sweet corn, soybean, mungbean, swamp morning glory, cucumber, tomato, pepper, cabbage and coriander. Cabbage and coriander were not affected by any herbicides.

Key words: kale leaf (*Brassica oleracea* L.), alachlor, atrazine, oxyfluorfen, weed seed bank, weed control, weed population

INTRODUCTION

Species composition and population of weed communities varied greatly and are closely linked to control practices and cropping history. Composition is influenced by farming practices and varies from field to field and among areas within field (Buhler, 1999). The largest source of seeds which comprises the seed bank comes from plants that escape control and produce seeds within the field. Determining the type and quantity of seeds in the soil is important to forecast weed population dynamics (Buhler *et al*., 1997). Within the seed bank there is a wide range of weed species present. However, in most cases a few dominant weed species will produce most of the seeds. Weed species become dominant when they are relatively resistant to weed control and well adapted to the conditions within the crop. Controlling these species should be the primary focus of weed control.

Kale leaf (*Brassica oleracea* L.) has been established throughout Asian countries as a significant crop in the past two centuries, being

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brought in from Europe. Kale leaf can be transplanted, but most of the production is direct-seeded into heavy, friable loam soils, with preferable pH of 6.5 to 6.8, as they produce the highest yields (Hodges, 1995). Commercially, the crop is produced for a one-time harvest around 40-55 days after planting with sequential plantings at 2-week intervals, to provide continuous supply for the market (Hall, 1995). In kale leaf crops in Thailand, much of the weed control still revolves around hand weeding. However, as this is becoming a less economically viable option more herbicides are being used. Three more commonly used herbicides are alachlor, atrazine and oxyfluorfen.

Alachlor can be applied mainly as a selective preemergence (PRE) herbicide to control a wide range of annual grasses, broadleaf weeds, and yellow nutsedge in corn and soybean (Thomson, 1993). The site of action is not known however a currently viable hypothesis involves the conjugation of acetyl coenzyme A and other sulfhydryl-containing biomolecules (Ahrens, 1994). The length of weed control varies from 6 to 10 weeks depending on soil types and weather conditions, with weeds affected before emergence, but seed germination is not inhibited.

Atrazine interferes with photosynthesis in many annual broadleaf weeds and grasses, while corn, sorghum, sugarcane, and a few other crops are tolerant of the chemical's effects at the recommended concentrations (Thomson, 1993). Atrazine kills plants by binding to the Q_B-binding niche on the D1 protein of the photosystem II complex in chloroplast thylakoid membranes, thus blocking electron transport from Q_A to Q_B. This stops production of ATP and NADPH (all needed for plant growth) (Ahrens, 1994). Death occurs when the plant is starved because photosynthesis is stopped from bleaching of the plant's chlorophyll, or from the release of the radicals, highly reactive molecules. After application, atrazine continues to control sprouting weeds for 5-6 weeks, allowing the desired crop to become well established without weed competition for moisture, nutrients and sunlight.

Oxyfluorfen is registered for preemergence (PRE) or early postemergence (POST) application in broccoli crops to control grass and broadleaf weeds (Thomson, 1993). The target site for oxyfluorfen appears to be protoporphyrinogen oxidase (Protox), an enzyme of chlorophyll and heme biosynthesis catalyzing the oxidation of protoporphyrinogen IX to protoporphyrin IX, resulting in loss of chlorophyll and carotenoids and leaky membranes, causing the cells to dry out (Ahrens, 1994).

Registered or unregistered herbicides occasionally damage crops, delay and decrease growth, and reduce harvest yield and quality. There has been much qualitative and quantitative information published on herbicide damage to crops (Boethel *et al*., 1999; Donal, 1998). The objective of this research was to evaluate the weed seed bank and control of weeds in kale leaf crop. These analyses included descriptions of herbicide damage symptoms, visually rate crop damage and changes in plant height and biomass. If potential yield losses could be estimated early in the growing season, this information might help farmers improve crop management decisions.

MATERIALS AND METHODS

Evaluation of existing seed bank

The site, at the Field Laboratory of the Department of Horticulture, Kasetsart University, Kamphaeng Sean Campus, used for growing the kale leaf had previously only been used for pasture and no herbicides had been used. Weed control methods used in the past were hand weeding and conventional tillage practices. A soil analysis was conducted in the plot area with four random samples taken, showing the soil to be a clay loam, pH 6.85; E.C. of 4.66 mS/cm; and an organic matter content of 2.9%. The plot had a net covering creating a greenhouse environment and more significantly protecting the plant from insect damage.

Temperatures were above 30°C in the greenhouse during the days and fell to around 25°C at night. Relative humidity was always above 85%.

To gain an accurate indication of the weed seed bank in the area, random soil samples were taken in a 50 m by 50 m site directly adjacent to the plot. In this site, 10 random 5 m by 5 m squares were allocated, within these squares, 5 soil samples were taken down to a depth of 15 cm. These samples were mixed together into 1 sample, and from this 1 sample, three equal amounts of soil were taken. This created three replicates at each of the ten squares. To gain an accurate indication of the seed bank within the plot area of 10 m by 20 m, the area was divided into four parts, with one random sample taken from the each part. These four samples were mixed to create 1 sample and from this 1 sample, three replicates were taken. Each soil replicate from the plot and adjacent area was placed in trays and placed in a greenhouse, which provided protection and the weeds were therefore under the same conditions as those in experiment 2. The trays were 0.125 m^2 by 5 cm deep. The replicates were watered regularly and this allowed the seeds within the soil to germinate and grow. From the plants that grew in the trays, the weed species composition and population were analysed. The trays were analysed three times, with the final survey 6 weeks after the initial soil collection. A weed survey was completed in places where soil samples were taken from, only the species composition was taken, not density.

Response of kale leaf and weeds to herbicides

The kale leaf cultivar Bang Buatong, was direct-seeded into the plot at a rate of 1 g/m^2. Plot preparation involved hand cultivation just prior to sowing. The plot was laid out into 15 separate subplots with 5 different treatments, three replications of each treatment. Within the layout each treatment was randomly allocated within a replication row, creating three replications containing each of the five treatments (randomised block design). The different treatments were a weedy control, hand weeding treatment and three different herbicides: alachlor at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Each herbicide, a commercial formulation, was sprayed onto the subplots directly after sowing by a knapsack spray volume of 500 L/ha. These herbicide application rates were as recommended by the manufacturer. The hand weeding treatment involved weeding 7 and 14 days after sowing (DAS). The plots were watered twice daily, partly due to the dry conditions and the extremely hot and humid conditions in the greenhouse. At intervals of 14 and 21 DAS weed species population and composition was analysed on each subplot. A 50 cm square was placed randomly in each subplot and the numbers of weeds per square metre. 28 DAS a visual rating for weed control was given for all treatments, 0 = no weed control and 10 = complete weed control. Crop phytotoxicity to each treatment was treated 14 and 21 DAS, this involved weighing and the height of a sample of five plants. Only the shoots of the plants were measured for weight with the roots cut off.

Phytotoxicity of herbicides on crops

Nine representative crops were grown in soil from the three herbicide treatments to test phytotoxicity. The crops used were sweet corn (var. ATS-2), soybean (var. SJ 4), mungbean (var. KPS 1), swamp morning glory (var. Tupai 7), cucumber (var. Plong), tomato (var. Sridatip 3), pepper (var. Bangchang), cabbage (var. Speed 047), and coriander (var. Carlbe). These crops were direct-seeded into soil treated with herbicides (alachlor, atrazine and oxyfluorfen) and a control which was a combination of the hand weeding and weedy control (untreated) treatments. Treatments were replicated three times. The soil was taken from the relevant subplots down to a depth of around 2.5 cm within the plot and placed into 200 ml polyethylene pots in a shaded area. Each replicate of the experiment contained 25 seeds of the crop, which was to be sown in that row. This experiment was repeated 0, 7, 14 and 21 DAS to give an estimate of how long the different herbicides would affect crop plants. To analyse the effect on the crop plants, the number of plants germinated was counted along with the height of five plants within each replicate to give a sample. A scoring system was used to assess crop injury caused by the herbicides. Crop injury was on a scale of 0 to 100; where 0 = no injury, 30 = moderate cotyledon necrosis and chlorosis and growth reduction, 70 = severe cotyledon injury and growth reduction, and 100 = all seedlings dead. The crop plants were analysed 10 DAS to allow a reasonable level of growth.

RESULTS

Evaluation of existing seed bank

Above ground, surveys were taken both in the field and within the plot. When comparing the above ground survey with the seed bank for the field sampled, four extra species were found in the seed bank, two broadleaf weeds and two grasses. The aboveground survey and seed bank composition of the plot were very similar.

In comparing the species composition of the field seed bank and the seed bank within the plot, more different species growing from seeds were collected from the field. Twelve extra broadleaf species and four extra grasses were present in the field seed bank compared with the plot seed bank.

When comparing the different populations of the weeds within the seed bank of the greenhouse and the field some differences became apparent (Table 1). In the greenhouse and field, the dominant weed population tended to differ. In the field seed bank, the broadleaf species *Portulaca oleracea* L., and *Eclipta alba* L. were dominant, whilst in the greenhouse *Amaranthus viridis* L., and *Euphorbia thymifolia* L. were at the hightest levels amongst the broadleaf weeds. Of the grasses, *Echinochloa crus-galli* L. was the dominant weed in the field, whilst in the greenhouse *Dactyloctenium aegyptium* was the major grass weed. The one sedge species *Cyperus rotundus* L. was present at much higher levels in the field seed bank. It was reasonable to suggest that there was a positive correlation between the weed seed bank and aboveground weed communities.

Response of kale leaf and weeds to herbicides

The results showed that the three herbicides caused a significant fall in kale leaf weight and plant height in accordance to the weedy control. Similar trends were observed (Figure 1), so the plant height data were omitted. The hand weeding and weedy control treatment had similar plant height and weight averages. Atrazine had the most detrimental effect on plant height and weight. Alachlor and oxyfluorfen affected the weight and height of the kale leaf plants at similar amounts but significantly less than the atrazine treatment.

In the plot the weeds were mainly broadleaf species and one sedge species with only relatively small numbers of grasses. Three species, two broadleaf species and one sedge, dominated the weed counts and were in even higher numbers in the control. The species were amaranth, mimosa and sedge, with amaranth clearly the highest in number in the weedy control (Figure 2). Many other species were found in the control but only in very small numbers from the herbicide treatments. The three main species were found in highest numbers in the control as expected. The alachlor and oxyfluorfen treatment had similar levels of control for mimosa and sedge. The oxyfluorfen treatment had a much greater control for amaranth compared with in the alachlor treatment. The atrazine treatment had a much greater control on sedge and mimosa compared with the other treatments and had a similar levels of control on amaranth when compared with the oxyfluorfen treatment.

Phytotoxicity of herbicides on crops

Four sets of results for germination and plant height were taken where the crops were sown 0, 7, 14, and 21 DAS. The results 14 and 21 DAS were not used in the analysis as there were no

Table 1 Above ground weed species identified in the field and weed seed bank in the greenhouse.

Weed species	Density (per m^2)		Weed species	Density (per m^2)	
	Above ground	Seed bank		Above ground	Seed bank
Broadleaf weeds :			**Grass weeds :**		
1. *Abutilon hirtum* Sweeet.	0.3	-	21. *Brachiarai mutica* Forssk. Stapf.	5.3	2.1
2. *Aeschynomene americaca* L.	0.3	-	22. *Brachiarai reptans* L. Grad. Et Hubb.	0.3	-
3. *Ageraturm conyzoides* L.	0.3	-	23. *Cynodon dactylon* L. Pers.	0.5	-
4. *Amaranthus spinosus* L.	0.5	-	24. *Dactyloctenium aegyptium* L. P.B.	2.9	12.0
5. *Amaranthus viridis* L.	1.9	40.0	25. *Digitaria ciliaris* Retz. Koel.	0.5	-
6. *Boerhavia diffusa* L.	0.8	2.7	26. *Echinochloa colona* L. Link.	13.0	2.1
7. *Cleome viscosa* L.	2.7	2.7	27. *Echinochloa crus-galli* L. Beauv.	43.0	1.9
8. *Corchorus aestuans* L.	0.8	-	28. *Eleusine indica* L. Gaertn.	5.9	-
9. *Eclipta aiba* L. Hassk.	42.0	2.7	29. *Ischaemum rugosum* Salisb.	1.1	1.3
10. *Euphorbia thymifolia* L.	7.2	21.0	30. *Leptochloa chinensis* L. Nees.	0.5	1.3
11. *Heliotropium indicum* L.	0.3	-	31. *Panicum repens* L.	2.9	1.9
12. *Ipomoea aquatica* Forssk.	0.3	-			
13. *Ipomoea pestigridis* L.	1.0	-	**Sedge :**		
14. *Macroptilium lathyroides* L. Urb.	0.3	-	32. *Cyperus rotundus* L.	15.0	1.3
15. *Mimosa invisa* Mart.	1.1	-			
16. *Mimosa invisa* Var. inermis Adelb.	0.5	8.0			
17. *Phyllathus ninuri* Auct.	0.5	-			
18. *Portulaca oleracea* L.	19.0	2.7			
19. *Pysalis minima* L.	1.6	2.7			
20. *Trianthema porutlacastrum* L.	0.3	2.7			

significant herbicide effects this long after application. To establish if there were any significant effects by herbicide, a one-way ANOVA was completed.

0 DAS the germination percentages of cucumber and tomato were significantly lowered by atrazine. Alachlor and oxyfluorfen did not significantly lower the germination percentages of the nine crops 0 DAS (Figure 3). 7 DAS sweet corn germination percentage was significantly lowered by alachlor and oxyfluorfen (Figure 4). Soybean germination was significantly lowered by atrazine, whilst pepper germination was significantly lowered by both atrazine and oxyfluorfen. When compared with the germination, 0 DAS the cucumber and tomato affected by atrazine were not significantly affected 7 DAS. Not until 7 DAS did all three herbicides began to affect the germination of the crops. Atrazine had the greatest effect on germination percentage followed by oxyfluorfen and then alachlor.

From the results, it could be seen that all herbicides had a more significant effect on plant height than germination. 0 DAS, cucumber was significantly affected by all three herbicides; soybean, mungbean and cucumber significantly affected by the atrazine; and sweet corn, mungbean, and cucumber by oxyfluorfen (Figure 5). 7 DAS the height of mungbean and swamp morning glory were significantly affected by all three herbicides, and the plant height of cucumber was significantly affected by atrazine (Figure 6). The plant height of 5 out of the nine crops were affected by herbicides: sweet corn, soybean, mungbean, swamp morning glory and cucumber. Of the three herbicides, atrazine lowered the mean heights of the plants to the greatest extent, followed by oxyfluorfen and then alachlor.

DISCUSSION

Determining the type and quantity of weed seed bank is important in forecasting weed population dynamics (James and Rahman, 1999). The result showing more different species present in the field seed bank than in the greenhouse were expected as the soil samples from the field covering a much greater area. As only 2 to 6% of weed seeds produced ever develop into seedling (Ball and Miller, 1989), some variation in field surveys and

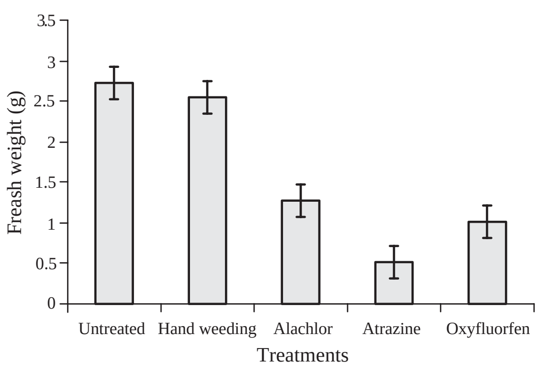

Figure 1 Growth response of kale leaf to different weed control treatments. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

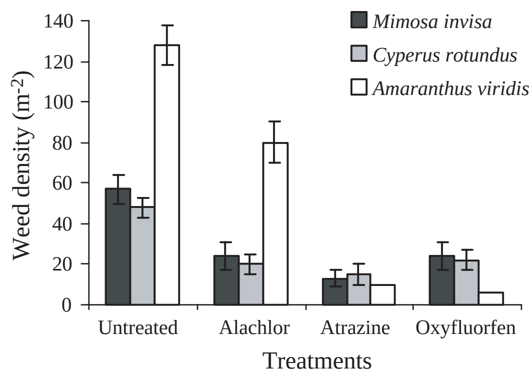

Figure 2 Density of three main weed species in separate treatments. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

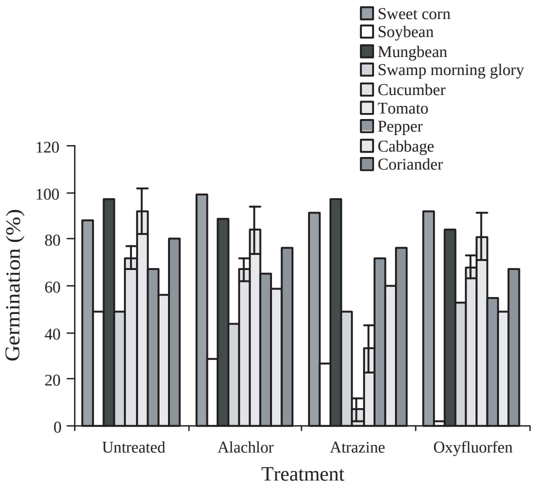

Figure 3 Germination percentages of the nine crops sown on day of herbicide application. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

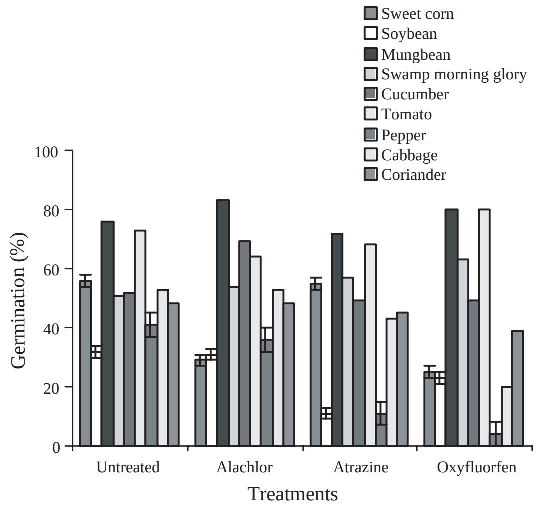

Figure 4 Germination percentages of the nine crops sown at 7 days after sowing. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

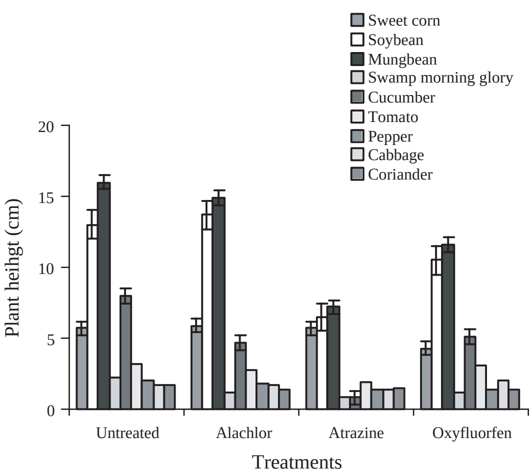

Figure 5 Plant height (cm) of the nine crops sown on day of herbicide application. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

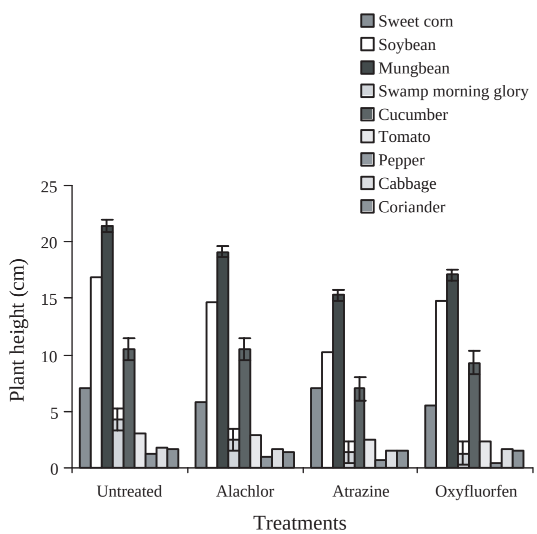

Figure 6 Plant height (cm) of the nine crops sown at 7 days after sowing. Alachlor was applied at 3.75 kg ai/ha, atrazine at 3.13 kg ai/ha, and oxyfluorfen at 1.56 kg ai/ha. Vertical bars indicate the standard error of the mean.

seed bank composition would be expected. All of the weed species present in the plot seed bank were found in the field seed bank showing that the plot gave a good indication of the weeds present in the area. As expected, more weed species were present in the field seed bank as this survey covered a much larger area and this area underwent differing management practices. Certain broadleaf and grass species dominated the weed population both in the field and the plot seed bank. Although seed banks and the resulting weed populations are composed of many species, a few dominant species generally comprise 70 to 90% of the total seed bank. In general, short-lived plants such as annual broadleaf and grass species have long-lived seeds and substantial seed banks. Seed can remain dormant in the soil for many years (e.g., several years to decades, or longer, depending on the plant species and environmental conditions), with only a fraction of the seeds germinating each year.

When comparing the weed populations of the plot seed bank and the field real patterns emerged. Some broadleaf species were at higher levels in the field and others in the greenhouse, the same was found with the grasses. The one sedge species was found in much higher levels in the field. This might be due to spraying in the field which controlled other species but not sedge. Spraying has a very limited control on sedge species (Patterson, 1998). The differing compositions of the greenhouse and the field could also be due to control methods such as spraying used in the field, whilst no spraying took place greenhouse.

The hand weeding treatment and weedy control had similar height and weight measurements for the kale leaf plants. It would be expected that kale leaf in the hand weeding treatment would be heavier and taller as they only had to compete with low levels of weeds. In the weedy control, there were higher levels of weeds but competition was not a problem as there was high levels of water and nutrients accounting for the similarities in the treatments. Atrazine had the most severe effect on growth of the plants. As these measurements were taken 28 DAS and the herbicides were sprayed PRE, these herbicide effects would be found right through to harvest. This effect of atrazine would suggest that it was not suitable to use in the kale leaf. Although the alachlor and oxyfluorfen do affect the kale leaf growth, these may be less phytotoxic at lower concentrations. In another experiment on oxyfluorfen effect on *Brassica oleracea* L., it was found that injury ranged from cotyledon crinkling and slight growth reduction at the lower rates to severe growth reduction, cotyledon necrosis, and seedling death at the higher rates (Harrison and Farnham, 1998). This suggests that alachlor may be the most suitable to use in kale leaf purely on the basis that it is the least phytotoxic to the crop.

The weed species composition found in the weedy control treatment of experiment 2 was comparable to the species found in the seed bank analysis, with more species found in the seed bank analysis. Of the weeds growing in the plot, the three dominated species were mimosa (*Mimosa invisa* Var. inermis Adelb.), sedge (*Cyperus rotundus* L.) and amaranth (*Amaranthus viridis* L.). It would not be expected that these three species were in high numbers because of resistance to the herbicides as the greenhouse had not been sprayed previously. Of these three species, amaranth was the only species which was at high level within the seed bank, suggesting that the other two species were highly competitive in this environment. One other broadleaf, *Euphorbia thymifolia* L., and one grass species *Dactyloctenium aegyptium* were present at high levels in the seed bank analysis but not in the weedy control in the plot showing the variability in weed growth from the seed bank.

Of the nine crop analysis, neither germination percentage nor plant height of cabbage and coriander were affected by any of the three herbicides. This meant that the three herbicides could be used in these crops, with atrazine the ideal choice as it had the greatest weed control. Atrazine affected either the plant height or germination of all the remaining crops asides from sweet corn, rendering it unusable in these crops. In other studies, it has been found that the corn is tolerant to the chemicals effects at recommended applications. Corn, a crop on which atrazine is heavily used, is resistant to atrazine because it can detoxify the posion by means of an enzyme present in its leaves. In addition, corn roots contain a substance that helps break down atrazine molecules. It has also been found that sensitive crops such as soybean can be affected in the following growing season when atrazine has been sprayed the previous year.

Of the three herbicide, alachlor caused the least phytotoxic. The germination and plant height of tomato, pepper and soybean were not affected by alachlor, suggesting that this herbicide would be suitable to use in these crops. This herbicide will generally persist long enough in the soil to provide 6-10 weeks of weed control depending on soil type and weather conditions (Ahrens, 1994). It has moderate mobility in sandy soil and thus can migrate to groundwater. Oxyfluorfen did not affect the germination or plant height of soybean and tomato making it a suitable herbicide for these crops. This herbicide provides weed control for around two months. It is immobile on most soils, but slightly mobile on extremely sandy soils. Oxyfluorfen has a strong tendency to adsorb soil particles and is nearly insoluble in water. Once oxyfluorfen is adsorbed to soil particles, it is not readily removed. It is, therefore, unlikely to leach downward or to contaminate groundwater.

Although herbicide use has been shown to be successful, it should coincide with the presence of sufficient weeds to warrant use and take place when weeds are most vulnerable. Factors which must be considered when developing a herbicide program are the herbicide itself, weed flora and application time, crop tolerance and cost effectiveness. Furthermore, adjusting sowing dates of crops could avoid weed emergence peaks and thus minimise yield losses from weed competition (Clay *et al*., 1999; Del Monte *et al*., 1999). It is suggested that estimates of seed bank populations in arable soils could also be used to predict future weed infestations (Callihan and Dobbins, 1996). Such information would have value in planning crop sequences and herbicide usage.

Crop production systems are dependent on management options which successfully reduce the effect that weeds have on crops. Herbicides reduce weed density and indirectly reduce weed seeds that are produced and enter the seed bank. Although herbicides are effective in controlling weeds, an increasing environmental awareness has created a desire to reduce the amount of herbicides applied to agricultural fields. Integrated weed management practices used in Thailand include good land preparation, suitable rates and timing of planting, well-times hand weeding, effective water management, chemical herbicides when necessary and more recently crop rotation.

CONCLUSION

In the seed bank analysis and above ground surveys the species compositions were very similar as expected. The seed bank analysis of the greenhouse differed from the field seed bank both in weed species composition and population. This was as expected since the field seed bank covered a much wider area and the conditions in the greenhouse, were much different to the field and favoured the broadleaf species which tended to dominate. Of the weed counts taken out within the greenhouse, three dominant species were two broadleaf, amaranth and mimosa and one sedge species. Atrazine provided the greatest control of these species followed by oxyfluorfen and alachlor. However, atrazine was the most detrimental of the three herbicides to the growth of the kale leaf followed by oxyfluorfen and alachlor. Among nine crops under study, atrazine had the most detrimental effect on germination and plant height followed by oxyfluorfen and alachlor. Cabbage and coriander were not affected by the herbicides.

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