EFFECT OF SPRAY VOLUME, WATER QUALITY, ADJUVANTS AND AMMONIUM SALTS ON SETHOXYDIM ACTIVITY

by

TOMÁS FERNANDO CHICONELA

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Department of Agronomy

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SUPERVISOR: Mr. G. M. CERONIO

CO-SUPERVISOR: Mr. B. L. DE VILLIERS

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	i
INDEX	ii
LIST OF TABLES	iv
LIST OF FIGURES	vi

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INDEX

Page

CHAPTER 1 INTRODUCTION 1

CHAPTER 2 LITERATURE REVIEW 5

2.1 Sethoxydim characterization 5
2.2 Mechanisms of overcoming sodium bicarbonate antagonism 8
2.2.1 Carrier volume 8
2.2.2 Adjuvants 10
2.2.3 Ammonium salts 11
2.2.4 pH 12

CHAPTER 3 MATERIALS AND METHODS 14

3.1 General procedure 14
3.1.1 Sethoxydim screening rates 15
3.1.2 Spray carrier 16
3.1.3 Carrier volume 17
3.1.4 pH 17
3.1.5 Addition of adjuvants and ammonium salts 17
3.1.6 Temperature, adjuvants and ammonium salts 18
3.2 Statistical analysis 19

CHAPTER 4 RESULTS AND DISCUSSION 20

4.1 Spray carrier 20
4.2 pH 24

4.3 Adjuvants and ammonium salts 28

4.4 Effect of temperature and adjuvants on sethoxydim activity 34

4.5 Carrier volume 41

CHAPTER 5 GENERAL DISCUSSION AND CONCLUSIONS 48

SUMMARY 51

REFERENCES 52

APPENDIX A 69

APPENDIX B 75

LIST OF TABLES

Page

TABLE 3.1: Oat fresh top mass reduction and percentage control as influenced by sethoxydim rates 16

TABLE 3.2: Chemical description of adjuvants and ammonium salts used 18

TABLE 4.1: Oat fresh top mass reduction from sethoxydim at 186.0 g $ai.ha^{-1}$ in 250 $\ell.ha^{-1}$ of spray water in the presence of sodium bicarbonate and potassium carbonate at different concentrations........ 21

TABLE 4.2: Oat fresh top mass reduction from sethoxydim at 186.0 g $ai.ha^{-1}$ as influenced by spray solution pH 25

TABLE 4.3: Oat fresh top mass reduction as affected by sethoxydim rates, spray carrier, spray adjuvants and ammonium salts 29

TABLE 4.4: Interaction of sethoxydim rates, spray carrier, spray adjuvants and ammonium salts on oats 33

TABLE 4.5: Effect of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g $ai.ha^{-1}$ in the presence of sodium bicarbonate at 0.03 M 35

TABLE 4.6: Interaction of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g $ai.ha^{-1}$ in the presence of sodium bicarbonate at 0.03 M 37

TABLE 4.7: Effect of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g $ai.ha^{-1}$ in the presence of sodium bicarbonate at 0.03 39

TABLE 4.8: Interaction of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g $ai.ha^{-1}$ in the presence of sodium bicarbonate at 0.03 M 40

TABLE 4.9: Effect of carrier volume and herbicide rate on sethoxydim activiy on oats in the presence of sodium bicarbonate and potassium carbonate at 0.03 M 42

TABLE 4.10: Interaction of carrier volume and herbicide rate on sethoxydim activity on oats in the presence of sodium bicarbonate and potassium carbonate at 0.03 M 43

LIST OF FIGURES

Page

FIGURE 4.1: The influence of sodium bicarbonate and potassium carbonate on sethoxydim activity at 186.0 g ai.ha^{-1} on oats 22

FIGURE 4.2: Relationship between sethoxydim activity, sodium bicarbonate and potassium carbonate concentrations in the spray water on oats 23

FIGURE 4.3: Effect of spray solution pH on sethoxydim activiy at 186.0 g ai.ha^{-1} on oats 26

FIGURE 4.4: Relationship between spray solution pH on sethoxydim activity at 186.0 g ai.ha^{-1} on oats 27

FIGURE 4.5: Effect of spray carrier, spray adjuvants and ammonium salts on sethoxydim activity at 139.5 g ai.ha^{-1} on oats 30

FIGURE 4.6: Effect of spray carrier, spray adjuvants and ammonium salts on sethoxydim activity at 186.0 g ai.ha^{-1} on oats 31

FIGURE 4.7: Effect of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M 36

FIGURE 4.8: Effect of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 186.0 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M 38

FIGURE 4.9: Effect of carrier volume, sodium bicarbonate and potassium carbonate at 0.03 M on sethoxydim activity at 139.5 g ai.ha^{-1} 44

FIGURE 4.10: Effect ofand carrier volume, sodium bicarbonate and potassium carbonate at 0.03 M sethoxydim activity at 186.0 g ai.ha^{-1} 45

FIGURE 4.11: Relationship between carrier volume and herbicide rates on sethoxydim activity on oats in the presence of sodium bicarbonate and potassium carbonate at 0.03 M 46

CHAPTER 1

INTRODUCTION

Many South African water sources are naturally high in dissolved salts (Fuggle & Rabie, 1992). Total dissolved salts (TDS) ranges from below 200 to 7000 mg.ℓ^{-1} (Anonymous, 1986). Ions such as calcium, sodium and bicarbonate are encountered at high levels in various water carriers utilized by farmers (de Villiers, 1994).

Progressive salination of water sources, along with water quality deterioration is a matter of growing concern in this country. This growing concern is of utmost importance in the southern african region in general, since many southern african rivers are international in character, either forming a boundary between states or, flowing through two or more states (Midgley, 1976; Anonymous, 1986).

Depending on the concentration and the composition of the total dissolved salts, salination of water resources holds a number of adverse consequences ranging from health threats and economic losses to environmental damage (Ballance & Olson, 1980; Gower, 1980; Storey, 1980; Van Rooyen & Herald, 1992). Economic losses attributed to salination of the water supply in Gauteng, per every one milligram per litre increase in TDS concentration, were already estimated to cost consumers R1,6 million per annum (Heynike, 1987). Fuggle & Rabie (1992) identified those consumers as farmers, since they are the largest users of fresh water in South Africa.

Water quality, particularly ions in agricultural water, appears to affect farming activities in different ways (Kolega & Wooding, 1979; Young & Horner, 1986; Pescod, 1992). Reduced activity of several herbicides has been attributed to the antagonistic effects of ions in water carriers (Sandberg, Meggit & Penner, 1978; Buhler & Burnside, 1983; de Villiers

& du Toit, 1993; Nalewaja & Matysiak, 1993). Sodium bicarbonate, a natural contaminant of water, has been reported to reduce the activity of several herbicides such as sethoxydim, 2,4-D amine, clethodim, and glyphosate (Nalewaja, Manthey, Szelezniak & Anyska, 1989; Nalewaja, Woznica & Matysiak, 1990; McMullan, 1994). Similar results have been found with calcium, potassium, and magnesium salts (Nalewaja & Matysiak, 1991; Nalewaja, Praczyk & Matysiak, 1995).

De Villiers (1994) tested the sensitivity of tralkoxydim to the antagonistic effect of ions in water carriers and found that tralkoxydim activity was antagonized by 20% with carriers collected at different locations in the Free State and Northen Cape. It was also found that sodium bicarbonate and potassium bicarbonate were the most antagonistic salts of tralkoxydim activity. Sodium bicarbonate at 0.03 M of the cation accounted for a reduction of 62% in tralkoxydim activity, and at a concentration as low as 0.001 M, for a 31% reduction in activity.

Nalewaja *et al.* (1989) showed that sethoxydim, when applied with water containing 650 $mg.\ell^{-1}$ sodium and 1650 $mg.\ell^{-1}$ bicarbonate, failed to control grasses. Sodium bicarbonate and sodium carbonate, when included in the sethoxydim spray, reduced the control of grass species in both glasshouse and field trials.

Linder (1972) as quoted by Shea & Tupy (1984) found that the antagonism by salts contained in carrier water for pesticides is due to physical and chemical interactions between the active ingredients or other formulation components and inorganic ions in solution. These interactions have resulted in reduced weed control caused by the formation of compounds which are not readly absorbed by plants (Wanamarta, Kells & Penner, 1989a; Thelen, Jackson & Penner, 1995; Nalewaja, de Villiers & Matysiak, 1996).

In South Africa, salt antagonism has been overcome by raising the herbicides rate (de Villiers, 1994; Anonymous, 1997a). Although this approach alleviates salt antagonism in spray water, it is undesirable because it increases herbicide costs, environmental concerns and phytotoxicity to crops (Ashton & Monaco, 1991; Cobb, 1992; Knobel, De Villiers, Smit & Lindeque, 1992; Wrubel & Gressel, 1994).

Millions of rands are spent annually in South Africa on herbicides. This also applies for neighbouring countries, although in the whole region financial resources by small-scale farmers are not available while herbicide use is very limited (Fowler, 1981; Ransom, 1989; Jimenez, Piccioto & Bata, 1990).

Projections indicate that all African countries need to triple their agricultural production, particularly in the Southern African region, where one in two people is reported food insecure, and one in four preschool children is malnourished (Schickele, 1968; Mellor, 1985; Anonymous, 1997b quoting IFPRI). Local governments claim that one of the greatest challenges is the intensification of agriculture by the development of a sustainable and profitable small-scale farming sector.

According to Akobundu (1979) many rural areas in Africa are approaching or have attained the same position as Nigeria, where the abundance of cheap labour has disappeared, due to factors such as rapid urbaniztion, improved living standards, increased education opportunities, changes in employment opportunities, social values and attitudes. It is thus often impossible to carry out timely weeding by hand (Okali, 1978). Therefore, intensification of agriculture requires the use of herbicides (Gower, 1980).

Maillet (1991) suggested that where the cost of hand-weeding is high, herbicide treatment is competitive and a promising way to control weeds. Many small-scale farmers are not prepared to handle herbicides safely. Baker (1991) reported that, where small-scale farmers can afford to buy herbicides, its use is increasing. Thus, with an increasing use of herbicides, there is an urgent need to motivate the people from both sectors (small-scale and commercial farmers) to learn to and pursue more advanced farming practices. Alternative environmental friendly approaches to reduce the dangers of highly residual and toxic herbicides to the environment, and especially to the supply of drinking water, should be pursued.

As will be shown, some approaches are more environmental friendly than others, e.g. where herbicide performance, including that of sethoxydim, is increased by using lower concentration, reduced spray volume or by utilizing adjuvants and ammonium salts. However, negligible information is available in South Africa, as well as in the southern african region in general. Therefore, screening and identifying appropriate adjuvants, as well as the effect of ammonium salts on sethoxydim phytotoxicity is of paramount importance for growers to increase their revenue with reduced herbicide costs. Moreover, determining reduced carrier volume which partially overcomes the antagonism of salts in spray water will contribute to the rationing of water, one of the southern african region's environmental resources which is becoming scarce rapidly (Anonymous, 1993; Anonymous, 1997b). Thus, the objectives of this research were:

- To study the effect of sodium bicarbonate and potassium carbonate on sethoxydim activity;

- To determine the reduced carrier volume which overcomes sodium bicarbonate and potassium carbonate in spray water with reduced sethoxydim concentrations;

- To identify suitable adjuvants and ammonium salts to overcome sodium bicarbonate and potassium carbonate antagonism with reduced sethoxydim concentrations;

- To determine the effect of the interaction of temperature, adjuvants and ammonium salts and water quality on sethoxydim activity.

CHAPTER 2

LITERATURE REVIEW

2.1 Sethoxydim characterization

Sethoxydim is a postemergence herbicide widely used to control annual and perennial grasses in 50 broadleaf crops (Beste, Radke, Humburg, Riggleman, Kempen, Stritzke, & Miller, 1983). In South Africa it is registered as a postemergent herbicide to control annual grasses in 16 broadleaf crops (Vermeulen, Dreyer, Grobler & Zyl, 1996). Sethoxydim is a member of the cyclohexanedione herbicide family, which are competitive inhibitors of acetylcoenzyme A carboxylase (ACCase) (Stoltenberg, Gronwald, Wyse, Burton, Somers & Gengenback, 1989; Harwood, 1991) and fatty acid biosynthesis (Rendina & Felts, 1988).

Sethoxydim is characterized by rapid degradation (Campbell & Penner, 1985), little movement in soil (Koskinen, Reynolds, Buhler, Wyse, Border & Jarvis, 1993), efficacy at low rates (Kleppe & Harvey, 1989) and low mammalian toxicity (Ahrens, 1994 quoted by Young, Hart & Wax, 1996).

Like many other postemergence herbicides, sethoxydim efficacy is dependent on many variables such as water quality (Nalewaja *et al.*, 1989), tank-mixing with other herbicides (Hartzler & Foy, 1983a; Rhodes & Coble, 1984b; Young, Hart & Wax, 1996), environmental conditions (Chernicky, Gosset & Murphy, 1984; Wills, 1984), the time of day that the herbicide is applied (Nalewaja, Matysiak & Szelezniak, 1994), addition of adjuvants (Chernicky, Gosset & Quisenberry, 1981; Hartzler & Foy, 1983b), carrier volume (Cranmer & Duke, 1983; Lassiter & Coble, 1985) and leaf and plant stage. These factors have been shown to influence absorption, translocation and subsequent control (Ahmadi, Harderlie & Wicks, 1980; Wills & Jordan, 1981).

Alkaline sodium salts in water carriers, particularly sodium bicarbonate, are reported to be antagonistic to sethoxydim and to cyclohexanedione herbicides in general (Nalewaja *et al.*, 1989). The antagonistic effect of sodium bicarbonate has been speculated to reduce foliar absorption of sethoxydim on quackgrass [*Elytrigia repens* (L.) Nevski.] (Wanamarta, Penner & Kells, 1989a), 2,4-D amine on kochia [*Kochia scorpia* (L.) Schrad.] and *Amaranthus retroflexus* L. (Nalewaja *et al.*, 1990), tralkoxydim on oats (*Avena sativa* L. cv. Witteberg) (de Villiers, 1994), glyphosate on wheat (*Triticum aestivum* L.) (Shea & Tuphy, 1984) and beans (*Phaseolus vulgaris* L.) (de Villiers & du Toit, 1993). Likewise, calcium chloride, calcium nitrate and potassium bicarbonate are reported to reduce chemical weed control with various herbicides such as diethanolamine 2,4-D and sodium 2,4-D, dimethylamine MCPA, sodium bentazon, dimethylamine dicamba and sodium dicamba, sodium acifluorfen, imazamethebenz, ammonium imazethapyr and isopropylamine glyphosate to kochia in glasshouse experiments (Nalewaja & Matysiak, 1993). Cations such as aluminium, iron, magnesium and zinc are also reported to reduce activity of several herbicides (Stahlman & Phillips, 1979; Nalewaja & Matysiak, 1991; Nalewaja, Woznica & Matysiak, 1991)

Tank-mixing sethoxydim and broadleaf herbicides, a common practice to provide broad spectrum weed control, delays build-up of resistance, saves time, and decreases labour and equipment costs with a single application has been proved to reduce grass control (Jordan & York 1989; Blackshaw & Harker, 1992; Wrubel & Gressel, 1994). Rhodes & Coble (1984a) reported that Na-bentazon reduced the foliar absorption of sethoxydim in goosegrass [*Eleusine indica* (L.) Gaertn.]. Na-bentazon also reduced absorption and thus activity of other grass herbicides, such as fluazifop (Gerwick, Tanguay & Burrough, 1990), and diclofop (Campbell & Penner, 1982). Grichar (1991) reported reduced grass control when sethoxydim was applied with Na-acifluorfen. Holshouser & Coble (1990) showed that sethoxydim efficacy was also reduced when applied in combination with acetolactate synthase (ALS) inhibiting herbicides, such as imazaquin and chlorimuron on *Panicum dichotomiflorum* Mich, *Eleusine indica*, and *Digitaria sanguinalis* (L.) Scop. in field experiments.

Several mechanisms have been proposed to explain sodium bicarbonate and broadleaf herbicidal action, particularly bentazon, antagonism of sethoxydim activity (Hatzios & Penner, 1985; Green, 1989; Courderchef & Retzlaff, 1990, 1991; Nalewaja *et al.*, 1994). Bayer & Lumb (1973) indicated epicuticular wax as the primary barrier for herbicide penetration. Wanamarta *et al.* (1989a) found increased ^{14}C-sethoxydim absorption, by removing the wax from the quackgrass leaf cuticle, but this did not prevent antagonism. Na-bentazon inhibited the diffusion of ^{14}C-sethoxydim into and through isolated tomato (*Lycopersicon esculentum* Mill.) fruit cuticles. It was concluded that the antagonism commonly observed is not only through the wax layer, but also due to suppression of ^{14}C-sethoxydim penetration, inhibited by bentazon, through the leaf cuticle. In addition to Na-bentazon, they also found that other monovalent (Li^+, K^+, Cs^+) and divalent (Ca^{++}, Mg^{++}) cations produced the same inhibitory effects on sethoxydim absorption through the detached cuticles.

Wanamarta *et al.* (1989a) postulated replacement of a proton at the hydroxyl group on the sethoxydim molecule with the sodium ion as the basis for antagonism. Courderchet & Retzlaff (1991) indicated that sethoxydim is a weak acid in solution with the pKa of the ring hydroxyl of 4.6. Therefore, in neutral solutions, the sethoxydim molecule would be primarily in the depronated state, which would facilitate association with Na^+ or other cations in the spray solutions. Thelen, Jackson & Penner (1995), using proton nuclear magnetic resonance spectroscopy, demonstrated that Na^+ from alternate sources associates with the sethoxydim molecule in the same manner as Na^+ form Na-bentazon. The formation of Na-sethoxydim or other alkaline earth salts of sethoxydim results in a less preferred absorption form of sethoxydim (Penner, 1989).

A reduction in the rate of sethoxydim absorption by sodium bicarbonate, which is more evident when carrier volumes of 300 ℓ.ha^{-1} and higher are applied, has resulted in increased photolysis of the herbicide and reduced weed control, since sethoxydim and many cyclohexenones are unstable in ultraviolet light (Smith & Vanden Born, 1992; McMullan, 1994).

Sodium bicarbonate antagonism of sethoxydim can be alleviated by increasing the rate of sethoxydim in the spray carrier (Nalewaja *et al.*, 1989; Nalewaja *et al.*, 1990). Rhodes & Coble (1989a) proved that a similar procedure was applicable to mixtures of sethoxydim and bentazon. However, this approach is undesirable because of environmental concern.

Reduced carrier volumes and adjuvants or ammonium ions applied with sethoxydim can increase sethoxydim activity, and reduce the amount of herbicide degraded by ultraviolet light, through enhancing the rate of herbicide uptake (McInnes, Harker, Blackshaw & Vanden Born, 1992; Wanamarta, Kells & Penner, 1993). Adjuvants and ammonium salts also reduce the antagonistic effect of herbicide tank mixtures, the number of applications and the amount of active ingredients (Johnson & Weeb, 1983; Foy, 1993; Nandula, Curran, Roth & Hartwig, 1995). As a result, reduced application rates also result in lower costs to farmers and a potential decline in the negative environmental impact (Harker, 1992).

2.2 Mechanisms of overcoming sodium bicarbonate antagonism

2.2.1 Carrier volume

Herbicides such as glyphosate and paraquat are more effective in low carrier volumes (Sandberg *et al.*, 1978; Stahlman & Phillips, 1979; Buhler & Burnside, 1983; Cranmer & Duke, 1983; Smeda & Putnam, 1989). Carrier volume has also been reported to have a significant effect on the phytotoxicity of herbicides applied sequentially. Buhler & Burnside (1984) found increased activity of fluazifop, sethoxydim and haloxyfop to forage sorghum, when carrier volume was decreased from 570 to 24 ℓ.ha^{-1}.

Chandrasena & Sagar (1989) applied fluazifop to quackgrass in carrier volumes of 100, 200, 400, and 800 $\ell.ha^{-1}$. A higher level of quackgrass control was achieved with carrier volume of 100, 200, or 400 than 800 $\ell.ha^{-1}$. Lassiter & Coble (1987) tested the effect of three carrier volumes on the antagonism between sethoxydim and bentazon, and found that 94 and 187 $\ell.ha^{-1}$ were more effective to the use of 374 $\ell.ha^{-1}$ for the control of large crabgrass, fall panicum and goosegrass, either applying sethoxydim alone or when sequentially applied with bentazon (Lassiter & Coble, 1987).

Qureshi & Vanden Born (1979) proved that carrier volume influenced the antagonism between diclofop and MCPA. According to Richard (1991) the effect of salts and impurities in the water, on herbicide activity, is reduced at low carrier volumes. Reduced water volume could be a possible method for overcoming antagonism between herbicides and salts or impurities which cause reduced absorption as reported by several researchers (Rhodes & Coble, 1984b; Holshouser & Coble, 1990; Thelen *et al.*, 1995; Young *et al.*, 1996).

On the other hand, some herbicides such as imazamethabenz, clopyralid and asulam have been proved not to respond to carrier volume or sometimes were more active when applied in high volumes compared to low water volumes (Brewester & Appleby, 1990; Bovery, Stermer & Bouse, 1991; Richard, 1991).

Control with higher volumes can be increased by increasing the adjuvant concentration. On the other hand, Smeda & Putnam (1989) found that there was no interaction between carrier volume and adjuvant concentration, suggesting that the effects of these two variables are independent of one another.

McWhorter & Hanks (1993) showed that the use of low carrier volumes may be more economical because of the reduced time needed to mix as well as load, and because of reduced fuel requirements for application. In addition, low water volume, also reduces herbicide rates, overall costs, as well as the problems of water accessibility and volume (McKinlay, Ashford & Ford, 1974; Buhler & Burnside, 1984; Maillet, 1991).

2.2.2 Adjuvants

The phytotoxic activity of herbicides is often dependent on nonherbicidal constituents in the spray solution that enhance herbicide performance (Harker, 1992).

Adjuvants and materials which enhance the action of the herbicide solution, are frequently added to postemergence spray solutions to reduce the adverse influence of leaf topography, epicuticular wax and trichomes on herbicide distribution, including the detrimental effect of salts and herbicide antagonism in the spray solutions (Penner, 1989; Wanamarta *et al.*, 1989b; Hess & Falk, 1990; Nalewaja & Matysiak, 1993).

Several studies have shown enhanced herbicidal activity after adding adjuvants to postemergence herbicides. Hartzler & Foy (1983b) tested the effect of a nonionic surfactant and two petroleum oil concentrates on the phytotoxicity of sethoxydim to crabgrass and found increased grass control, but no enhancement was observed at high herbicide concentrations. Wanamarta *et al.* (1989b) evaluated 11 adjuvants which were added to a sethoxydim spray solution at 1.2 $\ell.ha^{-1}$ (0.6% v/v) for surfactant and 1.2 $\ell.ha^{-1}$ (1.3% v/v) for petroleum oil concentrate or soybean oil concentrate. There was an increased sethoxydim uptake by quackgrass ranging from 6 to 77%.

De Villiers, Lindeque & Smit (1997) evaluated five adjuvants with glyphosate and found that one of the adjuvants tested was most effective in overcoming high calcium salt concentrations even when applied at half the recommended rate, while two were ineffective.

Jordan (1995) found that bentazon strongly antagonized sethoxydim and clethodim but, when BCH 815 was added, it reduced the antagonism with sethoxydim and clethodim compared with COC. Similarly York, Jordan & Wilcut (1990) proved that substituting BCH 81508 S for COC consistently increased the efficacy of sethoxydim. They further observed that, adding BCH 81508 S, increased the efficacy of lower rates of sethoxydim while providing little additional control at higher rates of sethoxydim. Thus, they concluded that the response of low sethoxydim rates with BCH 81508 S would be economically advantageous to crop producers.

Not all adjuvants are effective for all herbicides. O'Sullivan, O'Donovan & Hamman (1981) tested 14 different surfactants for glyphosate and found that six surfactants reduced glyphosate phytotoxicity. Nalewaja, Petersen & Gillespie (1985) compared several emulsifiers as components of crop oil concentrates (COC) and found that the effectiveness of the COC depended on the type of emulsifier used, the amount of emulsifier added and the herbicide.

Wixson & Shaw (1991) proved that whereas adjuvants often increase weed control, they may also increase herbicide phytotoxicity to crops. Smith (1974) reported that surfactant or COC added to propanil increased barnyardgrass control, but also increased injury to rice. Lee & Oliver (1982) also reported that COC added to MSMA plus linuron increased weed control in cotton, but also reduced yields in 12% compared with the same treatment and a surfactant. Screening and identification of the appropriate adjuvant for each individual herbicide usage is important.

Penner (1989) stated that adjuvants can reduce herbicide antagonism by increasing its absorption and by preventing formation of less preferred forms of weakly acidic herbicides. In turn, Harker (1992) stated that as adjuvants can make herbicides more effective, there is potential for reduced herbicide application rates, thus reducing herbicide costs and concerns of pesticides in the environment.

2.2.3 Ammonium salts

Addition of ammonium-containing fertilizers, such as urea ammonium nitrate (UAN), ammonium polyphosphate (AP) and ammonium sulfate (AS) to postemergence herbicides are known to increase herbicide activity. Nalewaja *et al.* (1989) found that the antagonistic effect of sodium bicarbonate at 6000 $mg.\ell^{-1}$ on sethoxydim was overcome by diammonium sulfate or ammonium sulfate at 2.8 $kg.ha^{-1}$ or 28% nitrogen liquid fertilizer at 9.4 $\ell.ha^{-1}$.

Similar results were found on johnsongrass, quackgrass, volunteer corn, settaria spp., shatercane (McKeague, Hutchins, Charvat, Gibson & Burdick, 1986), volunteer wheat and barley (Harker & O'Sullivan, 1986).

Harker (1992) tested the effect of ammonium sulfate (AS) on the activity of cyclohexanedione (CHD) and aryloxyphenoxypropanoate (APP) herbicides and found that the largest AS-attributed increase in APP herbicide phytotoxicity was 19% for wild oat with haloxyfop at 50 $g.ha^{-1}$, while with CHD herbicides, AS-attributed increases ranged from 34 to 100%. With added AS, he observed that barley fresh weight was reduced by 75% with BAS 517 at 50 $g.ha^{-1}$ and 100% with clethodim at 25 $g.ha^{-1}$.

Chow & MacGregor (1983) reported that adding ammonium salts such as AS, AP, NH_4Cl, NH_4NO_3, and NH_4SCN improved the activity of sethoxydim on wild oat. Of the ammonium salts evaluated, AS was the most effective. De Ruiter, Verbeek & Uffing (1994) showed that adding AS tripled the foliar uptake of glyphosate into wheat leaves. In turn, Jordan, York & Corbin (1989) found that adding AS to ^{14}C-sethoxydim increased absorption 6-fold at 0.5 h after application. Sethoxydim absorption was reduced by bentazon but when sethoxydim was applied with bentazon and AS, absorption and translocation were similar to those with sethoxydim alone.

Wanamarta, Penner & Kells (1986) found that if the spray solution contained a considerable amount of NH_4^+ supplied from adding diammonium sulfate, the antagonism of Na-bentazon on sethoxydim absorption could be overcome or prevented.

2.2.4 pH

Several researchers have reported the marked effect of pH on solute absorption, both at the cellular level and in overall foliar penetration. Herbicides such as 2,4-D, 2,4,5-T, dalapon, and glyphosate have been proved to be affected by solution pH (Blackman & Robertson-Cuninghame, 1953; Baur, Bovey & Rilley, 1974).

Crafts (1956) and Orgel & Weintraub (1957) indicated that the entry of 2,4-D into leaves was greater in acidic than neutral solutions. Foliar absorption of dalapon by corn leaves was found by Foy (1962) to be greatest from an aqueous solution of low pH. Similarly, Mersie & Foy (1987) indicated that chlorsulfuron is a weak acid with a pKa of 3.8 and, below this pH the molecule is mainly in the undissociated form. At pH 2.4 and 3.4, the undissociated molecule can penetrate the cuticle more readily than the anion which would be the dominant form at pH 5.6.

Nalewaja *et al.* (1994) evaluated the effect of different salts of sodium and calcium on sethoxydim phytotoxicity at various pH and found that sethoxydim efficacy with most calcium or sodium salts with a spray carrier pH from 2.3 to 5.3 was not different from that with sethoxydim applied in distilled water. On the other hand, sodium and calcium compounds with a spray solution pH of 7.6 to 11.6 were antagonistic to sethoxydim indicated that calcium and sodium salts which raised pH are potentially antagonistic to sethoxydim phytotoxicity.

Bridges (1989) found that sethoxydim phytotoxicity to johnsongrass was similar when the pH was varied between 3.5 and 6.5 with acetic acid and calcium hydroxide or ammonium hydroxide. In turn, Wanamarta *et al.* (1993) found that sethoxydim phytotoxicity to quackgrass was similar between pH 3.0 and 4.5 when adjusted with hydrocloric acid. Nalewaja *et al.* (1994) showed that the lack of response to spray carrier pH indicates that pH is not important to sethoxydim phytotoxicity or that response to pH is influenced by the associated ions. Norris & Bukovac (1972) suggested that although pH is not important for some herbicides it may indirectly influence penetration by modifying the membrane potential or the metabolic activity of cells involved in absorption and translocation.

CHAPTER 3

MATERIALS AND METHODS

3.1 General procedure

Glasshouse experiments were conducted during 1997 and 1998 at the University of the Orange Free State, Bloemfontein, RSA (29^{0}07' S, 26^{0}11' E), using oat (*Avena sativa* L. cv. SSH 241) and tomato (*Lycopersicum esculentum* L. cv. STAR 9001) as bioassay species for sethoxydim {2-[1-ethoxyimino-butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} activity.

Twelve seeds of oat were planted in 2 ℓ pots containing sandy loam soil with 12% clay content and a pH of 6.19. One week after germination established seedlings were thinned to eight plants per pot. Tomato seeds were first germinated in seed trays and at the 3-4 leaf stage, the seedlings were transplanted singly in similar pots as used for oat plants.

All pots were watered daily and fertilized weekly with Chemicult® hydroponic nutrient mixture as needed for optimal growth. The glasshouse was maintained at 25±5^{0}C and 15±5^{0}C during the day and night respectively with a natural light regime.

Sethoxydim, an emulsifiable concentrate formulation, Nabu® supplied by Zeneca, was applied to both species of plants at the 4-leaf stage with a moving sprayer with two 8001 flat-fan nozzles, delivering 250 ℓ.ha^{-1} except in the case of the carrier volume experiment in which the sprayer was calibrated to deliver 175, 350, 525, 700 and 875 ℓ.ha^{-1}. The nozzles were set 50 cm above the target plants and a constant pressure of 200 kPa was maintained by regulated compressed air, in all experiments. Root uptake of sethoxydim was prevented by covering the soil with vermiculite before spraying and removing the vermiculite after the spray had dried.

Sethoxydim phytotoxicity was evaluated visually and by weighing the fresh and dry top growth. Visual evaluation and fresh top growth were determined 14 days after treatment and dry topgrowth 48 hours later. Visual evaluation were based on a scale of 0 to 20% = no injury, 20 to 40% = minor injury, 40 to 60% = moderate injury, 60 to 80% = severe injury, and 80 to 100% = death of plants.

The top growth was cut above the soil surface and fresh mass determined by means of an electronic scale. The top growth was then placed into paper bags and dried for 48 hours at 60°C in a drying oven. Dry mass was then determined.

The experiments were layed out as a complete randomized designs, with four replications, where each pot represented a replication.

3.1.1 Sethoxydim screening rates

A preliminary study was conducted as described in 3.1. In this study six sethoxydim rates, including untreated control plants were tested for their phytotoxicity effect on oat and tomato plants at 46.5, 93, 139.5, 186.0, 232.5 and 279.0 g ai.ha^{-1} as this was necessary for determining the concentration to be used in this study, since the recommended rate ranges from 112 to 1120 g ai.ha^{-1} (Anonymous, 1983).

The 139.5 and 186 g ai.ha^{-1} rates were selected, although 232.5 and 279 g ai.ha^{-1} had resulted in higher reduction in fresh mass and the control superior to 50% on oat (Table 3.1). Tomato plants did not show any injury or reduction in fresh mass (data not presented). The two rates were selected since one of the aims was to evaluate reduced sethoxydim rates which, when applied with adjuvants, ammonium salts or reduced carrier volume, could achieve the same level of control as is achieved when higher sethoxydim rates are used.

TABLE 3.1: Oat fresh top mass reduction and percentage control as influenced by sethoxydim rates

Sethoxydim rates (g ai.ha^{-1})	**Fresh mass reduction^{A} (%)**	**Control (%) (visual damage)**
0.0	0.00	0.0
47.0	15.00 bc	0.0
93.0	18.00 bc	28.0
139.5	20.00 abc	34.0
186.0	21.00 abc	44.0
232.5	42.00 ab	53.0
279.0	55.00 a	72.0

LSD_T = 35.68

^{A}Means followed by same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

‾ Analysis of variance is indicated in Table 1 of Appendix A and data in Table 1 of Appendix B

3.1.2 Spray carrier

Aqueous solutions were prepared by the addition of analytical grade reagents of sodium bicarbonate and potassium carbonate to distilled water at concentrations of 0.001, 0.003, 0.005, 0.007, 0.009 and 0.03 M of the cations. Sethoxydim at 186.0 g ai.ha^{-1} was added prior to application and applied to the foliage of oat and tomato plants, using the various aqueous solutions as spray carriers. Sethoxydim was also applied using distilled water to which aqueous salt solutions were added and compared with the standard herbicide spray carrier.

3.1.3 Carrier volume

Treatments were applied with a sprayer calibrated to deliver 175, 350, 525, 700 and 875 $\ell.ha^{-1}$ at 200 kPa. Different delivery volumes were obtained by changing the sprayer's moving speed.

Aqueous solutions of deionized water with sodium bicarbonate and potassium carbonate at a concentration of 0.03 M of the cations were prepared and used as carrier for sethoxydim at 139.5 and 186.0 g $ai.ha^{-1}$. Each sethoxydim rate and carrier volume combination was also applied using distilled water to which aqueous solutions were compared.

3.1.4 pH

The spray carrier was prepared using analytical grade sodium hydroxide at 0.03 M of the cation which was dissolved in distilled water to which sethoxydim at 186.0 g $ai.ha^{-1}$ was added. The pH was adjusted to obtain single-unit values of 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, 8.5, 9.5, 10.5 and 11.5 by adding either sulfuric acid or concentrated sodium hydroxide. Solutions were stirred with a magnetic stirrer for 2 minutes and allowed to stand 30 seconds before reading.

3.1.5 Addition of adjuvants and ammonium salts

In this experiment, sodium bicarbonate and potassium carbonate at 0.03 M of the cations were first dissolved in distilled water. Sethoxydim followed by ammonium salts or adjuvants, were added subsequently except in the case of Bladbuff 5 which was added prior to sethoxydim. Adjuvants and ammonium salts and chemical descriptions are presented in Table 3.2.

Sethoxydim was applied at 139.5 and 186.0 g $ai.ha^{-1}$ for both plant species of plants, and each combination of sethoxydim-adjuvant or sethoxydim-ammonium salt, including sethoxydim alone was also applied for comparison with the combinations.

3.1.6 Temperature, adjuvants and ammonium salts experiment

Oat and tomato plants were treated with sethoxydim at 139.5 g ai.ha^{-1}, with and without adjuvants and ammonium salts.

The spray carrier to which sethoxydim, adjuvants and ammonium salts were added was prepared dissolving sodium bicarbonate at 0.03 M of the cation in distilled water. Immediatelly after treatment, plants were placed in controlled environment chambers at 15, 25 or 35^{0}C with a 45% relative humidity. Untreated control plants were also included in each environment for comparison.

TABLE 3.2: Chemical description of adjuvants and ammonium salts used

Adjuvants and ammonium salts	Chemical description	Rate (%)
Agral 90	90.0% nonylphenol ethoxylate	0.1
Ammonium nitrate	99.0% NH_4NO_3	0.5 and 1.0 w/v
Ammonium sulfate	99.7% $(NH_4)_2SO_4$	0.5 and 1.0 w/v
Bladbuff 5	Acid, surfactant and colour indicator	colour change at pH 4.5
Break-Thru	Organosilicone	1.0
Sadol	Methylated seed oil (850 ml.ℓ^{-1}) + emulsifier	5.0

3.2 Statistical analysis

Data were expressed as percentage reduction from the untreated control plants. Analysis of variance was carried out on all data from the individual experiments, using the statistical program SAS (SAS PC DOS 6.04 CARY. NC: SAS Institute INC, 1988), and means were separated using least significant difference values calculated according to Tukey method at a 5% probability level.

CHAPTER 4

RESULTS AND DISCUSSION

All data discussed pertains only to fresh mass of oats. This is because, in all the experiments, tomato plants were not affected and dry mass was an irreliable method.

4.1 Spray carrier

Sethoxydim activity on oats was reduced by both sodium bicarbonate and potassium carbonate salts added to distilled water, when compared to distilled water (Table 4.1). Fresh top mass reduction by both salts between 0 and 0.03M, decreased from 81 to 46% and 25%, respectively. A reduced sethoxydim effect in the presence of antagonistic salts has been observed previously (Nalewaja *et al.*, 1989; Wanamarta *et al.*, 1989b), and reduced foliar absorption was indicated as the cause of diminished herbicide activity (Rhodes & Coble, 1984a; Wanamarta *et al.*, 1993).

The antagonism of sethoxydim by potassium carbonate was greater than sodium bicarbonate at all concentrations tested except at 0.005M, where the opposite effect occurred. This is consistent with work done by Nalewaja *et al.* (1989) who found that the antagonism by sodium carbonate on sethoxydim generally was more than that from sodium bicarbonate. De Villiers (1993) also evaluated the antagonism of salts added to tralkoxydim, another member of the cyclohexadione herbicides, and found potassium bicarbonate to be more antagonistic than sodium bicarbonate.

A linear regression relationship between sethoxydim phytotoxicity and both salts individually illustrates that they are negatively correlated (Table 3-4, Appendix A and

Figure 4.2) and that potassium carbonate (R^2=77%) slightly accounted for more variance than sodium bicarbonate (R^2=61%).

TABLE 4.1: Oat fresh top mass reduction from sethoxydim at 186.0 g ai.ha^{-1} in 250 ℓ.ha^{-1} of spray water as influenced by sodium bicarbonate and potassium carbonate at different concentrations

Concentrations	Fresh top mass reduction as affected by antagonistic salts (%)[A]	
	Sodium bicarbonate	**Potassium carbonate**
None	81.0 a	81.0 a
0.001 M	66.0 ab	56.0 ab
0.003 M	64.0 ab	60.0 ab
0.005 M	59.0 ab	60.0 ab
0.007 M	55.0 ab	47.0 bc
0.009 M	66.0 ab	54.0 abc
0.030 M	46.0 bc	25.0 c

LSD_T (5%) = 29.231

[A] Numbers followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

‾ Analysis of variance is indicated in Table 2 of Appendix A and data in Table 2 of Appendix B.

Comparison of reduction in fresh mass at different salt concentrations suggested that significant differences only occurred when the salts were applied at 0.03 M and when sethoxydim was applied with distilled water as spray carrier (Figure 4.1). This may have possibly been caused by the inability of the herbicide to overcome these salts when they are present in water at high concentrations, like 0.03 M which was used in this experiment.

Distilled water contains no ions. Therefore, relative to the different salt concentrations it did not reduce the activity of the herbicide. This is accentuated by the fact that the highest reduction in fresh mass was observed in the control which contained only the herbicide in distilled water.

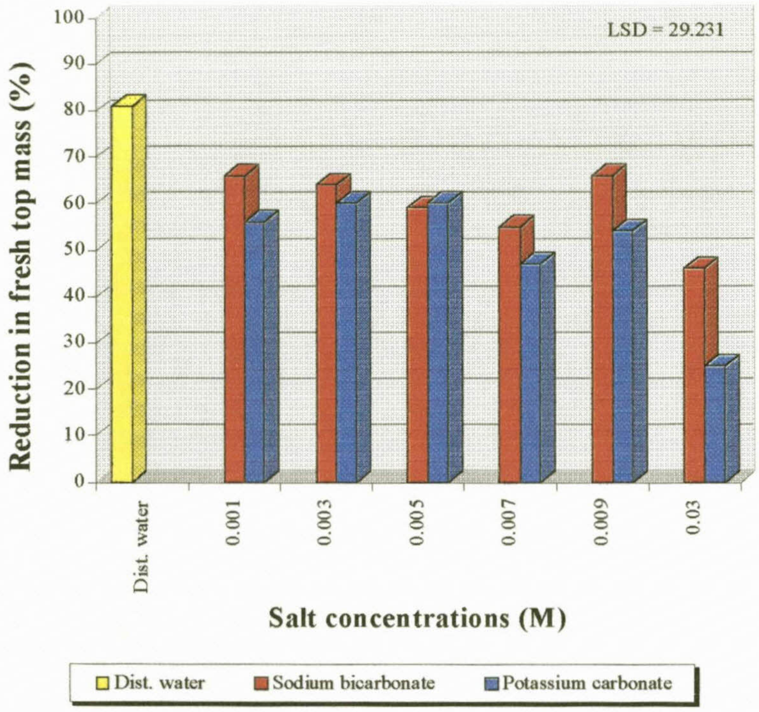

FIGURE 4.1: The influence of sodium bicarbonate and potassium carbonate on sethoxydim activity at 186.0 g ai.ha^{-1} on oats

There were no significant differences between the effects of the other concentrations whose range (0.001 to 0.009 M) is below 0.03 M. This could be attributed to the fact that the herbicide on its own had the ability to overcome the antagonistic effect of salts at those concentrations.

An increase in salt concentrations induced a slight decrease in mass reduction except for 0.009 M of the cations which, for both salts, demonstrated a different tendency. This did not differ significantly from the other concentrations except for the 0.03 M concentration and distilled water. Growth stimulation by sethoxydim at a reduced rate (186.0 g ai.ha^{-1}) in the presence of both salts at this particular concentration could be the cause of this trend observed, as reported for the case of glyphosate in the presence of calcium (Baur, Bovey &

Veech, 1977; Baur, 1979; Shilling & Haller, 1989), although this has not yet been reported for sethoxydim. This is one explanation. Another is that herbicides do not always induce good dose responses. The reason for this is not known.

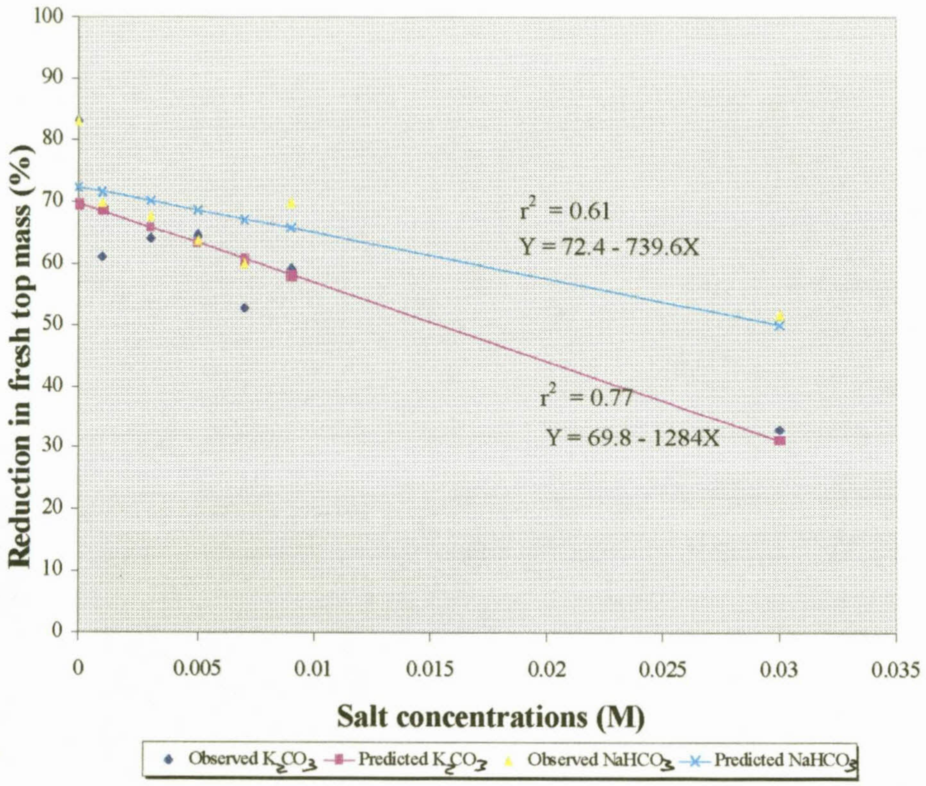

FIGURE 4.2: Relationship between sethoxydim activity, sodium bicarbonate and potassium carbonate concentrations in the spray water on oats

Although, sodium bicarbonate was less antagonistic than potassium carbonate, potassium is a less prevalent ion in water sources (De Villiers, 1994). Galvin (1996) proposed that this is due to the possibility of potassium substituting sodium in clay mineral layers, implying that the ratio (sodium/potassium) decreases between a river source and its mouth. Analysis of water from various water sources also showed that potassium ions do not constitute the same problem in South Africa when compared to sodium ions (De Villiers & Du Toit, 1993). Thus, in this study potassium ions were included for reference.

The possibility of sodium from sodium bicarbonate or sodium carbonate forming Na-sethoxydim, proposed by Rhodes & Coble (1984b) and Wanamarta *et al.* (1989a) and confirmed by Thelen *et al.* (1995) are high. Consequently, reduced control of grass weeds is accounted for by Na-sethoxydim a less absorptive form of sethoxydim (Wanamarta *et al.*, 1993).

4.2 pH

Control by sethoxydim with an increase in the spray solution pH was reduced from 71% at pH 2.5 to 13% at pH 11.5 (Table 4.2). Reduced control of grass weeds with sethoxydim with high pH has been indicated in previous reports (Wanamarta *et al.*, 1993; Nalewaja *et al.*, 1994).

Sethoxydim activity, when pH was varied between 2.5 and 5.5 did not differ significantly (Table 4.2). Sethoxydim activity decreased between pH values of 2.5 and 6.5. There was not a significant influence on activity when raising the pH from 3.5 to 6.5. This finding coincides with that of Bridges (1989) who found that varying the pH between 3.5 and 6.5 with acetic acid and calcium hydroxide or ammonium hydroxide, did not influence activity on *Sorghum halepense* (L.) Pers..

There were no significant differences in fresh mass reduction by increasing the pH from 6.5 to 10.5 (Table 4.2). This suggests that applying sethoxydim with spray solution pH within this range would not affect its bioactivity significantly. Increasing pH from 10.5 to 11.5 did also not differ significantly.

These results indicate that sethoxydim activity decreases with an increase in pH is probably due to the increasing presence of the sodium cation from sodium hydroxide added to increase the pH of the spray solution. Sethoxydim probably reacts with the sodium cation as suggested by Thelen *et al.* (1995) to form a less readily absorbed conjugate sodium salt of sethoxydim which could explain fresh mass increase with increasing pH.

TABLE 4.2: Oat fresh top mass reduction from sethoxydim at 186.0 g ai.ha^{-1} as influenced by spray solution pH

PH[B]	Reduction in fresh top mass (g)[A]
2.5	71.00 a
3.5	69.00 ab
4.5	55.00 abc
5.5	54.00 abc
6.5	49.00 bcd
7.5	44.00 cd
None (4.5)[C]	43.00 cd
8.5	43.00 cd
9.5	35.00 cd
10.5	33.00 de
11.5	13.00 e

LSD_T (5%) = 20.372

[A]Numbers followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

[B]pH was adjusted with NaOH at 0.03 M and H_2SO_4 at 1 N.

[C]Control (distilled water + sethoxydim at 1.0 ℓ.ha^{-1}).

‾Analysis of variance is indicated in Table 5 of Appendix A and data in Table 3 of Appendix B

The results in Figure 4.3 indicate that the percentage reduction in fresh top mass decreased progressively with an increase in pH from 2.5 to 11.5. Data regression analysis (Table 6, Appendix A and Figure 4.4) confirms this pattern. A similar response to pH has been reported for 2,4-D, chlorsulfuron, glyphosate, bentazon and imazethapyr (Szabo & Buchholtz, 1961; Mersie & Foy, 1987; Van Ellis & Shaner, 1988; Shilling & Haller, 1989; Sterling, Balke & Silverman, 1990). This coincides with the fact that at pH values below the pK, undissociated molecules predominate and penetrate rapidly. At high pH values, however most molecules are dissociated, and the dissociated ion penetrates less efficiently (Simon & Beever, 1952; Crafts, 1953; Sargent & Blackman, 1962; Swanson & Baur, 1969).

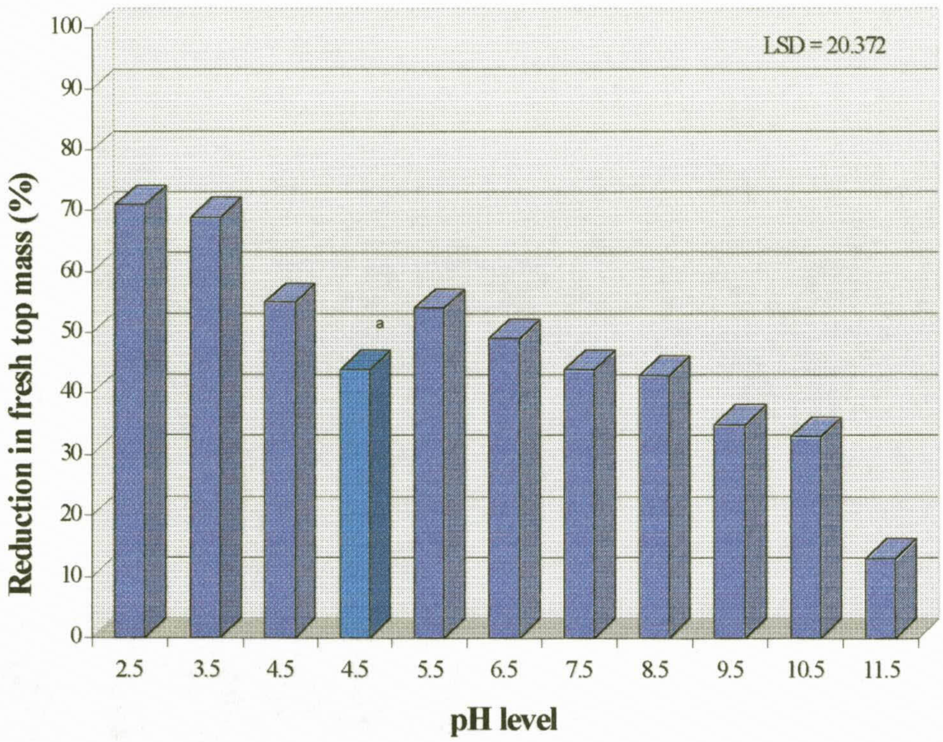

FIGURE 4.3: Effect of spray solution pH on sethoxydim activity at 186.0 g $ai.ha^{-1}$ on oats

[a]Control (distilled water + sethoxydim)

However, variable sethoxydim performance below the pKa has been reported. Bridges (1989) did not find significant differences in johnsongrass control by raising the pH from 3.5 to 6.5, but found slightly increased sethoxydim activity ranging from 85 to 88%. In turn, Wanamarta *et al.* (1993) also did not find significant differences varying pH from 3 to 4 but found rediced sethoxydim activity on quackgrass [*Elytrigia repens* (L.) Nevski.] from 95 to 88%, with increasing spray solution pH. This variable sethoxydim performance could be expalined by the fact that, while the first author used glacial acetic acid to lower the pH, the second author used hydrochloric acid (HCl) for the same purpose. Hence, as shown by Wanamarta *et al.* (1989a), ammonium cations interacted with sethoxydim and the plasmalemma to produce complex differential effects on absorption, thus preventing the formation of sethoxydim salts which cross the cuticle at reduced rate.

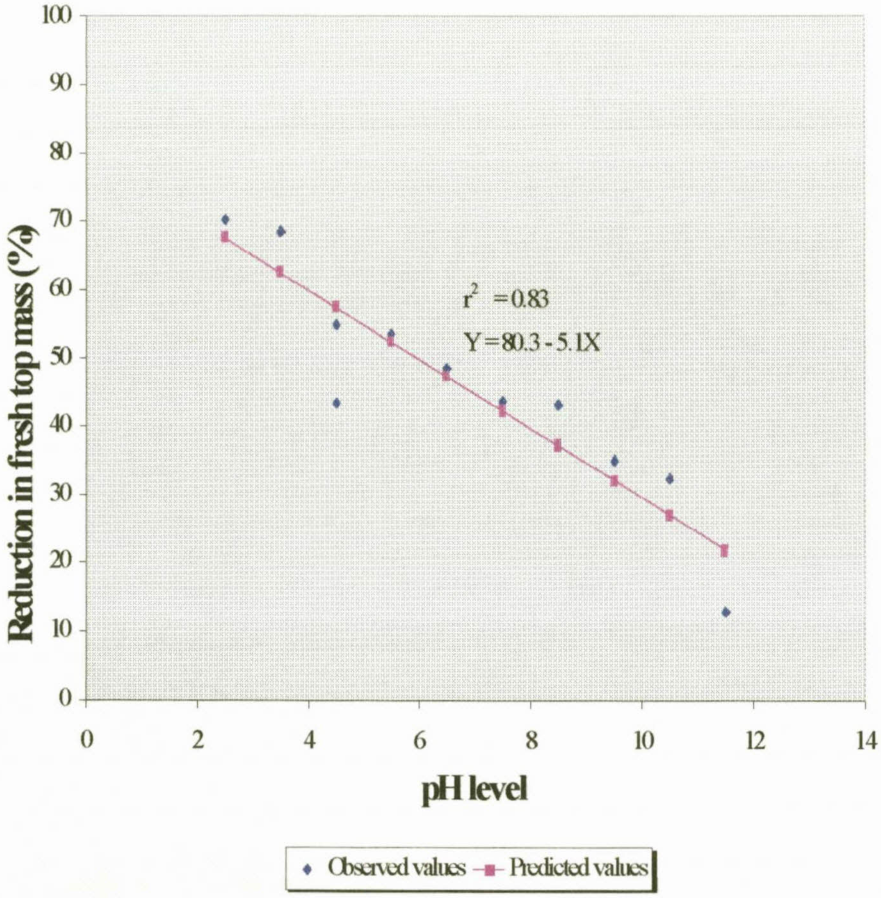

FIGURE 4.4: Relationship between spray solution pH on sethoxydim activity at 186.0 g ai.ha^{-1} on oats

In the present study, significant differences were not recorded at low pH. However, increasing the pH from 2.5 to 6.5 caused fresh top mass reduction from 71 to 49%. This is in agreement with results obtained by Wanamarta *et al.* (1993). A possible explanation for these similar findings could be that given by Nalewaja *et al.* (1994). The authors speculated that pH alone does not account for differences in sethoxydim activity. This occurs when the pH of the spray solution is equal to or below the pKa of sethoxydim. pH per se does therefore not seem important for sethoxydim activity but the response to pH is influenced by associated ions, since anions in the spray solution are involved in the formation of spray droplet residues. As indicated for glyphosate, the formation of the residues on the leaf surface could possibly decrease sethoxydim activity (Nalewaja & Matysiak, 1991).

4.3 Adjuvants and ammonium salts

Oat fresh top mass reduction was increased as sethoxydim rate increased, and as spray adjuvants and ammonium salts were added to the sethoxydim spray solution (Table 4.3). The interactions spray carrier by sethoxydim rate and sethoxydim rate by spray adjuvants were not significant. However, the interaction of the three factors was significant (Table 4.4). Thus, the main effects (Table 4.3) and interactions (Table 4.4) were discussed to show the their tendency.

The addition of adjuvants and ammonium salts increased the reduction of oat fresh top mass with all sethoxydim rates except in the case of Agral 90 and ammonium sulphate at 0.5% which resulted in little effect when sethoxydim was sprayed at 139.5 g $ai.ha^{-1}$. However, when sethoxydim was applied at 186.0 g $ai.ha^{-1}$, fresh top mass reduction was increased from 54 to 76% and from 38 to 74% with both adjuvants respectively. Increased sethoxydim activity with increased rates, as well as the addition of adjuvants and ammonium salts, have been reported previously (Chow & MacGregor, 1983; Harker & O'Sullivan, 1986; York, Jordan & Wilcut, 1990; Harker, 1992; Smith & Vanden Born, 1992).

York, Jordan & Wilcut (1990) found that increasing sethoxydim the rate from 50 to 150 $g.ha^{-1}$, increased maize control from 59 to 95% and adding ammonium sulphate (AS) or, substituting crop oil with BCH 81508 S increased maize control by 13 and 29% respectively. Chow & MacGregor (1983) in turn, reported that adding ammonium salts such as ammoniumsulphate (AS), $(NH_4)_2HPO_4$, NH_4Cl, NH_4NO_3 and NH_4SCN improved the activity of sethoxydim on wild oats (*Avena fatua* L.) while Hartzler & Foy (1983) and Buhler & Burnside (1984) found that adding COC to the sethoxydim spray solution increased sethoxydim activity on grasses.

TABLE 4.3: Oat fresh top mass reduction as affected by sethoxydim rates, spray carrier, spray adjuvants and ammonium salts[A]

Treatment factor	Fresh top mass reduction (%)
Rates (g ai.ha^{-1})	
186.0	63.00 a
139.5	53.00 b
Spray carrier	
Sodium bicarbonate	52.00 a
Potassium carbonate	60.00 a
None	62.00 b
Spray adjuvants	
Sadol	72.00 a
Ammonium nitrate (1%)	70.00 a
Ammonium sulfate (1%)	66.00 a
Ammonium nitrate (0.5%)	64.00 ab
Bladbuff 5	60.00 ab
Ammonium sulfate (0.5%)	60.00 ab
Break-Thru	51.00 bc
Agral 90	44.00 cd
None	36.00 d

LSD_T for sethoxydim rates = 4.053

LSD_T for spray carrier = 5.946

LSD_T for spray adjuvants and ammonium salts = 13.689

[A]Data for each treatment factor are pooled over all levels of the other factors. Means within the same treatment factor followed by the same letter do not differ significantly according to Tukey's studentized range at 5% probability level.

Analysis of variance is indicated in Table 7 of Appendix A and data in Table 4 of Appendix B

When adjuvants and ammonium salts were added to sodium bicarbonate and potassium carbonate carriers, sethoxydim efficacy was lower than to sethoxydim applied in distilled water together with adjuvants and ammonium salts (Figure 4.5 and Figure 4.6). The opposite response was observed with Sadol at both sethoxydim rates and ammonium sulphate at 1% and ammonium nitrate at 0.5 and 1.0% when sethoxydim was applied at 139.5 g ai.ha^{-1}. When sethoxydim was increased to 186.0 g ai.ha^{-1}, Bladbuff 5 in a potassium carbonate carrier increased efficacy to a higher degree than with distilled water and sodium bicarbonate. In turn, AS increased sethoxydim efficacy more than distilled water with either levels. This supports the findings described in point 4.1 that sodium bicarbonate and potassium carbonate are antagonistic to sethoxydim.

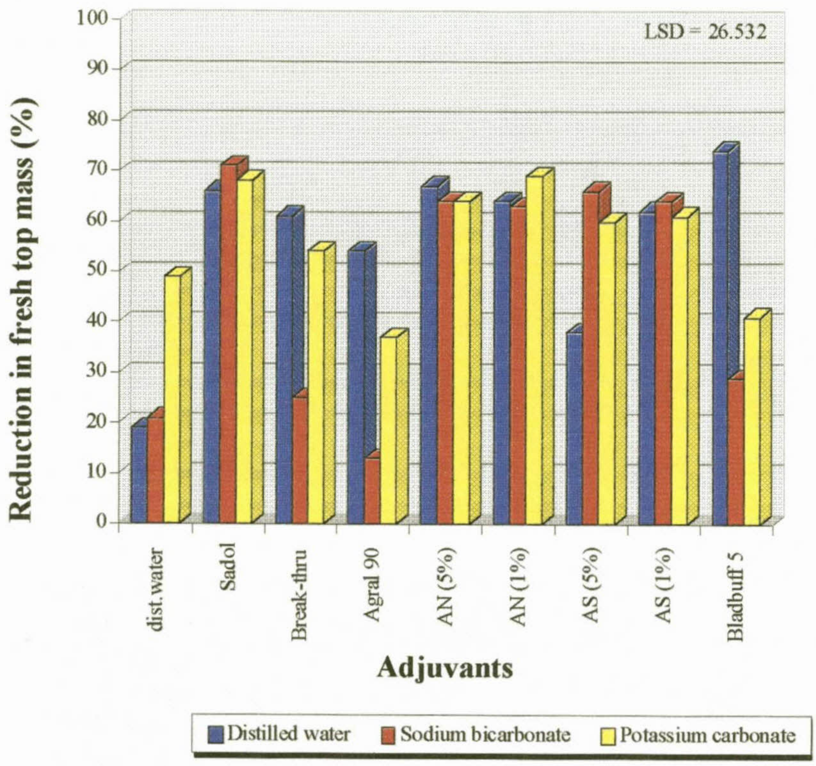

FIGURE 4.5: Effect of spray carrier, spray adjuvants and ammonium salts on sethoxydim activity at 139.5 g $ai.ha^{-1}$ on oats

Agral 90 and Break-Thru at all sethoxydim rates and Bladbuff 5, when sethoxydim was applied at 139.5 g $ai.ha^{-1}$, were found to be less effective or did not differ significantly to sethoxydim without an adjuvant. Agral 90 inefficacy was previously reported by Harker (1992) who found that when Agral 90 was applied with sethoxydim at 100 $g.ha^{-1}$, it was not effective in increasing herbicide activity to control green foxtail [*Setaria viridis* (L.) Beauv.], wild oats, wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). O'Sullivan, O'Donovan & Hamman (1981) also reported that adding Agral 90 to glyphosate failed to enhance barley control, but in combination with AS, glyphosate activity was dramatically enhanced, especially at the higher spray volume. Agral 90, however, increased the efficacy of difenzoquat and fluazifop (Merritt, 1980; Plowman, Stonebridge & Hawtree, 1980). Agral 90 therefore can influence herbicide activity either favourably or unfavourably depending on the herbicide. This, is in agreement with the finding of Wanamarta *et al.* (1989b) who, after evaluating 190 surfactants concluded that the selection of an inferior adjuvant could result in less sethoxydim absorbed than without an adjuvant.

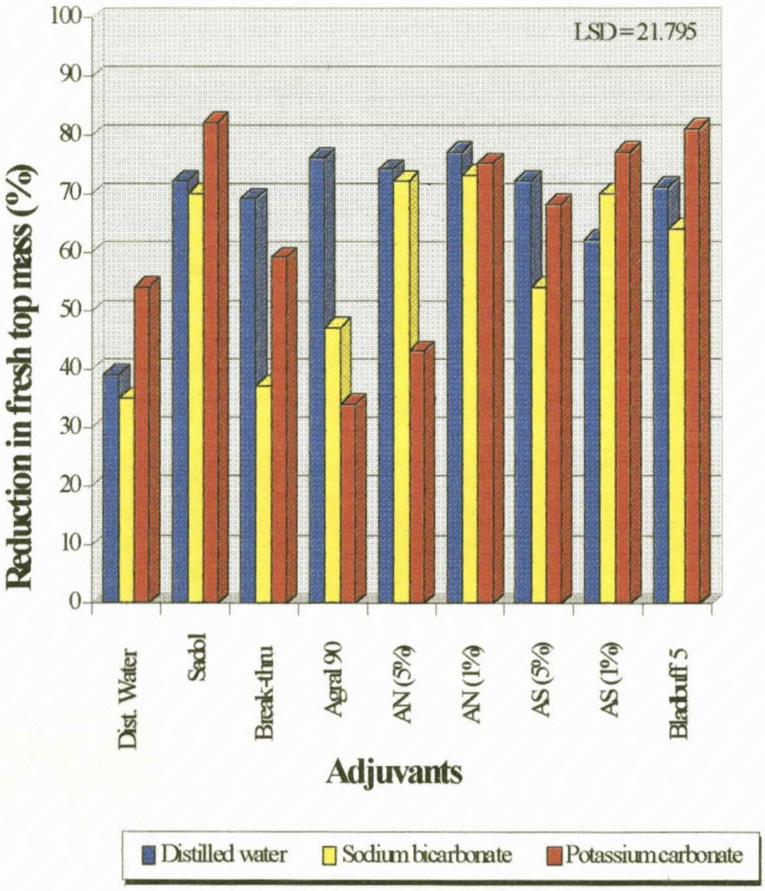

FIGURE 4.6: Effect of spray carrier, spray adjuvants and ammonium salts on sethoxydim activity at 186.0 g $ai.ha^{-1}$ on oats

Sadol, ammonium salts and Bladbuff 5 were found to be the most efficient adjuvants to increase efficacy of sethoxydim in the presence of sodium bicarbonate and potassium carbonate (Table 4.3 and Table 4.4), although the latter did not increase sethoxydim efficacy consistently, especially when sethoxydim was applied at 139.5 g $ai.ha^{-1}$.

Since Sadol was found to be the only adjuvant which consistently increased setoxydim efficacy at both sethoxydim rates this may allow for reduced rates of sethoxydim. Increased herbicide activity with methylated seed oils is consistent with results presented by Nalewaja & Skrzypczak (1986). The authors indicated that soybean [*Glycine max* (L.) Merr.], linseed (*Linum usatatissimum* L.), and sunflower (*Helianthus annus* L.) methylated oils together with an emulsifier were as effective as petroleum oils with emulsifier in enhancig sethoxydim activity, although sethoxydim absorption was more rapid with petroleum oils. In another study Nalewaja, Woznica & Manthey (1991) found that methylated seed oil enhanced green foxtail more than the other 9 adjuvants tested. Jordan, Vidrine, Griffin & Reynolds (1996) found that clethodim with Sun-It II, a methylated seed oil, and Dash, a petroleum oil adjuvant did not induce significant differences in enhancing the control of barnyardgrass and broadleaf signalgrass. Both adjuvants exceeded control from that of clethodim applied with other adjuvants even when the herbicide was applied at a rate as low as 70 $g.ha^{-1}$.

Ammonium salts were also found to enhance the efficacy of sethoxydim at both rates, although ammonium sulphate at 0.5% applied with sethoxydim at 139.5 g $ai.ha^{-1}$ in distilled water resulted in a negative response. Similar performance was also observed with ammonium nitrate when applied at 0.5% with sethoxydim at 186.0 g $ai.ha^{-1}$ in the presence of potassium carbonate. With the exception of these particular variations, the ammonium salts increased sethoxydim activity in general. This can allow for consideration of reduced rates of the herbicide, even at low ammonium concentrations. These data suggest that the ammonium salts, at 0.5% in the spray carrier, were adequate to overcome antagonism of sethoxydim activity on oats even at low herbicide rate, regardless of the antagonistic salt.

McKeague *et al.* (1986) reported that adding AS enhanced maize control with low sethoxydim rates but not with higher application rates. Nalewaja *et al.* (1994) also tested eight different ammonium salts and found that they generally enhanced sethoxydim activity and concluded that ammonium ions are important for sethoxydim efficacy. Wanamarta *et al.* (1989a) showed that if the spray solution contains a considerable amount of NH_4^+ supplied from adding diammonium sulfate, the antagonism of Na-bentazon on sethoxydim absorption could be overcome or prevented. The implications are that with excess NH_4^+ in the spray solution, NH_4-sethoxydim would be formed and the formulation of Na-sethoxydim, a less preferred form for foliar absorption, would be prevented.

TABLE 4.4: Interaction of sethoxydim rates, spray carrier, spray adjuvants and ammonium salts on oats[A]

Adjuvant	Adjuvant rate (%)	Herbicide rate	Fresh top mass reduction as affected by antagonistic salts (%)		
			None	Sodium bicarbonate	Potassium carbonate
None	-	139.5	19.0 gh	21.0 fgh	49.0 abcdefgh
Sadol	5.0	139.5	66.0 abcdef	71.0 abcde	68.0 abcde
Break-Thru	1.0	139.5	61.0 abcdefg	25.0 efgh	54.0 abcdefgh
Agral 90	1.0	139.5	54.0 abcdefgh	13.0 h	37.0 bcdefgh
Ammonium nitrate	0.5	139.5	67.0 abcdef	64.0 abcdef	64.0 abcdef
Ammonium nitrate	1.0	139.5	64.0 abcdef	63.0 abcdef	69.0 abcde
Ammonium sulphate	0.5	139.5	38.0 bcdefgh	66.0 abcdef	60.0 abcdef
Ammonium sulphate	1.0	139.5	62.0 abcdef	64.0 abcdef	61.0 abcdefg
Bladbuff 5	Colour change (pink) at pH 4.5	139.5	74.0 abcd	29.0 efgh	41.0 abcdefgh
None	-	186.0	39.0 bcdefgh	35.0 cdefgh	54.0 abcdefgh
Sadol	5.0	186.0	72.0 abcd	70.0 abcde	82.0 a
Break-Thru	1.0	186.0	69.0 abcde	37.0 bcdefgh	59.0 abcdefg
Agral 90	1.0	186.0	76.0 abc	47.0 abcdefgh	34.0 defgh
Ammonium nitrate	0.5	186.0	74.0 abcd	72.0 abcd	43.0 abcdefgh
Ammonium nitrate	1.0	186.0	77.0 ab	73.0 abcd	75.0 abcd
Ammonium sulphate	0.5	186.0	72.0 bc	54.0 abcdefgh	68.0 abcde
Ammonium sulphate	1.0	186.0	62.0 abcdef	70.0 abcde	77.0 ab
Bladbuff 5	Colour change (pink) at pH 4.5	186.0	71.0 abcde	64.0 abcdef	81.0 a

$LSD_T = 41.323$

[A]Means followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

Efficacious responses obtained by applying sethoxydim at 139.5 g ai.ha^{-1} with Sadol and ammonium salts confirms that the most consistent grass control can be achieved using methylated seed oil adjuvants and ammonium salts. Simultaneously, the use of these adjuvants when using water high in sodium or potassium, should minimize the antagonistic effects of the salts.

4.4 Effect of temperature and adjuvants on sethoxydim activity

The adjuvants tested in this experiment were divided into two groups. As there was a significant interaction in Experiment 1 and not in Experiment 2, sethoxydim treatment data were averaged separately across each experiment. For the former experiment, since the interaction was significant (Table 4.6), the main effects (Table 4.5) were discussed to show their tendency.

In experiment 1, averaged across all treatment factors, sethoxydim activity increased as the temperature was raised from 15 to 35°C, but there were not significant differences when temperature was varied between 25 and 35 °C (Table 4.5). Although these data did not differ from those obtained by Nalewaja *et al.* (1994) and Hartzler & Foy (1983b), they contrast the results of Wills (1984) and Rhodes & Coble (1983).

Nalewaja et al. (1994) reported that increasing temperature from 20 to 30°C did not influence sethoxydim activity on yellow foxtail [*Setaria lutescens* (L.) Beauv.], while Hartzler & Foy (1983b) reported that sethoxydim control of large crabgrass [*Digitaria sanguinalis* (L.) Scop.] was similar at 16, 24, and 32°C. In turn, Wills (1983) and Rhodes & Coble (1983) reported increased sethoxydim activity when the temperature was raised form 18 to 35°C on bermudagrass. These differences may be attributable to the different plant species used and the different experimental methods employed. While in this study, relative humidity (RH) was constant (45%) at all the different temperatures tested, the mentioned above authors varied it from 40 to 100%. Hence, as was found with 2,4-D and dalapon by Clor, Crafts & Yamagechi (1962) and Prasad, Foy & Crafts (1967), high RH may increase herbicide absorption through hydrated cuticles and translocation.

TABLE 4.5: Effect of temperature and adjuvants on oat control with sethoxydim at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M[A]

Treatment factor	Fresh top mass reduction
Temperature	**(%)**
35°C	54.00 a
25°C	53.00 a
15°C	39.00 b
Spray adjuvant	
Ammonium nitrate (0.5%) + Sodium bicarbonate	62.00 a
Break-Thru	58.00 a
Sadol	57.00 ab
Ammonium nitrate (1%) + Sodium bicarbonate	57.00 ab
Ammonium nitrate (1%)	53.00 ab
Sadol + Sodium bicarbonate	42.00 bc
Break-Thru + Sodium bicarbonate	34.00 cd
None	24.00 d

LSD_T for temperature = 7.167

LSD_T for spray adjuvants = 15.266

[A]Data for each treatment factor are pooled over all levels of other factors. Means within the same treatment factor followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

Analysis of variance is indicated in Table 8 of Appendix A and data in Table 5 of Appendix B.

Sethoxydim efficacy was greatly enhanced by all adjuvants tested when applied in distilled water. Sethoxydim efficacy in the presence of sodium bicarbonate was lower when compared with distilled water without added salt. (Table 4.6 and Figure 4.7). Ammonium nitrate was the only adjuvant which maintained efficacy of sethoxydim consistency with or without added salt at both rates. This is in agreement with Nalewaja *et al.* (1989) who reported that ammonium salts increase sethoxydim absorption. Again, these findings confirm results previously reported in 4.1 that sodium bicarbonate reduced sethoxydim efficacy.

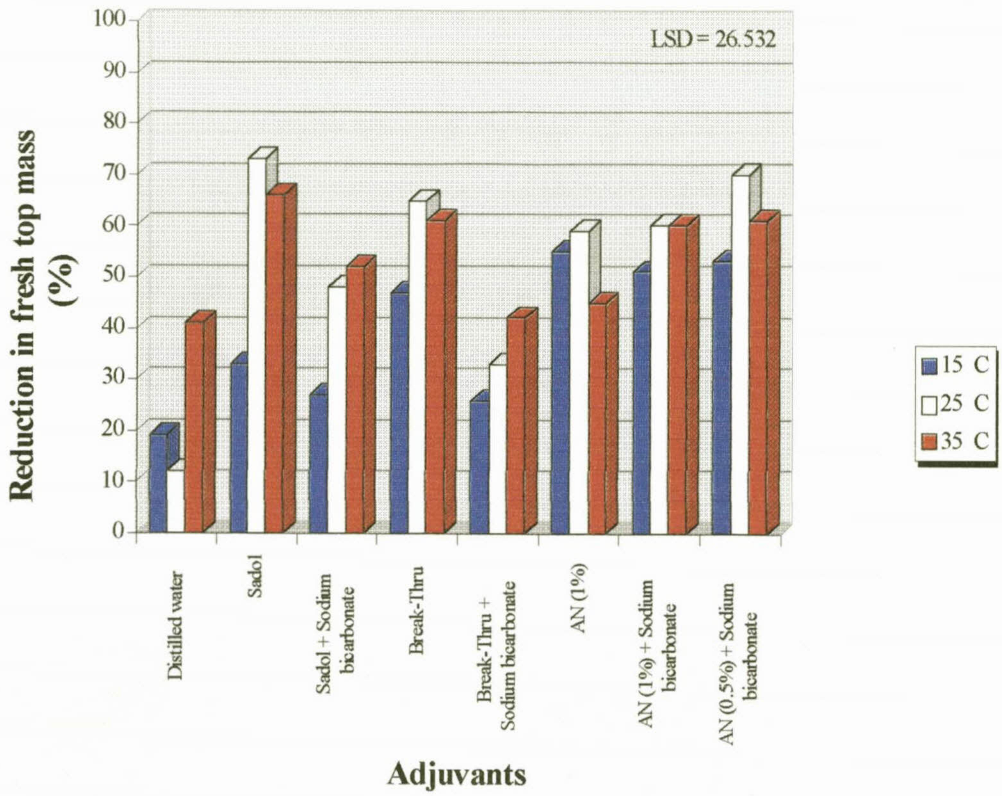

FIGURE 4.7: Effect of temperature, adjuvants and ammonium salts on oats control with Sethoxydim at 139.5 g $ai.ha^{-1}$ in the presence of sodium bicarbonate at 0.03 M

Ammonium nitrate at both rates, with or without added salt, demonstrated to be the most effective adjuvant in overcoming sodium bicarbonate antagonism of sethoxydim regardless of the temperature used. Ammonium nitrate did not differ significantly from Sadol and Break-Thru when applied with sethoxydim without added salt (Table 4.5).

Increased sethoxydim activity with added ammonium nitrate, irrespective of the temperature, may be related to NH_4-sethoxydim formation which was proved by (Wanamarta *et al.*, 1993).

The results in table 4.6 and Figure 4.7 indicate that the majority of the adjuvants added to sethoxydim in distilled water without salt were more effective at 25°C than at 15°C and

35°C. Reduced oat fresh top mass at 35°C when compared to 25°C, may be the result of herbicide volatilization from the leaf surface, while at 15°C decreased membrane fluidity at this temperature would have retarded sethoxydim absorption, since membrane fluidity decreases as the temperature is lowered (Hale & Orcutt, 1987).

TABLE 4.6: Interaction of temperature and adjuvants and ammoniumsalts on oat control with sethoxydim at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M[A]

Adjuvant	Adjuvant rate (%)	Fresh top mass reduction as affected by temperature (%)		
		15°C	25°C	35°C
None	-	19.00 fg	12.00 g	40.00 bcdef
Sadol	5.0	33.00 cdefg	73.00 a	66.00 ab
Sadol + Sodium bicarbonate	5.0	27.00 defg	48.00 abcde	52.00 abcde
Break-Thru	1.0	47.00 abcde	65.00 ab	61.00 ab
Break-Thru + Sodium bicarbonate	1.0	26.00 efg	33.00 cdefg	42.00 abcdef
Ammonium nitrate (1%)	1.0	55.00 abc	59.00 abc	45.00 abcdef
Ammonium nitrate (1%) + Sodium bicarbonate	1.0	51.00 abcde	60.00 ab	60.00 ab
Ammonium nitrate (0.5%) + Sodium bicarbonate	0.5	53.00 abcd	70.00 a	61.00 ab

$LSD_T = 26.532$

[A]Data followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

In Experiment 2, all adjuvants tested did not increase sethoxydim phytotoxicity significantly. The lack of significant differences on oat fresh top mass reduction observed in this experiment probably reflects the big, five- to seven-leaf plants, and sometimes 2 to three tillers compared to 4-leaf plants used in Experiment 1. This was caused by a technical problem in the growth chamber used to obtain different temperatures in this study. Hence, differences in application stages between the two experiments could have caused the differential responses observed.

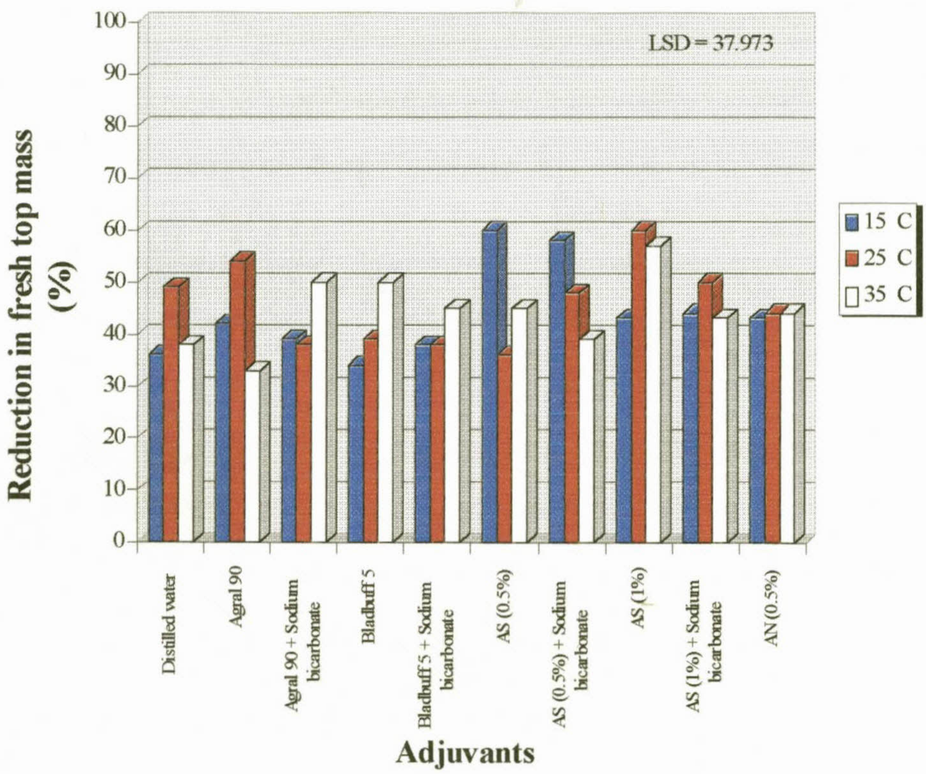

FIGURE 4.8: Effect of temperature, adjuvants and ammonium salts on oat control with Sethoxydim at 186.0 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M

Ammonium sulphate was the most effective adjuvant particularly at 15°C (Table 4.7 and Figure 4.8). This effect was however non-significant (Table 4.8). Agral 90 was ranked second following ammonium sulfate, although unlike AS, was more effective at 25°C without added salt and in the presence of sodium bicarbonate was found more effective at 35°C. The same was applied to Bladbuff 5 without added salt.

TABLE 4.7: Effect of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M[A]

Treatment factor	Fresh top mass reduction(%)
Temperature	
25°C	46.0 a
35°C	44.0 a
15°C	44.0 a
Spray adjuvant	
Ammonium sulfate (1%)	54.00 a
Ammonium sulfate (0.5%) + Sodium bicarbonate	48.00 a
Ammonium sulfate (0.5%)	47.00 a
Ammonium sulfate (1%) + Sodium bicarbonate	46.00 a
Ammonium nitrate (0.5%)	44.00 a
Agral 90	43.00 a
Agral 90 + Sodium bicarbonate	42.00 a
Bladbuff 5	41.00 a
None	41.00 a
Bladbuff 5 + Sodium bicarbonate	40.00 a

LSD_T for temperature = 7.565

LSD_T for spray adjuvants = 18.802

[A]Data for each treatment factor are pooled over all levels of other factors. Means within the same treatment factor followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

¯Analysis of variance is indicated in Table 9 of Appendix A and data in Table 6 of Appendix B.

The slight enhancement of oat reduction in fresh top mass with addition of AS to sethoxydim regardless of the temperature, could be due to the same action as ammonium nitrate. Ammonium ions could have reacted with sethoxydim to form NH_4-sethoxydim which is readly absorbed by plants.

TABLE 4.8: Interaction of temperature, adjuvants and ammonium salts on oat control with sethoxydim at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M[A]

Adjuvant	Adjuvant rate (%)	Fresh top mass reduction as affected by temperature (%) 15°C	25°C	35°C
None	-	36.0 a	49.0 a	38.0 a
Agral 90	1.0	42.0 a	54.0 a	33.0 a
Agral 90 + Sodium bicarbonate	1.0	39.0 a	38.0 a	50.0 a
Bladbuff 5	colour change	34.0 a	39.0 a	50.0 a
Bladbuff 5 + Sodium bicarbonate	colour change	38.0 a	38.0 a	45.0 a
Ammonium sulfate	0.5	60.0 a	36.0 a	45.0 a
Ammonium sulfate + Sodium bicarbonate	0.5	58.0 a	48.0 a	39.0 a
Ammonium sulfate	1.0	43.0 a	60.0 a	57.0 a
Ammonium sulfate + Sodium bicarbonate	1.0	44.0 a	50.0 a	43.0 a
Ammonium nitrate		43.0 a	44.0 a	44.0 a

LSD_T = 37.973

[A] Means followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

From these data one can speculate that, had treatments been applied in time, ammonium sulphate, would have enhanced sethoxydim activity as did ammonium nitrate in this study, as was reported by several researchers (Chow & MacGregor, 1983; Jordan & York, 1989; York et al., 1990; Harker, 1995) irrespective of the temperature. The same is also applicable for the mixture of Agral 90 and ammonium salts, as was found for glyphosate (O'Sullivan *et al.*, 1981).

4.5 Carrier volume

Sethoxydim activity on oat increased from 55 to 71% as carrier volume was decreased from 875 to 175 $\ell.ha^{-1}$ (Table 4.9). Oat control by increasing herbicide rates increased inconsistently, particularly in the presence of sodium bicarbonate and potassium carbonate in distilled water (Table 4.9). Thus, when both rates were averaged across all variables tested it was not found to be significantly different.

The lack of enhanced herbicide activity with increasing herbicide rates in this experiment contradict results previously found in this study (point 4.4) and those reported by several researchers (O'Sullivan, O'Donovan & Hamman, 1981; Bulher & Burnside, 1984; Smeda & Putnam, 1989). The differential response could be related to the fact that, whereas those authors were increasing herbicide rates by doubling it, in this study herbicide rates were increased by 25%.

When averaged over all treatment factors, oat fresh top mass reduction by the addition of sodium bicarbonate, potassium carbonate, even without added salt, did not differ significantly (Table 4.9). Potassium carbonate antagonised sethoxydim activity slightly more than sodium bicarbonate as was found previously in 4.1 and as was found by other researchers (Nalewaja *et al.*, 1989; De Villiers, 1993). This could have been caused by the dilution effect at high spray volumes, which might have reduced the detrimental effect of salts and high concentrations of active ingredients per droplet could have overcome it at low volume.

TABLE 4.9: Effect of carrier volume and herbicide rate on sethoxydim activity on oats in the presence of sodium bicarbonate and potassium carbonate at 0.03 M[A]

Treatment factor	Fresh top mass reduction (%)
Spray carrier	
None	65.0 a
Sodium bicarbonate	63.0 a
Potassium carbonate	62.0 a
Herbicide rate ($\ell.ha^{-1}$)	
0.75	63.0 a
1.0	64.0 a
Carrier volume	
875	55.0 a
700	60.0 ab
525	64.0 bc
350	67.0 dc
175	71.0 d

LSD_T for spray carrier = 3.433

LSD_T for herbicide rate = 2.336

LSD_T for spray carrier = 5.176

[A]Data for each treatment factor are pooled over all levels of other factors. Means within the same treatment factor followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

—Analysis of variance is indicated in Table 10 of Appendix A and data in Table 7 of Appendix B.

Although, the spray carrier by spray volume interaction and herbicide rates by spray volume interaction were found none significant, the interaction of the three factors was significant (Table 4. 10 and Figure 4.9 and 4.10). Sethoxydim activity increased by reducing spray volume without added salt at both rates when compared with sodium bicarbonate and potassium carbonate, which resulted in the lowest fresh top mass reduction (42%) at 875 ℓ.ha^{-1}.

TABLE 4.10: Interaction of carrier volume and herbicide rate on sethoxydim activity on oat in the presence of sodium bicarbonate and potassium carbonate at 0.03 M[A]

		Fresh top mass reduction as affected by antagonistic salts (%)		
Herbicide rate (g ai.ha^{-1})	**Carrier volume (ℓ.ha^{-1})**	**None**	**Sodium bicarbonate**	**Potassium carbonate**
139.5	175	72.0 def	73.0 ef	65.0 bcdef
139.5	350	68.0 bcdef	63.0 bcdef	66.0 bcdef
139.5	525	65.0 bcdef	62.0 bcdef	61.0 bcdef
139.5	700	60.0 bcdef	52.0 ab	66.0 bcdef
139.5	875	57.0 bcde	54.0 abc	56.0 abcd
186.0	175	74.0 f	73.0 ef	70.0 cdef
186.0	350	66.0 bcdef	69.0 cdef	69.0 cdef
186.0	525	63.0 bcdef	68.0 bcdef	61.0 bcdef
186.0	700	60.0 bcdef	68.0 abcdef	55.0 abc
186.0	875	43.0 a	63.0 abcdef	54.0 abc

LSD_T = 18.712

[A]Means followed by the same letter do not differ significantly according to Tukey's studentized range test at 5% probability level.

Increasing herbicide rates in the presence of sodium bicarbonate, increased oat fresh top mass reduction from 66 to 72% at 175 ℓ.ha^{-1}. When increasing volume from 350 to 525 ℓ.ha^{-1} and from 700 to 875 ℓ.ha^{-1} fresh top mass reduction was the same regardless of the herbicide rate. When sethoxydim was raised from 139.5 to 186.0 g ai.ha^{-1} at 700 ℓ.ha^{-1} fresh top mass decreased from 66 to 55%.

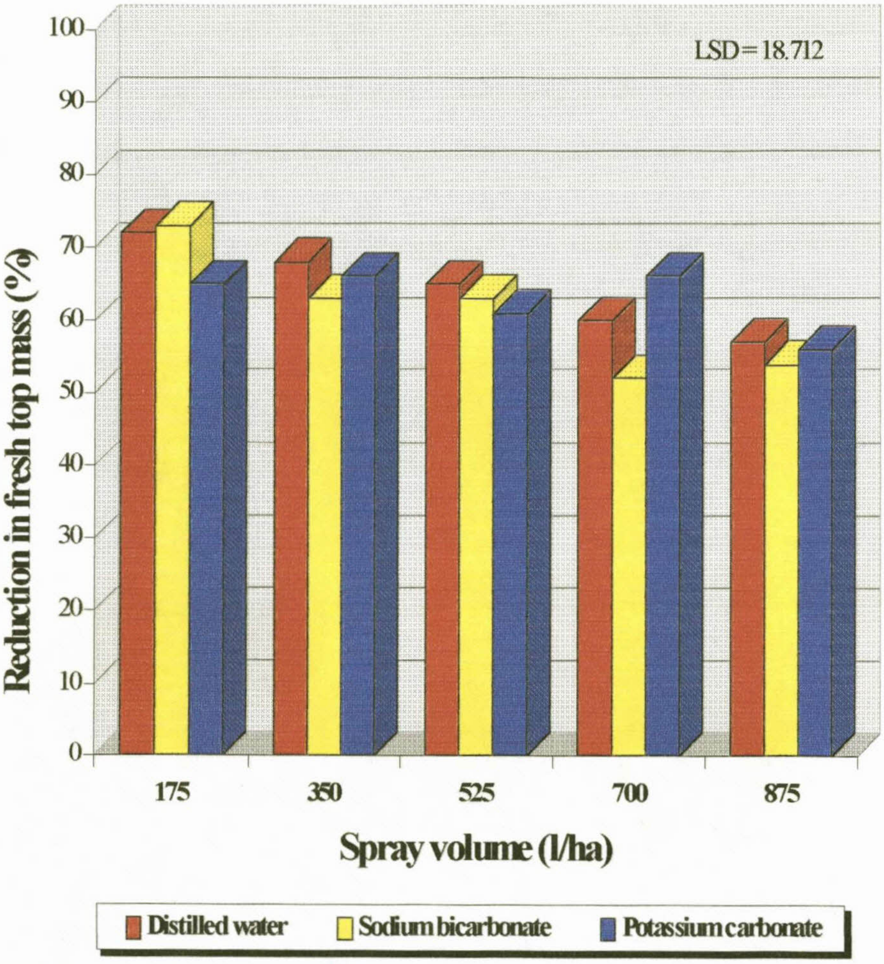

FIGURE 4.9: Effect of carrier volume, sodium bicarbonate and potassium carbonate at 0.03 M on sethoxydim activity at 139.5 g ai.ha^{-1}

Oat fresh top mass, by increasing herbicide rate from 139.5 to 186.0 g ai.ha^{-1}, in the presence of potassium carbonate, increased from 72 to 74% at 175 ℓ.ha^{-1}. An increase in carrier volume to 350 ℓ.ha^{-1} and above reduced fresh top mass reduction.

A linear regression relationship between mass reduction caused by sethoxydim activity and carrier volume indicated a significant (F_c = 2558,273, P > F_t = 1.70192) linear effect with the fresh top mass decreasing as the carrier volume of sethoxydim increased (Figure 4.11). This confirms previous reports (Sandberg *et al.*, 1978; Cranmer & Duke, 1983; Johnston & Weeb, 1983; Smeda & Putnam, 1989; McWhorther & Hanks, 1993), who illustrated increased phytotoxicity of postemergent graminicides when applied in low water volumes.

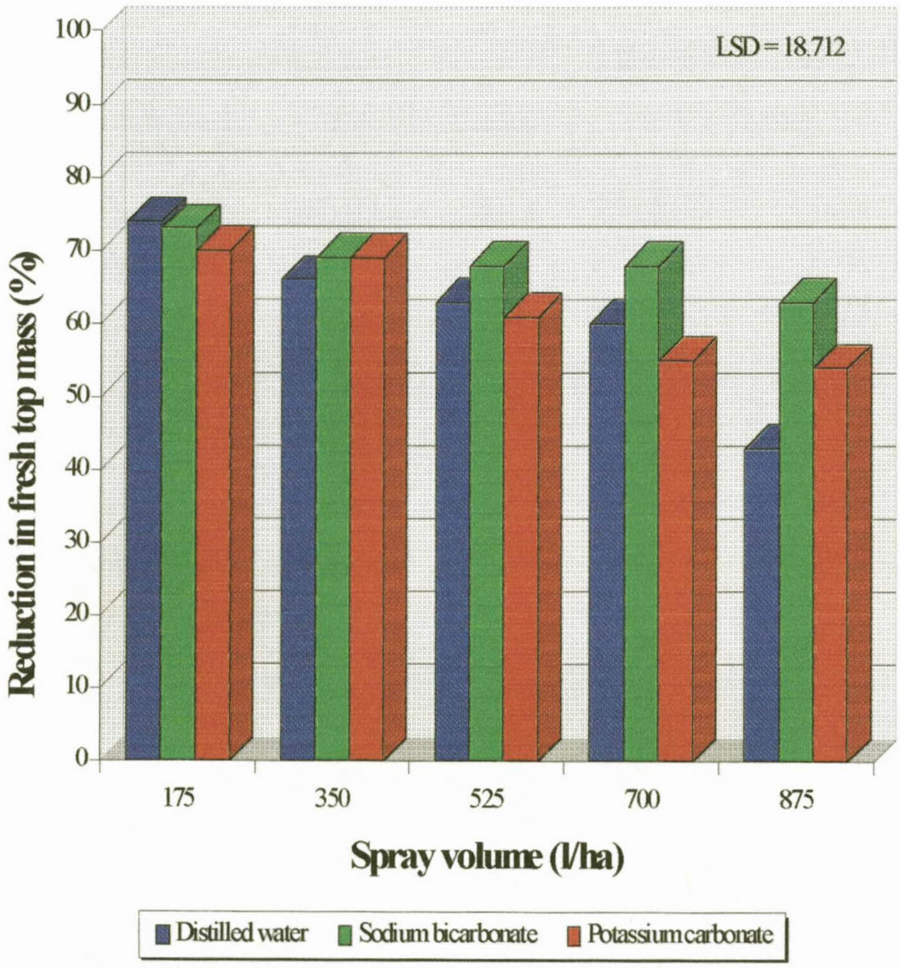

FIGURE 4.10: Effect of carrier volume, sodium bicarbonate and potassium carbonate at 0.03 M on sethoxydim activity at 186.0 g $ai.ha^{-1}$

Averaged across all treatment variables, carrier volumes of 175 and 350 $\ell.ha^{-1}$ did not differ significantly. Similar results were also found when increasing carrier volumes from 350 to 525, 525 to 700, and from 700 to 875 $\ell.ha^{-1}$ (Table 4.9). Although, 175 $\ell.ha^{-1}$

resulted in the greatest reduction in oat fresh mass when compared to the other volumes tested. These results are unlike those found by Sandberg *et al.* (1978), who reported that increasing carrier volume above 190 $\ell.ha^{-1}$ induced no significant differences. These contrasting results might be due to the high herbicide rates used by those authors.

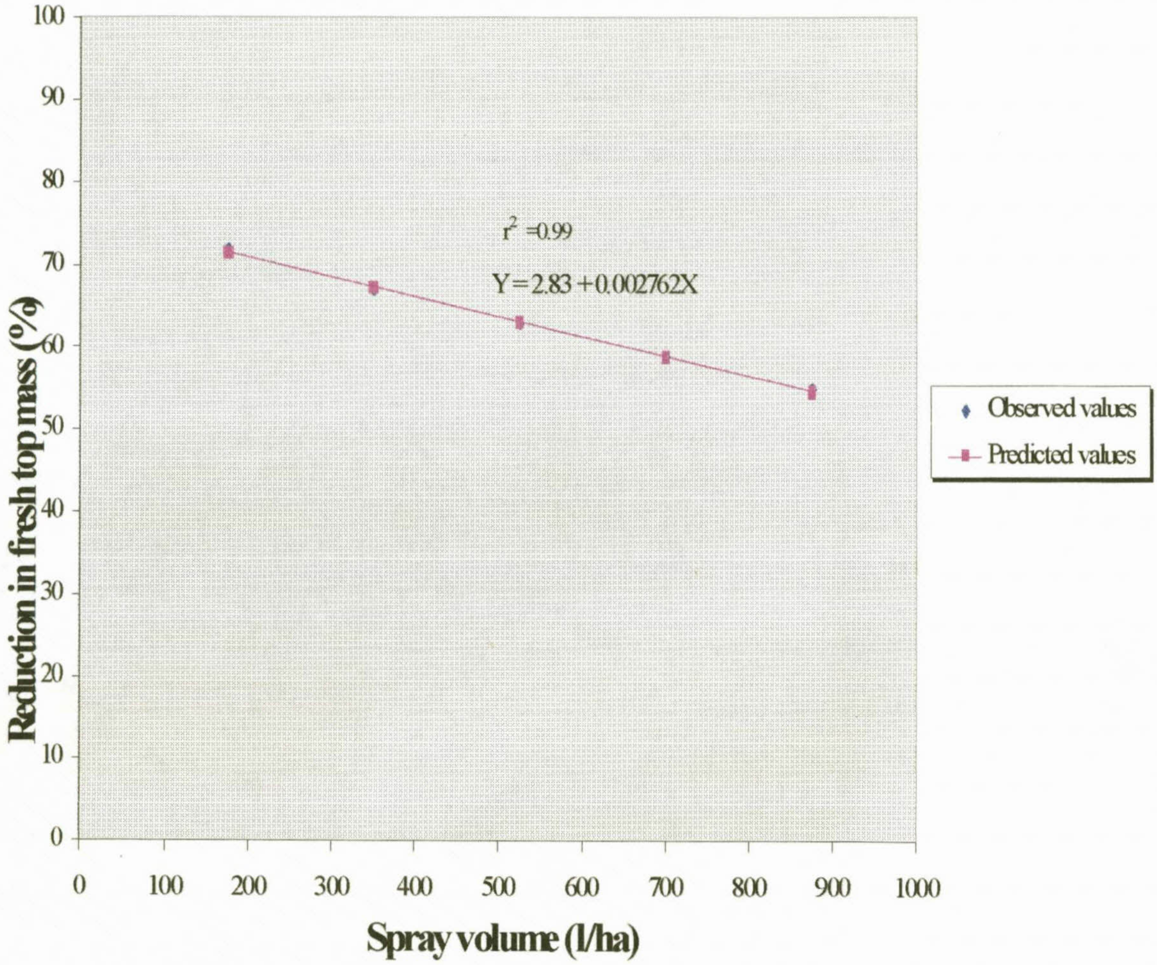

Figure 4.11: Relationship between carrier volume and herbicide rates on sethoxydim activity on oats in the presence of sodium bicarbonate and potassium carbonate at 0.03 M

Increasing herbicide efficacy by applying low volumes, seem to be a possible method of overcoming antagonistic salts in spray carriers. Buhler & Burnside (1984) attributed increased herbicide performance with decreased carrier volumes to higher herbicide concentration per droplet, which allows for more herbicide to be absorbed for each unit of spray solution retained on the leaf surface.

Chandrasena & Sagar (1989) illustrated that spraying herbicides at high carrier volume may affect the loss of herbicide through runoff from plant surfaces. In that study, quackgrass foliage at a volume of 800 $\ell.ha^{-1}$ was found to be nearly 100% wet but, much of the spray ran off the wet leaves. However, according to the same authors, although the 100 $\ell.ha^{-1}$ carrier volume did not wet more than 30% of the target foliage, enhanced quackgrass control compared to 800 $\ell.ha^{-1}$ was observed.

From these findings, results found in this study clearly indicate that grass control with sethoxydim using low herbicide rates and carrier volume of 175 $\ell.ha^{-1}$ can be used successfully. The use of this carrier volume could also reduce the time, herbicide costs, soil compaction, and fuel requirements of the herbicide application.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

Waters from different parts of the world, countries and even from the same region differ in their ability to antagonise herbicide performance depending on the concentration and composition of the total dissolved salts, particularly ions present in water used for herbicide applications. Therefore, in each agro-ecological zone, herbicide performance should be ascertained according to the prevalent environmental conditions and salts present in water used as spray carriers.

In order to assist in the formulation of future strategies to reduce the impact of salts, temperature, spray solution pH and ions present in spray carrier water, the beneficial effect of reduced spray volume, adjuvants and ammonium salts at low sethoxydim rates were investigated in this study.

Tomato and oat plants were used as biossay species for sethoxydim phytotoxicity in pot experiments conducted under controlled conditions in a glasshouse at the Faculty of Agriculture, University of the Orange Free State, Bloemfontein, South Africa.

In all experiments conducted, tomato plants did not show any sign of injury to negative growth. Thus, data pertaining to tomato experiments were not presented. The lack of activity of sethoxydim to negative growth on tomato indicates that this herbicide is safe for this crop, meaning that it can be applied for postemergence grass weed control without crop injury. Though, further investigations on tomato yield are suggested.

Both sodium bicarbonate and potassium carbonate were antagonistic to sethoxydim activity on oats. The antagonism of sethoxydim activity by potassium carbonate was greater than that from sodium bicarbonate. However, the prevalence of the latter salt in water indicates that its presence in the spray water with sethoxydim should be taken into account to achieve effective grass weed control.

The presence of sodium ions in spray water, particularly when the spray solution pH is higher than 6.5, was also to be taken into account since, as found previously by Nalewaja *et al.* (1994) and confirmed in this study, pH itself does not influence sethoxydim phytotoxicity directly. However, the associated ions in the spray carrier seems to be important. This is also applicable to the presence of Li, K, Cs, Ca and Mg salts (Wanamarta *et al.*, 1989b).

Sadol, ammonium nitrate and ammonium sulfate are beneficial adjuvants to increase sethoxydim activity when water with low sodium and potassium salts is not available, even when applied at low rates. Bladbuff 5 was ranked in fourth position, since at low herbicide rates such as 139.5 g $ai.ha^{-1}$ it was not consistent in enhancing sethoxydim performance. Agral 90 and Break-Thru were less effective in enhancing sethoxydim activity. This suggest that it is important to screen and identify appropriate adjuvants for each individual usage to obtain maximum herbicide activity.

However, when adjuvants and ammonium salt effectiveness were tested under various air temperatures, ammonium nitrate demonstrated to be more effective in enhancing sethoxydim phytotoxicity activity compared to Sadol and Break-Thru. These two adjuvants were effective only when the air temperature was 25 and 35°C respectively as compared to 15°C. In Experiment 2, ammonium sulfate also enhanced sethoxydim phytotoxicity more than the adjuvants with which it was tested, although a growth chamber technical problem did not allowed full potential exploitation of this last set of additives.

Bearing the predicted scarcity of water in the southern african region in mind, it was illustrated in this study, especially in semi-arid region where the availability of water is a limiting factor for agriculture production and ions such as sodium, potassium, calcium, bicarbonate and carbonate in the water available for agriculture are higher, that the use of reduced carrier volume should be adhered to. It was illustrated that reduced carrier volume, increases sethoxydim activity when the spray volume was reduced from 875 to 175 $\ell.ha^{-1}$. This could lower input cost where water is transported over relatively greater distances over difficult terrain to the point of use.

The potential role of spray carrier, adjuvants and ammonium salts in southern Africa region still need to be investigated. The studies conducted are intended to be a contribution for future research in this area. More glasshouse, particularly, field experiments are required in close collaboration with farmers in on-farm basis to help formulate recommendations on how to improve weed control with herbicides at lower costs and at the same time, in a sustainable manner, i. e., not polluting the environment.

SUMMARY

The effects of spray carrier, pH, adjuvants and ammonium salts, environmental factors, and spray volume on sethoxydim {2-[1-ethoxyimino-butyl]-5-[2-(etylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} activity in a glasshouse on tomato (*Lycopersicum esculentum* L. cv. Star 9001) and oats (*Avena sativa* L. cv. SSH 241) were studied.

Sodium bicarbonate, potassium carbonate and spray solution pH were antagonistic to sethoxydim phytotoxicity. Spray solution pH and ions present were antagonistic to sethoxydim phytotoxicity only when the spray carrier pH exceeded 6.5.

Sadol and ammonium salts (ammonium nitrate and ammonium sulfate) were equally effective in enhancing sethoxydim activity regardless of the presence of antagonistic salts. Bladbuff 5 was moderately effective in the enhancement of sethoxydim phytotoxicity only when sethoxydim was applied at 186.0 g ai.ha^{-1} and not at 139.5. Addition of Agral 90 and Break-Thru were not beneficial, or were both of little value as adjuvants with sethoxydim.

Sethoxydim applications at temperatures ranging between 25 and 35°C were equally more effective as compared to 15°C. However, Sadol, Break-Thru and ammonium salts were most effective in enhancing sethoxydim performance at 25°C than at 15 or 35°C.

When averaged across sethoxydim rates and the presence of sodium bicarbonate and in potassium carbonate in the spray solution, oat fresh top mass reduction increased as carrier volume was decreased from 875 to 175 ℓ.ha^{-1}.

In all the experiments conducted, tomato plants did not show any injury to negative growth suggesting that sethoxydim may be considered for control of grass weeds in tomatoes.

REFERENCES

ANONYMOUS, 1983. Herbicide handbook of the Weed Science Society of America. 5th ed. Weed Science Society of America. Champaign. Illinois.

ANONYMOUS, 1986. Management of the water resources of the Republic of South Africa. Department of Water Affairs. Pretoria.

ANONYMOUS, 1993. Managing South Africa's environment resources: A possible new approach. Department of Environment Affairs. Pretoria. South Africa.

ANONYMOUS, 1997a. Southern Africa's food supply threatened by water scarcity. *Official Newsletter of the National Department of Agriculture*. No. 24.

ANONYMOUS, 1997b. Guidelines for small grain production in the summer rainfall region. (ARC) Small-Grain Institute. Bethlehem.

AHMADI, M.S, HARDELIE, L.C. & WICKS, G.A. 1980. Effect of growth stage and water stress on barnyardgrass (*Echinochloa crus-gali*) control and on glyphosate absorption and translocation. *Weed Sci.* 28, 277-282.

AKOBUNDU, I.O., 1979. Weed control in Nigeria.*PANS.* 25, 287-298.

AKOBUNDU, I.O., 1991. Weeds in human affairs in Sub-Saharan Africa: Implications for sustainable food production. *Weed Tech.* 5, 680-690.

ASHTON, F.M. & MONACO, T.J., 1991. Weed Science: Principles and practice. 3rd ed. John Wiley & Sons, New York.

BALLANCE, R.C. & OLSON, B.H., 1980. Water quality and health. In A.M. Gower. (ed.). Water quality in catchment ecosystems. John Wiley & Sons, New York.

BAKER, F.W.G., 1991. Herbicide resistance. In F.W.G. Baker & P.J. Terry (ed.). Tropical grassy weeds. CASAFA Report Series No. 2. *CAB*. Bristol.

BAUR, J.R., BOVEY, R.W. & RILEY, I., 1974. Effect of pH on foliar uptake of 2,4,5-T-1 ^{14}C. *Weed Sci.* 22:481-486.

BAUR, J.R., BOVEY, R. W. & VEECH, J.A., 1977. Growth responses in sorghum and wheat induced by glyphosate. *Weed Sci.* 25, 238-240.

BAUR, J.R., 1979. Reduction of glyphosate-induced tillering in sorghum (*Sorghum bicolor*) by several chemicals. *Weed Sci.* 27, 69-73

BAYER, D.E. & LUMB, J.M., 1973. Penetration and translocation of herbicides. In W. Van Valkenburg (ed.). Pesticide formulations. Marcel-Dekker, New York.

BECKET, H. T.; STOLLER, E. W. & BODE, L. E. 1992. Quizalofop and sethoxydim activity as affected by adjuvants and ammonium fertilizers. *Weed Sci.* 40, 12-19.

BESTE, C.E., RADKE, R.O., HUMBURG, N.E., RIGGLEMAN, J.D., KEMPEN,H.M., STRITZKE, J.F. & MILLER, G.R., 1983. Herbicide handbook. 5th ed. Weed Sci. Soc. Am. Champaign IL.

BLACKMAN, G.E. & ROBERTSON-CUNINGHAME, R.C. 1953. The influence of pH on the phytotoxicity of 2,4-Dichlorophenoxyacetic acid to Lemna minor. *New Phytol.* 52, 71-75.

BLACKSHAW, R.E. & HARKER, K.N., 1992. Combined postemergence grass and broadleaf weed control in canola (*Brassica napus*). *Weed Tech.* 6, 892-897.

BOVERY, R.W., STERMER, R.A. & BOUSE, L.S., 1991. Spray deposition of clopyralid on honey mesquite (*Prosopis glandulosa*). *Weed Tech.* 5, 499-503.

BREWESTER, B.D. & APPLEBY, A.P., 1990. Effect of rate, carrier volume and surfactant on imazamethabenz efficacy. *Weed Tech.* 4, 291-293.

BRIDGES, D. C., 1989. Adjuvant and pH effects on sethoxydim and clethodim activity on rhizome johnsongrass. *Weed Tech.* 3, 615-620.

BUHLER, D. D. & BURNSIDE, O. C., 1983. Effect of water quality, carrier volume and acid on glyphosate phytotoxicity. *Weed Sci.* 31, 163-169.

BUHLER, D. D. & BURNSIDE, O. C., 1984. Effect of application factors on postemergence phytotoxicity of fluazifop-butyl, haloxyfop-methyl, and sethoxydim. *Weed Sci.* 32, 574-583.

CAMPBELL, J.R. & PENNER, D., 1982. Compatibility of diclofop and BAS 9052 with bentazon. *Weed Sci.* 30, 458-462.

CAMPBELL, J. R. & PENNER, D., 1985. Abiotic transformation of sethoxydim. *Weed Sci.* 33, 435-439.

CHANDRASENA, N. R. & SAGAR, G.R., 1989. Fluazifop toxicity to quackgrass (*Agropyron repens*) as influenced by some application factors and site of application. *Weed Sci.* 37, 790-796.

CHERNICKY, J. P.; GOSSET, B. J., & QUISENBERRY, V. L., 1981. Factors influencing the response of annual grasses to BAS-9052 and RO-13-8895. *Proc. South. Weed Sci. 34:97*

CHERNICKY, J. P., GOSSET, B. J. & MURPHY, T.R. 1984. Factors influencing control of annual grasses with sethoxydim or RO-13-8895. *Weed Sci.* 32, 174-177.

CHOW, P.N.P. & MCGREGOR, A.W., 1983. Effect of ammonium sulfate and surfactants on activity of the herbicide sethoxydim. *J. Pestic. Sci.* 8, 519-528.

CLOR, M.A., CRAFTS, A.S. & YAMAGECHI, S., 1962. Effect of high humidity on translocation of foliar-applied labeled compounds in plants. Part 1. *Plant Physiol.* 37, 609-617.

COBB, A., 1992. Herbicides and plant physiology. *Chapman and Hall.* London.

COURDERCHET, M. & RETZLAFF, G. 1990. Bentazon-sethoxydim antagonism: The role of ATP and plasma membrane ATPase. *Pest. Sci.* 30, 415-460.

COURDERCHET, M. & RETZLAFF, G. 1991. The role of the plasma membrane ATPase in bentazon-sethoxydim antagonism. *Pest. Sci.* 32, 295-306.

CRAFTS, A.S., 1953. Herbicide, their absorption and translocation. *J. Agr. Food Chem.* 1, 51-55.

CRAFTS, A.S., 1956. Translocation of herbicides I. The mechanism of translocation: Methods of study with 14C-labeled 2,4-D. *Hilgardia.* 26, 287-334.

CRANMER, J. R. & DUKE, W. B. 1983. Controlled droplet application of fluazifop and sethoxydim for annual and perennial weed control. *Abst. Weed Sci. Soc. Am. p.* 23-24.

DE RUITER, H. VERBEEK, M.A.M. & UFFING, A.J.M., 1994. Influence of ammonium sulphate and two surfactants on the phytotoxicity and uptake of glyphosate. *Med. Fac. Landbouww. Univ. Gent.* 59/3b, 1403-1408.

DE VILLIERS, B. L. & DU TOIT, D., 1993. Chemical composition of carrier water influences glyphosate efficacy. *S. Afr. J. Plant Soil.* 10 (4), 178-182.

DE VILLIERS, B. L., 1994. Salts in carrier water affect tralkoxydim activity. *S. Afr.J. Plant Soil.* 11 (4), 186-188.

DE VILLIERS, B. L., LINDEQUE, R.C. & SMIT, H.A., 1997. Optimizing glyphosate performance with adjuvants. *S. Afr. J. Plant Soil.* 14(4), 146-148.

FOWLER, R.H., 1981. Development of a weed control system for small maize farmers in Swaziland. In H. A. Van de Venter & M. Mason (ed.). Proceedings of the Fourth National Weeds Conference of South Africa. Cape Town. A.A. Balkema. Rotterdam.

FOY, C.L, 1962. Penetration and initial translocation of 2,2-dichloropropionic acid (dalapon) in individual leaves of *Zea mays*. *Weed.* 10, 35-39.

FOY, C. L., 1993. Progress and development in adjuvant use since 1989 in USA. *Pest Sci.* 38, 2-3, 65-67.

FRIESEN, G. H & HALL, D. A. 1990. Improving the efficiency of sethoxydim in flax. *Weed Tech.* 4, 749-753.

FUGGLE, R.F. & RABIE, M.A.,1992. Environmental management in South Africa. Juta & Co Ltd. Cape Town.

GALVIN, R.M., 1996. Ocurrence of metals in waters: An overview. *Water SA.* 22 (1), 7-18.

GERWICK, B.C.; TANGUAY, L.D. & BURROUGHS, F.G., 1990. Differential effects of UAN on antagonism with bentazon. *Weed Tech.* 4, 620-624.

GOWER, A.M., 1980. Water quality in catchment ecosystems. John Wiley & Sons Ltd, London.

GREEN, J.M., 1989. Herbicide antagonism at the whole plant level. *Weed Tech.* 3, 217-226.

GRICHAR, W.J., 1991. Sethoxydim and broadleaf herbicide interaction effects on annual grass control in peanuts (*Arachis hypogea*). *Weed Tech.* 5, 321-324.

HAGEN, J. L. & KREBS, P. J., 1992. Photodegradation and absorption of sethoxydim as adjuvant-influenced surface effects. In C. L. FOY (ed.). Adjuvants for Agrichemicals, CRC Press, Boca Raton, FL.

HALE, M.G. & ORCUTT, D.M., 1987. The physiology of plants under stress. John Wiley & Sons, New York.

HARKER, K.N. & O'SULLIVAN, P.A., 1986. Enhancement of sethoxydim activity with ammonium sulfate. *North Cent. Weed Control Conf. Proc.* 41, 38-39.

HARKER, K. N. 1992. Effects of various adjuvants on sethoxydim activity *Weed Tech.* 6, 865-870.

HARKER, K.N., 1995. Ammonium sulphate effects on the activity of herbicides for selective grass control. *Weed Tech.* 9, 260-266.

HARRISON, S. K. & WAX, L. M., 1986. Adjuvant effects on absorption, translocation, and metabolism of haloxyfop-metyl in corn (*Zea mays*). *Weed Tech.* 34, 185-195.

HARRISON, S. K.; WAX, L. M. & BODE, L. E., 1986. Influence of adjuvants and application variables on postemergence weed control with bentazon and sethoxydim. *Weed Sci.* 34, 462-466.

HARTZLER, R.G. & FOY, C. L., 1983a. Compatibility of BAS 9052 OH with acifluorfen and bentazon. *Weed Sci.* 31, 597-599.

HARTZLER, R.G. & FOY, C. L. 1983b. Efficacy of three postemergence grass control in soybeans. *Weed Sci.* 32, 557-561.

HARWOOD, J.L., 1991. Lipid synthesis. In R.C. Kirkwood (ed.). Target sites for herbicide action.. (Series Topics in Applied Chemistry). Plenum Press, New York.

HATZIOS, K.K. & PENNER, D., 1985. Interactions of herbicides with other agrochemicals in higher plants. *Rev. Weed Sci.* 1, 1-63.

HESS, F.D. & FALK, R.H., 1990. Herbicide deposition on leaves.*Weed Sci.* 38, 280-288.

HEYNIKE, J.J.C., 1987. Salination of Vaal River water : Economic effects (a desk study). Report KV 2-87, Water Research Commission. Pretoria.

HOSAKA, H.; INABA, H. & ISHIKAWA, H. 1984. Response of monocotyledons to BAS 9052 OH. *Weed Sci.* 32, 28-32.

HOLSHOUSER, D.L. & COBLE, H.D., 1990. Compatibility of sethoxydim with five postemergence broadleaf herbicides. *Weed Tech.* 4; 128-133.

JIMENEZ, H.; PICCIOTO, G & BATA, F., 1990. Traditional and improved production systems in Chokwe. Field Document No. 8. INIA-DASP. Maputo.

JOHNSON, W. C.; III MULLINIX, B. G., JR, & BROW, S. M., 1992. Phytotoxicity of chlorimuron and tank mixtures on peanut (*Arachis hypogea*). *Weed Tech. 6*, 404-408.

JOHNSTON, G. B. & WEEB, F. J. 1983. Spray pressure, volume and tip study. *Proc. Northest. Weed Sci. Soc.* 37, 51-52.

JORDAN, D.L., YORK, A.C. & CORBIN, F.T., 1989. Effect of ammonium sulfate and bentazon on sethoxydim absorption. *Weed Tech.* 3, 674-677.

JORDAN, D.L. & YORK, A.C., 1989. Effects of ammonium fertilizers and bch 81508 s on antagonism with sethoxydim plus bentazon mixtures. *Weed Tech.* 3, 450-454.

JORDAN, D.L., 1995. Influence of adjuvants on the antagonism of gaminicides by broadleaf herbicides. *Weed Tech.* 9, 741-747.

JORDAN, D.L., VIDRINE, R.P., GRIFFIN, J.L. & REYNOLDS, D.B., 1996. Influence of adjuvants on efficacy of clethodim. *Weed Tech.* 10, 738-743.

KLEPPE, C.S. & HARVEY, R.G., 1989. Tolerance of corn (*Zea mays*) to sethoxydim applied with precision postemergence-directed sprayer equipment. *Weed Tech.* 3,663-667.

KNOBEL, H.H., DE VILLIERS, B.L., SMIT, H.A. & LINDEQUE, R.C., 1992. Differensiële fitotoksisiteit van tralkoksidim, bromoksinil en 'n mengsel van die twee produkte op Suid-Afrikaanse korincultivars. *S. Afr. J. Plant Soil.* 9, 173-176.

KOLEGA, J.J. & WOODING, N.H., 1979. Water quality for farm processing. Quality water for home and farm. *Proc. 3rd Domestic water quality.* Symposium.

KOSKINEN, W.C., REYNOLDS, K. M., BUHLER, D. D., WYSE, D. L., BARBER, B. L., & JARVIS, L. J.,1993. Persistence and movement of sethoxydim residues in three Minnesota soils. *Weed Sci. 41, 634-640.*

LASSITER, R.B. Jr. & COBLE, H.D., 1985. The influence of carrier volume and herbicide rate on the antagonism between sethoxydim and bentazon. *Proc. South. Weed Sci. Soc.* 38, 38.

LASSITER, R.B. Jr. & COBLE, H.D., 1987. Carrier volume effects on the antagonism of sethoxydim by bentazon. *Weed Sci.* 35, 541-546.

LEE, S.D. & OLIVER, L.R., 1982. Efficacy of acifluorfen on broadleaf weeds, times and methods of application. *Weed Sci.* 30, 520-526.

MAILLET, J., 1991. Control of grassy weeds in tropical cereals. In F.W.G. Baker & P.J. Terry (ed.). Tropical grassy weeds. CASAFA Report Series No. 2. *CAB.* Bristol.

MCINNES, D.; HARKER, K. N.; BLACKSHAW, & VANDEN BORN, W. H., 1992. The influence of ultraviolet light on the phytotoxicity of sethoxydim tank mixtures with various adjuvants. In C. L. FOY, (ed.). Adjuvants for Agrichemicals. CRC Press, Boca Raton, FL.

MCKEAGUE, M., HUTCHINS, A.P., CHARVAT, L.D., GIBSON, S.W., & BURDICK, B., 1986. Fertilizer additives with sethoxydim on annual and perennial grasses in soybeans. *North Cent. Weed Control Conf.* 41, 41.

MCKINLAY, K.S., ASHFORD, R. & FORD, R.J., 1974.Effects of drop size, spray volume, and dosage on paraquat toxicity. *Weed Sci.* 22, 31-34.

MCMULLAN, P. M. 1994. Effect of sodium bicarbonate on clethodim or quizalofop efficacy and the role of ultraviolet light. *Weed Tech.* 8, 572-575

MCWHORTER, C. G. & JORDAN, T. N., 1978. Effects of adjuvants and environments on the toxicith of dalapon to johnsongrass. *Weed Sci.* 24, 257-260.

MCWHORTER, C. G. & HANKS, J.E., 1993. Effect of spray volume and pressure on postemergence johnsongrass (*Sorghum halepense*) control. *Weed tech.* 7, 304-310.

MELLOR, J.W., 1985. The changing world food situation-A CGIAR perspective. In International Food Policy Research Institute: Report 1984. International Food Policy Research Institute. (IFPRI). Washington, DC:

MERRITT, C.R., 1980. The influence of application variables on the biological performance of foliage applied herbicides. BCPC. Monograph. 24, 35-43.

MERSIE, W. & FOY, C.L., 1987. Influence of pH on the absorption of chlorsulfuron by leaves and excised roots of velvetleaf (*Abutilon theophrasti* Medik). *Weed Sci.* 35, 11-14.

MIDGLEY, D.C., 1976. Water resources- The southern African picture. In G. Baker (ed.). Resources of Southern African today and tomorrow. *ASTSSA*, Johanesburg.

NALEWAJA, J.D., PETERSEN, D.E. & GILLESPIE, G.R., 1985. Seed oil compounds with postemergence herbicides. *Proc. North Cent. Weed Control Conf.* 40, 38-39.

NALEWAJA, J.D. & SKRZYPCZAK, G.A., 1986. Absorption and translocation of sethoxydim with additives. *Weed Sci.* 34, 657-663.

NALEWAJA. J. D., MANTHEY, F. A., SZELEZNIAK, E. F. & ANYSKA, Z., 1989. Sodium bicarbonate antagonism of sethoxydim. *Weed Tech.* 3, 654-658.

NALEWAJA, J. D., WOZNICA, Z. & MATYSIAK, R., 1990. Sodium bicarbonate antagonism of 2,4-D amine. *Weed Tech.* 4, 588-591.

NALEWAJA. J. D. & MATYSIAK, F.A., 1991. Salt antagonism of glyphosate. *Weed Sci.* 39, 622-628.

NALEWAJA, J.D., WOZNICA, Z. & MANTHEY, F.A., 1991. DPX-V9360 efficacy with adjuvants and environment. *Weed Tech.* 5, 92-96.

NALEWAJA, J. D., WOZNICA, Z. & MATYSIAK, R., 1991. 2,4-D amine antagonism by salts. *Weed Tech.* 5, 873-880.

NALEWAJA, J. D. & MATYSIAK, R. 1993. Spray carrier salts affect herbicide toxicityto kochia (*Kochia scoparia*). *Weed Tech.* 7, 154-158.

NALEWAJA, J. D., MATYSIAK, R. & SZELEZNIAK, E. 1994. Sethoxydim response to spray carrier chemical properties and environment. *Weed Tech.* 8, 591-597.

NALEWAJA, J. D., PRACZYK, T. & MATYSIAK, R., 1995. Surfactants and oil adjuvants with nicosulfuron. *Weed Tech.* 9, 689-695.

NALEWAJA, J.D, DE VILLIERS, B.L. & MATYSIAK, R., 1996. Surfactant and salt affect glyphosate retention and absorption. *Weed Res.* 36, 241-247.

NANDULA, V. K., CURRAN, W. S, ROTH, G. W., & HARTWIG, N. L., 1995. Effectiveness of adjuvants with nicosulfuron and primisulfuron for wirestem muhl (*Muhlenbergia frondosa*) control in no-till corn (*Zea mays*). *Weed Tech.* 9, 525-530.

NORRIS, R.F. & BUKOVAC, M.J., 1972. Effect of pH on penetration of naphthalene acetic acid and naphthalene acetamide through isolated pear leaf cuticle. *Plant Physiol.* 49, 615-618.

OKALI, C., 1978. Weeds and their control in humid and sub-humid tropics. *Internat. Weed Sci. Conf.* 24, 537-539.

ORGEL, W.H. & WEINTRAUB, R.L., 1957. Influence of some ions on foliar absorption of 2,4-D. *Bot. Gaz.* 119, 88-93.

O'SULLIVAN, P.A., O'DONOVAN, J.T. & HAMMAN, W.M., 1981. Influence of non ionic surfactants, ammonium sulphate, water quality and spray volume on the phytotoxicity of glyphosate. *Can. J. Plant Sci.* 61, 391-400.

PENNER, D.D., 1989. The impact of adjuvants on herbicide antagonism. *Weed Tech.* 3, 227-231.

PESCOD, M.B., 1992. Wastewater treatment and use in agriculture. Irrigation and drainage paper 47. *FAO*. Rome.

PLOWMAN, R.E., STONEBRIDGE, W.C. & HAWTREE, J.N., 1980. Fluazifop-butyl, a new selestive herbicide for the control of annual and perennial grass weeds. *Proc. Br. Crop Prot. Conf.-Weeds.* 29-37.

PRASAD, R., FOY, C.L. & CRAFTS, A.S., 1967. Effect of relative humidity on absorption and translocation of foliarly applied dalapon. *Weeds.* 15, 149-156.

QURESHI, F.A. & VANDEN BORN, W.H., 1979. Spray droplet distribution and herbicide uptake in sequential applications of diclofop-methyl and MCPA for weed control in barley. *Can. J. Plant Sci.* 32, 436-441.

RANSOM, J.K., 1989. Weed control in maize/legume intercrops. In Research methods for cereal/legume intercropping. Lilongwe. p. 41-44.

RENDINA, A.R. & FELTS, J.M., 1988. Cyclohexanedione herbicides are selective and potent inhibitors of acetyl-coA carboxylase from grasses. *Plant Physiol.* 86, 983-986.

RHODES, G.N., Jr., & COBLE, H.D., 1983. Envrionmental factors affecting the performance of sethoxydim. *Proc. South. Weed Sci. Soc.* 154-155.

RHODES, G.N., Jr., & COBLE, H.D., 1984a. Influence of bentazon on absorption and translocation of sethoxydim in goosegrass (*Eleusine indica*). *Weed Sci.* 32, 595-597.

RHODES, G.N., Jr., & COBLE, H.D., 1984b. Influence of application variables on antagonism between sethoxydim and bentazon. *Weed Sci.* 32, 436-441.

RICHARD, E.P., Jr., 1991. Optimizing diluent volume improves johnsongrass control in sugarcane (*Saccharum sp.*) with asulam. *Weed Tech.* 5, 363-368.

SANDBERG, C. L., MEGGIT, W. F. & PENNER, D., 1978. Effect of diluent volume and calcium on glyphosate phytotoxicity. *Weed Sci.* 26, 476-479.

SARGENT, J.A. & BLACKMAN, G.E., 1962. Studies on foliar penetration. I. Factors controlling the entry of 2,4-dichlorophenoxyacetic acid. *J. Exp. Bot.* 13, 348-368.

SCHICKELE, R., 1968. Overcoming institutional obstacles to agricultural progress in developing countries. In Anonymous (ed.). Alternatives for balancing world food production and needs. Iowa State University. Center for Agricultural and Economic Development. Iowa. 273p.

SHEA, P. J. & TUPY, D.R. 1984. Reversal of cation-indiced reduction of glyphosate activity with EDTA. *Weed Sci.* 34, 802-806.

SHILLING, D. G. & HALLER, W.T., 1989. Interactive effects of diluent pH and calcium content on glyphosate activity on Panicum repens L. (torpedograss). *Weed Res.* 29, 441-448.

SIMON, E.W. & BEEVER, H., 1952. The effect of pH on the biological activities of weak acids and bases. I. The most usual relationship between pH and activity. *New Phytol.* 51, 163-190.

SMITH, R.J.,Jr., 1974. Propanil and adjuvants for barnyardgrass control in rice. *Weed Sci.* 22, 419-426.

SMEDA, R.J. & PUTNAM, A.R., 1989. Effect of adjuvants concentration and acrrier volume on large crabgrass (*Digitaria sanguinalis*) control with fluazifop. *Weed Tech.* 3, 105-109.

SMITH, A. M. & VANDEN BORN, W. N., 1992. Ammonium sulphate increases efficacy of sethoxydim through increased absorption and translocation. *Weed Sci.* 40, 351-358.

SNIPES, C. E. & WILLS, G. D., 1994. Influence of temperature and adjuvants and environment on the toxicity of dalapon to johnsongarss. *Weed Sci.* 24, 257-260.

STAHLMAN, P.W. & PHILLIPS, W.M., 1979. Effects of water quality and spray vlume on glyphosate phytotoxicity. *Weed Sci.* 27, 38-41.

STERLING, T.M., BALKE, N.E. & SILVERMAN, D.S., 1990. Uptake and accumulation of the herbicide bentazon by cultured plant cells. *Plant Physiol.* 92, 1121-1127.

STOLTENBERG, D.E., GRONWALD, J.W., WYSE, D.L., BURTON, J.D., SOMERS, D.A., & GENGENBACK, B.G., 1989. Effect of sethoxydim and haloxyfop on acetyl-coenzyme A carboxylase activity in Festuca species. *Weed Sci.* 37, 512-516.

STOREY, D.J., 1980. The economics of water quality. In A.M. Gower (ed.). Water quality in catchment ecosystems. John Wiley & Sons, New York.

SZABO, S.S. & BUCHHOLTZ, K.P., 1961. Penetration of living and non-living surfaces by 2,4-D as influenced by ionic additives. Weeds. 9, 177-184.

SWANSON, C.R & BAUR, J.R., 1969. Absorption and penetration of picloram in potato tuber discs. *Weed Sci.* 17, 311-314.

THELEN, K.D., JACKSON, E.P. & PENNER, D. 1995. Characterizing the sethoxydim-bentazon interaction with proton nuclear magnetic ressonance spectrometry. *Weed Sci.* 43, 337-341.

VAN ELLIS, M.R. & SHANER, D.L., 1988. Mechanism of cellular absorption of imidazolinones in soybean (*Glycine max*) leaf discs. *Pest. Sci.* 23, 25-34.

VAN ROOYEN, J.A. & HERALD, C.E., 1992. Mineral quality of the Vaal River system: Influences, trends and predictions. Water Week Conference. *CSIR* Conference Centre. p. 83-97.

VERMEULEN, J. B., DREYER, M., GROBLER, H., & ZYL, K., 1996. A guide to the use of herbicides. National Department of Agriculture.. *15th ed.* Pretoria. RSA.

WANAMARTA, G., PENNER, D. & KELLS, J. J. 1986. Overcoming the antagonism of sethoxydim and bentazon on grass control. *Abstr. Weed Sci. Soc. Am.* 78-79.

WANAMARTA, G., PENNER, D. & KELLS, J. J. 1989a. The basis of bentazon antagonism on sethoxydim absorption and activity. *Weed Sci.* 37, 400-404.

WANAMARTA, G., PENNER, D. & KELLS, J. J., 1989b. Identification of efficacious adjuvants for sethoxydim and bentazon. *Weed Tech.* 3, 60-66.

WANAMARTA, G., KELLS, J. J. & PENNER, D., 1993. Overcoming antagonistic effects of Na-bentazon on sethoxydim absorption. *Weed Tech.* 7, 322-325.

WILLS, G.D. & JORDAN, P.M., 1981. Factors affecting toxicity and translocation of metriflufen in cotton (*Gossypium hirsutum*). *Weed Sci.* 29, 308-313.

WILLS, G.D., 1984. Toxicity and translocation of sethoxydim in bermudagrass (*Cynodon dactylon*) as affected by environment. *Weed Sci.* 32, 20-24.

WIXSON, M.B. & SHAW, D.R., 1991. Development of AC 263,222 AS a postemergence soybean herbicide. *Proc. South. Weed Sci.* 43, 46.

WRUBEL, R.P. & GRESSEL. J., 1994. Are herbicide mixtures useful for delaying the rapid evolution of resistance? A case study. *Weed Tech.* 8, 635-648.

YOUNG, R.A. & HORNER, G.L., 1986. Irrigated agriculture and mineralized water. Agriculture and environmental. *The National Center for Food and Agricultural Policy.* Annual policy review. Resources for the future. Washington, D.C.

YORK, A.C., JORDAN, D.L. & WILCUT, J.W., 1990. Effects of $(NH_4)_2SO_4$ and BCH 81508 S on efficacy of sethoxydim. *Weed Tech.* 4, 76-80.

YORK, A.C., WILCUT, J.W., SWANN, C.W., JORDAN, D.L. & WALLS, F.R., Jr., 1995. Efficay of imazethapyr in peanut (*Arachis hypogea*) as affected by time of application. *Weed Sci.* 43, 107-116.

YOUNG, B. G., HART, S. E. & WAX, L. M., 1996. Interactions of sethoxydim and corn (*Zea mays*) postemergence broadleaf herbicides on three annual grasses. *Weed Tech.* 10, 914-922.

APPENDIX A

TABLE 1: Analysis of variance of data from preliminary study on the effect of different sethoxydim rates on oats fresh top mass reduction

Source	Df	SS	MSS	F_c	Pr > F
Rates	6	7940.791450	1323.465242	5.49	0.0015
Error	21	5060.157950	240.959904		
Corrected total	27	13000.94940			

R^2 = 0.610786 % CV = 62.82 LSD_T = 35.68

TABLE 2: Analysis of variance of oats fresh top mass as influenced by sethoxydim at 186.0 g ai.ha^{-1} in 250 ℓ.ha^{-1} in the presence of sodium bicarbonate and potassium carbonate

Source	Df	SS	MSS	F_c	Pr > F
Model	12	10534.067480	877.838957	7.03	0.0001
Salts	1	982.9205021	982.9205021	7.87	0.0075
Concentrations	5	4271.8324354	854.3664871	6.84	0.0001
S*C	5	550.7888854	110.1577771	0.88	0.5016
Error	43	5372.855675	124.950132		
Corrected total	55	15906.923155			

R^2 = 0.662232 % CV = 19.06174 LSD_T = 17.282

TABLE 3: Summary of linear regression for sodium bicarbonate at different concentrations added to distilled water on sethoxydim activity at 186.0 g ai.ha^{-1}

(a)

Regression statistics	
Multiple R	0.781394
R square	0.610577
Adjusted R square	0.532692
Standard error	6.645513
Observations	7

(b)

ANOVA						
Source	Df	SS	MSS	F_c	Significance F	
Regression	1	346.2144	346.2144	7.839495	0.037998	
Residual	5	220.8142	44.16284			
Total	6	567.0286				
	Coeficients	Standard error	t Stat.	P-value	lower 95%	Upper 95%
Intercept	72.42753	3.258378	22.22754	3.42E-06	64.04982	80.80165
X variable	-739.639	264.1652	-2.79991	0.037998	-1418.7	-60.5816

TABLE 4: Summary of linear regression for potassium carbonate at different concentrations added to distilled water on sethoxydim activity at 186.0 g ai.ha^{-1}

(a)

Regression statistics	
Multiple R	0.878236
R square	0.771298
Adjusted R square	0.725557
Standard error	7.866031
Observations	7

(b)

ANOVA						
Source	Df	SS	MSS	F_c	Significance F	
Regression	1	1043.356	1043.356	16.86248	0.009297	
Residual	5	309.3722	61.87444			
Total	6	1352.729				
	Coeficients	Standard error	t Stat.	P-value	lower 95%	Upper 95%
Intercept	69.80282	3.856813	18.09858	9.46E-06	59.88858	79.71706
X variable	-1284	312.6819	-4.10639	0.009297	-2087.77	-408.222

TABLE 5: Analysis of variance of the effect of pH on sethoxydim activity at 186.0 g ai.ha^{-1}

Source	Df	SS	MSS	F_c	Pr > F
PH	10	10637.045455	1063.704545	15.28	0.0001
Error	33	2297.750000	69.628788		
Corrected total	43	12934.795455			

$R^2 = 0.822359$ % CV = 18.11312 $LSD_T = 20.372$

TABLE 6: Summary of linear regression for the effect of pH on sethoxydim activity at 186.0 g ai.ha^{-1}

(a)

Regression statistics	
Multiple R	0.920357
R square	0.847057
Adjusted R square	0.830064
Standard error	6.717567
Observations	11

(b)

ANOVA						
Source	Df	SS	MSS	F_c	Significance F	
Regression	1	2249.316	2249.316	49.84556	5.92E-05	
Residual	9	406.1313	45.1257			
Total	11	2655.447				
	Coeficients	Standard error	t Stat.	P-value	lower 95%	
Intercept	80.26031	5.251241	15.28407	9.58E-08	68.38117	92.13945
X variable	-5.05052	0.715356	-7.06014	5.92E-05	-6.66877	-3.43227

TABLE 7: Analysis of variance of the effect of adjuvants and ammonium salts on sethoxydim activity at 139.5 and 186.0 g ai.ha^{-1} in 250 ℓ.ha^{-1} in the presence of sodium bicarbonate and potassium carbonate

Source	Df	SS	MSS	F_c	Pr > F
Model	53	62650.711820	1182.088902	5.20	0.0001
Salts (A)	1	6079.954446	6079.954446	26.73	0.0001
Sethoxydim rates (B)	2	3760.580340	1880.290170	8.27	0.0004
A*B	2	216.526351	108.263175	0.48	0.6221
Adjuvants (C)	8	28060.933937	3507.616742	15.42	0.0001
A*C	8	2527.865837	315.983230	1.39	0.2047
B*C	16	14501.137594	906.321100	3.98	0.0001
A*B*C	16	7503.713316	468.982082	2.06	0.0123
Error	162	36845.972150	227.444273		
Corrected total	215	99496.683970			

R^2 = 0.629676 % CV = 26.01 LSD_T for sethoxydim rates = 4.053

LSD_T for spray carrier = 5.946

LSD_T for spray adjuvants and ammonium salts = 13.689

TABLE 8: Analysis of variance of the effect of temperature, adjuvants and ammonium salts on sethoxydim activity at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M

Source	Df	SS	MSS	F_c	Pr > F
Model	23	24753.760633	1076.250462	7.50	0.0001
Temperatures (A)	2	4184.021602	2092.010801	14.58	0.0001
Adjuvants (B)	7	15683.312917	2240.473274	15.61	0.0001
A*B	14	4886.426115	349.030437	2.43	0.0074
Error	72	10330.802300	143.483365		
Corrected total	95	35084.562933			

R^2 = 0.705546 % CV = 24.74 LSD_T for temperatures = 7.167

LSD_T for adjuvants = 15.266

TABLE 9: Analysis of variance of the effect of temperature, adjuvants and ammonium salts on sethoxydim activity at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M

Source	Df	SS	MSS	F_c	Pr > F
Model	29	6899.2914242	237.9066008	1.18	0.2721
Temperatures (A)	2	70.7445267	35.3722633	0.18	0.8393
Adjuvants (B)	9	1826.2548242	202.9172027	1.01	0.4405
A*B	18	5002.2920733	277.9051152	1.38	0.1617
Error	90	18136.1464750	201.5127386		
Corrected total	119	25035.4378992			

R^2 = 0.275581 % CV = 31.80 LSD_T for temperatures = 7.5645
LSD_T for adjuvants = 18.802

TABLE 10: Analysis of variance of carrier volume on sethoxydim activity at 139.5 and 186.0 g ai.ha^{-1} in the presence of sodium bicarbonate and potassium carbonate

Source	Df	SS	MSS	F_c	Pr > F
Model	29	6111.15068417	210.72933394	5.08	0.0001
Sethoxydim rates (A)	1	32.85486750	32.85486750	0.79	0.3759
Salts (B)	2	135.16144667	67.58072333	1.63	0.2019
A*B	2	634.78754000	317.39377000	7.65	0.0009
Spray volume (C)	4	3957.07067167	989.26766792	23.84	0.0001
A*C	4	95.48406167	23.87101542	0.58	0.6812
B*C	8	396.24382833	49.53047854	1.19	0.3117
A*B*C	8	859.54826833	107.44353354	2.59	0.0136
Error	90	3734.14267500	41.49047417		
Corrected total	119	9845.29335917			

R^2 = 0.620718 % CV = 10.178 LSD_T for rates = 2.3364
LSD_T for salts = 3.4325
LSD_T for spray volumes = 5.1764

TABLE 11: Summary of linear regression for the effect of carrier volume on sethoxydim activity at 139.5 and 186.0 g ai.ha^{-1} in the presence of sodium bicarbonate and potassium carbonate

(a)

Regression statistics	
Multiple R	0.999414
R square	0.998829
Adjusted R square	0.998438
Standard error	0.030216
Observations	5

(b)

ANOVA						
Source	Df	SS	MSS	F_c	Significance F	
Regression	1	2.335789	2.335789	2558.273	1.70192E-05	
Residual	3	0.002739	0.000913			
Total	4	2.338528				
	Coeficients	Standard error	t Stat.	P-value	lower 95%	Upper 95%
Intercept	2.8251	0.031691	89.14442	3.11E-06	2.724244137	2.925956
X variable	0.002762	5.46E-05	50.57938	1.7E-05	0.002587948	0.002935

APPENDIX B

TABLE 1: Original oats fresh top mass (g) data of preliminar study on sethoxydim screening rates

Herbicide rate (g ai.ha^{-1})	Replications	Means
Control check (untreated)	4	15.5
0.25	4	13.25
0.5	4	12.25
0.75	4	12.5
1.0	4	12.25
1.25	4	9.25
1.5	4	7.0

TABLE 2: Original oat fresh top mass (g) data of the effect of spray carrier on sethoxydim activity at 186.0 g ai.ha^{-1}

Concentrations (M)	Replications	Salt	
		Sodium bicarbonate	Potassium carbonate
		Means	
Control check (untreated)	4	27.477	
Control (treated)	4	4.5	4.50
0.001	4	8.25	10.75
0.003	4	8.75	9.75
0.005	4	10.0	9.75
0.007	4	11.0	13.00
0.009	4	8.25	11.25
0.03	4	13.25	18.25

TABLE 3: Original oat fresh top mass (g) data of the effect of pH on sethoxydim activity

PH	Replications	Means
Control check (untreated)	4	21.47
Control (treated)	4	12.25
2.5	4	6.5
3.5	4	6.75
4.5	4	9.5
5.5	4	9.75
6.5	4	11.25
7.5	4	12.25
8.5	4	12.25
9.5	4	13.75
10.5	4	14.50
11.5	4	19.00

TABLE 4: Original oat fresh top mass (g) data of the effect of adjuvants, ammonium salts and herbicide rates no sethoxydim activity

Adjuvant	Herbicide rate (g ai.ha^{-1})	Replications	Salt		
			None	Sodium bicarbonate	Potassium carbonate
			Means		
Control check (untreated)	-	4	7.082		
Control (treated)	139.5	4	3.25	2.25	5.25
Sadol	139.5	4	2.25	5.25	2.00
Break-Thru	139.5	4	2.75	6.00	3.25
Agral 90	139.5	4	3.50	2.50	4.50
Ammonium nitrate (0.5%)	139.5	4	2.00	2.75	2.25
Ammonium nitrate (1%)	139.5	4	2.75	2.50	2.00
Ammonium sulfate (0.5%)	139.5	4	4.50	2.25	2.75
Ammonium sulfate (1%)	139.5	4	2.75	5.00	2.75
Bladbuff 5	139.5	4	1.50		4.50
Control (treated)	186.0	4	2.75	3.00	4.50
Sadol	186.0	4	2.00	2.00	1.25
Break-Thru	186.0	4	2.25	4.50	2.75
Agral 90	186.0	4	1.50	3.75	4.75
Ammonium nitrate (0.5%)	186.0	4	1.75	1.75	4.00
Ammonium nitrate (1%)	186.0	4	1.75	2.00	1.50
Ammonium sulfate (0.5%)	186.0	4	1.75	3.25	2.25
Ammonium sulfate (1%)	186.0	4	2.75	2.25	1.75
Bladbuff 5	186.0	4	2.00	2.50	1.25

TABLE 5: Original oat fresh top mass (g) data of the effect of temperature, adjuvants and amonium salts on sethoxydim activity at 139.5 g ai.ha^{-1} in the presence of Sodium bicarbonate at 0.03 M (Experiment 1)

Adjuvant	Adjuvant rate (%)	Replications	Temperature 15°C	25°C	35°C
			Means		
Control check (untreated)	-	4	14.903		
Control (treated)	-	4	12.00	12.75	8.75
Sadol	5.0	4	10.00	4.00	5.25
Sadol + Sodium bicarbonate	5.0	4	10.75	7.75	7.00
Break-Thru	1.0	4	8.00	5.25	6.00
Break-Thru + Sodium bicarbonate	1.0	4	10.75	10.00	8.75
Ammonium nitrate	1.0	4	6.50	5.75	8.75
Ammonium nitrate + Sodium bicarbonate	1.0	4	7.00	6.00	5.75
Ammonium nitrate + Sodium bicarbonate	0.5	4	7.00	4.50	5.75

TABLE 6: Original oat fresh top mass (g) data of the effect of temperature, adjuvants and ammonium salts on sethoxydim activity at 139.5 g ai.ha^{-1} in the presence of sodium bicarbonate at 0.03 M (Experiment 2)

Adjuvant	Adjuvant rate (%)	Replications	Temperature 15°C	25°C	35°C
			Means		
Control check (untreated)	-	4	24.66		
Control (treated)	-	4	15.75	12.50	15.50
Agral 90	1.0	4	14.00	11.25	16.75
Agral 90 + Sodium bicarbonate	1.0	4	15.00	15.25	12.25
Bladbuff 5	Colour change	4	16.00	14.75	12.25
Bladbuff 5 + Sodium bicarbonate	Colour change	4	15.50	15.00	13.75
Ammonium sulfate	0.5	4	10.00	15.75	13.50
Ammonium sulfate + Sodium bicarbonate	0.5	4	10.25	12.75	15.00
Ammonium sulfate	1.0	4	14.00	9.75	10.50
Ammonium sulfate + Sodium bicarbonate	1.0	4	13.50	12.25	14.00
Ammonium nitrate	0.5	4	14.00	13.75	14.00

TABLE 7: Original oat fresh top mass (g) data of the effect of spray volume and herbicide rate on sethoxydim activity in the presence of sodium bicarbonate and potassium carbonate at 0.03 M

Herbicide rate	Water Volume (ℓ/ha)	Replications	Salt		
			Control (treated)	Sodium bicarbonate	Potassium carbonate
(g ai.ha^{-1})			Means		
Control check (untreated)		4	11.619		
139.5	175	4	3.00	4.00	3.25
139.5	350	4	4.25	3.75	3.75
139.5	525	4	4.25	4.50	4.00
139.5	700	4	5.75	4.00	4.75
139.5	875	4	5.00	5.25	5.00
186.0	175	4	3.25	3.25	3.00
186.0	350	4	3.50	3.75	4.00
186.0	525	4	4.00	4.50	4.25
186.0	700	4	3.75	5.25	5.00
186.0	875	4	4.25	5.25	6.75