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GLYPHOSATE FOR THE CONTROL OF SEEDLING ANNUAL WEEDS

by

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Glyphosate was applied to seedling annual weeds in the field, in the greenhouse and in the growth cabinet in order to determine the rates required and the best method of application, i.e, spray volume and surfactant concentration, for optimum weed control.

In the field under conditions of moderate crop competition .21 kg/ha, .14 kg/ha, .42 kg/ha, and .28 to .42 kg/ha was required to control *Avena fatua* (wild oat), *Setaria viridis* (green foxtail), *Polygonum convolvulus* (wild buckwheat), and *Brassica kaber* (wild mustard) respectively.

In the field with no crop competition .56 kg/ha glyphosate did not give sufficient control of wild buckwheat but controlled *Polygonum persicaria* (lady's thumb). Under the same conditions .14 kg/ha glyphosate controlled green foxtail. In the greenhouse the ED_{50} for wild oats, green foxtail, wild buckwheat, and wild mustard was .44 kg/ha, .04 kg/ha, .51 kg/ha, and .05 kg/ha, respectively.

The addition of surfactant[1] to the spray solutions (up to 0.50 per cent) generally increased the phytotoxicity of glyphosate to plants grown in the growth cabinet. In the field, using wild buckwheat as the

[1] MON-0011 - Surfactant supplied by Monsanto Company Limited.

major indicator, optimum control was achieved with glyphosate when the surfactant comprised at least 0.50 per cent of the spray solution. The addition of surfactant to the spray solution increased the retention on grassy species but did not increase the spray retention on broad leaved species.

The method used to measure spray retention on plants involved the recovery of the water-soluble dye, Niagra Sky Blue. A differential dye recovery was obtained from plants, washed 36 or more hours after spray application. Less dye was recovered from plants sprayed with solutions of high surfactant concentrations.

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INTRODUCTION

Tillage of the soil for growth of agricultural crops is becoming increasingly expensive due to rising costs of fuel, machinery and labour. It has been shown that tillage is not necessary for crop growth provided weed control is adequate. The compound paraquat has given excellent control of seedling annual weeds prior to emergence of the crop. However, paraquat does not control perennial weed species. In attempting to control perennial weeds, researchers have turned to N-(phyosphonomethyl) glycine, (glyphosate). Glyphosate is a suitable herbicide for zero tillage seed bed preparation because of its wide spectrum control, its nonresidual action, and its effective control of perennial weeds through single applications.

Donaghy (1973) found glyphosate at .56 kg/ha resulted in annual weed control equivalent to the control obtained from the use of paraquat plus diquat at .84 + .28 kg/ha. Since the rates of glyphosate required and the methods of its application for control of seedling annual weeds had not been fully investigated, a study was initiated using glyphosate in the field and in the greenhouse to determine the potential of this compound for zero tillage seed bed preparation.

Four seedling annual weeds including *Avena fatua* (wild oat), *Setaria viridis* (green foxtail), *Polygonium convolvulus* (wild buckwheat), and *Brassica kaber* (wild mustard) were chosen for this study.

LITERATURE REVIEW

A. Glyphosate

Glyphosate is formulated as an isopropylamine salt and sold under the trade name Roundup.[2] Roundup contains 4 pounds of the salt or the equivalent of 3 pounds of the glyphosate acid per U.S. gallon (Monsanto 1973).

Glyphosate is essentially a nonselective herbicide, killing most green vegetation at normal use rates of 1.12 to 3.36 kg/ha active. The use of glyphosate as a broad-spectrum herbicide was first reported by Baird *et al.* in 1971. At that time it was also reported that glyphosate was a nonresidual type chemical.

Work by Sprankle *et al.* (1974) demonstrated that the nonresidual effects of glyphosate are partly due to adsorption of the glyphosate to the soil constituents and possibly due to rapid breakdown. Addition of 1 per cent montmorillonite clay to the herbicide spray solution reduced the herbicidal effects by 80 to 90 per cent, thus supporting the soil adsorption theory. Rieck *et al.* (1974) stated that soil adsorption cannot account for all the reduction in herbicidal effect.

Reports by Freeman, by Dhindsa and by Molberg in the 1973 Resarch Report of the Canada Weed Committee, Western Section, demonstrated that many weed and crop species are controlled by foliar applications of glyphosate. However because glyphosate is nonresidual, weeds emerging after treatment are not affected. Weeds germinating prior to emergence

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[2]Roundup is manufactured and sold by Monsanto Company Limited.

of the crop compete much more severely with the crop than those germinating 5 days after emergence of the crop Dew (1973).

Perennial weeds such as *Agropyron repens* (quack grass) and *Cirsium arvense* (Canada thistle), which presented problems under zero tillage (Donaghy, 1973), have been controlled by the use of glyphosate according to reports by: Gottrup (1974), Valgardson (1974), Hughes (1974), and Friesen (1974). Gottrup (1974), reported effective control of Canada thistle from glyphosate applications at all growth stages. Best control was obtained from applications made at mature growth stages but application to young regrowth after cutting or harvest was also effective.

Hughes (1974) reported good quack grass control from spring applications of glyphosate at 1.68 to 3.68 kg/ha. Friesen (1974) reported good control of quack grass from September applications of glyphosate at 1.12 to 3.36 kg/ha.

Valgardson (1974) reported effective control of quack grass when glyphosate was applied in spring at a rate of 2.24 to 3.36 kg/ha. No residual effects of the herbicide were seen on rapeseed or buckwheat from using 2.8 kg/ha of glyphosate in the field. Some toxic effects were seen on rapeseed and buckwheat sown in soil sprayed with high dosages of glyphosate (4.48 to 8.96 kg/ha).

Jaworski (1972), based on studies with *Lemma gibba* and *Rhizobium japonicum*, suggested that glyphosate interfered with the synthesis of aromatic amino acids. Plants treated with glyphosate did not suffer herbicidal effects if the aromatic amino acids, L-phenylalanine and/or L-tyrosine, were added to the nutrient media.

B. Zero Tillage

The first successful work on zero tillage crop production was reported by Russel in 1945, cited by Donaghy (1973). Since that time much work has been done on the zero tillage production of cereal and oil seed crops as well as corn, soybeans, and several fruit and vegetable crops.

In Manitoba Donaghy (1973) concluded wheat, barley, flax, and rape crops could be produced under zero tillage conditions provided that proper management practices were carried out. Weed growth at the time of seeding was controlled with paraquat plus diquat at 0.84 + 0.28 kg/ha, with paraquat plus 2,4-D ester at 0.84 + 1.12 kg/ha, and with paraquat plus bromoxynil at 0.28 + 0.56 kg/ha. The perennial weeds, quack grass and Canada thistle, became a problem under zero tillage conditions in these test areas. Glyphosate at .56 kg/ha resulted in weed control equivalent to control from paraquat plus diquat at 0.84 + 0.28 kg/ha.

C. Phytotoxicity of Foliar Applied Herbicides

Blackman (1952) stated that the phytotoxicity of a systemic type herbicide depends upon the amount of herbicide reaching the site of action and the tolerance of the species at that point. The amount of material reaching the site of action in the case of a foliar applied herbicide is determined by retention, penetration, translocation, and the degree of localized accumulation in the different tissues. For materials easily translocated, methods of growth analysis are of value for assessing toxic effects (especially of nonlethal dosages). If per cent mortality is plotted against the amount of toxicant a sigmoid relationship exists. This curve forms a straight line when per cent mortality is converted to the probit scale and then plotted against the log of the dosage. Dosages should be chosen so that the lower dose kills some of the plants and the higher dose does not kill all the plants. Concentrations should increase on a geometric scale.

Blackman also stated that if the probit regression lines were parallel, the modes of action were similar, because the relationship between toxicity and the amount of herbicide reaching the site of action (i.e., per cent retained, penetrated, and translocated, etc., to the site of action) was the same in each case. By changing the formulations it would be possible then to change the slope of the regression line. Sampford (1952) stated that parallel regression lines suggest similar physiological action.

McKinlay *et al.* (1972) studied the herbicidal effect of the droplet number and the droplet concentration of 2,4-D on sunflower seedlings. He found that for any given droplet size the dosage could be effectively increased either by increasing the droplet number or by increasing the droplet concentration. Microscopic examinations of sprayed leaves confirmed work done by Ennis (1963) that the smaller droplets were more effective in controlling plants than larger droplets, because the larger droplets became physiologically isolated. The cells under the 400 μ droplet died whereas the cells under a 100 μ or 200 μ droplet didn't die. It appeared that less herbicide was translocated from under the larger droplet as compared to the smaller droplet because dead cells did not translocate. Another factor would be that the total area of leaf contacted from many small droplets was greater as compared to the same amount of herbicide sprayed in large droplets.

In McKinlay's tests 3 times and 6 times as much 2,4-D was required to produce the same herbicidal effect on sunflower seedlings when applied as 200 μ and 400 μ droplets respectively, as compared to applications of 100 μ droplets.

D. Retention of Foliar Applied Herbicides

Aslander (1927) concluded that the effectiveness of sulphuric acid as a selective herbicide for broadleaved weed control in cereal crops was dependent on the differential retention of spray droplets. Differential retention was mainly due to the different angles of incidence and the difference in wax development of the cuticle on broadleaved weeds compared to cereal plants. Blackman (1936, cited by Blackman *et al.*, 1957) demonstrated that the addition of a surface active agent to the spray solution could bring about greater toxicity of the acid to species with a waxy cuticle owing to the enhanced retention. Smith (1956, cited by Blackman *et al.*, 1957) found that depressions in the growth of kidney beans induced by 2,4-D varied with the droplet size and the spray volume, and that both of these factors influenced retention. Fogg (1947) demonstrated that with the large contact angle between the spray droplet and the leaf surface in cereals, the area of contact was small and the droplet tended to roll off. The contact angle is different for cotyledons than for true leaves so differential retention could be expected for these different plant parts.

Loomis (1949, cited by Blackman *et al.*, 1957) noted that for translocated herbicides, coarse sprays of high surface tension were more effective than a combination of a fine spray and a low surface tension.

Ennis *et al.* (1952) concluded that the greater growth depression induced in a pubescent as opposed to a glabrous variety of soybeans when using 2,4-D could be attributed to the greater retention. These workers also demonstrated that the addition of a wetting agent reduced the incidence of droplets bouncing off the leaf surface (regardless of leaf type).

Hellquist (1955, cited by Blackman *et al.*, 1957) found that particularly the larger droplets had greater tendency to roll off leaves where the angle of incidence was greater, eg., with *Hordeum vulgare* (barley) than where the angle of incidence is smaller (eg., with *Pisum sativum*, field peas).

Woofter (1953) and Hellquist (1955, cited by Blackman *et al.*, 1957) demonstrated that with *Triticum vulgare* (wheat), *Hordeum vulgare* (barley), *Linum usitatissium* (flax), *Pisum sativum* (field peas), *Chenopodium album* (lamb's quarters), and *Brassica kaber* (wild mustard) as output increased the proportion of spray droplets retained diminished. Hellquist also demonstrated that as surface tension was reduced from 50 to 35 dynes per centimeter the amounts retained by field peas and barley increased.

It was shown by Fraser *et al.* (1956, cited by Blackman *et al.*, 1957) that for fan spray nozzles the mean droplet size was linked with the surface tension of the spray solution and with the orifice area but for any orifice there was a wide distribution of droplet size formed.

Brunskill (1957), using field peas as a horizontal surface, demonstrated that when surface tension was high a very high proportion of the droplets with diameter 250 μ to 350 μ bounce off the leaves but below a critical value of surface tension (45 to 50 dynes/cm) there was a sharp rise in the number of droplets retained. For small droplets (80 μ to 95 μ) of a high surface tension, retention was almost complete but as size increased up to 250 μ to 325 μ the percentage retained falls progressively. That is, reducing the surface tension to 45 dynes/cm has little influence on the retention of the smaller droplets but causes more of the larger droplets to remain on the leaf.

Brunskill demonstrated that if the velocity of a large droplet (380 μ and surface tension 55 dynes/cm) was accelerated five-fold then the percentage of droplets retained rose from 57 to 95. Also, as the surface tension increased the percentage of large droplets retained decreased and it decreased to a greater degree as the angle of incidence increased from 0^{o} to 60^{o}C.

Contrary to Brunskill's findings (1957) (that the critical range for surface tension as it affects retention was from 47 to 42 dynes/cm), Blackman *et al.* (1957) found that retention was not greatly augmented until surface tension was reduced from 40 to 30 dynes/cm. Davies *et al.* (1967) suggested that the discrepancy mentioned above could have been due to the differences in surfactants used, in the nature of the surfaces examined, and/or in the droplet sizes used.

Blackman *et al.* (1957) demonstrated that spray retention on a leaf surface was influenced by the spray output, the mean droplet size, and the droplet surface tension. The magnitude of the induced changes were dependent on the species involved. Plant characteristics affecting spray retention were morphology of the shoot, particularly the ease or difficulty of wetting the surfaces, the types and position of the leaves, and the stage of plant development. They found that repeated applications with smaller nozzles gave higher total retention than single applications using larger nozzles. They concluded that maximum differences in retention would be with large spray droplets of a high surface tension where the leaf surfaces of one species repelled the droplets and those of the other species did not. Blackman *et al.* also concluded that optimum spray volumes were just below where run-off takes place.

Furmidge (1962) found that run-off caused little reduction in retention on leaves with rough surfaces, however, on smooth surfaced leaves the reduction in retention was considerable. He stated that retention was reduced by wind moving the leaves and this reduction in retention was taking place because the impact velocity of droplets striking the leaf surface was increasing. Furmidge found that for surfaces that show little contact angle hysteresis with water, the addition of wetters in low concentrations increased both the retention of spray solution and the degree of cover on the surface.

Davies *et al.* (1967) found retention of ioxynil by mustard leaves, which are easy to wet, was proportional to the concentration sprayed and was not affected by the surface tension of the spray solution. Addition of the surface active agent (Tween 20) up to 1.0 per cent to ioxynil spray solution increased the retention on field peas and barley. Phytotoxicity, however, was not increased on barley to the same extent as it was with field peas as a result of the addition of Tween 20 to the ioxynil spray solution. Leaf angle studies by Davies confirmed that the angle of incidence with barley was an important factor in determining the degree of retention.

Schafer (1973) using the Niagra Sky Blue water-soluble dye found that the addition of surfactant (Tween 20) only enhanced retention on those species which were difficult to wet.

MATERIALS AND METHODS

Field Experiments 1973

Field experiments in 1973 (Experiments 1, 2, and 3) were carried out on an Almasippi very fine sandy loam soil at Carman, Manitoba. Seven rates of glyphosate, .07, .14, .21, .28, .42, .56, and .84 kg/ha were applied at 3 different postemergence stages. *Vicia faba* (faba beans) were planted over the experimental area on May, 1973 so that the tolerance of this crop to glyphosate could be assessed.

The experimental design used was a randomized complete block design with 4 replications. Plots, 2.0 m x 6.4 m, were sprayed with a hand operated bicycle type push sprayer. Spray applications were made using Tee-jet 6502 nozzles delivering 138.2 l/ha at 2.46 kg/cm^2 pressure and 5.6 kph.

Visual ratings were based on a 0 to 9 scale which is outlined in Table 1.

Dry weight measurements were obtained from labeled plants. Plants in the appropriate stage were labeled with plastic colored rings at the time of spraying. Five wild oat plants, 5 green foxtail plants, 5 wild buckwheat plants, and 3 wild mustard plants were labeled from each plot in 2 replications.

On September 10, 1973 labeled plants were cut off at ground level, dried and weighed. The results are reported as the average weight in mg per plot for the two replications harvested. A statistical analysis was not carried out on this limited sampling as trends were obvious and in some cases where higher rates of glyphosate were used, death of the plant had occurred. The rates of glyphosate used ranged from 0.07 kg/ha to 0.84 kg/ha for all 3 experiments.

TABLE 1

Visual rating scale.

	Rating	Weed control	Crop tolerance
not commercially acceptable range	0	No weed control.	No crop tolerance (everything dead)
	1	Very slight evidence of weed control.	Very slight crop tolerance.
	2	Slight evidence of weed control.	Slight crop tolerance.
	3	Very poor weed control.	Very poor crop tolerance.
	4	Poor weed control.	Poor crop tolerance.
	5	Moderate weed control.	Moderate crop tolerance.
	6	Inadequate weed control.	Inadequate crop tolerance.
commercially acceptable range	7	Acceptable weed control.	Acceptable crop tolerance.
	8	Very good weed control.	Very good crop tolerance.
	9	Complete weed control (all weeds dead)	Complete crop tolerance.

Experiment 1. Inhibition of weed growth by glyphosate, plants cotyledon to 2 leaf stage.

Spray application was made on May 26, 1973 when faba beans had 2 bifoliate leaves fully expanded, 90 per cent of the wild oats were in the 1 leaf stage and 10 per cent were in the 2 leaf stage, green foxtail was in the 2 leaf stage, wild buckwheat was in the cotyledon stage, and wild mustard had 2 true leaves.

Experiment 2. Inhibition of weed growth by glyphosate, plants 2 to 4 leaf stage.

Spray application was made on June 6, 1973 when faba beans had 2 to 3 bifoliate leaves fully expanded, wild oats were in the 3 to 4 leaf stage, green foxtail was in the 4 leaf stage, and wild buckwheat and wild mustard were in the 2 leaf stage.

Experiment 3. Inhibition of weed growth by glyphosate, plants 3 to 6 leaf stage.

Spray application was made on June 14, 1973 when faba beans were 15 to 20 cm tall and had 3 to 4 bifoliate leaves. Wild oats, green foxtail, and wild mustard had 5 to 6 leaves, while wild buckwheat had 5 leaves.

Greenhouse Experiments 1973-1974

Greenhouse experiments (Experiments 4 through 7) were conducted on plants grown in metal pots (juice cans) 10.9 cm in diameter x 17.6 cm tall. Pots were arranged on the greenhouse bench in a randomized complete block design with 8 replications per treatment. Supplementary light ($2710\ \mu W/cm^2$) was provided by using very high output fluorescent tubes for a 16 hour light period. Growth media consisted of 3 parts clay loam soil, 1 part shredded peat moss, and 1 part sand. The media was fertilized as required with 11-48-0 plus 34-0-0 and RX 15 (6-12-6) fertilizers to maintain good plant growth.

Spraying was carried out in a cabinet type sprayer equipped with a Tee-jet nozzle. All treatments were sprayed at 135.4 l/ha and 2.46 kg/cm^2 pressure using a Tee-jet 6502 nozzle.

Control plants were harvested at spraying and with treated plants 10 days after spraying. Plants were dried and weighed, and the results are reported as relative growth. Relative growth (RG) was calculated according to the following formula.

$$R.G. = \frac{W_T - W_o}{W_c - W_o}$$

where: W_o = mean dry weight of plants at the time of spraying.

W_c = mean dry weight of the control plants 10 days after spraying.

W_T = mean dry weight of the treated plants 10 days after treatment.

Relative growth was converted to the probit growth analysis scale and plotted against the $\log_{10}$ of the dosage to give the ED_{50} value.[3]

[3] $E.D._{50}$ value = the dosage of herbicide required to reduce the relative growth by 50 per cent.

Experiment 4. Wild oat inhibition using glyphosate .

Wild oats in the 2 leaf stage were sprayed with glyphosate. Each replication consisted of 1 pot containing 3 plants.

Experiment 5. Green foxtail inhibition using glyphosate.

Green foxtail in the 4 leaf stage was sprayed with glyphosate. Each replication consisted of 1 pot containing 6 plants.

Experiment 6. Wild buckwheat inhibition using glyphosate.

Wild buckwheat had 3 true leaves when sprayed with glyphosate. Each replication consisted of 1 pot containing 4 plants.

Experiment 7. Wild mustard inhibition using glyphosate.

Wild mustard had 4 true leaves when sprayed with glyphosate. Each replication consisted of 1 pot containing 3 plants.

Growth Chamber Experiments 1974

Growth chamber experiments (experiments 8 through 11) were conducted in a Coldstream Plant Growth Cabinet with bench area 1.2 m x 2.7 m. Temperature in the growth cabinet ranged from $16^{o}C$ to $20^{o}C$.

Light energy in the growth cabinet resulting from incandescent and fluorescent lights was 3810 $\mu W/cm^2$. Experiments 8 and 9, involving wild oats and green foxtail respectively, received 14 hours of light and 10 hours of darkness. Experiments 10 and 11, involving wild buckwheat and wild mustard respectively, received continuous light.

Plants were grown in metal pots (juice cans) 10.9 cm in diameter x 17.6 cm tall. Pots were arranged in a completely random design in the growth cabinet with 7 replications per treatment.

Plants were sprayed in the same manner as in the greenhouse experiments. A Tee-jet 6502 nozzle delivering 135.4 l/ha at 2.46 kg/cm was used.

Experiment 8. Wild oat inhibition using glyphosate at several surfactant concentrations.

Wild oats in the 2 to 3 leaf stage were sprayed with glyphosate. Each replication consisted of 1 pot containing 3 plants.

Experiment 9. Green foxtail inhibition using glyphosate at several surfactant concentrations.

Green foxtail in the 4 leaf stage was sprayed with glyphosate. Each replication consisted of 1 pot containing 6 plants.

Experiment 10. Wild buckwheat inhibition using glyphosate at several surfactant concentrations.

Wild buckwheat in the 3 to 4 leaf stage was sprayed with glyphosate. Each replication consisted of 1 pot containing 4 plants.

Experiment 11. Wild mustard inhibition using glyphosate at several surfactant concentrations.

Wild mustard in the 3 leaf stage was sprayed with glyphosate. Each replication consisted of 1 pot containing 3 plants.

Field Experiments 1974

Field experiments in 1974 were carried out on an Almasippi very fine sandy loam soil at Carman, Manitoba. No crop was planted or fertilizer was added to the field in 1974. The major weeds present were green foxtail, wild buckwheat, and lady's thumb.

Experiments were sprayed with a hand operated push type bicycle sprayer. Plot size was 9 square meters. The experimental design was a randomized complete block with 4 replications per treatment.

The surfactant concentrations for each glyphosate treatment were obtained by formulating the spray mixture using MON 0011 and glyphosate.

Experiment 12. Control of green foxtail, wild buckwheat and lady's thumb using several rates of glyphosate and paraquat.

Six rates of glyphosate, .07, .14, .21, .28, .42, and .56 kg/ha, and 2 rates of paraquat, .56 and .84 kg/ha, were applied on June 17, 1974 when the green foxtail has 4 to 5 leaves, the wild buckwheat had 5 to 6 leaves, and the lady's thumb had 5 to 6 leaves. All rates were sprayed at 157.3 l/ha and 2.46 kg/cm^2 pressure using Tee-jet 8002 nozzles. The surfactant level for all rates of glyphosate was .5 per cent of the total spray volume.

Visual assessments were made on July 2 and July 28, 1974 for the control of wild buckwheat and lady's thumb. Green foxtail was rated on July 2, 1974 after which time regrowth of this weed made future evaluations impossible. Wild buckwheat plants were harvested on July 5, 1974. One sample was harvested from each of the 4 replications. Each sample consisted of 10 wild buckwheat plants.

Experiment 13. Control of green foxtail, wild buckwheat, and lady's thumb using glyphosate at several surfactant concentrations.

Four different concentrations of surfactant were applied with 0.14 kg/ha glyphosate and with 0.28 kg/ha glyphosate. Application was made on June 17, 1974 when green foxtail had 4 to 5 leaves and wild buckwheat and lady's thumb had 5 to 6 leaves. All treatments were applied at 157.3 l/ha and 2.46 kg/cm^2 pressure using Tee-jet 8002 nozzles.

Visual assessments were made on July 2, 1974 for the control of green foxtail, wild buckwheat, and lady's thumb. In addition, ten wild buckwheat plants were harvested on July 5, 1974 from each replication.

Sublethal dosages were used in an effort to ensure that differences between treatments were obtained.

Experiment 14: Control of green foxtail, wild buckwheat, and lady's thumb using glyphosate at several spray volumes.

Four different spray volumes were applied with 0.14 kg/ha glyphosate and with 0.28 kg/ha glyphosate. Application was made on July 17, 1974 when green foxtail had 4 to 5 leaves, and wild buckwheat and lady's thumb had 5 to 6 leaves. The surfactant concentration for all spray volumes was 0.5 per cent of the total spray volume. The spray pressure for all treatments was 2.46 kg/cm^2.

Tee-jet nozzles were used at 4.8 kilometers per hour to apply 6.29 l/ha, Tee-jet 65015 nozzles were used at 5.6 kilometers per hour to apply 115.7 l/ha, Tee-jet 6502 nozzles were used at 4.8 kilometers per hour to apply 173.0 l/ha, and Tee-jet 6504 nozzles were used at 5.6 kilometers per hour to apply 237.0 l/ha.

Visual ratings for the control of wild buckwheat and lady's thumb were taken on July 2, July 5, and July 28, 1974 (the averages of all 3 dates are reported for each treatment). Green foxtail control was evaluated on July 2, 1974 after which time regrowth of this weed made future evaluations impossible. Ten lady's thumb plants were harvested from each plot on July 5, 1974 (the averages for each treatment of all four replications are reported).

Experiment 15. Retention of glyphosate applied at several surfactant concentrations to green foxtail and wild buckwheat in the field.

Glyphosate was applied to green foxtail and wild buckwheat at 5 different surfactant concentrations ranging from 0.00 per cent to 1.00 per cent of the total spray solution. All spray solutions contained the water-soluble dye, Niagra Sky Blue at a concentration of 1000 mg per 100 ml of solution. Two spray volumes were used. Tee-jet 650067 nozzles were used at 2.46 kg/cm^2 to deliver 62.9 l/ha and Tee-jet 6502 nozzles were used at 2.46 kg/cm^2 to deliver 173.0 l/ha.

An area 9 square meters was sprayed for each treatment. Plants were allowed to dry for 3 to 4 minutes before being cut off at ground level and washed in 30 ml of water to remove the dye. Plants were then dried and weighed. Washings were filtered through a fritted glass filter to remove any debris. Optical density of the filtered washings was determined on a Bausch and Lomb spectronic 20 colorimeter at 630 nm. Optical density readings were converted to µl of spray solution from the standard regression line $y = 1.034x - 0.041$. The results are expressed as µl of spray solution retained per gram dry weight, obtained by dividing the μl of spray solution retained on the plants by the dry weight of the plant sample in grams.

At spraying the green foxtail plants were in the 5 leaf stage and the wild buckwheat plants were in the 3 to 4 leaf stage. Five samples of 5 plants per sample were taken from each treatment for both species.

Experiment 16. Retention of glyphosate applied at several surfactant concentrations to wild oats and wild mustard in the field.

The same treatments as in Experiment 15 were applied to a field infested with wild oats and wild mustard in the 3 leaf stage. Experimental procedures were the same as in Experiment 15 except for wild oats where 8 samples (10 plants per sample) and for wild mustard where 10 samples (5 plants per sample) were taken from each treatment. Wild oats were washed in 30 ml of water and wild mustard plants were washed in 20 ml of water.

Experiment 17. The effect of delayed washing on the amount of Niagra Sky Blue dye recovered from the surfaces of green foxtail and wild buckwheat plants sprayed with glyphosate solutions containing several surfactant concentrations.

Glyphosate solutions containing 0.00, 0.05, 0.10, 0.50 and 1.00 per cent surfactant concentration and 1000 mg of Niagra Sky Blue per 400 ml of solution were applied to green foxtail plants in the 3 to 4 leaf stage and to wild buckwheat plants in the 3 leaf stage. All treatments were applied at 62.9 l/ha using Tee-jet 650067 nozzles at 2.46 kg/cm^2 pressure and at 173.0 l/ha using Tee-jet 6502 nozzles at 2.46 kg/cm^2 pressure.

An area 9 square meters was sprayed with each treatment. Plants were allowed to dry for at least 36 hours before being cut off at ground level and washed in 30 ml of water to remove the dye. Six samples (20 plants per sample) were harvested for both species from all treatments. Plant samples were then dried and weighed. Washings were handled in the same manner as in experiments 15 and 16. Results are reported as μl of spray solution remaining on the surface of the plants per gram dry weight.

There was no rainfall and the relative humidity was low between spraying and washing the plants.

Analysis of Variance

The analysis of variance were carried out for the randomized complete block designs and the complete random designs according to Steel and Torrie pages 134 and 99, respectively.

RESULTS AND DISCUSSION

Field Experiments 1973

Experiment 1. Inhibition of weed growth by glyphosate, cotyledon to 2 leaf stage.

Plants at the cotyledon to 2 leaf stage desiccated quickly and ring markers were blown off by the wind, therefore, no plant dry weights could be obtained. The regrowth of some of the grassy weeds and the new flush of broadleaves weeds made it impossible to visually evaluate the treatments in this experiment.

Experiment 2. Inhibition of weed growth by glyphosate, 2 to 4 leaf stage.

Results of glyphosate treatments applied to weeds at the 2 to 4 leaf stage are given in Table 2.

The visual assessments made on June 26 indicated that .21 kg/ha glyphosate controlled wild oats and green foxtail and that .42 kg/ha was required to control wild buckwheat and wild mustard. Dry weight measurements of labeled plants harvested September 10, 1973 indicated that .14 kg/ha glyphosate controlled green foxtail and .21 kg/ha controlled wild mustard. The growth of additional weed flushes after application caused the discrepancy between the 2 methods of evaluation.

Visual ratings for green foxtail appear low (7) for the higher rates of glyphosate (.14 kg/ha and higher) due to the additional weed flushes after spraying. Green foxtail plants present in the appropriate

TABLE 2

Visual ratings and dry weight measurements of weeds treated with glyphosate, 2 to 4 leaf stage.

Glyphosate rate kg/ha	Wild Oat		Green Foxtail		Wild Buckwheat		Wild Mustard	
	V.R.	D.W.	V.R.	D.W.	V.R.	D.W.	V.R.	D.W.
0.00	0	16,526	0	66	0	1,598	0	14,917
0.07	3	11,161	1	47	1	1,895	2	6,653
0.14	6	6,839	5	--*	4	1,882	4	337
0.21	8	--	7	--	6	1,798	7	--
0.28	8	--	7	--	6	497	6	28
0.42	8	--	7	--	7	553	8	--
0.56	8	--	7	--	7	106	7	--
0.84	8	--	7	--	7	30	7	--

V.R. = Visual rating on 0 to 9 scale (average of 4 replications). Rating made on June 26, 1973.

D.W. = Dry weight in mg of plants harvested on September 10, 1973 (average of 2 replications).

* Plants within the rings were dead.

stage at the time of spraying were killed with rates of .14 kg/ha and higher.

Experiment 3. Inhibition of weed growth by glyphosate, 3 to 6 leaf stage.

Results of weeds treated with glyphosate at the 3 to 6 leaf stage are given in Table 3.

TABLE 3

Visual ratings and dry weight measurements of weeds treated with glyphosate, 3 to 6 leaf stage.

Glyphosate rate kg/ha	Wild Oat		Green Foxtail		Wild Buckwheat		Wild Mustard	
	V.R.	D.W.	V.R.	D.W.	V.R.	D.W.	V.R.	D.W.
0.00	0	37,230	0	7,003	0	5,505	0	23,013
0.07	6	5,558	4	158	3	6,736	3	21,075
0.14	7	898	7	--*	4	4,786	5	814
0.21	8	--	7	--	4	6,666	6	5,679
0.28	8	--	7	--	6	988	6	545
0.42	9	--	7	--	7	629	8	--
0.56	8	--	7	--	8	100	9	--
0.84	8	--	7	--	8	--	8	--

V.R. = Visual rating on 0 to 9 scale made June 26, 1973 (average of 4 replications).

D.W. = Dry weight in mg of plants harvested September 11, 1973 (average of 2 replications).

* Plants within the rings were dead.

The results of Experiment 3 indicated .14 kg/ha glyphosate controlled wild oats and green foxtail, .42 to .56 kg/ha controlled wild buckwheat and .42 kg/ha controlled wild mustard.

Although lady's thumb was not monitored in all cases, it might be added that .42 kg/ha glyphosate controlled this weed in Experiment 3. Lady's thumb had 5 to 6 leaves at the time of spraying.

From Experiments 2 and 3 it can be noted that the rate of glyphosate required to control wild mustard was dependent upon the stage of growth at the time of application.

Greenhouse Experiments 1973-1974

Experiment 4. Wild oat inhibition using glyphosate.

The results of Experiment 4 are reported as the dry matter accumulation of untreated and of glyphosate treated wild oat plants in Table 4. The $E.D._{50}$ was .440 kg/ha as interpolated from Figure 1 – regression line $y = -2.11058x + 10.58097$.

Experiment 5. Green foxtail inhibition using glyphosate.

The results of Experiment 5 are reported as the dry matter accumulation of untreated and of glyphosate treated green foxtail plants in Table 5. The ED_{50} was .035 kg/ha as interpolated from Figure 1 – regression line $y = -2.95667x + 9.58006$.

TABLE 4

Effects of glyphosate on the dry matter accumulation of wild oats in the greenhouse.

Glyphosate rate kg/ha	WILD OAT - DRY MATTER ACCUMULATION	
	mg dry weight* (increase after spraying)	Expressed as % of control
0.00	348	100
0.10	330	95
0.20	236	68
0.29	186	54
0.39	199	57
0.49	156	45
0.59	131	38
0.69	129	37
0.78	113	33
1.03	85	24

$LSD_{.05}$ = 68

* Complete data on plants recorded included in Appendix Table 1.

TABLE 5

Effects of glyphosate on the dry matter accumulation of green foxtail in the greenhouse.

Glyphosate rate kg/ha	GREEN FOXTAIL - DRY MATTER ACCUMULATION	
	mg dry weight* (increase after spraying)	Expressed as % of control
0.00	1,875	100
0.03	1,169	62
0.06	428	23
0.09	207	11
0.12	83	4
0.15	57	3
0.18	49	3

$LSD_{.05} = 300$

*Complete data on plants recorded included in Appendix Table 2.

Experiment 6. Wild buckwheat inhibition using glyphosate.

The results of Experiment 6 are reported as the dry matter accumulation of untreated and of glyphosate treated wild buckwheat plants in Table 6. The ED_{50} was .508 kg/ha as interpolated from Figure 1 — regression line $y = -2.04868x + 10.54418$.

TABLE 6

Effects of glyphosate on the dry matter accumulation of wild buckwheat in the greenhouse.

Glyphosate rate kg/ha	WILD BUCKWHEAT - DRY MATTER ACCUMULATION	
	mg dry weight* (increase after spraying)	Expressed as % of control
0.00	2,477	100
0.26	1,647	67
0.52	1,262	51
0.65	1,472	59
0.78	772	31
0.91	791	32
1.05	445	18
1.31	489	20

$LSD_{.05}$ = 412

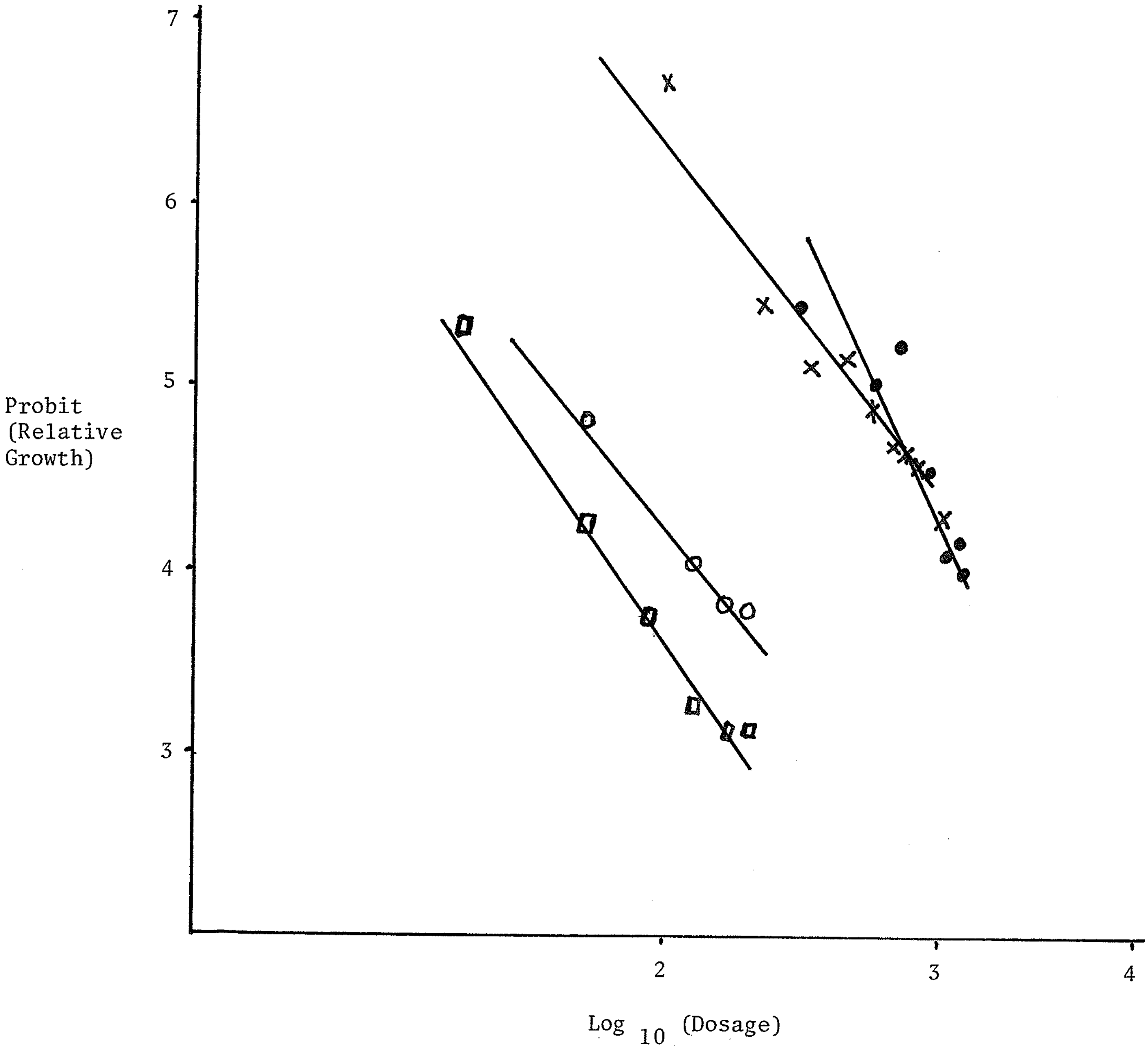
* Complete data on plants recorded included in Appendix Table 3.

Experiment 7. Wild mustard inhibition using glyphosate.

The results of Experiment 7 are reported as the dry matter accumulation of untreated and of glyphosate treated wild mustard plants in Table 7. The ED_{50} was .048 kg/ha as interpolated from Figure 1 — regression line $y = -2.23518x + 8.75151$.

FIGURE 1. Growth inhibition curves for wild oats, green foxtail, wild buckwheat, and wild mustard.

Probit (Relative Growth) vs. Log $_{10}$ (Dosage)



x	Wild Oat	$y = -2.11083x + 10.58097$
	Green Foxtail	$y = -2.95667x + 9.58006$
o	Wild Buckwheat	$y = -2.04868x + 10.54418$
o	Wild Mustard	$y = -2.23518x + 8.75151$

TABLE 7

Effects of glyphosate on dry matter accumulation of wild mustard in the greenhouse.

Glyphosate rate kg/ha	WILD MUSTARD - DRY MATTER ACCUMULATION	
	mg dry weight* (increase after spraying)	Expressed as % of control
0.00	1,832	100
0.06	785	43
0.12	292	16
0.15	223	12
0.18	221	12

$LSD_{.05}$ = 293

* Complete data on plants recorded included in Appendix Table 4.

In the field under conditions of moderate competition (faba bean crop) .21 kg/ha, .14 kg/ha, .42 kg/ha, and .28 to .42 kg/ha of glyphosate was required to control wild oats, green foxtail, wild buckwheat, and wild mustard, respectively. However, in the greenhouse the same 4 weed species did not respond to glyphosate treatment in a corresponding manner. ED_{50} for wild oats, green foxtail, wild buckwheat, and wild mustard was .44 kg/ha, .04 kg/ha, .51 kg/ha, and .05 kg/ha, glyphosate, respectively. The apparent discrepancy between field and greenhouse results could have been due to the different cuticular development of the various species in the field and in the greenhouse. Another cause for discrepancy was the fact that wild oat plants sprayed with glyphosate in the greenhouse tended to react very slowly, thus dry matter continued to accumulate for a considerable period of time after spraying. Wild oats died or stopped growing much more quickly in the field due to competition from the faba bean crop.

Growth Chamber Experiments 1974

The effect of surfactant concentrations on the performance of glyphosate was studied in the growth cabinet. The results[4] of Experiment 8 (wild oats), Experiment 9 (green foxtail), Experiment 10 (wild buckwheat), and Experiment 11 (wild mustard) are given in Figures 2, 3, 4, and 5 respectively.

The addition of surfactant (MON 0011) to .5 per cent of the total glyphosate spray solution, generally increased phytotoxicity of the herbicide to all 4 weed species in the growth cabinet, although the differences were not always significant. There was a significant increase in phytotoxicity to wild oat plants from added surfactant at the .14 kg/ha rate of glyphosate.

Field Experiments 1974

Experiment 12. Control of green foxtail, wild buckwheat and lady's thumb using several rates of glyphosate and paraquat.

The results of plants treated with glyphosate and paraquat are reported as visual ratings and dry weight measurements in Table 8.

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[4] Complete data for Experiments 8, 9, 10, and 11 are given in Appendix Tables 5, 6, 7, and 8 respectively.

FIGURE 2. Wild oat inhibition resulting from glyphosate applied at several surfactant concentrations.

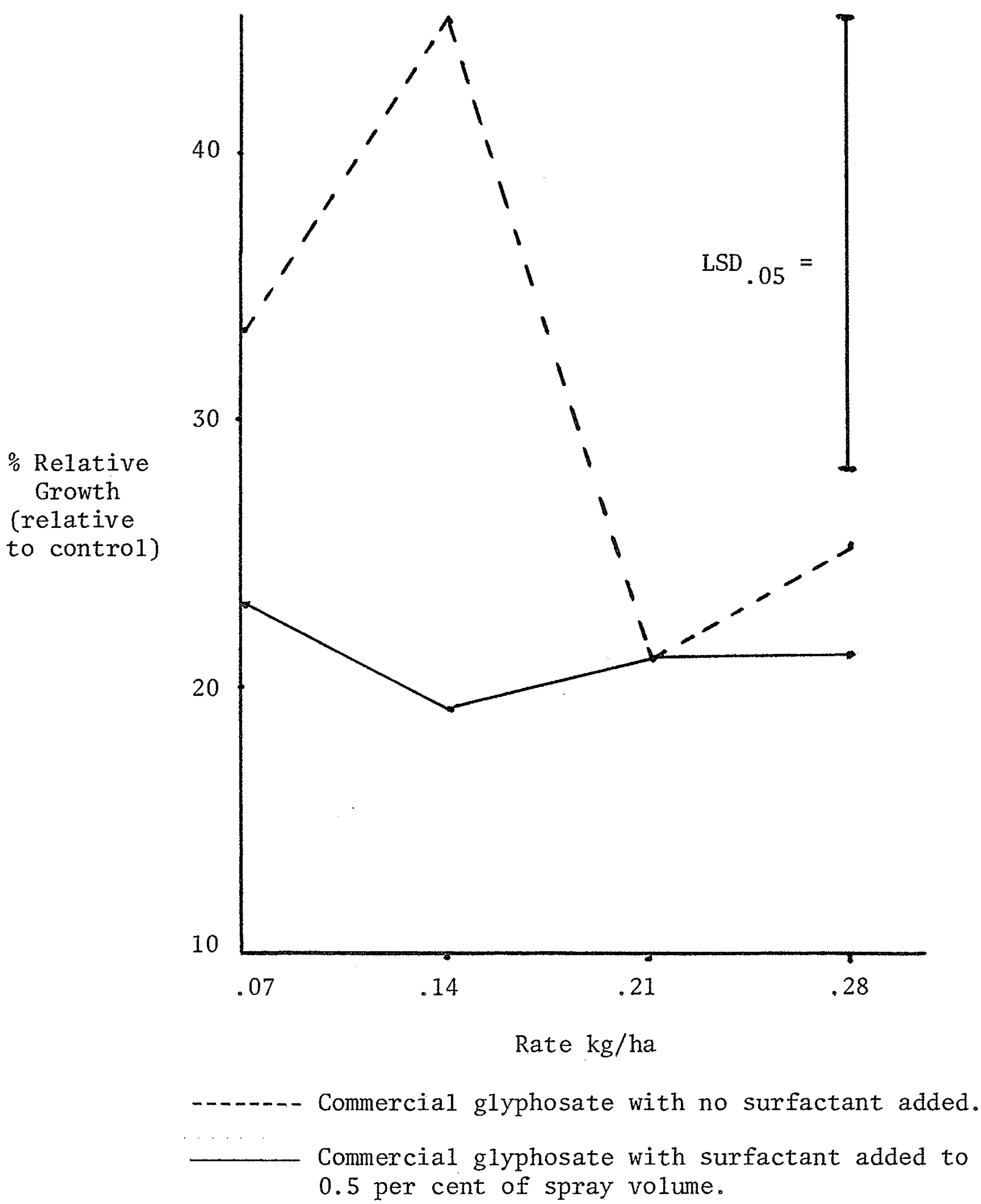
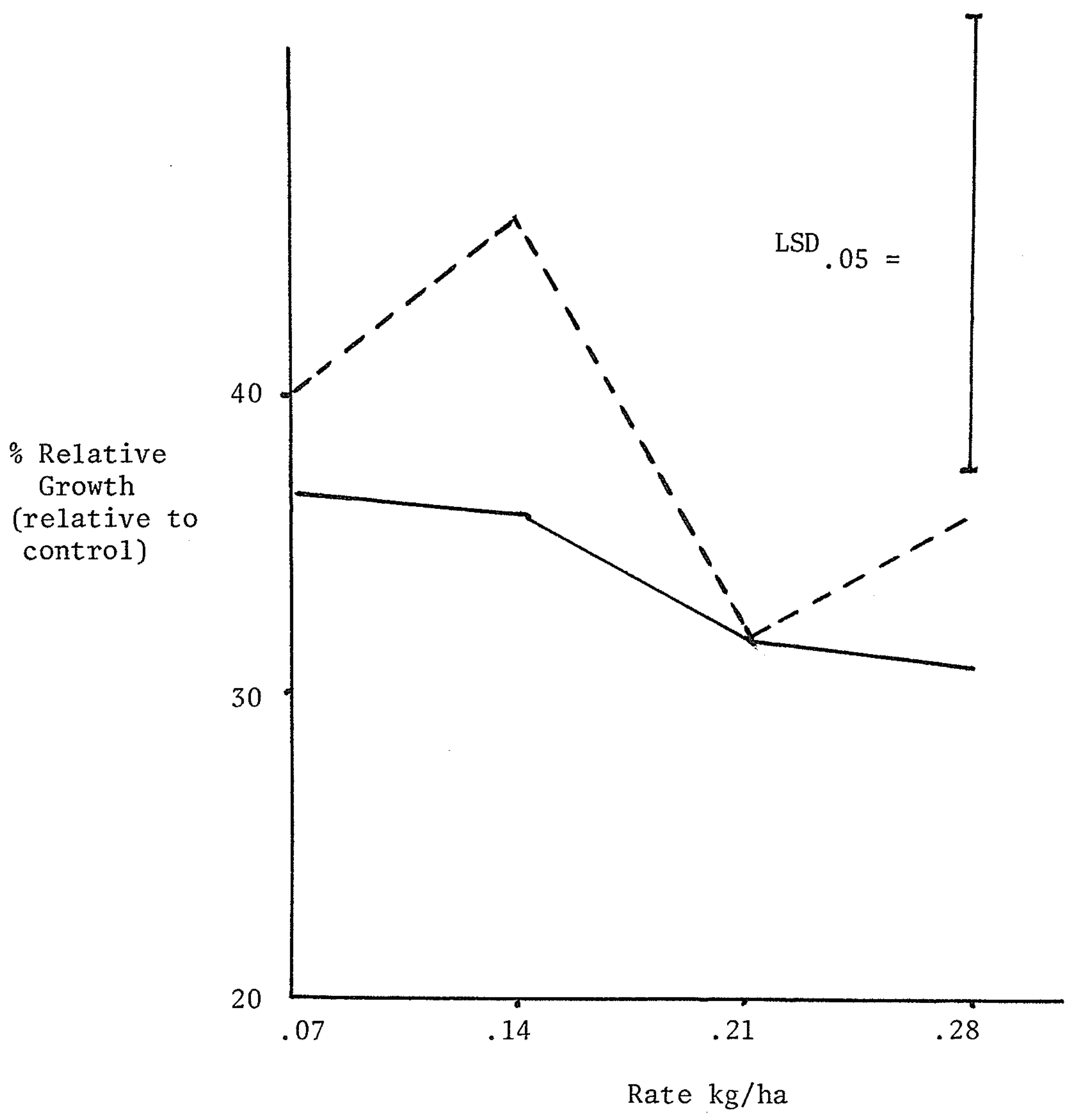


FIGURE 3. Green foxtail inhibition resulting from glyphosate applied at several surfactant concentrations.



-------- Commercial glyphosate with no surfactant added.

———— Commercial glyphosate with surfactant added to 0.5 per cent of spray volume.

FIGURE 4. Wild buckwheat inhibition resulting from glyphosate applied at several surfactant concentrations.

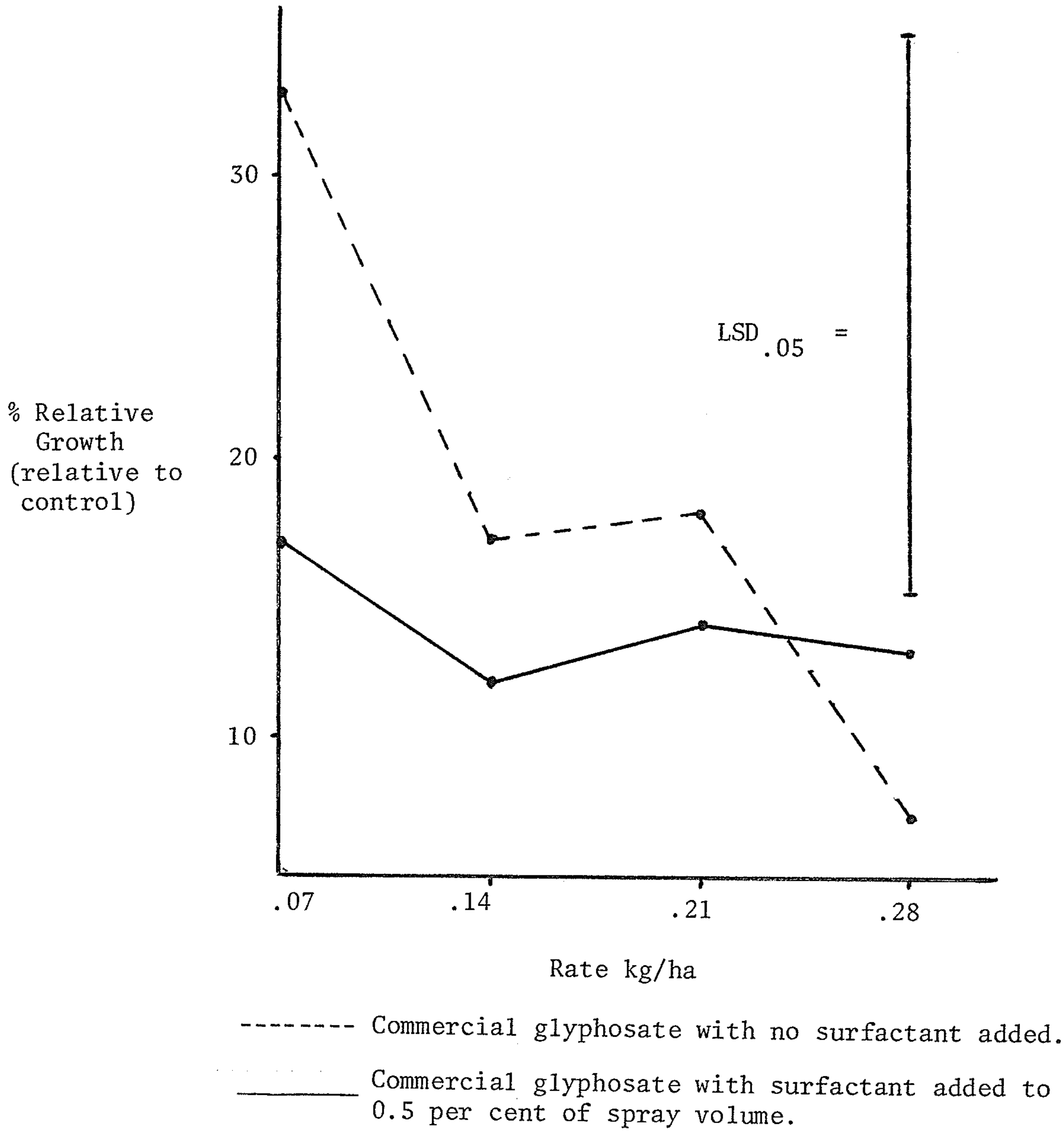
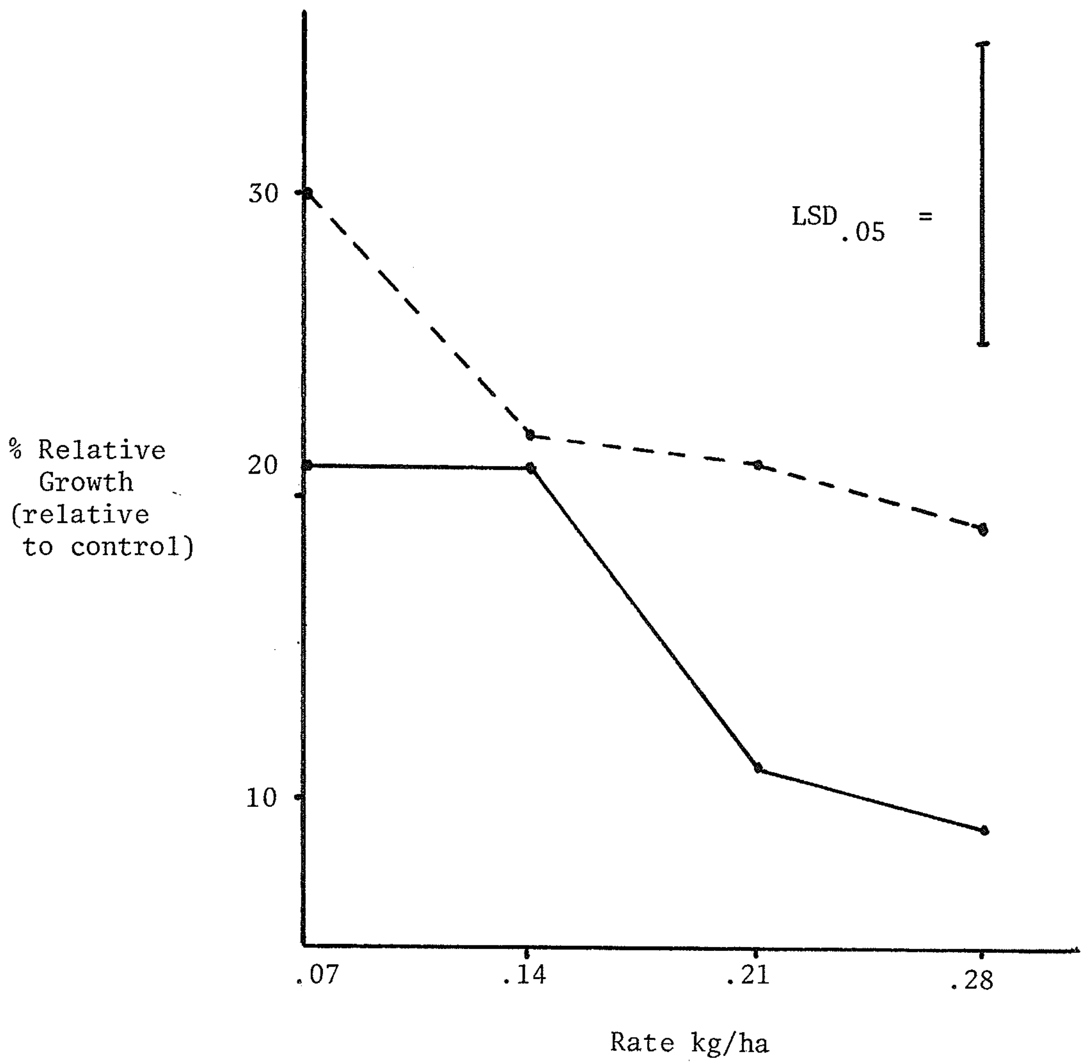


FIGURE 5. Wild mustard inhibition resulting from glyphosate applied at several surfactant concentrations.



------- Commercial glyphosate with no surfactant added.

——— Commercial glyphosate with surfactant added to 0.5 per cent of spray volume.

TABLE 8

Visual ratings and dry weight measurements of weeds sprayed with glyphosate and paraquat.

Treatment	Rate kg/ha	Visual ratings W.B.	L.T.	G.F.	Dry weights* wild buckwheat mg per 10 plants
Control	--	0	0	0	1,445
Glyphosate	0.07	2	3	7	1,519
"	0.14	2	4	8	1,317
"	0.21	3	4	8	1,126
"	0.28	4	5	8	1,296
"	0.42	4	6	8	1,166
"	0.56	5	8	9	720
Paraquat	0.56	4	2	7	1,613
"	0.84	4	3	8	1,355

$LSD_{.05}$ = 466

W.B. = wild buckwheat L.T. = lady's thumb G.F. = green foxtail

* Complete data on plants recorded included in Appendix Table 9.

In Experiment 12 with no crop competition, as in Experiment 3, 0.56 kg/ha glyphosate did not give sufficient control of wild buckwheat but controlled lady's thumb. All herbicide treatments in Experiment 12 controlled green foxtail.

Experiment 13. Control of green foxtail, wild buckwheat, and lady's thumb using glyphosate at several surfactant concentrations.

The results of plants treated with glyphosate at several surfactant concentrations are reported as visual ratings and dry weight measurements of wild buckwheat plants in Table 9.

TABLE 9

Visual ratings and dry weight measurements of weeds sprayed with glyphosate at several surfactant concentrations.

Glyphosate rate kg/ha	Surfactant concentration % of total spray solution	Visual ratings			Dry weight* wild buckwheat mg per 10 plants
		G.F.	W.B.	L.T.	
0.00	--	0	0	0	2,026
0.14	0.05	7	2	4	1,411
0.14	0.10	7	2	4	1,472
0.14	0.50	8	4	4	1,176
0.14	1.00	7	4	4	1,154
0.28	0.05	8	4	5	1,133
0.28	0.10	8	4	5	1,197
0.28	0.50	8	5	6	1,145
0.28	1.00	8	6	6	907
					N.S.

* Complete data (not significant) on plants recorded included in Appendix Table 10.

Although the differences in dry weight measurements of wild buckwheat plants in Experiment 13 were not statistically significant it appears that at least 0.50 per cent surfactant is required for optimum control. This is evident from the dry weight measurements at the 0.14 kg/ha rate of glyphosate.

Experiment 14. Control of green foxtail, wild buckwheat, and lady's thumb using glyphosate at several spray volumes.

The results of plants treated with glyphosate at several spray volumes are reported as visual ratings and dry weight measurements of lady's thumb plants in Table 10.

TABLE 10

Visual ratings and dry weight measurements of weeds sprayed with glyphosate at several spray volumes.

Glyphosate rate kg/ha	Spray volume l/ha	Visual ratings			Dry weight* lady's thumb mg per 10 plants
		G.F.	W.B.	L.T.	
0.00	--	0	0	0	2,465
0.14	62.9	7	3	4	1,545
0.14	115.7	8	4	5	1,360
0.14	173.0	7	2	3	1,742
0.14	237.0	7	2	3	1,905
0.28	62.9	8	4	6	1,059
0.28	115.7	8	4	6	1,407
0.28	173.0	8	3	5	1,284
0.28	237.0	8	4	5	1,252

$LSD_{.05}$ = 537

* Complete data on plants recorded included in Appendix Table 11.

From Experiment 14 it appears that the lower spray volumes are slightly superior to the higher spray volumes when surfactant concentrations remained constant, 0.50 per cent. When considering the 0.14 kg/ha rate of glyphosate, the 115.7 l/ha volume appears best, however, at the 0.28 kg/ha rate best results were obtained using the 62.9 l/ha spray volume.

Retention Experiments in Field 1974

Experiment 15. Retention of glyphosate applied at several surfactant concentrations to green foxtail and wild buckwheat in the field.

The results[5] of Experiment 15 are given graphically in Figures 6 and 7 for green foxtail and wild buckwheat, respectively.

Spray retention by green foxtail plants was not affected by different surfactant concentrations except between 0.50 per cent and 1.00 per cent when using the 173.0 l/ha spray volume. At this point increased surfactant increased retention.

Spray retention by wild buckwheat plants (waxy surface) was affected very little by additional surfactant added to the spray solution especially at the 62.9 l/ha spray volume. At 173.0 l/ha spray volume additional surfactant reduced the amount of spray retained. For both spray volumes, maximum spray retention was achieved when surfactant concentrations were 0.00% of the total spray solution. The waxy leaf surface of the wild buckwheat plant could have promoted run-off in the

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[5] Complete data for green foxtail is given in Appendix Table 12 and for wild buckwheat in Appendix Table 13.

FIGURE 6. Retention of glyphosate applied at several surfactant concentrations to green foxtail.

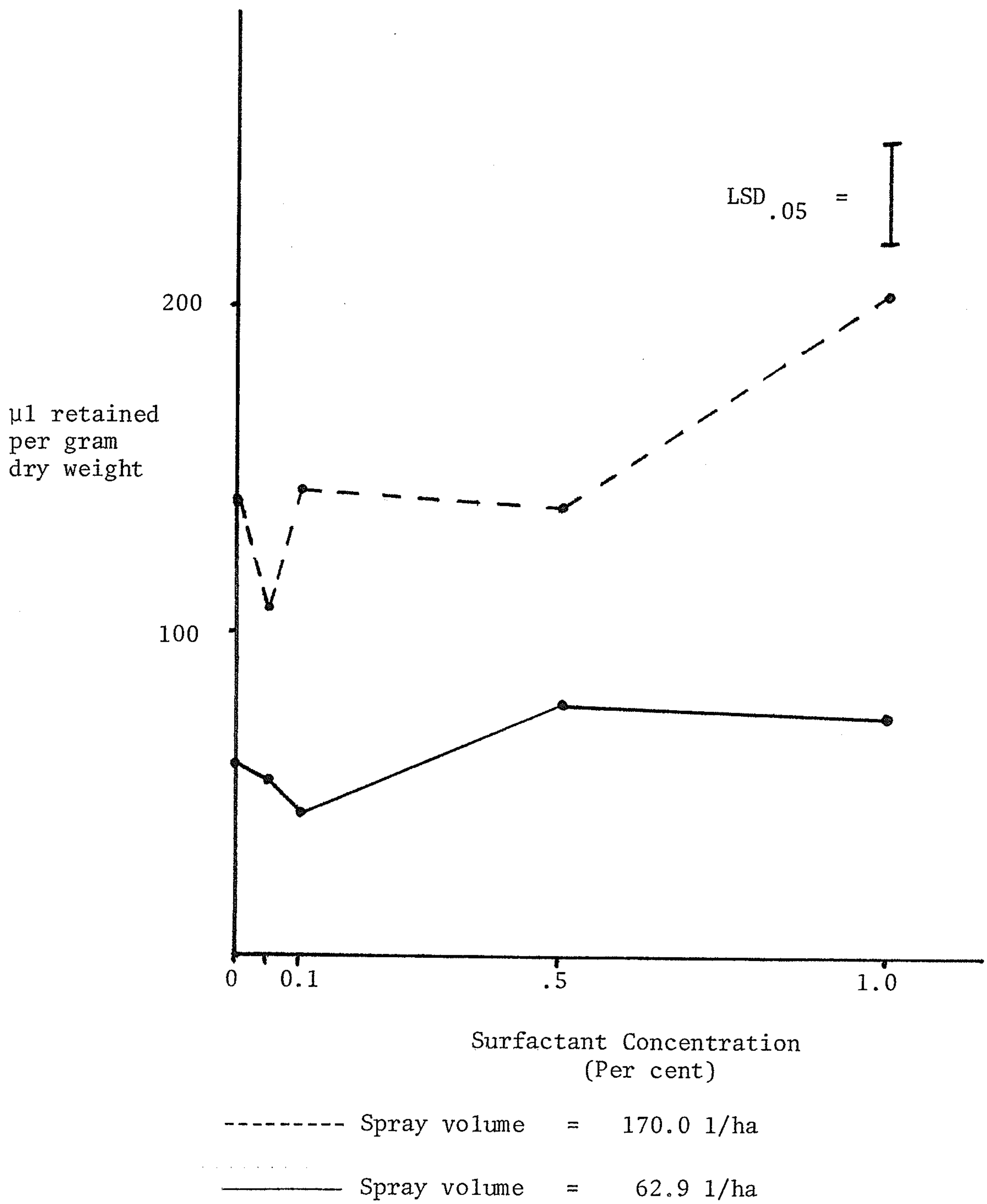
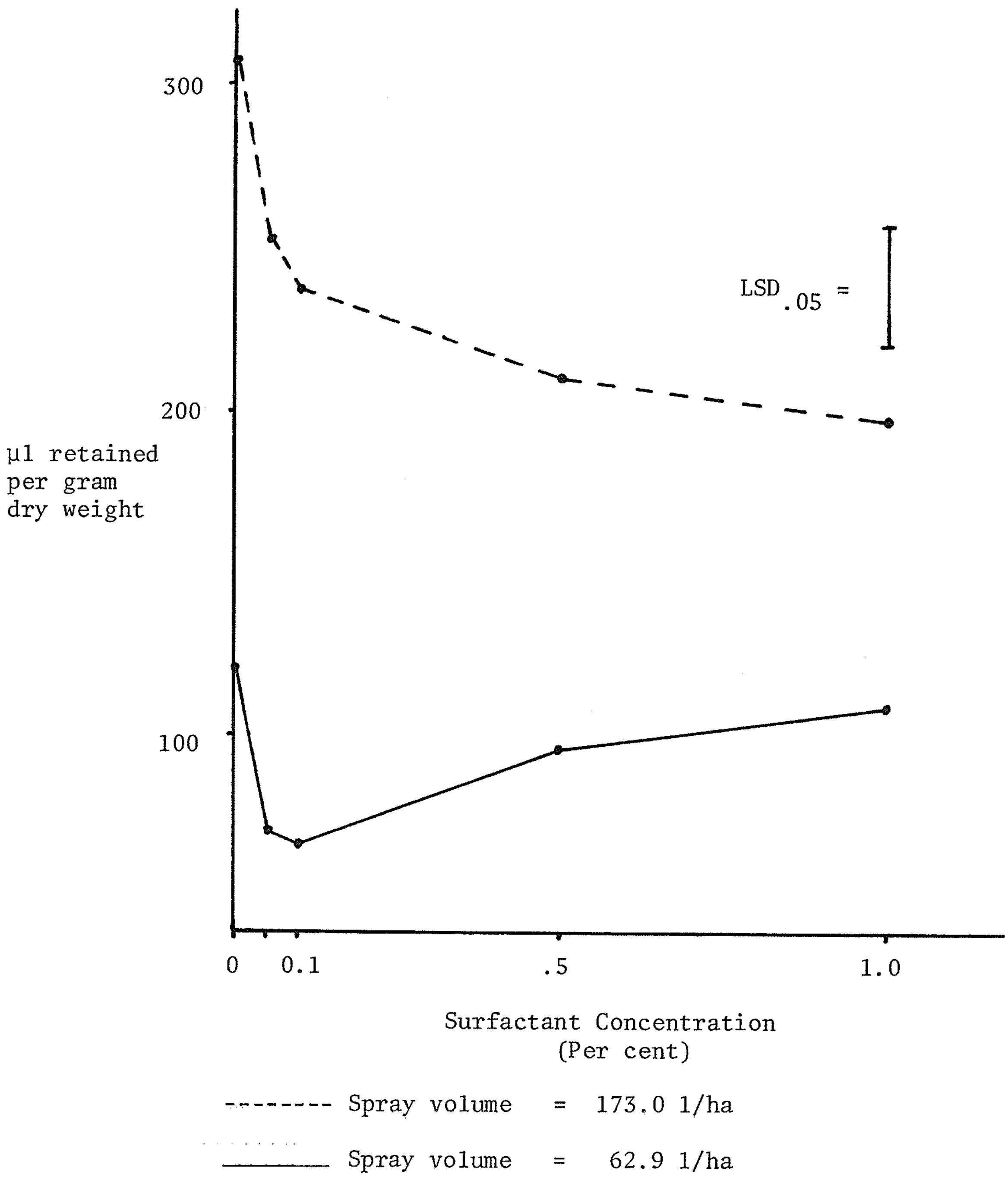


FIGURE 7. Retention of glyphosate applied at several surfactant concentrations to wild buckwheat.



case of solutions of high surfactant concentration (low surface tension).

Experiment 16. Retention of glyphosate applied at several surfactant concentrations to wild oats and wild mustard in the field.

The results[6] of Experiment 16 are given graphically in Figures 8 and 9 for wild oats and wild mustard, respectively.

The addition of surfactant did improve retention of spray solution on wild oat plants, except at the higher volume 173.0 l/ha, where a 1.00 per cent surfactant concentration reduced the spray retention.

The addition of surfactant did not affect the retention of spray solution on wild mustard plants to a large extent. At the 62.9 l/ha spray volume the trend was toward more solution retained at higher surfactant concentrations. At the 173.0 l/ha spray volume the trend was toward less solution being retained at higher surfactant levels.

In Experiment 16, 5 samples of 5 wild mustard plants per sample were harvested from each treatment 15 days after application. Harvested plants were dried and weighed. The results are expressed as per cent control and are given along with the retention volume for the same treatments in Figure 10 for the 62.9 l/ha volume and in Figure 11 for the 173.0 l/ha volume. All treatments contained 0.14 kg/ha glyphosate. The close relationship, especially at the 173.0 l/ha spray volume, between the control of wild mustard and the spray retention of glyphosate spray solutions can be observed in these figures.

The results of Experiment 13, although not statistically significant, did show some trends. Generally better control was achieved with

[6] Complete data for wild oats is given in Appendix Table 14, and for wild mustard in Appendix Table 15.

FIGURE 8. Retention of glyphosate applied at several surfactant concentrations to wild oats.

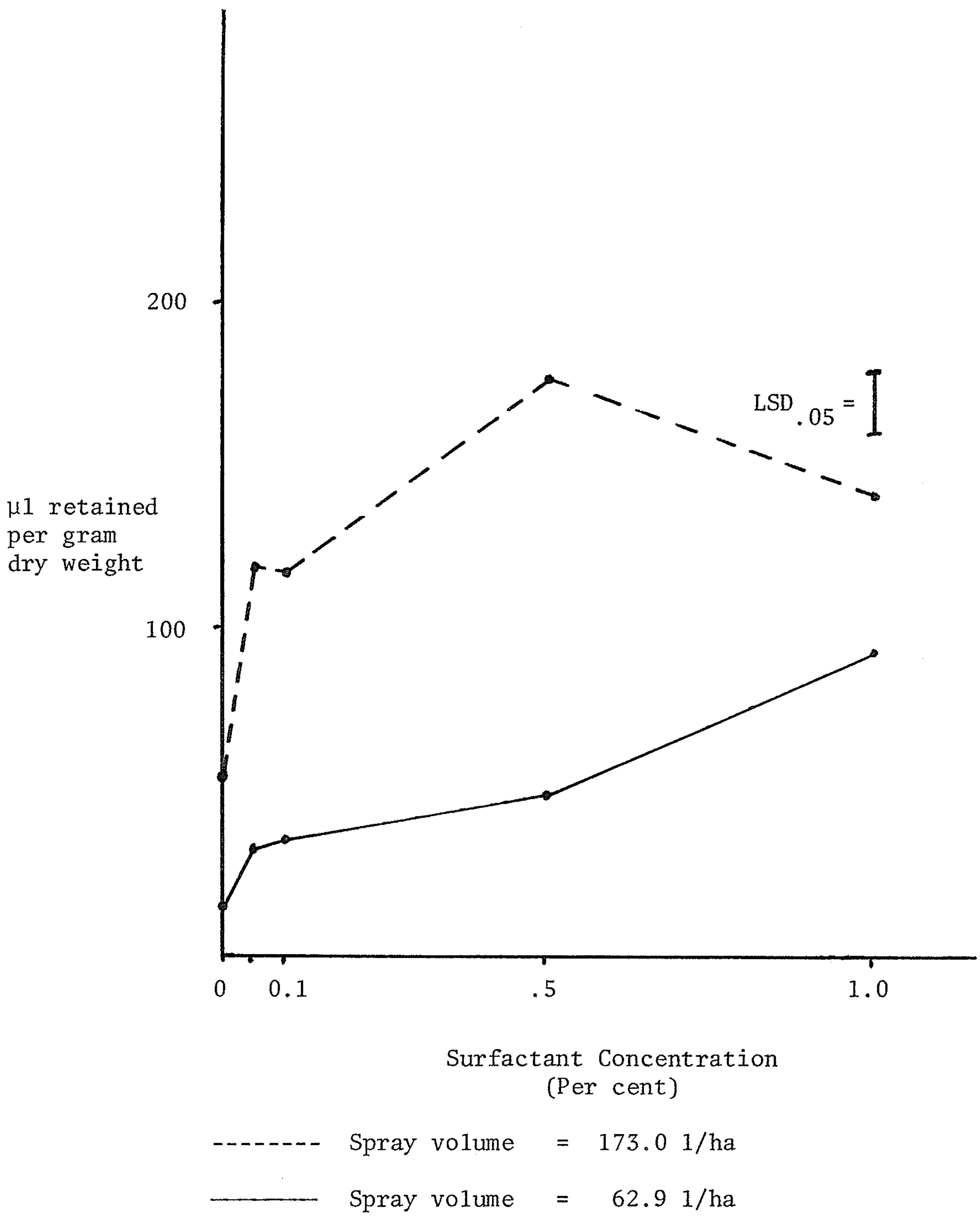


FIGURE 9. Retention of glyphosate applied at several surfactant concentrations to wild mustard.

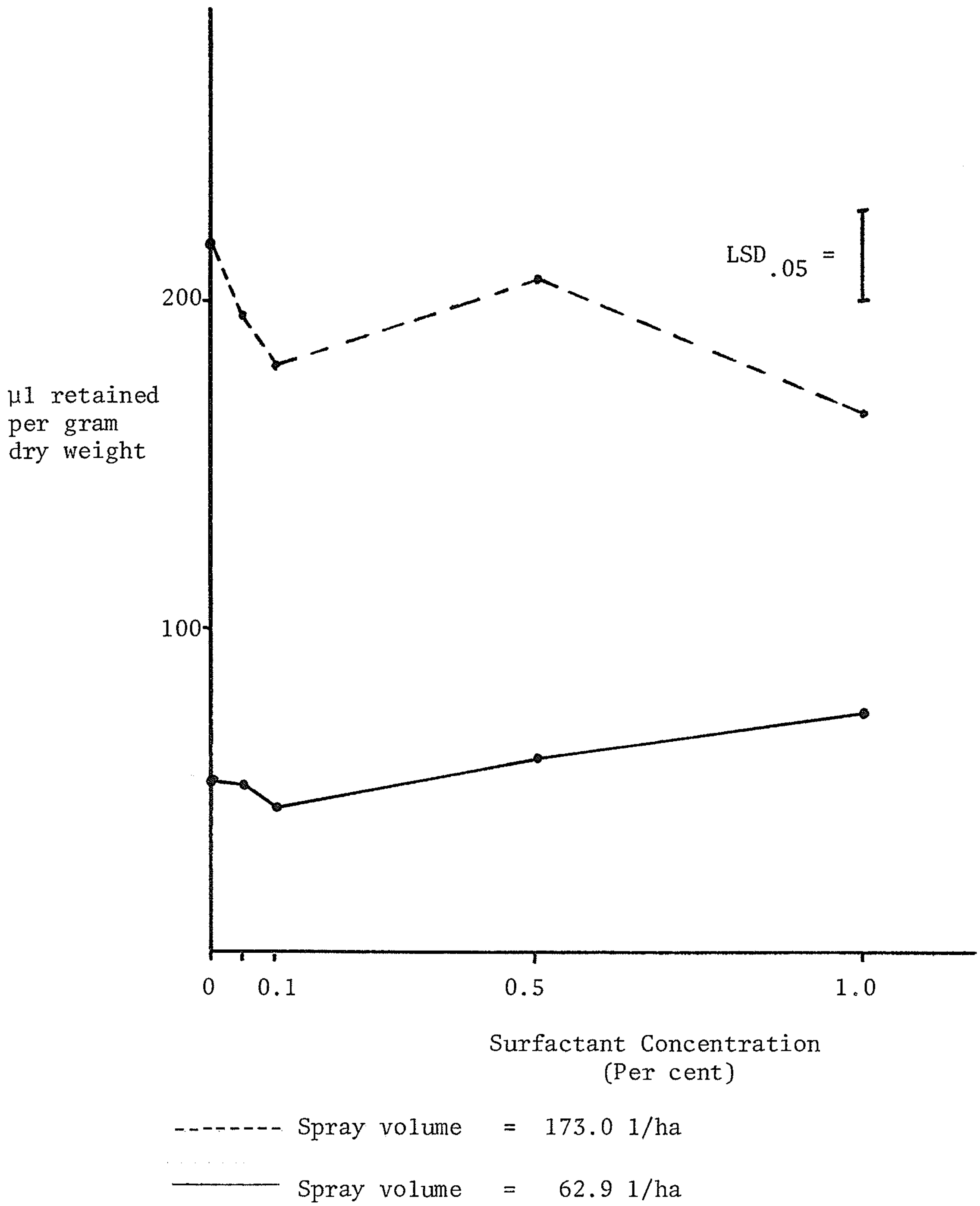
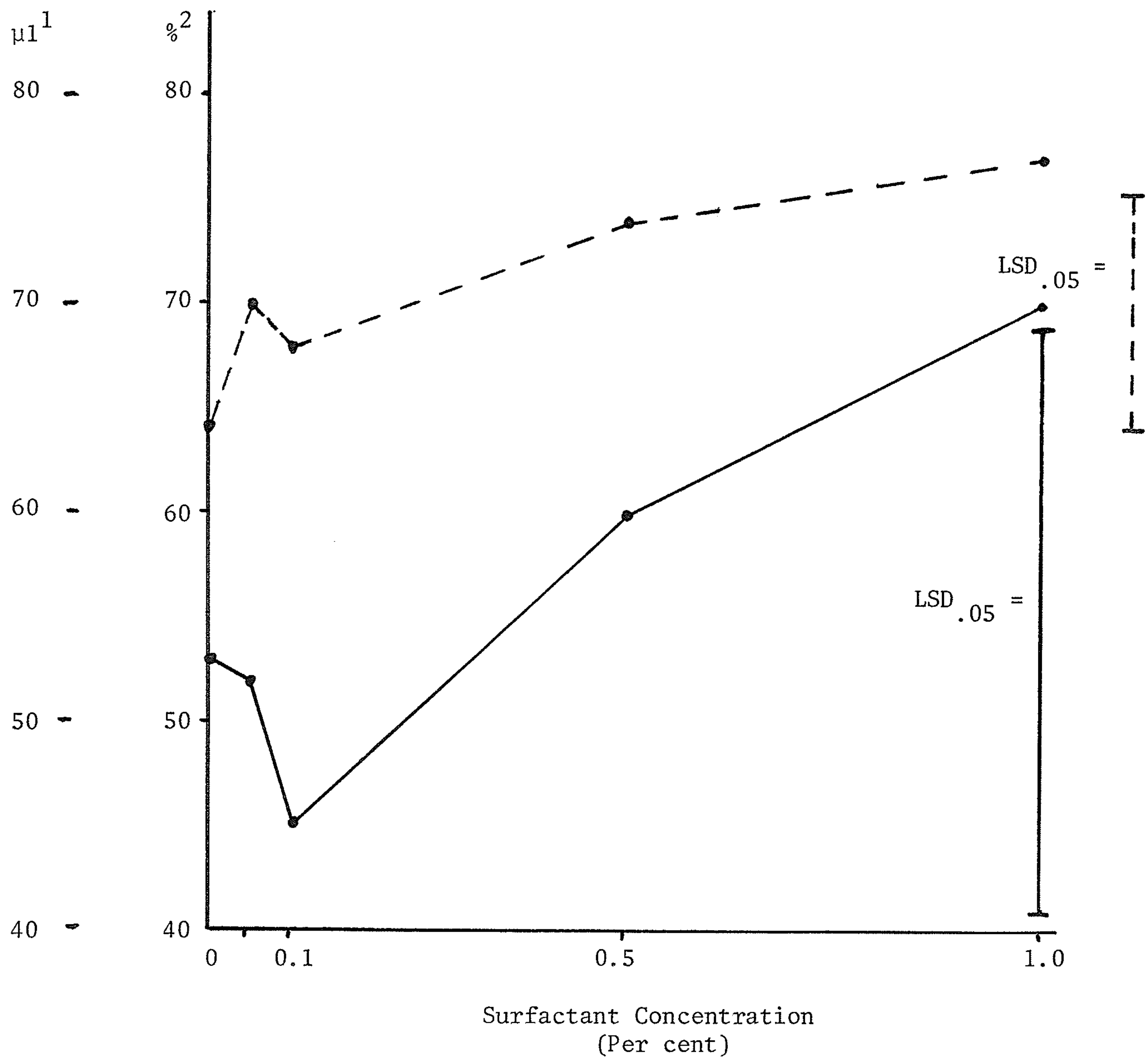


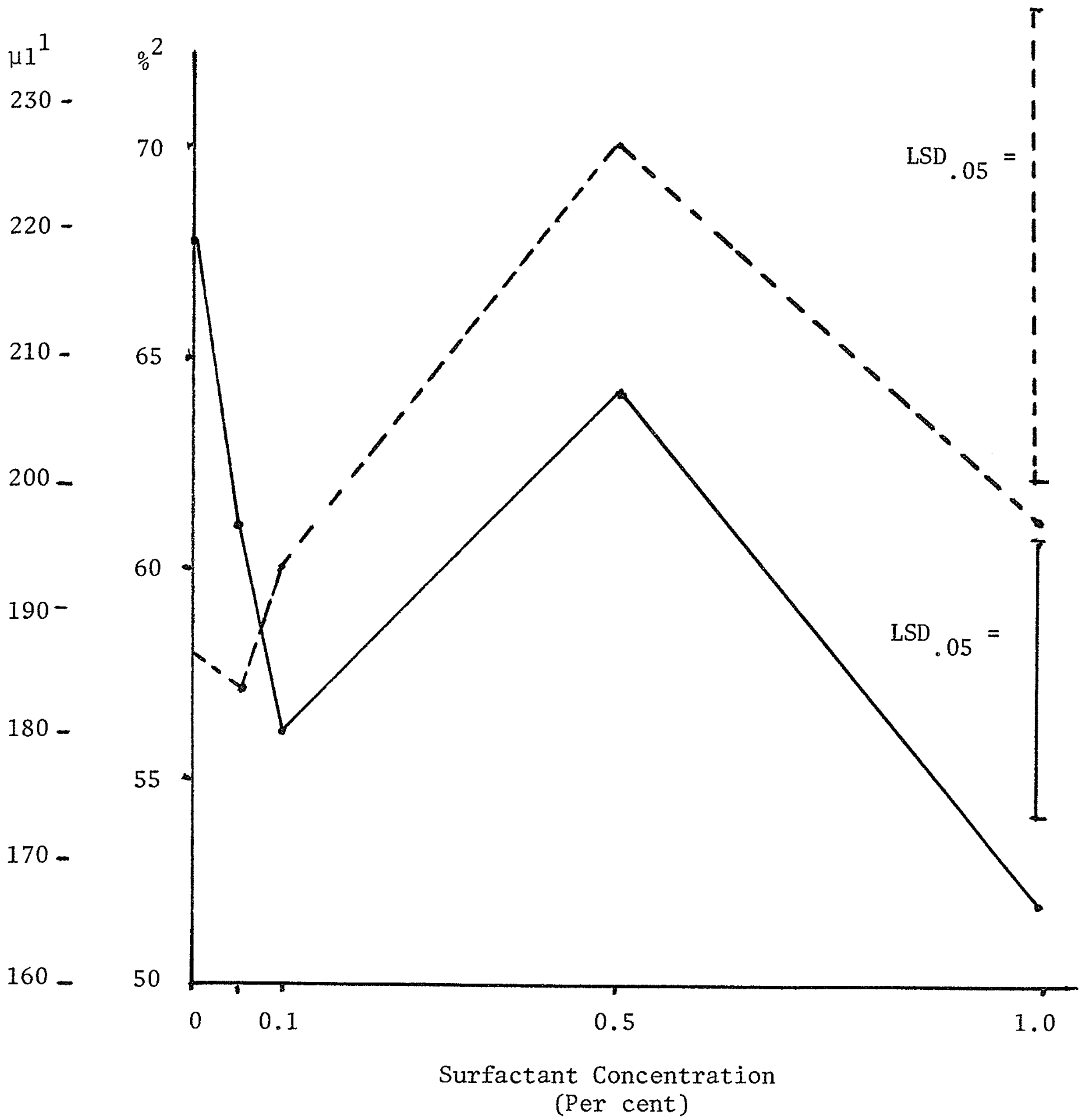
FIGURE 10. Comparison of retention vs. surfactant concentration and control vs. surfactant concentration for wild mustard when spray volume = 62.9 l/ha.



[1] μl apray retained per gram dry weight ————————

[2] % control relative to control plants ------------

FIGURE 11. Comparison of retention vs. surfactant concentation and control vs. surfactant concentration for wild mustard when spray volume = 173.0 l/ha.



[1]µl spray retained per gram dry weight ____________

[2]% control relative to control plants ------------

higher surfactant concentrations. The results of Experiment 13 are given along with the results of wild buckwheat retention from Experiment 15 in Figure 12.

The variation in control of wild buckwheat resulting from glyphosate applications at several surfactant concentrations was not great enough to see the same relationship observed with wild mustard.

Experiment 17. The effect of delayed washing on the amount of Niagra Sky Blue dye recovered from the surface of green foxtail and wild buckwheat plants sprayed with glyphosate solutions containing several surfactant concentrations.

The results of delayed washing on sprayed plants from Experiment 17 are given in graphic form in Figure 13.

In all cases there was a decrease in the amount of dye remaining on the surface of the plants as the concentration of surfactant increased from 0.00 per cent to 1.00 per cent of the total spray solution. In 3 out of 4 cases there was a slight increase in the amount of dye retained as the surfactant increased from 0.00 per cent to 0.05 or 0.10 per cent of the total spray solution. This latter observation was not true of wild buckwheat when the 62.9 l/ha spray volume was used.

If the water-soluble dye, Niagra Sky Blue, was entering the plant along with the herbicide solution then these figures would represent some measure of penetration. Considering these results as an indication of penetration of herbicide into the plant, it follows that the improved control using glyphosate with higher surfactant concentrations would be partially due to improved penetration.

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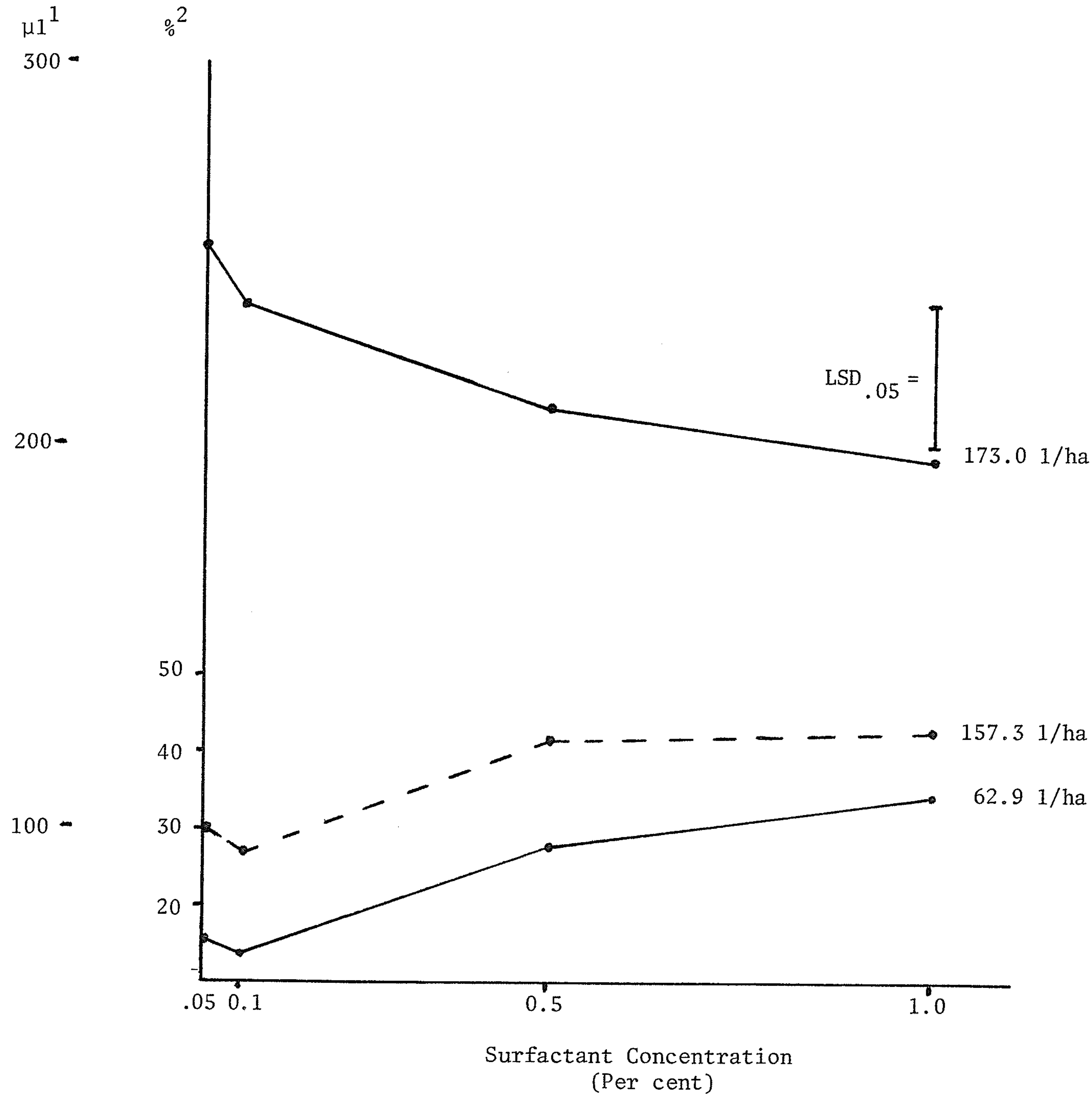
[7] Complete results of Experiment 17 are given in Appendix Table 17.

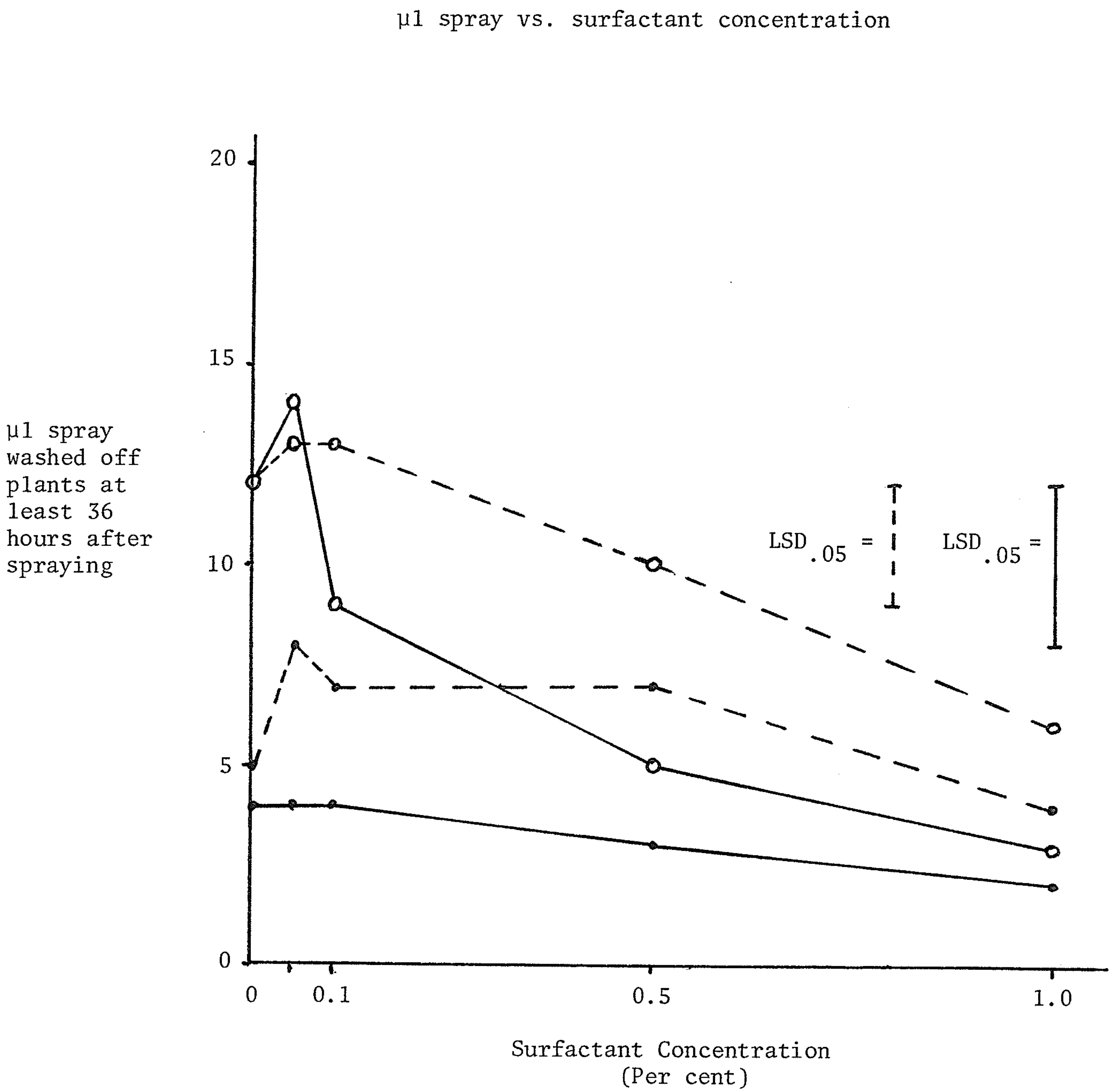
FIGURE 12. Comparison of retention vs. surfactant concentration and control vs. surfactant concentration for wild buckwheat.



[1] μl spray retained per gram dry weight ___________

[2] % control relative to control plants -----------

FIGURE 13. Delayed washing of green foxtail and wild buckwheat.



o - Spray volume = 173.0 l/ha

o - Spray volume = 62.9 l/ha

------- Green foxtail.

_______ Wild buckwheat.

SUMMARY AND CONCLUSIONS

Competition from the faba bean crop affected the rates of glyphosate required to control wild buckwheat and to a lesser extent green foxtail plants. With crop competition less glyphosate was required to control these weeds.

Differences in rates of glyphosate required to achieve weed control in the field and in the greenhouse were attributed to the relative differences in cuticular development and to the differences in the methods used to measure control. In the field the cuticular development which is a secretion of the epidermal cells is often more extensive than in the greenhouse. The magnitude of this change is dependent upon the species. In the field control of the plants treated with glyphosate was determined by dry weight measurements at the end of the growing season. The competition in the field caused plants sprayed with glyphosate to die quickly, whereas in the greenhouse some plants (wild oats) continued to accumulate dry matter (method used in assessing control) for a period of time after spraying. For these reasons field and greenhouse results did not always coincide for all species used in the tests.

The addition of surfactant to the glyphosate spray solutions in general increased phytotoxicity on plants grown in the growth cabinet. In the field optimum control of wild buckwheat was achieved with glyphosate when the surfactant concentration was at least 0.50 per cent of the spray solution.

The addition of surfactant to the spray solution in general increased the retention on grassy species except between 0.50 and 1.00 per cent at the 173.0 l/ha spray volume on wild oats. This supported the work of Ennis (1952), Fogg (1947) and Hellquist (1955, cited by Blackman *et al.*, 1957). Ennis concluded that the addition of a surfactant reduced the incidence of droplets bouncing off the leaf surface. Fogg demonstrated that for the large contact angle between the spray droplet and the leaf surface in cereals (same for the grassy weeds, wild oats and green foxtail), the area of contact was small and the droplet tended to roll off. Hellquist found that particularly the larger droplets had a greater tendency to roll off leaves where the angle of incidence was higher (eg., with barley) than where the angle of incidence was smaller (eg., with field peas).

Maximum retention on wild buckwheat plants was obtained when the surfactant concentration was 0.00 per cent of the spray solution. The reduction in retention by the addition of surfactant when using a spray volume of 173.0 l/ha on wild oats and wild buckwheat agreed with the findings of Furmidge (1962). He found that run-off reduced the retention on leaves with smooth surfaces.

The addition of surfactant to glyphosate solutions had very little effect on the retention of spray solution by wild mustard plants. This supported the work of Schafer (1973) in which the addition of surfactant did not enhance the retention of spray solutions on plants with easy to wet surfaces. Although not statistically analyzed, the data suggested that control of wild mustard appeared to be correlated to spray retention.

The addition of surfactant to the spray solution had very little effect on spray retention when using lower spray volumes. One exception was with wild oats where added surfactant caused an increase in retention at the lower spray volume. These results support the work of Brunskill (1957) in which he concluded that reducing the surface tension of the spray solution had a greater influence on the retention of large droplets than of small droplets. High spray volumes result in large droplet size.

On wild buckwheat, wild mustard and green foxtail using spray volumes of 62.9 l/ha and 173.0 l/ha, retention was reduced when small additions of surfactant, 0.05 and 0.10 per cent were used. Spray retention was increased, however, when the surfactant percentage was greater than 0.10.

In the field better results were obtained when glyphosate was applied at lower spray volumes. This agreed with the work of McKinlay *et al.* (1972). The explanation put forth by this group was that when a herbicide is applied at a lower spray volume, a more concentrated spray solution must be used in order to achieve the same herbicide rate per unit area as when a larger spray volume is being used. This more concentrated spray solution forms a greater concentration gradient between the spray droplet and the inside of the leaf. It is believed that due to this increased concentration gradient, crossover will be greater and faster. However, factors such as environmental conditions and the characteristics of the spray solution (eg., surfactant concentrations) which affect the length of time the spray droplet remains in liquid form on the leaf surface, will influence the effect of herbicide concentrations on penetration.

The other explanation for improved activity at lower spray volumes put forth by McKinlay *et al.* was that of physiological isolation of the large droplets. Based on the work of Jaworski (1972) and due to the fact that there doesn't appear to be any leaf spotting from glyphosate applications, physiological isolation would not be a logical explanation for improved glyphosate activity at lower spray volumes. The work of

Jaworski indicated that the mode of action of glyphosate was in the inhibition of the synthesis of aromatic amino acids which would not appear as a contact action.

A difference was achieved in the amount of dye recovered from plants sprayed with herbicide solutions containing the water-soluble dye, Niagra Sky Blue and left for at least 36 hours before being washed. Less dye was recovered from plants which had been sprayed with solutions containing a high concentration of surfactant, 0.50 or 1.00 per cent. It appeared that the surfactant enhanced penetration of the spray solution (and the dye into the plant).

In conclusion glyphosate has potential for the control of seedling annual weeds in stale seedbed preparation. The rate of glyphosate used should be based on the annual grassy weeds present, and may not control certain broadleafed weeds such as wild buckwheat. Glyphosate at rates required to control annual grassy weeds, in combination with broadleafed weed killers, may present an economically feasible method of stale seedbed prepearation and warrants further study.

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A P P E N D I X

APPENDIX TABLE 1

Effects of glyphosate on dry matter accumulation of wild oat plants in the greenhouse.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha									$\bar{x}$
0.00	383	208	326	323	470	502	242	330	(348)
0.10	351	257	448	332	268	306	320	359	(330)
0.20	219	171	220	332	218	204	248	277	(236)
0.29	204	171	222	176	202	153	198	159	(186)
0.39	156	336	159	239	200	177	168	156	(199)
0.49	132	171	138	246	137	106	159	159	(156)
0.59	111	145	115	152	176	91	157	103	(131)
0.69	123	148	158	184	123	116	108	70	(129)
0.78	69	177	122	124	123	70	165	53	(113)
1.03	119	70	36	75	114	127	88	53	(85)

$LSD_{.05}$ = 68

APPENDIX TABLE 2

Effects of glyphosate on dry matter accumulation of green foxtail plants in the greenhouse.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha									$\bar{x}$
0.00	1202	2347	2168	1880	2344	2301	1214	1540	(1875)
0.03	738	1335	2222	1004	1322	504	1390	837	(1169)
0.06	399	590	418	192	511	104	641	572	(428)
0.09	215	312	177	288	270	102	90	198	(207)
0.12	97	39	102	27	40	125	128	106	(83)
0.15	45	102	33	14	43	87	45	86	(57)
0.18	6	62	78	30	96	21	46	51	(49)

$LSD_{.05}$ = 300

APPENDIX TABLE 3

Effects of glyphosate on dry matter accumulation of wild buckwheat plants in the greenhouse.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha									$\bar{x}$
0.00	1962	2482	1934	1934	2992	2481	3038	2990	(2477)
0.26	963	2210	1575	1445	2185	1456	1864	1480	(1647)
0.52	1509	1976	1092	1400	1318	1398	791	608	(1262)
0.65	1373	1725	1662	1170	1265	1270	1390	1917	(1472)
0.78	644	241	1015	608	713	1676	868	414	(772)
0.91	706	1394	726	1349	949	91	931	180	(791)
1.05	279	603	396	939	128	0	387	827	(445)
1.31	347	809	557	1186	449	358	116	86	(489)

$LSD_{.05}$ = 412

APPENDIX TABLE 4

Effects of glyphosate on dry matter accumulation of wild mustard plants in the greenhouse.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha									$\bar{x}$
0.00	1544	1780	1805	1570	2211	2011	1900	1836	(1832)
0.06	433	777	1094	1197	362	838	512	1068	(785)
0.12	497	226	215	298	322	309	288	181	(292)
0.15	123	320	145	303	269	251	85	285	(223)
0.18	269	249	162	187	295	217	290	96	(221)

$LSD_{.05}$ = 293

APPENDIX TABLE 5

Wild oat - dry matter accumulation in the growth cabinet after application of glyphosate at several surfactant concentrations.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha	Surfactant conc.								$\bar{x}$
0	--	210	521	530	465	351	239	467	(398)
.07	commercial[1]	92	138	143	92	170	146	166	(135)
.07	.5%[2]	89	42	108	110	156	91	48	(92)
.14	commercial	131	149	258	135	130	260	201	(181)
.14	.5%	120	63	26	144	18	88	58	(74)
.21	commercial	76	42	102	122	108	62	99	(87)
.21	.5%	55	97	62	66	21	104	168	(82)
.28	commercial	61	149	119	90	98	45	135	(100)
.28	.5%	53	26	135	85	173	93	9	(82)

$LSD_{.05} = 65.7$

[1] No surfactant added to the commercial formulation of glyphosate (Roundup).

[2] Surfactant comprised .5% by weight of total spray solution.

APPENDIX TABLE 6

Green foxtail - dry matter accumulation in the growth cabinet after application of glyphosate at several surfactant concentrations.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha	Surfactant conc.								$\bar{x}$
0	--	203	229	205	155	187	172	324	(211)
.07	commercial[1]	59	56	104	107	115	44	106	(84)
.07	.5%[2]	49	90	85	117	63	72	69	(78)
.14	commercial	117	64	143	111	93	60	88	(97)
.14	.5%	77	81	78	78	60	91	60	(75)
.21	commercial	62	92	35	97	80	51	62	(68)
.21	.5%	40	40	80	100	63	78	78	(68)
.28	commercial	100	44	71	89	87	89	51	(76)
.28	.5%	31	49	69	34	63	127	86	(66)

$LSD_{.05} = 32.1$

[1] No surfactant added to the commercial formulation of glyphosate (Roundup).

[2] Surfactant comprised .5% by weight of total spray solution.

APPENDIX TABLE 7

Wild buckwheat - dry matter accumulation in the growth cabinet after application of glyphosate at several surfactant concentrations.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha	Surfactant conc.								$\bar{x}$
0	--	1135	856	781	507	700	801	1709	(927)
.28	commercial[1]	160	624	70	204	677	87	319	(306)
.28	.5%[2]	258	295	180	153	69	131	8	(156)
.42	commercial	94	117	191	243	99	161	174	(154)
.42	.5%	91	418	29	55	53	29	120	(114)
.56	commercial	57	125	111	138	231	273	207	(163)
.56	.5%	77	87	275	86	126	191	87	(133)
.70	commercial	93	138	21	40	4	101	31	(61)
.70	.5%	21	78	118	212	125	110	173	(120)

$LSD_{.05}$ = 185.2

[1] No surfactant added to the commercial formulation of glyphoaate (Roundup).

[2] Surfactant comprised .5% by weight of total spray solution.

APPENDIX TABLE 8

Wild mustard - dry matter accumulation in the growth cabinet after application of glyphosate at several surfactant concentrations.

[Results reported as the increase in dry weight (mg) over the check plants at spraying]

Glyphosate kg/ha	Surfactant conc.								$\bar{x}$
0	--	1840	1373	1523	1825	2055	1458	1186	(1609)
.07	commercial[1]	556	295	562	612	299	489	529	(477)
.07	.5%	484	460	305	377	231	264	251	(339)
.14	commercial	298	358	254	403	410	450	342	(359)
.14	.5%	449	332	408	94	574	272	210	(334)
.21	commercial	106	294	326	201	624	463	344	(337)
.21	.5%	181	103	57	278	260	225	190	(185)
.28	commercial	201	308	270	205	138	413	554	(298)
.28	.5%	135	151	217	119	106	292	3	(146)

$LSD_{.05}$ = 166.5

[1] No surfactant added to the commercial formulation of glyphosate (Roundup).

[2] Surfactant comprised .5% by weight of total spray solution.

APPENDIX TABLE 9

Effects of rates of glyphosate and paraquat on dry weight measurements of wild buckwheat plants in the field.

[Results reported as dry weight (mg) of 10 wild buckwheat plants per replication]

Treatment	Rate kg/ha					$\bar{x}$
Check	0.00	1580	1707	1285	1209	(1445)
Glyphosate	0.07	2289	2029	816	941	(1519)
Glyphosate	0.14	2300	1510	751	706	(1317)
Glyphosate	0.21	1350	1642	671	840	(1126)
Glyphosate	0.28	1193	1767	821	1401	(1296)
Glyphosate	0.42	1514	1350	728	1072	(1166)
Glyphosate	0.56	451	1043	692	695	(720)
Paraquat	0.56	2378	1751	1059	1264	(1613)
Paraquat	0.84	1817	1855	698	1048	(1355)

$LSD_{.05}$ = 466

APPENDIX TABLE 10

Effects on dry weight measurements of glyphosate applied at several surfactant concentrations to wild buckwheat plants in the field.

[Results reported as dry weight (mg) of 10 wild buckwheat plants per replication]

Glyphosate kg/ha	Surfactant % of total spray solution					$\bar{x}$
0.00	0.00	3721	949	1492	1942	(2026)
0.14	0.05	1606	904	1458	1675	(1411)
0.14	0.10	1157	1802	1148	1781	(1472)
0.14	0.50	886	1472	1085	1262	(1176)
0.14	1.00	1131	1234	1004	1245	(1154)
0.28	0.05	1379	1255	1069	829	(1133)
0.28	0.10	973	1427	1133	1256	(1197)
0.28	0.50	1148	1716	861	856	(1145)
0.28	1.00	746	955	840	1088	(907)
						N.S.

N.S. = Not significant.

APPENDIX TABLE 11

Effects on dry weight measurements of glyphosate applied at several spray volumes to lady's thumb plants in the field.

[Results reported as dry weight (mg) of 10 lady's thumb plants per replication]

Glyphosate kg/ha	Spray volume l/ha					$\bar{x}$
0.00	--	2134	1827	2855	3044	(2465)
0.14	62.9	1635	1695	2044	806	(1545)
0.14	115.7	1184	1381	1684	1190	(1360)
0.14	173.0	1525	2202	1943	1298	(1742)
0.14	237.0	1665	1739	2946	1269	(1905)
0.28	62.9	1145	917	1681	493	(1059)
0.28	115.7	1022	1740	1935	930	(1407)
0.28	173.0	961	1130	1944	1100	(1284)
0.28	237.0	1465	858	2046	640	(1252)

$LSD_{.05}$ = 537

APPENDIX TABLE 12

Effects of surfactant concentration in the spray solution on retention on green foxtail plants in the field.

[μl spray retained per gram dry weight]

Spray volume l/ha	Surfactant % of total spray solution						$\bar{x}$
62.9	0.00	56	52	59	73	56	(59)
62.9	0.05	45	46	51	70	54	(53)
62.9	0.10	47	44	38	46	45	(44)
62.9	0.50	89	69	80	76	75	(78)
62.9	1.00	87	60	73	70	74	(73)
173.0	0.00	132	130	100	103	137	(120)
173.0	0.05	70	74	122	115	155	(107)
173.0	0.10	133	117	134	109	128	(124)
173.0	0.50	86	131	118	126	134	(119)
173.0	1.00	181	236	165	147	290	(204)

$LSD_{.05}$ = 31

APPENDIX TABLE 13

Effects of surfactant concentration in the spray solution on retention on wild buckwheat plants in the field.

[μl spray retained per gram dry weight]

Spray volume l/ha	Surfactant % of total spray solution						$\bar{x}$
62.9	0.00	113	118	149	125	100	(121)
62.9	0.05	82	77	70	60	65	(71)
62.9	0.10	55	71	67	70	73	(67)
62.9	0.50	98	89	105	97	91	(96)
62.9	1.00	99	90	129	93	134	(109)
173.0	0.00	339	314	239	288	356	(307)
173.0	0.05	210	242	304	252	253	(252)
173.0	0.10	248	219	183	272	261	(237)
173.0	0.50	282	182	190	201	196	(210)
173.0	1.00	177	226	234	203	145	(197)

$LSD_{.05} = 37$

APPENDIX TABLE 14

Effects of surfactant concentration in the spray solution on retention on wild oat plants in the field.

[μl spray retained per gram dry weight]

Spray volume l/ha	Surfactant % of total spray solution									$\bar{x}$
62.9	0.00	10	15	8	9	23	17	17	14	(14)
62.9	0.05	58	47	31	23	37	19	23	17	(32)
62.9	0.10	14	10	37	22	32	57	45	59	(35)
62.9	0.50	62	72	31	44	32	37	47	67	(49)
62.9	1.00	131	73	98	83	92	83	96	87	(93)
173.0	0.00	53	62	50	46	39	67	54	55	(53)
173.0	0.05	79	96	132	115	140	149	143	99	(119)
173.0	0.10	134	113	91	143	89	138	114	113	(117)
173.0	0.50	225	134	173	174	189	187	176	157	(177)
173.0	1.00	139	167	121	130	125	121	134	194	(141)

$LSD_{.05}$ = 19

APPENDIX TABLE 15

Effects of surfactant concentration in the spray solution on retention on wild mustard plants in the field.

[μl spray retained per gram dry weight]

Spray volume l/ha	Surfactant % of total spray solution											$\bar{x}$
62.9	0.00	39	38	48	40	44	84	47	72	60	60	(53)
62.9	0.05	44	28	40	84	70	53	57	56	47	42	(52)
62.9	0.10	36	55	58	38	43	24	52	69	39	38	(45)
62.9	0.50	33	47	68	44	38	89	75	83	71	49	(60)
62.9	1.00	56	82	100	76	74	54	89	66	76	67	(74)
173.0	0.00	243	228	209	156	255	209	245	159	197	276	(218)
173.0	0.05	180	264	216	209	185	192	154	206	187	167	(196)
173.0	0.10	202	230	163	206	218	190	148	157	148	139	(180)
173.0	0.50	259	292	108	204	286	256	184	157	155	170	(207)
173.0	1.00	168	165	88	190	160	131	193	189	186	187	(166)

$LSD_{.05} = 28$

APPENDIX TABLE 16

Wild mustard - control in Experiment 16 - plants harvested 15 days after spraying dye solutions.

[Results reported as dry weight (mg) of 5 wild mustard plants per replication]

Spray volume 1/ha	Surfactant % of total spray volume						$\bar{x}$
62.9	0.00	529	549	484	687	682	(682)
62.9	0.05	442	461	653	506	430	(498)
62.9	0.10	530	562	439	530	522	(517)
62.9	0.50	540	346	498	322	440	(429)
62.9	1.00	389	313	443	302	430	(375)
173.0	0.00	615	912	578	792	526	(685)
173.0	0.05	873	634	627	554	809	(699)
173.0	0.10	595	731	654	541	752	(655)
173.0	0.50	575	453	522	495	359	(481)
173.0	1.00	695	651	614	494	685	(629)
Unsprayed control		2077	1469	1900	1532	1157	(1627)

$LSD_{.05}$ = 184

APPENDIX TABLE 17

Effests of delayed washing on the amount of Niagra Sky Blue recovered from the surfaces of green foxtail plants sprayed with glyphosate solutions containing several surfactant concentrations.

[Results expressed here as µl spray washed off plants at least 36 hours after spraying]

Spray volume 1/ha	Surfactant % of total spray solution							$\bar{x}$
62.9	0.00	8	7	4	3	6	1	(5)
62.9	0.05	9	11	10	9	6	4	(8)
62.9	0.10	10	10	7	7	4	6	(7)
62.9	0.50	5	10	3	9	9	7	(7)
62.9	1.00	6	5	3	3	5	2	(4)
173.0	0.00	9	9	8	11	8	10	(9)
173.0	0.05	16	18	14	13	7	7	(13)
173.0	0.10	18	19	12	11	10	7	(13)
173.0	0.50	12	11	9	10	6	9	(10)
173.0	1.00	8	8	5	6	3	4	(6)

$LSD_{.05}$ = 3

APPENDIX TABLE 18

Effects of delayed washing on the amount of Niagra Sky Blue recovered from the surfaces of wild buckwheat plants sprayed with glyphosate solutions containing several surfactant concentrations.

[Results expressed here as μl spray washed off plants at least 36 hours after spraying]

Spray volume l/ha	Surfactant % of total spray solution							$\bar{x}$
62.9	0.00	4	5	4	5	4	4	(4)
62.9	0.05	7	5	3	3	4	4	(4)
62.9	0.10	6	5	4	4	3	4	(4)
62.9	0.50	2	4	2	2	2	3	(3)
62.9	1.00	3	3	1	1	1	2	(2)
173.0	0.00	16	16	11	10	11	10	(12)
173.0	0.05	30	16	7	11	9	9	(14)
173.0	0.10	12	13	8	8	8	7	(9)
173.0	0.50	8	8	3	4	4	4	(5)
173.0	1.00	4	5	2	2	2	2	(3)

$LSD_{.05}$ = 4

APPENDIX A

The surfactant used in these and later experiments was obtained from Monsanto Company Ltd., and was the surfactant mix recommended for use in the commercial formulation of glyphosate (Roundup). The surfactant used was called MON 0011.

In experiments where 0.00% surfactant was used, glyphosate with no surfactant was obtained from Monsanto Company Ltd. Glyphosate with no surfactant was called MON 0039.