EFFICACY OF HERBICIDES APPLIED WITH VARIOUS NOZZLE TIPS

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Conor John Dobson

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ABSTRACT

Dobson, Conor John, M.Sc., The University of Manitoba, October, 1981. Efficacy of Herbicides Applied with Various Nozzle Tips. Major Professor; I.N. Morrison.

Field and laboratory experiments were conducted to investigate the effect of nozzle type on the efficacy of propanil, diclofop methyl, difenzoquat, bromoxynil octanoate and metribuzin applied as postemergence sprays to susceptible weeds.

The nozzles used in these experiments were the flat fan 80015, flat fan 80015LP, flooding TK 0.75 and TK 1.5 and Raindrop RA-2 tips. Applications with the 80015LP tip were at a low (150 kPa) and high (275 kPa) pressure, while applications with all other tips were at 275 kPa. The TK 0.75 tips were spaced on the boom to give an overlapping pattern.

Field treatments were applied at an optimal and sub-optimal leaf stage of the susceptible weeds. The effect of nozzle efficacy was recorded by comparing the differences in crop yield, weed dry weights and weed counts to a weedy check.

With all herbicides tested levels of weed control were highest with the flat fan 80015, flat fan 80015LP applied at 275 kPa and the TK 0.75 tips. Application with the 80015LP at the low pressure (150 kPa) resulted in inconsistent levels of control. Least satisfactory weed control consistently occurred with the flooding TK 1.5, and Raindrop RA-2 nozzles.

The laboratory experiments included an efficacy study where differences were assessed by recording weed dry weight reductions compared to a check, a retention study where retention was measured by use of a

fluorescent tracer and a droplet contact angle study. Results analagous to the field studies were found in the efficacy experiments. Differences in retention between nozzle types occurred, which corresponded to the results of the efficacy studies. In the contact angle studies differences in wettability were found between grass and broadleaf species.

The differences in nozzle performance were attributed to different spray patterns and droplet sizes produced among the nozzles.

INTRODUCTION

The majority of herbicides used in Manitoba are applied as post-emergence treatments with a pull-type sprayer. The proper selection and maintenance of the nozzles on a sprayer is probably one of the most critical factors in an effective spraying operation. A number of hydraulic nozzle types are available to the farmer. These include the conventional flat fan, low pressure (LP) flat fan, flooding and Raindrop nozzle tips, each of which produce different droplet size distribution and spray patterns. Numerous studies have shown that both these factors influence the activity of herbicides under laboratory conditions, but there have been few reports on what their effect is under practical field conditions.

For the farmer, a primary objective is to obtain the highest levels of weed control at the least cost. In view of the fact that little information was available on the effect various nozzles might have on herbicide performance in the field, this study was undertaken to determine if appreciable differences in levels of weed control could be distinguished when a number of different herbicides were applied with a variety of commonly available nozzle tips. Field studies were conducted to study the effect of nozzle type on the efficacy of propanil, diclofop methyl, difenzoquat and bromozynil in wheat and metribuzin in barley. Further experiments were conducted in the laboratory to assess the performance characteristics of the nozzles under controlled conditions. The final objective of the study was to help develop recommendations which would assist farmers in maximizing the effectiveness of their chemical weed control program.

LITERATURE REVIEW

The biological activity of pesticidal sprays is a function of many factors relating to the physico-chemical interaction of toxicant formulation and plant material (Johnstone 1973). Physical factors of the spray such as droplet size, spray volume and surface tension have been shown to affect the efficacy of herbicides applied whenever entry is mainly via the foliage. These properties interact with the gross morphology of the plant and physico-chemical properties of the leaf surface to affect herbicide efficacy by determining the amount of spray on the leaf.

Droplet Size

Droplet size is a critical factor in determining the biological performance of herbicidal sprays (McKinlay et al. 1972). Ennis and Williamson (1963) point out however, that droplet size has a greater effect on the biological activity of herbicidal sprays applied in low volumes compared to those applied in high volumes. When foliage is sprayed to the saturation point, droplet size generally exerts a reduced effect on herbicidal performance.

A mixture of the translocated herbicides, dicamba, mecoprop and MCPA, applied with a controlled droplet application (CDA) system in uniform droplet sizes of 250 µm or 350 µm in diameter resulted in there being no differences in control of Stellaria media and Polygonum persicaria when the chemical was sprayed in volumes of 15 L/ha or 45 L/ha (Ayres and Merritt 1978). At a volume of 5 L/ha, increased herbicide efficacy resulted with the 250 μm drops. However, control at this volume was not as effective as at a volume of 15 L/ha or 45 L/ha regardless of droplet size. The CDA system was compared to a conventional application of the herbicide mixture with a TeeJet 6502 nozzle tip. This tip has a large droplet size spectrum and delivers a spray volume of 225 L/ha. Application with the conventional nozzle resulted in similar broadleaf weed control to that obtained with the CDA system at 45 L/ha and 15L/ha.

Studies of the inhibitory effects of large (2,900 - 7,200 μm) and small (200 - 600 μm) droplets of solutions of the triethanolamine salt of 2,4-D and the ethyl ester of 2,4-D applied at a volume of 23.9 L/ha showed the small droplet spray reduced yields of soybeans more than the corresponding larger droplet sprays (Ennis and Williamson 1963). McKinlay _et al_. (1972) reported similar results with sunflower. Based on measurements of stem curvature, drops of 100 μm were more effective than larger ones (200 μm and 400 μm). MCPA applied at sub-lethal doses in droplets of 100 μm or less caused significantly more damage to lettuce leaves than when applied in droplets of approximately 500 μm in diameter (Way 1969). When the dosage of MCPA was increased and applied as small droplets (100 μm), the fresh weight of the lettuce decreased significantly compared to the same application with large droplets (500 μm).

Ennis and Williamson (1963) investigated the effect of various herbicides applied with different sized droplets on crop plants differing in morphology. Soybean and flax treated with 2,4,5-T butyl ester, sugarbeet treated with 2,4-D butyl ester and wheat treated with CIPC at volumes ranging from 24 to 60 L/ha resulted in greater inhibition of growth as droplet diameter decreased from 800 to 100 μm.

A mixture of the contact herbicides, bromoxynil and ioxynil, applied with a conventional TeeJet 6502 at 225 L/ha or with a CDA unit at 5, 15, and 45 L/ha with either 150 μm or 250 μm droplets showed that the 45 L/ha volume compared in level of broadleaf weed control with the conventional nozzle regardless of droplet size (Ayres and Merritt 1978). As with the translocated herbicide mixture of dicamba, mecoprop and MCPA reported earlier (Ayres and Merritt 1978), lower volume rates of the contact herbicide mixture resulted in poorer broadleaf weed control. Differences due to droplet size appeared to be more pronounced at the lower volume rates (15 L/ha and 5 L/ha). However, in contrast to the translocated herbicide mixture, the larger droplet size of 250 μm resulted in the most effective control with the contact herbicide mixture.

McKinlay et al. (1974) applied paraquat to seedling *Helianthus annuus* at rates of 35 g/ha and 140 g/ha in volumes of 5.5 L/ha or 22 L/ha in 100 μm or 350 μm droplets. At all volume and herbicide rates, with the exception of 35 g/ha paraquat in 22 L/ha of water, homogeneous sprays of 100 μm droplets were more phytotoxic than equivalent sprays made up of larger, 350 μm droplets. At 35 g/ha, with both drop sizes the lower spray volume (5.5 L/ha) produced significantly more damage than the more dilute spray (22 L/ha). This effect was especially evident when 100 μm drops were used.

Douglas (1968) calculated that there was an optimum droplet size for the bipyridyl herbicides, paraquat and diquat. A droplet size range of 250 - 1000 μm was tested and optimum efficacy occurred with droplets of 400 - 500 μm at concentrations of 0.09 - 0.34% diquat and 0.25% paraquat. Towards each end of the droplet size spectrum the droplets became considerably less efficient in causing leaf lesions.

Barban and difenzoquat applied with a CDA unit at 5, 15 and 45 L/ha with small and large drop sizes performed similarly at recommended rates and at reduced rates of active ingredient (Wilson and Taylor 1978). Barban was applied with 150 μm and 250 μm droplets and difenzoquat with 250 μm and 350 μm droplets. Drop size had little influence on the level of control of wild oats except at 5 L/ha where better control was achieved with the smaller drops. Barban applied with a TeeJet 650015 nozzle at 175 L/ha and difenzoquat with a TeeJet 6502 at 225 L/ha performed significantly better than CDA applications at 5 L/ha. At 15 L/ha and 45 L/ha comparable wild oat control was achieved with both large and small droplet sizes. The same type of response was observed by Lake and Taylor (1974) with barban applied to wild oats. They showed that barban was more effective at low volumes when applied as small droplets.

McKinlay _et_ _al_. (1972), Ennis and Williamson (1963) and Behrens (1957) concluded that there are at least two factors tending to make translocated herbicides sprayed in smaller droplets more effective: (1) the total area of leaf contacted by a given volume of herbicide is greater when it is applied in smaller droplets, and consequently the rate of penetration of the herbicide is increased and (2) the very high localized concentrations of herbicide beneath a larger droplet could possibly injure or kill the underlying cells and reduce the rate of translocation out of this area. The effect of droplet size is no longer apparent when these herbicides are applied at high volumes with CDA or conventional TeeJet nozzles. Good weed control is achieved because the high volume provides good contact over a large leaf area with a dilute solution of the herbicide.

The reported effects of droplet size on performance of contact type herbicides is somewhat contradictory. The results of McKinlay et al. (1974) indicate that a smaller droplet size is more phytotoxic while Ayres and Merritt (1978) and Douglas (1968) conclude that a larger droplet size is most effective. But an observation by McKinlay et al. (1974) would support the findings of Douglas (1968) and Merritt and Taylor (1977). They observed that 35 g/ha of paraquat applied at 5.5 L/ha in large droplets (350 μm) resulted in necrotic lesions surrounding each droplet. By contrast, when 35 g/ha of paraquat was applied in 100 μm droplets at 22 L/ha the damage was limited to the upper surface of the cotyledon, while cells of the lower surface remained healthy. These observations would suggest that localized concentrations of paraquat on the surface is of major importance. A single, concentrated drop of paraquat applied to a limited area results in lethal effects, while the same amount of paraquat spread over a large area may never exceed the lethal threshold and result in minimal damage.

The majority of experiments reported thus far have been conducted under laboratory conditions. Field data is very limited.

Ashford (1974) reports that under field conditions herbicide efficacy is not necessarily increased when droplet size is decreased. Comparable doses of 2,4-D amine applied as 200 μm droplets were just as effective in controlling susceptible weed species in a wheat crop as sprays applied with 100 μm droplets. This discrepancy with laboratory results could relate to the fact under field conditions 100 μm droplets are more readily deflected away from the target area by air currents than 200 μm droplets.

Retention of Herbicidal Sprays

The two principle factors involved in retention of herbicidal sprays are: (1) the physical characteristics of the spray, and (2) the physical characteristics of the target plant and the nature of the leaf surface.

Spray Characteristics

The size of spray droplets and surface tension of the spray solution can exert a considerable influence on the retention of herbicides. Brunskill (1956) found that for any given spray fluid a certain critical droplet diameter exists above which retention is very low and below which retention is very high. When the surface tension of the spray solution was high, the larger droplets (250 - 350 μm) tended to bounce off the leaves whereas retention of small droplets (80 - 95 μm) was nearly complete. A sharp rise in the number of large droplets retained occurred when the surface tension of the spray liquid was reduced below a critical value of 45 - 50 dynes/cm by addition of surface active agents. In support of the work by Brunskill (1956), Furmidge (1962a) found that retention on artificial surfaces of beeswax and cellulose acetate increased when the mean droplet size of the spray was reduced.

In an examination of spray deposits on leaves of wild oat and barley, Lake (1977) found that small uniform droplets of 100 μm diameter produced the greatest deposits of spray on the leaves. As drop size was increased to 200 μm, retention decreased considerably, followed by a gradual decrease in amount retained as droplet diameter was increased from 200 μm to 600 μm.

Retention is dependent not only upon droplet size and surface tension, but the nature of the surface that the droplet contacts. A general rule is that surfaces which are water repellant or hydrophobic in nature tend to retain more spray as surface tension is lowered, while more hydrophyllic easy-to-wet surfaces tend to retain less spray solution as surface tension is lowered due to increased runoff (Brunskill 1956; Furmidge 1962b). Runoff occurs when droplets begin to overlap and coalesce resulting in the droplets becoming gravitationally unstable and rolling down the inclined surface of a leaf to discharge from the lower edge (Johnstone 1973).

On a given surface, as the volume of spray increases the amount of solution retained will increase up to a maximum value (Furmidge 1962a). As described by Johnstone (1973), the point of maximum retention is when droplet runoff begins to occur. The point of maximum retention is very dependent on the nature of the surface and surface tension of the spray solution. Lake and Taylor (1974) further established that as spray volume increased the maximum value of retention is influenced by droplet size. Using a fluorescent dye as a tracer, barban was applied to wild oats at the two-leaf stage with 110, 220 and 440 μm droplets. At spray volumes ranging from 50 to 90 L/ha the largest amount of herbicide solution was retained with the 220 μm droplet followed closely by the 110 μm and 440 μm droplets. When volumes were increased from 90 to 150 L/ha the 440 μm droplet diameter spray reached a maximum retention at 95 L/ha and the 220 μm droplet spray at 115 L/ha. With the 110 μm droplets, the amount of spray retained was still increasing at 150 L/ha.

Maximum retention will occur with a minimum size of droplets impacting at negligible velocity (Brunskill 1956; Furmidge 1962b; Johnstone 1973; Lake 1977). Large droplets at a high terminal velocity will exhibit "droplet bounce" (Brunskill 1956). Once a droplet strikes the surface it is flattened out into an unstable state. If impact momentum is insufficient to shatter the droplet, elastic recovery follows, and at this stage the recoil may in certain instances cause detachment from the surface

(Johnstone 1973). Smaller droplets have a reduced tendency to bounce because at impact they will not have sufficient momentum to overcome the surface energy of the droplet and retract from the surface. Conversely, larger droplets will be more likely to have enough momentum upon impact to overcome the surface energy and retract from the surface. These generalizations are further complicated by such factors as surface tension of the spray liquid and water repellancy of the leaf surface (Furmidge 1962b; Johnstone 1973). Decreasing surface tension increases retention by causing the droplet at impact to spread irregularly over the surface with little or no retraction. A droplet falling on a highly water repellant surface would have a reduced tendency to flatten out and would quickly retract increasing the tendency for droplet bounce. The tendency for droplet bounce to occur on a repellant surface, would, of course, be related to the surface tension of the spray solution.

Plant Characteristics

The amount of spray retained by a plant is dependent on both the gross morphology of the leaf and the physical and chemical nature of the leaf surface.

Leaf angle is of particular importance in influencing retention of droplets (Davies _et al_. 1967; Hibbitt 1969). Davies _et al_. (1967) applied ioxynil with a fan type TeeJet nozzle at 325 L/ha to barley leaves positioned at angles ranging from 0 to 80 degrees from the horizontal. The amount of ioxynil retained per gram of plant dry weight declined marginally as leaf angle increased from 0 to 40 degrees with a sharp decline in retention occurring from 40 to 80 degrees. This decline in retention is attributed to both droplet bounce due to reflection, droplet roll-off, and a reduction in projected leaf area available for contact with the spray. In a similar experiment, Hibbitt (1969) applied water to wild oat leaves with a fan jet nozzle at a volume of 220 L/ha. Volume retained per unit leaf area decreased steadily from 1.25 ml/cm^2 at 0 degrees to almost zero at 90 degrees from the horizontal. To single out the effect of leaf angle, Hibbitt (1969) also measured retention based on volume retained per unit projected leaf area. These measurements revealed that if the leaf was horizontal or at a slight angle from the horizontal (15 degrees) the spray retained per unit projected area was the same. Between 15 degrees and 45 degrees the volume retained fell considerably, but leaf strips held at 45, 60 and 75 degrees retained a similar quantity of spray. The decline in retention as the leaves became more vertical in position was attributed to increased droplet bounce and runoff of droplets. The slight deviations between the results of Hibbitt (1969) and Davies _et al_. (1971) could be attributed to differing leaf surface characteristics between wild oats and barley, differences in the type of spray solution used and volumes of spray applied. Even though minor differences do exist, it can be concluded that increasing leaf angle from the horizontal does result in lower retention values.

Due to differing characteristics in morphology and leaf surface characteristics, different species of plants retain different amounts of spray per unit dry weight of tissue. Blackman _et al_. (1958) sprayed a number of plant species at similar growth stages (2 - 3 leaf) with a water soluble dye solution at 116 L/ha. Retention was highest with _Brassica alba_ (2.5 ml/g) followed by _Helianthus annuus_ (2.0 ml/g), _Linum usitatissimum_ (1.1 ml/g), _Pisum sativum_ (0.4 ml/g), and _Hordeum vulgare_ (0.3 ml/g). Davies _et al_. (1967) largely attributed the differential phytotoxicity of ioxynil to barley and mustard to differences in retention between the species. Based on shoot dry weight, mustard retained 26 and 10 times more ioxynil with and without surfactant, respectively, at equal volumes of application. In a study of the differential retention of a water soluble dye solution on flax and wild oats, Hibbitt (1969) discovered that the amount of spray retained per unit dry weight changed as the plants became older. The amount of solution retained on flax decreased at more advanced leaf stages. This is related to the two morphologically different types of leaves on flax plants. The cotyledons are readily wetted by aqueous sprays and in early stages of growth retained a very high proportion of the total spray deposited. The true leaves of older plants are very water repellant and retain a negligible amount of spray while the cotyledons became increasingly shielded. In contrast, wild oat plants retained more spray as plant age increased. When wild oat plants become older the leaves bend horizontally exposing more area for the spray solution to contact.

Sharma _et al_. (1978) sprayed asulam on wild oats and flax and found the same type of retention characteristics for each species as that reported by Hibbitt (1969). Sharma _et al_. (1978) point out that not only are the cotyledons shaded as flax plants become older, but older leaves tend to hang down allowing for greater droplet bounce and run-off. Davies _et al_. (1967) obtained comparable results with barley which is similar in morphology to wild oats. Changes in retentitive capability in crop and weed species could be of significance in herbicide application. Hibbitt (1969) suggests that more effective control of wild oats without injury to flax could be achieved by herbicide application at a later leaf stage of the wild oats.

The morphology of the leaf, in particular the detailed structure of the surface, is of major significance in affecting the distribution and retention of chemicals (Brunskill 1956; Challen 1960; Holloway 1969a; Hess et al. 1974).

Trichomes are an obvious feature of certain plant surfaces and play an important role in the retention of spray solutions. Challen (1962) explained the trichome patterns on a number of leaves and distinguished two main types. The first is the open pattern. This type of pattern would enhance retention due to capillary action holding and drawing the spray droplets towards the leaf surface. The second type is a closed pattern which would produce a highly water repellant surface causing a reduction in the potential for a liquid to be retained.

The stellate hairs of the pubescent leaf surface of Eremocarpus setigerus provided a good retaining surface for solutions of MCPA applied at low and high volumes (Hess et al. 1974). At a volume of 748 L/ha the distribution pattern indicated that the spray droplets had broken into numerous smaller droplets upon impact with the stellate hairs. Most of the herbicide remained on the hairs; however, in some instances significant amounts of herbicide reached the leaf surface in a given area. Lower volume applications with nozzles having smaller orifices resulting in smaller droplets at volumes of 117 and 23 L/ha resulted in most of the herbicide adhering to the hairs with none of the droplets breaking on impact. Although retention was high with all volumes it is questionable whether the application was effective due to the hairs causing a barrier to herbicide contact with the leaf surface.

Once the spray liquid reaches the leaf surface, retention is governed by the wettability of the particular surface. A leaf surface that is easily wetted would be expected to have a high retentitive capability whereas; a hard to wet leaf surface would have a reduced ability to retain a liquid. Ebling (1939) concluded that the most effective way of assessing the wettability of a surface is by measuring the contact angle of a droplet placed on that surface. Holloway (1970) further observed that wettability is most conveniently measured by means of contact angles which give an inverse measure of adhesion between a solid and a liquid.

Wetting of the leaf surface is governed by the same physicochemical factors which control the wetting of any solid surface, these being the nature of the chemical groups exposed on the surface and the surface roughness (Fogg 1947; Holloway 1969a). The nature of the exposed groups depends upon the chemical composition of the groups which differs among plant species (Holloway 1969a; Holloway 1969b; Fernandes 1965).

By measuring contact angles of distilled water on individual wax constituents of leaf waxes, Holloway (1969a) established relationships between composition and hydrophobic properties of leaf waxes. The most hydrophobic wax constituents are alkanes followed closely by esters, ketones and secondary alcohols. The least hydrophobic classes are, α-β diols, sterols and triterpenoids. Variations between classes are most likely a result of the presence or absence of methyl groups and differential packing of these groups at the surface. For example, functional groups in the chains prevent close packing and consequently close arrangement of methyl groups resulting in a reduction in water repellancy.

Leaf surfaces can be roughly divided into two groups: those with contact angles above 90 degrees and those below 90 degrees (Holloway 1970). He suggested that contact angles below 90 degrees implied that wax was not a prominent feature of the leaf surface, and contact angles above 90 degrees signified that surface wax played a major part in wettability. Contact angles ranging from 90 - 110 degrees indicated that the leaf surface had a smooth, superficial wax layer. Contact angles above 110 degrees signified the presence of other factors which were capable of modifying the hydrophobic properties of the leaf surface. It has been determined that the principle factor involved in this modification is roughness of the wax layer on the cuticle surface (Challen 1960, 1962; Fernandes 1965; Holloway 1970).

The effects of roughness caused by veination or epidermal cells have been regarded as unimportant in affecting leaf wettability by Holloway (1970), but could influence retention due to effects on herbicidal dispersal patterns as reported by Hess et al. (1974). MCPA applied to leaves of sugarbeets tended to accumulate in depressions above the anticlinal walls of the epidermal cells. This definitely would have an effect on retention by providing an area for the spray to accumulate. The same effect would most likely occur on leaves which are coarsely veined.

Fernandes (1965) classified plants into water repellant classes and non-water repellant classes by determining the concentration of surfactant required to make a water droplet lose its hemispherical shape and spread over the leaf surface. The waxes on the leaf surface of the water repellant plants exhibited a microscopic surface roughness in the form of crystalline rodlets and threads evenly or irregularly distributed on the leaf surface. The non-repellant surfaces generally exhibited smooth and flat wax surfaces. Holloway (1970) reports that wax surfaces that exhibit roughness characteristics of rodlets give contact angles greater than 120 degrees.

The significance of surface roughness is exemplified by the work of Holloway (1970). Wax removed from leaves by chloroform washing and then spread as smooth film only accounted for 50 - 60% of the original contact angle when measurements were made. Surface roughness must, therefore, have accounted for the remaining increase in contact angle.

Large reductions in the contact angle after wax removal demonstrate the importance of wax on leaf wettability (Challen 1960; Holloway 1970). For example, Challen (1960) reported a 34% reduction in contact angle when the upper surface of *Agropyron repens* was washed with ether and Holloway (1970) reported a 12% reduction in the contact angle of *Trifolium repens* when the upper surface of the leaf was washed with chloroform. Usually the contact angle of the lower surface of most leaves was lower than the upper, and wax removal from the lower surface results in somewhat smaller reductions in contact angle (Challen 1960; Holloway 1970). The reduction in contact angle measured with removal of the superficial wax is due to the resulting exposure of the cuticle which is more hydrophylic in nature (Holloway 1970).

Increased wettability upon removal of surface waxes is generally seen for all plant surfaces although a few exceptions do exist. An example of this occurred with *Plantago lanceolata* (Holloway 1970). Upon removal of the surface waxes no change in contact angle occurs. The reason for this still remains unanswered.

A lower contact angle not only increases retention but also coverage of the target surface (Johnstone 1973). Under a low volume application rate of 10 L/ha with 250 μm droplets, a reduction in contact angle from 90 degrees to 35 degrees by addition of a wetting agent gives a 2½-fold increase in coverage. At the same volume and a droplet size of 125 μm, the decrease in contact angle from 90 degrees to 35 degrees results in a 5-fold increase in coverage of the target surface. This increase in coverage is attributed to greater spreading of the droplets as surface tension of the liquid is lowered by the wetting agent.

The significance of contact angle measurements in determining wettability and, therefore, spray retention is most clearly illustrated by Brunskill (1956). He states that no bouncing of droplets has been observed where the contact angle was less than 140 degrees. From this he concluded, "As contact angles greater than 140 degrees are never encountered with the normal range of spray liquids on any smooth surface, it can only be assumed that bouncing is associated with a certain roughness of the surface".

Due to the differences in wax chemical composition and surface roughness among all plant species, a wide variation in measured contact angle exists (Challen 1960, 1962; Holloway 1969a, 1969b, 1970). This, in combination with variation in gross morphology of plant leaves and overall structure, probably accounts, in part, for the different retention characteristics between plant species.

Performance Under Field Conditions

The majority of the foliar-applied herbicides are applied with hydraulic nozzle tips. These include the flat fan, flooding and, to a lesser extent, raindrop nozzle tips. Droplet size, spray patterns and spray volume vary with the nozzle type used. From the literature it is clear that the physical properties of the spray play a significant role in determining herbicide efficacy, but unfortunately data on the effect of nozzle types on herbicide efficacy under field conditions is limited.

Schafer and Stobbe (1972) studied the effect of nozzle type on the toxicity of barban to wild oats under both laboratory and field conditions. The standard TeeJet 560067 at 57 L/ha, the low profile TeeJet 650067 (a standard TeeJet 650067 application but at a lower boom height) at 114 L/ha and wide angle FloodJet TKSS 0.75 at 51 L/ha were compared. Under greenhouse conditions at a rate of 0.11 kg/ha and an application pressure of 3.16 kg/cm^2 similar wild oat control was obtained with the standard 650067 and TKSS 0.75 nozzle tips. Application with the low profile 630067 resulted in a much poorer wild oat control. In the field study, 0.28 kg/ha barban was applied at a pressure of 3.16 kg/cm with the three nozzle types under low (0.9 - 4.5 km/hr) and high wind conditions (17.4 - 19.2 km/hr). Under low wind conditions the standard 650067 and TKSS 0.75 produced satisfactory wild oat control, while control with the low profile 650067 tip was variable. Under conditions of high wind the best wild oat control occurred with the low profile 650067 and wide angle TKSS 0.75. Control with the standard 650067 was erratic due to spray drift being a problem.

MATERIALS AND METHODS

General Procedures - Field Experiments

Field experiments were conducted at the University of Manitoba research site near Graysville, Manitoba in 1979 and 1980. The soil type is an Almasippi very fine sandy loam containing 79% sand, 7% silt and 14% clay. The organic matter content of the soil is 3.7%. The weather data for May through September 1979 and 1980 are presented in the Appendix (Tables 1 and 2).

In 1979, the experiments were situated on land which was summer-fallowed the previous year. In 1980 the experiments were conducted on land which was sown to corn the previous year. In 1979 a broadcast application of 258 kg/ha of 27-27-00 urea ammonium phosphate was applied to the experimental area while in 1980, 278 kg/ha of 27-27-00 urea ammonium phosphate was broadcast on the experimental area.

The effect of various nozzle tips on the efficacy of commercial formulations of propanil[1], diclofop methyl[2], difenzoquat[3], bromoxynil octanoate[4] and metribuzin[5] was evaluated in five separate experiments.

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[1] Stampede, 240 g a.i./L emulsifiable concentrate (EC), Rohm and Haas Co.

[2] Hoe-Grass, 179 g a.i./L EC, Hoechst Canada Inc.

[3] Avenge 200-C 200 g a.i./L soluble liquid (SN), Cyanamid of Canada Ltd.

[4] Torch, 227 g a.i./L EC, Allied Chemical Services.

[5] Sencor 5 flowable, 500 g a.i./L suspension (SU), Chemagro Ltd.

The propanil, diclofop methyl, difenzoquat and bromoxynil experiments were seeded to Neepawa wheat at 98 kg/ha and the metribuzin experiment was seeded to Bonanza barley at 100 kg/ha. All seeding was done with a double disc drill. In 1979 wheat was seeded on June 5 and barley on June 6. Both crops emerged on June 11. In 1980 both crops were seeded on July 2 and emerged on July 6.

The nozzle treatments were the same for each experiment and are as follows:

1. Unsprayed check
2. TeeJet 80015 at 275 kPa
3. TeeJet 80015LP at 275 kPa
4. TeeJet 80015LP at 150 kPa
5. FloodJet TK 1.5 at 275 kPa
6. Floodjet TK 0.75 at 275 kPa
7. Raindrop RA-2 at 275 kPa

Diagramatic representations of the various nozzle tips are depicted in Figure 1. The TeeJet[6] 80015 and 80015LP are both flat fan stainless steel nozzles producing an 80 degree fan type spray pattern with tapered edges. The 80015 is designed to produce a uniform spray pattern at 275 kPa, while the 80015LP is designed to deliver the same spray pattern as the 80015 but at a pressure of 150 kPa. The 80015LP is designed to reduce spray drift potential by producing a larger droplet size than the 80015. In treatment 3 the 80015LP is used at a higher than recommended pressure (275 kPa). At this pressure droplet size is reduced and the spray pattern is distorted giving an angle of slightly greater than 80

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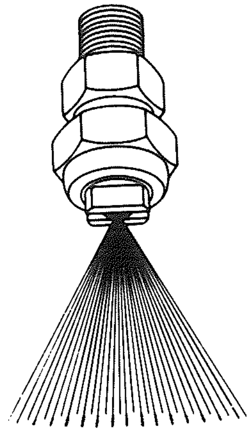
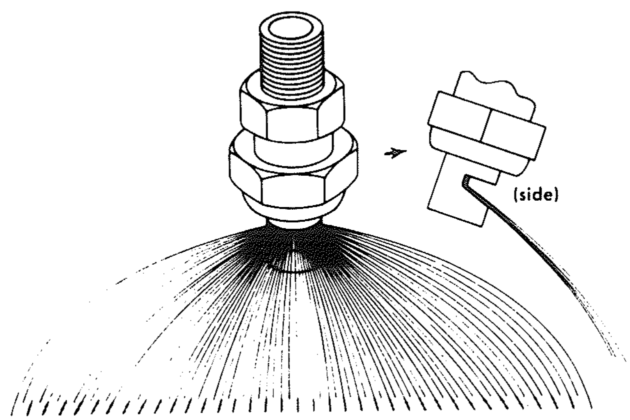
[6] Spraying Systems, Wheaton, Illinois, USA.

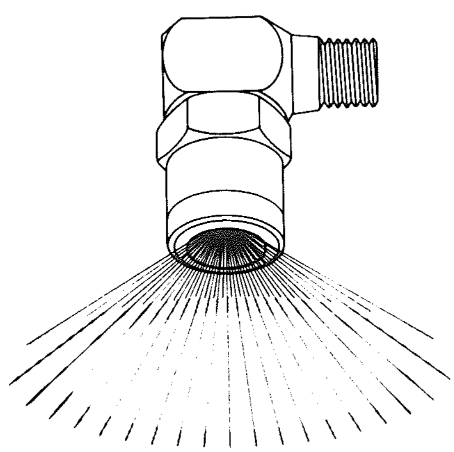
Figure 1. Diagramatic representations of the various nozzle tips.



Regular Flat Fan



Flooding Flat Fan
(front)



RA Raindrop

degrees. Droplet size distribution data for the 80015 and 80015LP tips provided by the manufacturer, Spraying Systems Co., are presented in the Appendix (Figures 1 and 2). Volume median diameters of the 80015 and 80015LP nozzle tips are presented in Table 1. Volume median diameter is the droplet diameter which divides the spray into two equal portions by volume.

The FloodJet TK 0.75 and 1.5 stainless steel nozzle tips both produce a wide angle spray pattern of approximately 120 degrees. The TK 1.5 delivers twice the volume output as the TK 0.75 and produces a larger droplet size. The TK 0.75 was spaced on the sprayer boom so as to give an overlapping pattern (0.5 m spacing), while the TK 1.5 was spaced so as to give a non-overlapping pattern (1.0 m spacing). Droplet size distribution data for the Floodjet nozzles provided by the manufacturer, Spraying Systems Co., are presented in the Appendix (Figure 3). Volume median diameters for the TK 0.75 and TK 1.5 nozzle tips are presented in Table 1.

The Raindrop[7] RA-2 nozzle produces a hollow cone shape spray pattern. Droplet size distribution data was unavailable for the RA-2 nozzle. The Delavan Agspray Products catalogue reports that the RA-2 nozzle delivers a spray with a volume median diameter of 330 µm.

All treatments were applied using a small plot bicycle sprayer. Treatments 5 and 7 were applied using a 3 meter boom. For all other treatments a 1½ meter boom was used for application. The herbicides were sprayed in a volume of approximately 110 L/ha of water. Details on nozzle height, nozzle spacing and forward walking speed are presented in Table 2. The TeeJet 80015 and 80015LP nozzles were directed 45° forward for

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[7] Delavan Corporation, West Des Moines, Iowa, USA.

TABLE 1. Spray droplet volume median diameters (VMD) of the various nozzle types.

Nozzle tips	Pressure (kPa)	VMD (microns)
80015	275	370
80015LP	275	375
80015LP	150	410
TK 1.5	275	400
TK 0.75	275	300
RA-2	275	330

TABLE 2. Nozzle height, nozzle spacing on the sprayer boom and foreward walking speed used in the various treatments, 1979 and 1980.

	Treatment[1]	Nozzle height (cm)	Nozzle spacing (cm)	Foreward speed (kph)
2	80015	45	50	5.5
3	80015LP	38	50	9.0
4	80015LP (150 kPa)	45	50	5.5
5	TK 1.5	44	100	7.0
6	TK 0.75	44	50	5.5
7	RA-2	35	100	4.0

[1]Treatment number 4 was applied at 150 kPa; all other treatments were applied at 275 kPa.

the applications of the wild oat herbicides (diclofop methyl, difenzoquat).

Each of the chemicals was applied at an optimal and sub-optimal leaf stage for effective control of the susceptible weeds. For the chemicals propanil, diclofop methyl, bromoxynil and metribuzin susceptible weeds are most effectively controlled when the chemicals are applied at an early leaf stage. With difenzoquat susceptible weeds are most effectively controlled at a later, more advanced leaf stage.

Weather conditions including wind velocity, temperature and relative humidity were recorded at time of spraying. Weather data for 1979 and 1980 are recorded in Table 3. Relative humidity was measured with sling psychrometer[8] and wind velocity with an anemometer[9].

In both 1979 and 1980, overall treatments of Buctril M at 0.55 kg/ha active ingredient were necessary to remove broadleaf weeds from the propanil, diclofop methyl and difenzoquat experiments. In both years, wild oats and green foxtail were removed from the bromoxynil and metribuzin experiments by an overall application of Hoe-Grass at a rate of 0.7 kg/ha active ingredient.

Weed control was assessed by taking weed counts and weed dry weights from plants sampled 6 - 8 weeks after treatment. The sample size in 1979 was two 1/4 m^2 quadrants and in 1980 was one 1 m^2 quadrant.

The experimental design in 1979 was a randomized complete block design. In 1980 the experimental design was a split plot design with time of application being the main plots and treatments being sub-plots. In both years the treatments were replicated four times and plot size was 2.8 x 5.0 m.

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[8]Taylor Instrument Ltd., Toronto, Canada.

[9]Borrowed from the Department of Agricultural Engineering, University of Manitoba.

TABLE 3. Weather conditions at the time of spraying, 1979 and 1980.

Experiment	Treatment date	Temperature (C)	Wind velocity (kph)	RH (%)
1979				
Propanil	E[1] June 22	18	6	56
	L[2] July 3	22	13	90
Diclofop methyl	E June 27	30	4	69
	L July 7	23	13	43
Difenzoquat	E June 28	29	5	82
	L July 5	28	8	43
Bromoxynil	E June 26	25	5	65
	L July 5	29	10	90
Metribuzin	E June 26	25	3	65
	L July 5	30	10	45
1980				
Propanil	E[1] July 8	25	5	77
	L[2] July 17	25	4	86
Diclofop methyl	E July 10	30	0	40
	L July 17	24	10	58
Difenzoquat	E July 15	28	0	53
	L July 24	27	10	38
Bromoxynil	E July 22	27	0	46
	L July 26	22	0	22
Metribuzin	E July 22	30	0	42
	L July 25	23	0	22

[1]Early application.

[2]Late application.

In 1979, all experiments were harvested using a Hege 125 small plot combine. The yield results in 1980 were recorded by taking total crop dry weight samples of 1 m^2 from each plot. Grain yields were not taken in 1980 because the late seeding dates due to dry conditions in the spring did not allow the crop to reach maturity. Treatment, sampling, harvest dates and weed and crop leaf stages at time of treatment for 1979 and 1980 are presented in Tables 4 and 5.

The data collected was statistically analyzed and the treatment means compared using Duncan's Multiple Range Test. Only differences significant at the 10% level of probability were considered meaningful.

Details pertaining to specific experiments are outlined below.

Propanil Applied to Green Foxtail in Wheat

Propanil was applied at a rate of 0.98 kg/ha.

In both years green foxtail seeds were broadcast on the experimental area at a rate of 400 seeds/m^2 and lightly incorporated into the soil with a harrow.

Diclofop Methyl Applied to Wild Oats and Green Foxtail in Wheat

Diclofop methyl was applied at a rate of 0.7 kg/ha.

Green foxtail was broadcast at a rate of 400 seeds/m^2 on the experimental area and lightly incorporated into the soil with a harrow in 1979. In 1980 both wild oats and green foxtail were broadcast on the experimental area at rates of 100 and 400 seeds/m^2, respectively, and incorporated into the soil by a shallow discing.

Difenzoquat Applied to Wild Oats in Wheat

Difenzoquat was applied at a rate of 0.70 kg/ha.

TABLE 4. Treatment dates, weed and crop stages, sampling and harvest dates, 1979.

Experiment	Treatment date	Weed leaf[3] stage	Crop leaf stage	Dry matter sample and weed count	Harvest date
Propanil	E[1] June 22	2-3 GF	2-3	July 27	September 10
	L[2] July 3	3-5 GF	5	July 27	September 10
Diclofop methyl	E June 27	3-5 GF; 2-4 WO	4	July 31	September 10
	L July 7	5-7 GF; 5-6 WO	5-6	July 31	September 10
Difenzoquat	E June 28	3-4 WO	3-5	July 31	September 14
	L July 5	4-6 WO	5-6	July 31	September 14
Bromoxynil	E June 26	2-4 WB; 2-4 RRP 4 LQ; 3-4 WM	2-4	July 27	September 14
	L July 5	3-5 WB; 4-7 RRP 7-10 LQ; 4-7 WM	5-6	July 27	September 14
Metribuzin	E June 26	2-4 WB; 4-5 RRP 5 LQ; 5 WM	3-4	July 28	August 31
	L July 5	5-7 WB; 6-7 RRP 6 LQ; 6-7 WM	6	July 28	August 31

[1]Early application.

[2]Late application.

[3]GF = Green Foxtail; WO = Wild Oats; WB = Wild Buckwheat; RRP = Redroot Pigweed; LQ = Lamb's Quarters; WM = Wild Mustard.

TABLE 5. Treatment dates, weed and crop leaf stages and sampling dates, 1980.

Experiment	Treatment date	Weed leaf[3] stage	Crop leaf stage	Dry matter sample and weed count
Propanil	E[1] July 8	2-3 GF	1	August 18
	L[2] July 17	4-6 GF	3	August 18
Diclofop methyl	E July 10	2 WO; 3 GF	1-2	August 19
	L July 17	3-5 WO; 4-6 GF	3	August 19
Difenzoquat	E July 15	3 WO	2-3	August 24
	L July 24	5-6 WO	5	August 24
Bromoxynil	E July 22	3-4 WB; 4-6 RRP 5-8 LQ; 3-6 WM	4-5	August 21
	L July 26	5-6 WB; 6-8 RRP 8-10 LQ; 5-8 WM	5-6	August 21
Metribuzin	E July 22	3-6 WM; 4-6 RRP 5-8 LQ	5-6	August 25
	L July 25	5-7 WM; 5-8 RRP 6-10 LQ	5-7	August 25

[1]Early application.

[2]Late application.

[3]GF = Green Foxtail; WO = Wild Oats; WB = Wild Buckwheat; RRP = Redroot Pigweed; LQ = Lamb's Quarters; WM = Wild Mustard.

In 1980, only wild oat seed was broadcast on the experimental area at a rate of 100 seeds/m^2 and incorporated by a shallow discing.

Bromoxynil Applied to Broadleaf Weeds in Wheat

Bromoxynil was applied at a rate of 0.28 kg/ha.

In 1980, wild buckwheat seeds at a rate of 50 seeds/m^2 were broadcast over the experimental area and incorporated into the soil by a shallow discing.

Metribuzin Applied to Broadleaf Weeds in Barley

Metribuzin was applied at a rate of 0.21 kg/ha.

No weed seeds were broadcast over the experimental area in either year.

General Procedures - Laboratory Experiments

Nozzle Efficacy Experiments

Experiments were conducted to study the effect of nozzle type on the efficacy of propanil applied to green foxtail, diclofop methyl applied to green foxtail and wild oats and metribuzin applied to wild mustard. All plants for these experiments were grown in a walk-in growth room. Lighting was supplied by VHO/Ws Growlux Sylvania Lighting, which provided 230 $E\mu m^{-2}s^{-1}$ photosynthetic photon flux density (PPFD) as measured by a quantum sensor. The photoperiod and temperature was 16 hours of light at 20 C and 8 hours darkness at 15 C. The plants were grown in plastic pots containing a 1:1:1 soil, sand and peat mix, combined with 1.05 grams of 16-20-00 ammonium phosphate sulphate fertilizer/kg of soil mix. The plants were watered every 2 days.

Herbicide rates to be used in the experiments were predetermined by establishing ED_{50} values for propanil applied to green foxtail, diclofop methyl applied to wild oats and green foxtail and metribuzin applied to wild mustard. The ED_{50} value is the rate at which there is a 50% reduction in plant dry matter increase over a 2 week period after herbicide treatment compared to the untreated control. The TeeJet 80015 nozzle at a pressure of 275 kPa was used to determine these values.

The treatments were exactly the same for each experiment and were as follows:

1. Unsprayed check
2. TeeJet 80015 at 275 kPa
3. TeeJet 80015LP at 275 kPa
4. TeeJet 80015LP at 150 kPa
5. FloodJet TK 1.5 at 275 kPa
6. FloodJet TK 0.75 at 275 kPa
7. Raindrop RA-2 at 275 kPa

Applications were made from a single nozzle in a cabinet sprayer. Due to an inability to adjust spraying speed, volumes of water output varied between treatments. These are presented in Table 6. Nozzle height for each treatment is also presented in Table 6. Treatment with the TK 0.75 nozzle required two sprayer passes to simulate the overlapping pattern in the field experiments.

After herbicide treatment the plants were allowed to grow for 2 weeks in the growth chamber and then harvested for dry weight determinations. Control was based on dry weight reductions.

The experimental design was a randomized complete block design with seven replicates. Each pot represented a plot.

The experimental results were statistically analyzed and the treatment means compared using Duncan's Multiple Range Test. Only differences

TABLE 6. Volumes, pressures and heights used in nozzle treatments.

	Treatment[1]	Volume (l/ha)	Pressure (kPa)	Nozzle height (cm)
2	TeeJet 80015	109.05	275	45
3	TeeJet 80015LP	258.09	275	38
4	TeeJet 80015LP (150 kPa)	186.04	150	45
5	FloodJet TK 1.5	107.22	275	44
6	FloodJet TK 0.75	106.11	275	44
7	Raindrop RA-2	116.10	275	35

[1]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

significant at the 10% level of probability were considered meaningful.

Details pertaining to specific experiments are given below.

Propanil Applied to Green Foxtail. The ED_{50} rate for propanil applied to green foxtail at the three-leaf stage was 0.19 kg/ha.

Propanil was applied with the various nozzle tips to pots containing 10 green foxtail plants per pot at the three-leaf stage. The experiment was repeated two times.

Diclofop Methyl Applied to Green Foxtail. The ED_{50} rate for diclofop methyl applied to green foxtail at the three-leaf stage was 0.035 kg/ha.

Diclofop methyl was applied with the various nozzle tips to pots containing 10 green foxtail plants per pot at the three-leaf stage. The experiment was repeated two times.

Diclofop Methyl Applied to Wild Oats. The ED_{50} rate for diclofop methyl applied to wild oats at the three-leaf stage was 0.5 kg/ha.

Diclofop methyl was applied with the various nozzle tips to pots containing five wild oat plants per pot at the three-leaf stage. The experiment was repeated two times.

Metribuzin Applied to Wild Mustard. The ED_{50} rate for metribuzin applied to wild mustard at the four-leaf stage was determined to be 0.03 kg/ha.

Metribuzin was applied with the various nozzle tips to pots containing five wild mustard plants per pot at the four-leaf stage. The experiment was repeated two times.

Retention Study

Experiments were conducted to determine the effect of various nozzle tips on the retention of diclofop methyl applied to wild oats and green foxtail. All plants were grown in the greenhouse in plastic pots in a 1:1:1 soil, sand and peat mixture mixed with 1.05 g/kg of 16-20-00 ammonium phosphate fertilizer. The plants were watered every 2 days.

The treatments were exactly the same as in the nozzle efficacy experiments. The treatments were also applied in the same cabinet sprayer as in the nozzle efficacy experiments. Nozzle volume outputs and heights are presented in Table 6.

The supplemental lighting in the greenhouse was provided by CW 235 Lifeline Sylvania Lighting which provided 235 uE $m^{-2}s^{-1}$ PPFD. The photoperiod provided by supplemental lighting and temperature was 16 hours of light at 18-23 C and 8 hours darkness at 18 C.

To determine the amount of herbicide retained on the leaf surface the fluorescent dye, Fire Orange Red E.4 E Series Pigment[10], was used as a tracer. The method used is similar to the method described by Lake (1974), who used the fluorescent dye, Saturn Yellow MF Series[11], as the tracer. A Turner Model 111 Fluorometer[12] was used to measure fluorescence. The filters used were a 7-60 primary filter with a cut-off of 365 nm and a secondary 2A-15 filter with a cut-off of 520 nm. The light source was a general purpose #110-850 lamp.

First a calibration curve was established from which the amount of fluorescent dye present in a particular test solution can be determined by measuring the fluorescence emitted from the test solution. The procedure for preparing solutions from which the calibration curve is derived is as follows:

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[10]Swada (London) Limited.

[11]Swada (London) Limited, London, England.

[12]G.K. Turner Associates, Palo Alto, California.

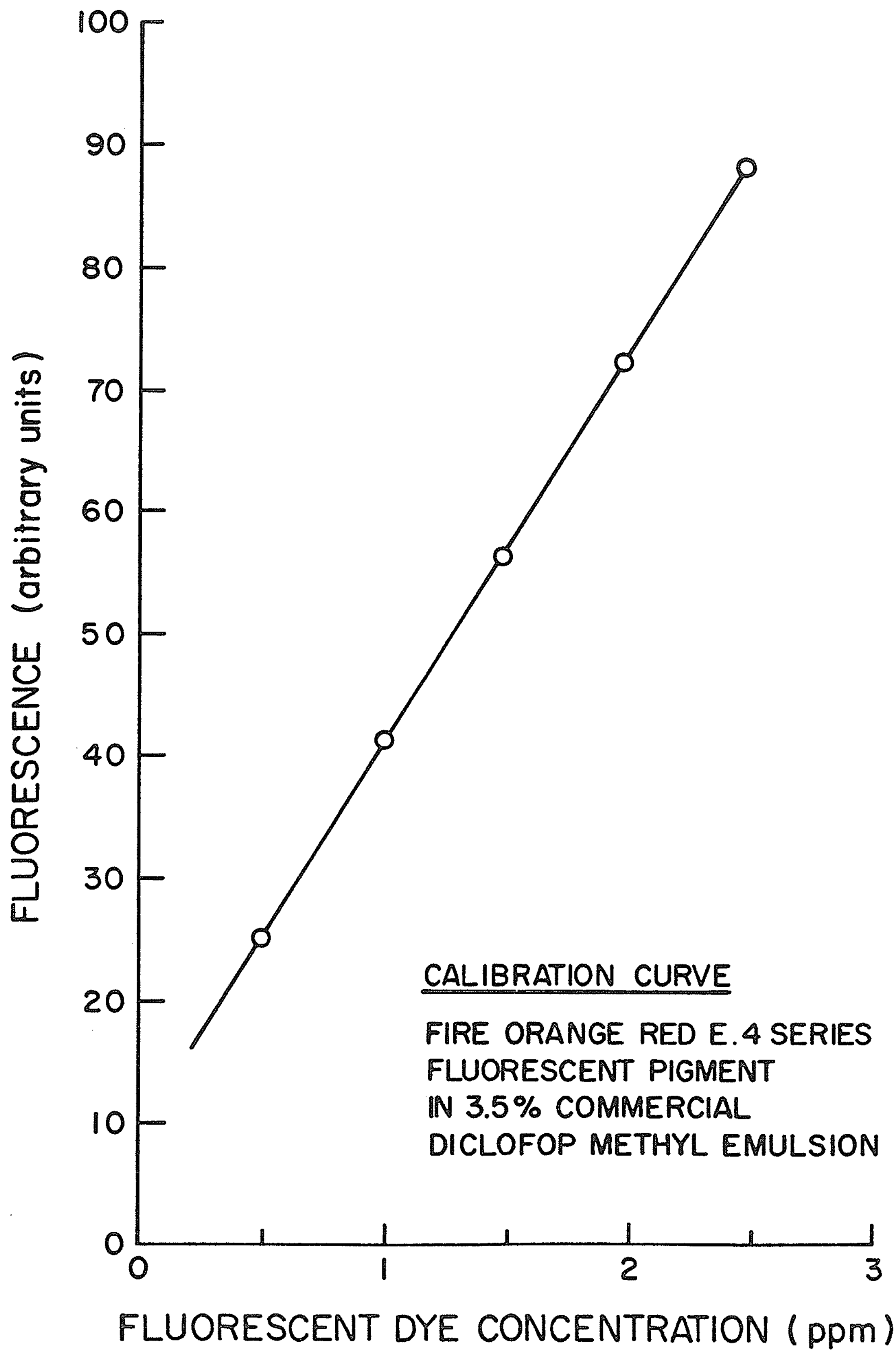
1. A stock dye solution was established by mixing 0.1 g of fluorescent dye with 100 ml of a 3.5% commercial diclofop methyl (Hoe-Grass) emulsion. This represents the amount of commercial diclofop methyl in a typical spray solution of 0.7 kg/ha active ingredient applied in 110 L/ha of water.
2. One ml of the stock dye solution was then added to 10 ml of the commercial diclofop methyl emulsion and mixed. The fluorescence of this solution was then measured with the Turner Fluorometer.
3. One ml of stock dye solution was mixed with 20 ml of the commercial diclofop methyl emulsion and the fluorescence measured. This procedure was continued in 10 ml increments up to 250 ml. Before each measurement the fluorometer was blanked using the diclofop methyl solution with no dye added. This assured that only fluorescence from the dye was measured.

   From this procedure a calibration curve with a correlation coefficient (R) of 0.9874 was established (Figure 2). The vertical axis represents fluorescence while concentration of dye in parts per million is on the horizontal axis. By determining the fluorescence of a sample solution, through extrapolation the concentration of dye in that solution can be determined.

For retention measurements a 3.5% commercial diclofop methyl (Hoe-Grass) emulsion was mixed with a known quantity of fluorescent dye and sprayed on the test plants.

Immediately after spraying, the plants from each pot were cut at

Figure 2. Calibration curve for Fire Orange Red E.4 Series fluorescent pigment in a 3.5% commercial diclofop methyl solution.



100
90
80
70
60
50
40
30
20
10
0
FLUORESCENCE (arbitrary units)
0
1
2
3
FLUORESCENT DYE CONCENTRATION (ppm)
CALIBRATION CURVE
FIRE ORANGE RED E.4 SERIES
FLUORESCENT PIGMENT
IN 3.5% COMMERCIAL
DICLOFOP METHYL EMULSION

soil level and placed into a bottle containing 20 ml of the 3.5% commercial diclofop methyl emulsion. The bottle was capped and shaken vigorously for 5 seconds to wash the dye solution off the plants. The plants were then removed from the bottle and kept for dry weight determinations. A blank solution was prepared by the same procedure except that the plants were sprayed with the diclofop methyl emulsion without any dye added.

Before any measurements of fluorescence were taken, the fluorometer was blanked with the blank solution. Fluorescence was measured for the various treatments and from the values obtained dye concentration was determined from the calibration curve. Fluorescence was measured from samples contained in glass curvettes.

Knowing the concentration of the dye solution sprayed on the plants, then the amount of solution retained on the plants was determined mathematically by the formula

$$\frac{\frac{\text{Concentration (ppm)}}{10^6} \times \text{Volume of wash solution}}{\text{Concentration of fluorescent dye in the spray solution (g/ml)}} = x \text{ (ml of solution retained).}$$

The following is a sample calculation where 0.5% dye solution (0.5 g of dye per 100 ml of commercial diclofop methyl emulsion) was sprayed on 10 green foxtail plants at the three-leaf stage. The plants were washed in 20 ml of diclofop methyl emulsion and the fluorescence of the emulsion was measured. From the calibration curve it was determined that 2.44 ppm of dye was retained on these plants.

$\frac{2.44}{10^6} \times 20$ ml $= 4.8 \times 10^{-6}$ g of dye per 20 ml of diclofop methyl emulsion. The spray solution contained 0.5 g of dye/100 ml of diclofop methyl emulsion or 0.005 g/ml. Therefore, the amount (x) retained by 10 green foxtail plants was determined as follows:

$$\frac{5 \times 10^{-3}\ g}{1\ ml} = \frac{4.8 \times 10^{-6}}{x};\ x = 9.76 \times 10^{-3}\ ml$$ of solution retained by 10 green foxtail plants.

By determining the dry weight of the 10 green foxtail plants, retention per gram of plant dry matter can then be calculated. In each experiment leaf areas of 20 representative plants were taken and an average value determined. From this value, the amount retained/cm^2 was calculated.

The experimental design for these experiments was a completely randomized design with each treatment repeated six times.

Since the volume outputs of the various nozzle treatments are not the same, retention was based on a volume output of 110 L/ha. For each treatment 110 was divided by the output of that nozzle treatment and a value (X) was calculated. The measured amount of spray retained by the treatment was then multiplied by X to give an adjusted retention value. This procedure was necessary to make data comparison between treatments meaningful.

The data was analyzed statistically, and treatment means compared using Duncan's Multiple Range Test. Only differences significant at the 10% level of probability were considered meaningful.

Details of each of the experiments are given below.

Retention of Diclofop Methyl Applied to Green Foxtail. The spray solution contained 0.25 g of fluorescent dye per 100 ml of the commercial diclofop methyl emulsion. This was sprayed onto pots containing 10 green foxtail plants per pot at the three- to three-and-a-half-leaf stage. The experiment was repeated two times.

Retention of Diclofop Methyl Applied to Wild Oats. The spray solution contained 0.30 g of fluorescent dye per 100 ml of the commercial diclofop methyl emulsion. This was sprayed onto pots containing seven wild oat plants per pot at the two-leaf stage. The experiment was repeated two times.

Water Droplet Contact Angle Measurements

Contact angles were measured on leaves of green foxtail, wild oats and wild buckwheat. Plants were grown in a walk-in growth room and outdoors at the University of Manitoba campus. All plants were grown in plastic pots containing a 1:1:1 soil, sand, and peat mix, combined with 1.05 g/kg of 16-20-00 ammonium phosphate sulphate fertilizer. The plants grown outdoors were grown during August 1980. Plants grown outside and in the growth room were watered every 2 days.

Lighting in the growth room was supplied by VHO/WS Growlux Lighting which provided 230 $uE^{-2}s^{-1}$ PPFD as measured by a quantum sensor. The photoperiod and temperature was 16 hours of light at 20 C and 8 hours darkness at 15 C.

The apparatus[13] used to measure contact angles is shown in Figures 3, 4 and 5. The apparatus consists of a light source (A), specimen chamber (B), specimen mounting block (C) and an f80[14] lens (D). The light source is mounted directly behind the chamber and the lens is mounted on the opposite side of the chamber 3-5 cm from the front.

For contact angle measurements a piece of leaf about 1/2 cm^2 was placed on the mounting block and affixed by two-sided adhesive tape with the adaxial surface facing upwards. Great care was taken not to touch the adaxial surface during placement. A droplet of distilled water from microsyringe (E) was then formed on the leaf surface (Figure 5). The size of the droplet was approximately 1 mm in diameter.

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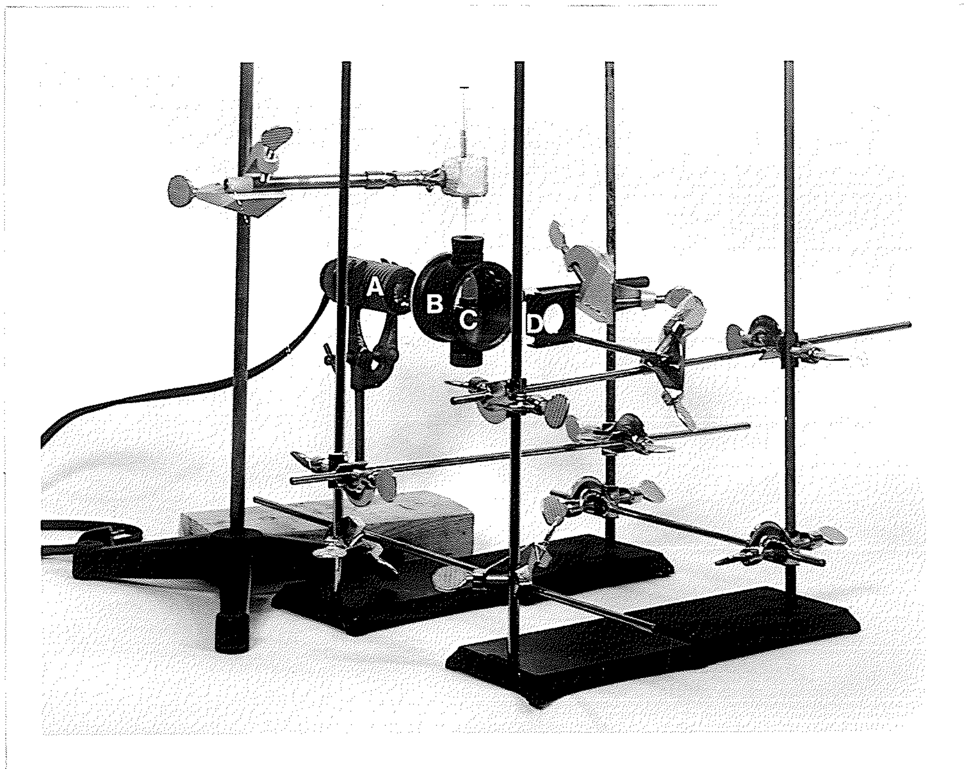
[13]Obtained from the Department of Botany, University of Manitoba.
[14]Manufacturer, Carl Zeiss (Germany).

Figure 3. Apparatus for measuring droplet contact angles.

A. light source
B. specimen chamber
C. specimen mounting block
D. f80 lens

Figure 4. Light source (A), specimen chamber (B), specimen mounting block (C) and f80 lens (D) used for measuring droplet contact angles.


A
B
C
D

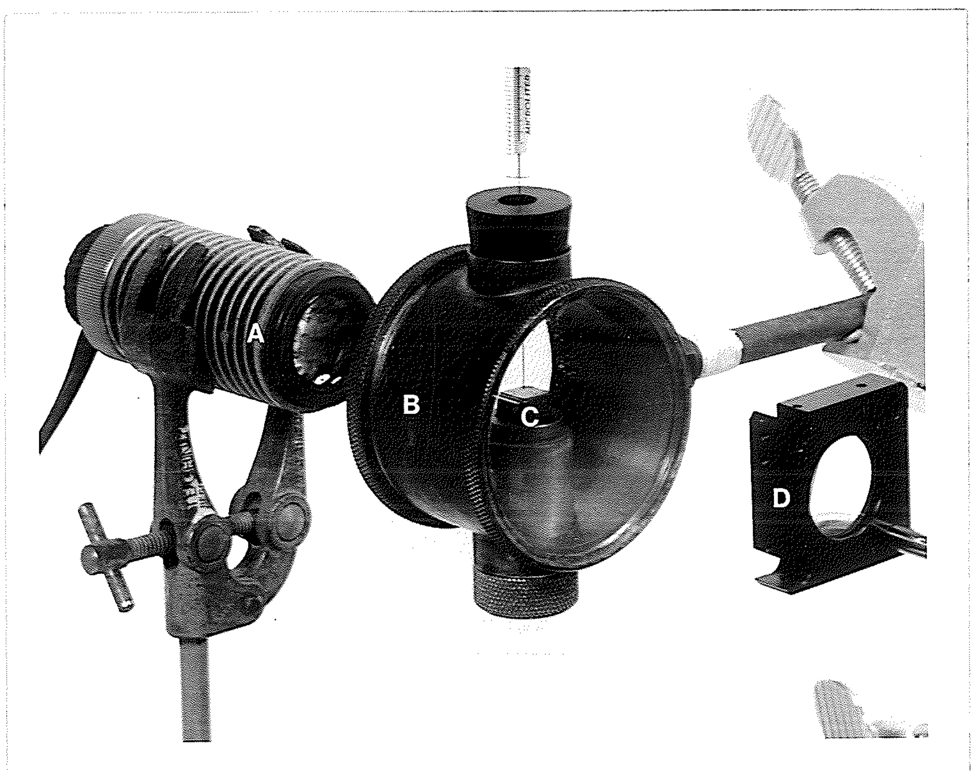
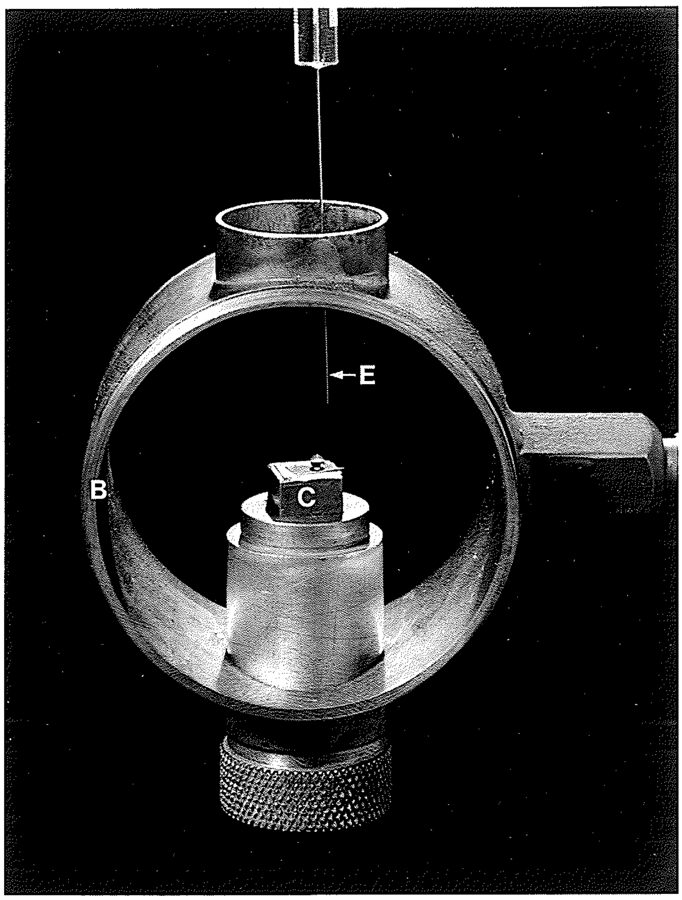

A
B
C
D

Figure 5. A droplet of distilled water placed on a leaf in the specimen chamber of the contact angle apparatus.

B. specimen chamber
C. specimen mounting block
E. micro syringe


E
B
C

An inverted magnified image of the droplet and the leaf surface on the block was projected onto a piece of paper mounted on the wall 1 m in front of the chamber. A horizontal line along the edge of the leaf surface was drawn. Contact angle (0) measurements were then made by drawing a line tangent to the surface of the drop at the point of contact with the leaf surface (Figure 6). This contact angle is the advancing contact angle (Holloway 1970). Further advancing contact angles were measured by adding 2 μl increments of distilled water to the droplet with a microsyringe. With each addition the contact angle was measured. Measurements were made on both sides of the droplet.

From two to five measurements were made with each droplet. The number of measurements made was dependent on how long the droplet remained on the leaf surface before rolling off. Once measurements on one droplet were complete a new section of leaf was used for the next set of measurements with a new droplet. The sides of the chamber were coated with damp filter paper to minimize water evaporation from the droplets.

For measurements on green foxtail and wild oats, leaf sections were taken from the middle section of the leaf and measurements were made from the end view of the leaf. The mid rib was removed to avoid an uneven surface for contact angle measurement. Contact angle measurements were made from plants grown outdoors and in the growth room.

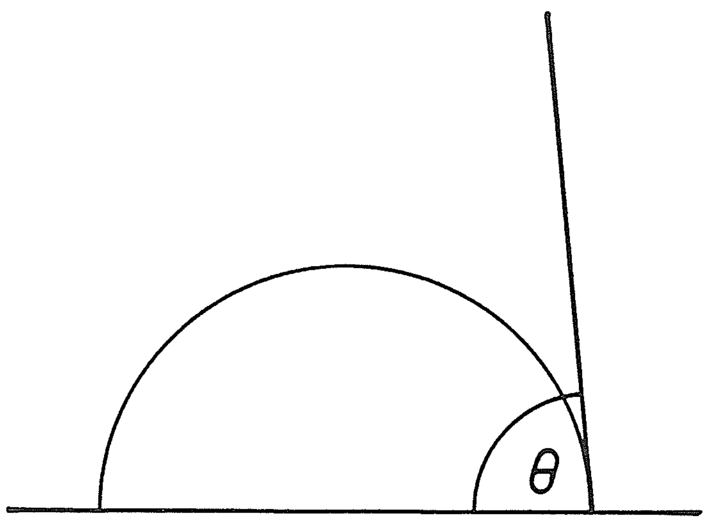
The data was analyzed by determining means and standard deviations of the measurements.

Details for the specific experiments are given below:

<u>Contact Angle Measurements of Water Droplets on Wild Oat Leaves</u>. Contact angles were measured on the following wild oat leaves:

first leaf of a 2 1/2-leaf stage plant,

Figure 6. An illustration of a contact angle measurement made on a leaf surface.



Contact angle (θ)

second leaf of a 2 1/2-leaf stage plant,

third leaf of a 4 1/2-leaf stage plant,

fourth leaf of a 4 1/2-leaf stage plant.

Contact Angle Measurements of Water Droplets on Green Foxtail Leaves. Contact angles were measured on the following green foxtail leaves:

first leaf of a 2-leaf stage plant,

second leaf of a 3-leaf stage plant,

third leaf of a 4-leaf stage plant,

fourth leaf of a 4 1/2-leaf stage plant.

Contact Angle Measurements of Water Droplets on Wild Buckwheat Leaves. Contact angles were measured on the following leaves:

first leaf of a 2-leaf stage plant,

second leaf of a 3-leaf stage plant,

third leaf of a 4-leaf stage plant,

fourth leaf of a 4 1/2-leaf stage plant.

RESULTS

Field Experiments 1979 and 1980

In 1979, adequate weed populations existed in all experiments to assess herbicide performance except in the difenzoquat experiment.

The spring of 1980 was extremely dry resulting in poor and non-uniform weed populations in all experiments. The experimental area in 1980 contained high and low areas where moisture conditions differed considerably. Generally fair weed populations existed in the lower areas and very poor populations occurred in the high areas.

Propanil Applied to Green Foxtail in Wheat

Analysis of the 1979 data showed there was a time of treatment by treatment interaction with respect to green foxtail densities and dry weights (Table 7). Reduction in green foxtail density was an average of 6% greater when the treatments were applied at the late application date even though the green foxtail was beyond the optimum leaf stage recommended for control with propanil (Table 7). Weather conditions at the time of treatment could possibly account for this unexpected response. The RH at the time of application was much higher than at the early treatment date (Table 3). The high humidity at the time of spraying may have accentuated the activity of the herbicide on the green foxtail.

At the early application date the greatest reduction in green foxtail density occurred when propanil was applied with the 80015LP nozzle at a pressure of 275 kPa (Table 7). Performance with this nozzle was significantly better than with the TK 0.75 and 80015 nozzle tips. Late appli-

TABLE 7. Densities and dry weights of green foxtail plants treated with propanil applied with the various nozzle tips, 1979 and 1980.

Treatment[2]	Density[1]		Dry Weight[1]	
	Plants/m^2	% Reduction	g/m^2	% Reduction
1979				
Early Application				
1 Check	346 f	--	23.5 d	--
2 80015	185 d	46	6.2 a	74
3 80015LP	122 ab	65	7.2 a	69
4 80015LP (150 kPa)	159 bcd	54	10.2 bc	57
5 TK 1.5	140 abcd	59	6.9 a	70
6 TK 0.75	182 cd	47	6.3 a	73
7 RA-2	152 bcd	56	6.5 a	72
Late Application				
1 Check	346 f	--	22.2 d	--
2 80015	99 a	71	5.1 a	77
3 80015LP	115 ab	67	7.7 ab	65
4 80015LP (150 kPa)	132 abc	62	7.6 ab	66
5 TK 1.5	135 abcd	61	7.0 a	68
6 TK 0.75	111 ab	68	6.8 a	69
7 RA-2	236 e	32	11.6 c	48
1980				
1 Check	348 b	--	113.2 b	--
2 80015	31 a	91	5.1 a	95
3 80015LP	81 a	77	8.9 a	92
4 80015LP (150 kPa)	104 a	70	11.5 a	90
5 TK 1.5	133 a	62	19.4 a	83
6 TK 0.75	72 a	79	11.7 a	90
7 RA-2	123 a	64	17.8 a	84

[1]For each year values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

cation of propanil produced a somewhat different trend with the 80015, 80015LP at 275 kPa and TK 0.75 nozzle tips performing the best. Propanil applied with the RA-2 nozzle resulted in significantly less control compared to all other treatments at both early and late treatment dates.

Dry weight reductions of green foxtail in 1979 were similar at both the early and late application dates (Table 7). At the early application date significantly poorer weed control occurred when propanil was applied with the 80015LP nozzle tip at 150 kPa compared to all other treatments. Late application of propanil resulted in the 80015 nozzle giving the highest level of green foxtail control and the RA-2 nozzle giving the least satisfactory control.

The data in Table 7 shows that a discrepancy exists between weed control based on density and control based on dry weight reduction with the conventional 80015 nozzle at the early application date. This nozzle resulted in the best performance based on green foxtail reduction in weight but the worst performance based on reduction in density. This could reflect the fact that the chemical did not kill a large portion of the green foxtail present but those which survived were damaged severely, inhibiting further growth.

Analysis of green foxtail control data in 1980 shows that there only being a significant interaction between treatments. There was no time of application by treatment interaction so the data for both early and late applications were combined (Table 7). No significant differences in green foxtail dry weight or densities between treatments applied with the various nozzles occurred. Even though differences were non-significant, treatments 2, 3 and 6 reduced green foxtail density the most while treatments 5 and 7 reduced the density the least. A similar but less pronounced trend in dry weight reduction was observed. These results are similar to the results found at the late application date in 1979.

Even though dry weights and densities of green foxtail differed considerably between treatments in 1980, significant differences were not evident. This is likely due to the high variability in green foxtail population in the experimental area.

In 1979, analysis of grain yield showed that there was a significant time of application by treatment interaction, while in 1980 no significant differences in crop dry weight occurred between the treatments applied either at the early or late dates (Table 8). In 1979, the early applications with all nozzles, except the 80015, resulted in significantly higher yields than applications at the later date. No significant differences occurred between the nozzle treatments either at the early or late application date.

In 1979, there was a significant time of application by treatment interaction for both weed control and grain yield. Yields and levels of weed control did not correspond at the early treatment date. The same was true for the late application date except in the case of the 80015 tip, where both good weed control and high yields occurred. The lack of yield response to the treatments in 1980 could have been influenced by the variable nature of the weed populations.

Diclofop Methyl Applied to Green Foxtail and Wild Oats in Wheat

The weed control data for 1979 is presented in Table 9 and represents average values of the early and late applications combined. Nozzle efficacy data was only collected for control of green foxtail because of the extremely poor wild oat populations in the experiment. Significant differences between treatments based on green foxtail density and dry

TABLE 8. Wheat yield of plots treated with propanil applied with the various nozzle tips, 1979.

	Treatment[2]	Grain Yield[1]	
		g/m²	% Increase
	Early Application		
1	Check	210 e	--
2	80015	280 bc	32
3	80015LP	315 ab	48
4	80015LP (150 kPa)	310 ab	46
5	TK 1.5	325 a	53
6	TK 0.75	308 ab	45
7	RA-2	316 ab	49
	Late Application		
1	Check	215 de	--
2	80015	255 cd	20
3	80015LP	237 de	11
4	80015LP (150 kPa)	229 de	7
5	TK 1.5	243 cde	14
6	TK 0.75	240 cde	13
7	RA-2	249 cde	17

[1]Values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

TABLE 9. Density and dry weight of green foxtail plants treated with diclofop methyl applied with the various nozzle tips, 1979.

	Treatment[2]	Density[1]		Dry Weight[1]	
		Plants/m^2	% Reduction	g/m^2	% Reduction
1	Check	152 c	--	65.8 d	--
2	80015	75 b	50	37.7 c	43
3	80015LP	27 a	82	9.1 a	86
4	80015LP (150 kPa)	59 ab	61	31.9 bc	51
5	TK 1.5	84 b	44	41.3 c	37
6	TK 0.75	49 ab	67	20.0 ab	69
7	RA-2	56 ab	63	33.6 bc	49

[1]Density or dry weight values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

weight occurred.

Based on green foxtail density, diclofop methyl applied with the 80015LP nozzle tip at 275 kPa resulted in significantly better weed control than when the chemical was applied with the 80015 and TK 1.5 nozzle tips (Table 9). The 80015LP at 275 kPa performed the best when dry weights were compared. It performed significantly better than all other nozzles except the TK 0.75 flooding tip. Poorest performance consistently occurred when diclofop methyl was applied with the TK 1.5 flooding tip.

Although there were no time of application by treatment interactions, the early application of diclofop methyl did provide significantly better weed control. On average, green foxtail densities and dry weights were 36 and 49% lower, respectively, from the early treatments compared to the later treatments. This would be expected since green foxtail is more susceptible to diclofop methyl at the early leaf stage.

In 1979, a significant time of application by treatment interaction between grain yields of the various plots occurred. In most cases greater yield increases occurred with the early application of diclofop methyl in 1979 (Table 10). This would be expected since weed competition with the crop is removed at an earlier date. At the earlier application date the TK 0.75 flooding tips resulted in significantly higher yield increases than all nozzles except the 80015LP applied at 275 kPa and the RA-2. This trend did not occur with the late application where the greatest yield increase resulted from application with the 80015 nozzle tip. Only the RA-2 nozzle tip resulted in significantly less grain yield.

Generally speaking, levels of green foxtail control did not relate to yield response in 1979. The only consistent trend occurred with the TK 0.75 nozzle which produced relatively high levels of weed control and

TABLE 10. Wheat yields in 1979 and wheat dry weight in 1980 of plots treated with diclofop methyl applied with the various nozzle tips.

	Treatment[2]	Grain Yield[1] g/m²		% Increase
1979				
	Early Application			
1	Check	266.0	g	--
2	80015	321.0	bcde	20
3	80015LP	336.0	abc	26
4	80015LP (150 kPa)	308.0	bcdef	16
5	TK 1.5	300.0	cdefg	13
6	TK 0.75	350.0	a	32
7	RA-2	343.0	ab	29
	Late Application			
1	Check	273.0	fg	--
2	80015	336.0	abcd	23
3	80015LP	299.0	defg	9
4	80015LP (150 kPa)	317.0	bcde	16
5	TK 1.5	315.0	bcde	15
6	TK 0.75	324.0	abcde	18
7	RA-2	289.0	efg	6
		Wheat Dry Weight[1]		
1980				
1	Check	210.0	c	--
2	80015	344.0	a	64
3	80015LP	328.0	ab	56
4	80015LP (150 kPa)	307.0	ab	46
5	TK 1.5	276.0	b	31
6	TK 0.75	326.0	ab	55
7	RA-2	281.0	b	34

[1]For each year values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

grain yield.

In 1980, efficacy data was collected for diclofop methyl applied to both green foxtail and wild oats within the same experiment (Table 11). Statistical analysis of the 1980 data showed that there was a time of application by treatment interaction with respect to green foxtail density, while dry weight measurements only showed significance between treatments.

Based on the variables, green foxtail density and dry weight, no significant differences in weed control occurred when diclofop methyl was applied with the various nozzle tips. Reduction in green foxtail density was marginally higher from the late treatment date, although this may be somewhat misleading due to the much higher densities in the check plots at the later treatment date.

Treatment values for green foxtail weed dry weight presented in Table 11 are based on average values of the early and late treatments combined. Generally the least satisfactory green foxtail control occurred with the TK 1.5 and RA-2 tips.

From the 1980 data just presented, it can be seen that there are large differences in dry weights and densities between treatments, but due to the extreme variability of green foxtail populations significant differences could not be shown.

Diclofop methyl applied at the early or late treatment dates did not result in any significant differences in wild oat control based on density and dry weight determinations (Table 12). There were only significant differences between treatments when the data for early and late applications were combined. With both variables, the 80015LP tips at 275 kPa performed the best, providing significantly better weed control than the TK 1.5 and RA-2 nozzle tips.

TABLE 11. Density and dry weight of green foxtail plants treated with diclofop methyl applied with the various nozzle tips, 1980.

	Treatment[2]	Density[1]	
		Plants/m[2]	% Reduction
	Early Application		
1	Check	136.0 a	--
2	80015	19.0 a	86
3	80015LP	4.0 a	97
4	80015LP (150 kPa)	13.0 a	90
5	TK 1.5	22.0 a	84
6	TK 0.75	21.0 a	85
7	RA-2	37.0 a	73
	Late Application		
1	Check	705.0 b	--
2	80015	23.0 a	97
3	80015LP	16.0 a	98
4	80015LP (150 kPa)	28.0 a	96
5	TK 1.5	127.0 a	81
6	TK 0.75	14.0 a	98
7	RA-2	76.0 a	89
		Dry Weight[1]	
		g/m[2]	% Reduction
1	Check	81.4 b	--
2	80015	6.0 a	93
3	80015LP	0.9 a	99
4	80015LP (150 kPa)	4.4 a	94
5	TK 1.5	15.6 a	88
6	TK 0.75	2.5 a	97
7	RA-2	9.5 a	81

[1]Density or dry weight values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

TABLE 12. Density and dry weight of wild oats treated with diclofop methyl applied with various nozzle tips, 1980.

Treatment[2]	Density[1]		Dry Weight[1]	
	Plants/m^2	% Reduction	g/m^2	% Reduction
1 Check	26 d	-	45.5 d	-
2 80015	3 ab	89	3.6 ab	92
3 80015LP	1 a	95	1.5 a	97
4 80015LP (150 kPa)	6 abc	78	5.9 abc	87
5 TK 1.5	6 bc	76	6.5 bc	86
6 TK 0.75	2 ab	90	2.3 ab	95
7 RA-2	10 c	61	9.0 c	80

[1]Values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

Crop dry weights in 1980 did not differ significantly between times of application. Dry weight values presented in Table 10 represent average values of the early and late treatments combined. The plots in which diclofop methyl was applied with the conventional 80015 nozzle tips had significantly higher dry weights than those where the chemical was applied with the RA-2 and TK 1.5 flooding tips.

Crop dry weights in 1980 corresponded closely to the measured levels of green foxtail and wild oat control. Both the lowest crop dry weights and levels of weed control occurred where diclofop methyl was applied with the TK 1.5 and RA-2 nozzle tips.

Difenzoquat Applied to Wild Oats in Wheat

As previously mentioned in the Materials and Methods Section, efficacy data for difenzoquat was only recorded in 1980 due to extremely poor wild oat populations in 1979. In 1980, wild oat populations were low, but sufficient to obtain nozzle efficacy data.

Statistical analysis of the data in 1980 revealed that there were significant differences between application times and treatments based on wild oat dry weight determinations and a time of application by treatment interaction in the case of wild oat densities (Table 13). No significant differences in crop dry weight with respect to time of application or treatment occurred.

Based on wild oat densities, the late application of difenzoquat resulted in excellent control of wild oats with all treatments. Significant differences between treatments were only seen at the early treatment date. At the early date, excellent control of wild oats occurred with all treatments except when the chemical was applied with the TK 1.5 flooding tip and the RA-2 tip. The 80015LP at 275 kPa resulted in the best control

TABLE 13. Density and dry weight of wild oat plants treated with difenzoquat applied with the various nozzle tips, 1980.

	Treatment[2]	Density[1]	
		Plants/m[2]	% Reduction
	Early Application		
1	Check	51.0 e	--
2	80015	2.0 ab	96
3	80015LP	0.0 a	100
4	80015LP (150 kPa)	2.0 ab	96
5	TK 1.5	10.0 c	80
6	TK 0.75	1.0 ab	98
7	RA-2	9.0 bc	82
	Late Application		
1	Check	34.0 d	--
2	80015	0.0 a	100
3	80015LP	0.0 a	100
4	80015LP (150 kPa)	0.0 a	100
5	TK 1.5	0.0 a	100
6	TK 0.75	0.0 a	100
7	RA-2	1.0 ab	98
		Dry Weight[1]	
		g/m[2]	% Reduction
1	Check	88.4	--
2	80015	4.6	95
3	80015LP	0.0	100
4	80015LP (150 kPa)	1.2	99
5	TK 1.5	8.4	90
6	TK 0.75	1.6	98
7	RA-2	7.5	91

[1]Density or dry weight values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at 150 kPa; all other treatments were applied at 275 kPa.

of wild oats. The TK 0.75 flooding tip at 50 cm spacings on the sprayer boom resulted in significantly better control than the larger TK 1.5 flooding tip at 100 cm spacings.

Difenzoquat applied at the late leaf stage of wild oats provided significantly better wild oat control than at the early leaf stage when dry weights were compared. On average, wild oat dry weights were 50% lower from the late treatments. This difference would be expected since difenzoquat is more active on wild oats as they reach the four- or five-leaf stage. The dry weight values in Table 13 are combined dry weights of the treatments at the early and late application dates. No significant differences between treatments occurred but again the 80015LP nozzle tip at 275 kPa performed the best and the TK 1.5 and RA-2 tips the poorest.

No significant difference in crop dry weights occurred. Due to a low initial population of wild oats, competition with the crop was minimal.

Bromoxynil Applied to Broadleaf Weeds in Wheat

In both 1979 and 1980, a number of broadleaf weed species were present in the experimental areas. Weed control in both years was assessed by taking total dry weights of all broadleaf weeds present.

In 1979, the predominant weed was wild buckwheat. Other broadleaf weeds present included wild mustard, lamb's quarters and redroot pigweed. Significant differences in weed control were observed between treatments in 1979 and are presented as average dry weights of the early and late treatments combined (Table 14). Broadleaf weed control was excellent with all treatments except when the chemical was applied with the RA-2 tip. The timing of bromoxynil applications had no significant effect on the level of weed control.

TABLE 14. Dry weight of broadleaf weeds treated with bromoxynil applied with various nozzle tips, 1979 and 1980.

Treatment[2]	Dry Weight[1]	
	g/m^2	% Reduction
1979		
1 Check	174.7 c	--
2 80015	2.6 a	98
3 80015LP	3.2 a	98
4 80015LP (150 kPa)	1.3 a	99
5 TK 1.5	6.1 a	96
6 TK 0.75	3.1 a	98
7 RA-2	22.5 b	87
1980		
Early Application		
1 Check	86.7 c	--
2 80015	4.2 a	95
3 80015LP	6.8 a	92
4 80015LP (150 kPa)	36.8 b	57
5 TK 1.5	6.9 a	92
6 TK 0.75	3.0 a	96
7 RA-2	5.1 a	94
Late Application		
1 Check	41.9 b	--
2 80015	3.9 a	91
3 80015LP	5.9 a	86
4 80015LP (150 kPa)	3.4 a	92
5 TK 1.5	9.4 a	77
6 TK 0.75	3.1 a	93
7 RA-2	17.6 ab	58

[1]For each year values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

In 1980, broadleaf weed populations were low and variable. The broadleaf weeds within the experimental area included wild buckwheat, wild mustard, lamb's quarters and redroot pigweed, with no one species being predominant. Statistical analysis of broadleaf dry weights in 1980 showed that there is a time of application by treatment interaction based on broadleaf weed dry weights (Table 14).

On average the early application resulted in slightly better broadleaf weed control than the treatments applied later although the differences were not significant. At the early application date, bromoxynil applied with the 80015LP tip at 150 kPa resulted in significantly poorer broadleaf weed control compared to the other treatments. No significant differences between treatments occurred at the late application date. Treatments 2, 4 and 6 gave the highest level of weed control while treatment 7 resulted in the poorest level of weed control.

In 1979, a significant time of application by treatment interaction with grain yield occurred, while in 1980 measurements of crop dry weights only resulted in significant differences between treatments (Table 15). The treatment values for 1980 are based on average values of the early and late treatments combined.

Wheat yields in 1979 were approximately 25% higher in plots treated at the early date. This could be attributed to the early removal of broadleaf weeds when they were at the most susceptible leaf stage. At the early application date, there were no significant differences between treatments although treatments 3, 4 and 7 gave somewhat smaller yield increases than the other treatments. At the late application date, treatment with the 80015LP tip at 150 kPa resulted in significantly higher yield increases than either the conventional flat fan (80015) or the Raindrop (RA-2) tips.

TABLE 15. Yield and dry weight of wheat plants in plots treated with bromoxynil applied with various nozzle tips in 1979 and 1980, respectively.

Treatment[2]	Grain Yield[1]	
	g/m^2	% Increase
1979		
Early Application		
1 Check	238.0 e	--
2 80015	357.0 a	50
3 80015LP	330.0 ab	38
4 80015LP (150 kPa)	344.0 a	40
5 TK 1.5	357.0 a	50
6 TK 0.75	345.0 a	45
7 RA-2	323.0 ab	35
Late Application		
1 Check	227.0 e	--
2 80015	252.0 de	11
3 80015LP	265.0 cde	17
4 80015LP (150 kPa)	296.0 bc	30
5 TK 1.5	281.0 cd	24
6 TK 0.75	264.0 cde	16
7 RA-2	251.0 de	10
	Dry Weight[1]	
	g/m^2	% Increase
1980		
1 Check	164.0 b	--
2 80015	232.0 a	41
3 80015LP	234.0 a	42
4 80015LP (150 kPa)	230.0 a	40
5 TK 1.5	240.0 a	46
6 TK 0.75	231.0 a	41
7 RA-2	239.0 a	45

[1]Yield or dry weight values followed by the same letter are not statistically (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

In 1980, time of bromoxynil application had no effect on dry weights of the wheat crop. Similar dry weight increases occurred with all treatments (Table 15).

Measurements of weed control and yield did not correspond closely in 1979. Weed control with all treatments except with the RA-2 tip was excellent while grain yields varied considerably between treatments. The only similarity between yield response and weed control occurred with the RA-2 nozzle. Weed control and grain yields were the poorest in plots treated with this nozzle. In 1980, crop dry weight response and level of broadleaf weed control were not related. Levels of weed control varied between treatments while crop dry weights were uniform between the treatments.

Metribuzin Applied to Broadleaf Weeds in Barley

In both 1979 and 1980, a number of broadleaf weed species were present in the experimental areas. As in the bromoxynil experiments, weed control was assessed by taking total dry weights of all broadleaf weeds present.

In 1979, the broadleaf weed populations in the metribuzin experiments were very low. The weed species present included wild buckwheat, wild mustard, lamb's quarters and redroot pigweed. Metribuzin is not registered for the control of wild buckwheat since the weed is relatively tolerant to the chemical.

In 1979, a time of application by treatment interaction occurred when the broadleaf weed dry weights were statistically analyzed (Table 16). At the early application date the 80015LP tip at 275 kPa provided the best performance, giving significantly better weed control than application with all other nozzle tips except the 80015LP at a pressure of 150 kPa. The RA-2 nozzle tip resulted in significantly poorer weed control when compared to all

TABLE 16. Dry weight of broadleaf weeds treated with metribuzin applied with the various nozzle tips, 1979 and 1980.

Treatment[2]	Dry Weight[1]	
	g/m[2]	% Reduction
1979		
Early Application		
1 Check	15.9 f	--
2 80015	9.4 e	41
3 80015LP	1.0 ab	94
4 80015LP (150 kPa)	2.4 abc	85
5 TK 1.5	7.5 de	53
6 TK 0.75	5.6 cde	65
7 RA-2	13.6 f	14
Late Application		
1 Check	17.4 f	--
2 80015	0.0 a	100
3 80015LP	0.3 ab	98
4 80015LP (150 kPa)	0.0 a	100
5 TK 1.5	1.8 abc	90
6 TK 0.75	4.7 bcd	73
7 RA-2	16.2 f	7
1980		
1 Check	62.3 b	--
2 80015	0.1 a	99
3 80015LP	0.0 a	100
4 80015LP (150 kPa)	0.0 a	100
5 TK 1.5	0.2 a	99
6 TK 0.75	0.0 a	100
7 RA-2	2.9 a	95

[1]For each year values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

other nozzles tested. At the late application date treatments 2, 3 and 4 all gave excellent levels of weed control. Again, as at the early application date the RA-2 nozzle tip performed poorly. Although there were no significant differences between times of application, higher levels of weed control occurred at the late treatment date. The early treatments averaged a 58% reduction in weed dry weight while the late treatments averaged a 78% reduction in weed dry weight.

In 1979, treatments 2, 3 and 4 resulted in extremely high levels of weed control when metribuzin was applied at the later date, even though the tolerant weed, wild buckwheat, was present. As mentioned previously, higher levels of weed control occurred at the late treatment date. This, together with the observed high degree of wild buckwheat control, would not be expected since the broadleaf weeds were at a sub-optimum leaf stage for control. Weather conditions at the time of treatment could possibly account for the unexpected response. The high temperature at the time of spraying may have accentuated the activity of the herbicide on the broadleaf weeds (Table 3).

In 1980, broadleaf weed populations were low and variable. The broadleaf weeds within the experimental area included redroot pigweed, lamb's quarters and wild mustard. Timing of metribuzin application had no effect on broadleaf weed control. There were significant differences between treatments although these differences only occurred between the nozzle treatments and the check (Table 16). The treatment values represent average values of the early and late treatments combined. All treatments resulted in excellent control of all broadleaf although the lowest level of broadleaf weed control resulted from using the RA-2 nozzle tip.

Yield increases from control of broadleaf weeds by metribuzin in

1979 were small due to low weed populations (Table 17). Timing of application had no effect on barley yield, therefore the yield values in Table 17 are averages of the early and late treatments combined. Metribuzin applied with the TK 1.5 and TK 0.75 nozzles resulted in significantly greater yield increases than with the RA-2 tip. In 1980, due to the poor broadleaf weed population significant differences in crop dry weights between times of application and treatments did not occur.

The poorest yields in 1979 came from plots treated with the 80015 and RA-2 tips. This result would be expected for the RA-2 nozzle since it produced the poorest levels of broadleaf weed control. Since the yield values on Table 17 are averages of the early and late treatments the poor performance of the 80015 in increasing barley yield can be attributed to its poor control of broadleaf weeds at the early treatment date.

Laboratory Experiments

Nozzle Efficacy Experiments

The herbicide rates used in these experiments were ED_{50} values which had been determined previously. ED_{50} refers to the herbicide dosage required to reduce dry weight increases to 50% of the control. These rates were used since complete control of susceptible weeds was not wanted. By using reduced dosages differences in level of weed control between the various nozzles could be more readily observed.

Propanil Applied to Green Foxtail. In the first trial the largest reduction in green foxtail dry weight occurred when propanil was applied with the standard 80015 nozzle tip (Table 18). This nozzle performed

TABLE 17. Barley yields of plots treated with metribuzin applied with the various nozzle tips, 1979.

Treatment[2]		Yield[1]	
		g/m[2]	% Increase
1	Check	317 c	--
2	80015	341 abc	7
3	80015LP	356 ab	12
4	80015LP	358 ab	13
5	TK 1.5	367 a	16
6	TK 0.75	369 a	16
7	RA-2	335 bc	6

[1]Values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at 150 kPa; all other treatments were applied at 275 kPa.

significantly better than both the 80015LP at 150 kPa and the RA-2 tip.

In the second trial significant differences only occurred between the check and the nozzle treatments (Table 18). Green foxtail dry weight reductions were similar with all treatments although the largest reduction occurred with the 80015 tip and 80015LP at 275 kPa and the least reduction with the RA-2 tip.

Diclofop Methyl Applied to Green Foxtail. Application of diclofop methyl in the first trial with the flooding TK 0.75 nozzle tip resulted in a significantly greater reduction in green foxtail dry weight than when the chemical was applied with all other nozzles except the TK 1.5 (Table 19). The 80015LP nozzle resulted in significantly better control when diclofop was applied at the high pressure (275 kPa) compared to the low pressure (150 kPa).

In the second trial, as in the first, the greatest dry weight reductions occurred when diclofop methyl was applied with the flooding TK 0.75 tip (Table 19). Diclofop methyl applied with this nozzle performed significantly better than all nozzles except the 80015 and 80015LP at 275 kPa. As happened in the first trial, green foxtail dry weight reduction was the least with the 80015LP at 150 kPa and the RA-2 nozzles.

Diclofop Methyl Applied to Wild Oats. In both trials differences between treatments were not large (Table 19). In trial 1, the 80015, TK 1.5 and RA-2 nozzles performed the best reducing wild oat dry weights by equal amounts. Wild oat dry weights were reduced the least when diclofop methyl was applied with the 80015LP nozzle at both pressures.

Dry weight reductions were generally much lower in the second trial (Table 19). Significant differences only occurred between the TK 0.75

TABLE 18. Dry weights of green foxtail plants treated with propanil applied with the various nozzle tips.

Treatment[2]		Trial 1		Trial 2	
		Dry Weight[1]		Dry Weight[1]	
		g/10 Plants	% Reduction	g/10 Plants	% Reduction
1	Check	0.90 d	--	1.13 b	--
2	80015	0.51 a	43	0.63 a	44
3	80015LP	0.56 ab	38	0.64 a	43
4	80015LP (150 kPa)	0.68 c	24	0.67 a	41
5	TK 1.5	0.57 ab	37	0.67 a	41
6	TK 0.75	0.57 ab	37	0.67 a	41
7	RA-2	0.64 bc	29	0.71 a	37

[1]In each trial values followed by the same letter within a column are not significantly different according to Duncan's multiple range test.

[2]Treatment number 4 was applied at 150 kPa; all other treatments were applied at 275 kPa.

TABLE 19. Dry weights of green foxtail and wild oats treated with diclofop methyl applied with the various nozzle tips.

Treatment[2]	Trial 1 Dry Weight[1]		Trial 2 Dry Weight[1]	
	g/10 Plants	% Reduction	g/10 Plants	% Reduction
Green Foxtail				
1 Check	1.36 e	--	0.70 c	--
2 80015	0.65 bc	52	0.34 a	51
3 80015LP	0.64 bc	53	0.38 ab	46
4 80015LP (150 kPa)	1.01 d	26	0.44 b	37 37
5 TK 1.5	0.45 ab	67	0.41 b	41
6 TK 0.75	0.37 a	73	0.32 a	54
7 RA-2	0.84 cd	39	0.45 b	36
	Trial 1 Dry Weight[1]		Trial 2 Dry Weight[1]	
	g/5 Plants	% Reduction	g/5 Plants	% Reduction
Wild Oats				
1 Check	1.98 d	--	1.59 c	--
2 80015	0.70 a	65	1.23 b	23
3 80015LP	0.91 bc	50	1.13 ab	29
4 80015LP (150 kPa)	0.98 c	54	1.16 ab	27
5 TK 1.5	0.79 ab	60	1.11 ab	30
6 TK 0.75	0.70 a	65	0.99 a	38
7 RA-2	0.70 a	65	1.21 b	24

[1]In each trial values followed by the same letter within a column are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at 150 kPa; all others were applied at 275 kPa.

nozzle which reduced wild oat dry weights the most and the 80015 and RA-2 tips which reduced dry weights the least.

Metribuzin Applied to Wild Mustard. In the first trial dry weight reductions between all treatments varied less than 10% but significant differences did occur (Table 20). Greatest wild mustard dry weight reductions occurred when metribuzin was applied with the 80015LP at 275 kPa and the flooding TK 0.75 tip. Application with the 80015LP at 275 kPa resulted in significantly better control than application with the RA-2 tip and 80015LP tip at 150 kPa.

A similar trend in nozzle performance occurred in the second trial (Table 20). Wild mustard dry weights were reduced the most when metribuzin was applied with the flat fan 80015LP at 275 kPa. The performance of this nozzle was followed closely by the nozzles in treatments 2, 4 and 6. Least satisfactory control occurred with the RA-2 nozzle which resulted in statistically less wild mustard control than all treatments except when the chemical was applied with the TK 1.5 nozzle tip.

Retention Study

The retention values and retention ratios for the dye solution applied with the various nozzle tips are presented in Tables 21 and 22. Retention measurements are based on the amount of solution retained/gram dry weight and /cm^2 of leaf area. Both the actual and adjusted retention values are included in the tables. As described in the Materials and Methods the adjusted retention value was determined by dividing 110 L/ha by the volume output of the treatment and multiplying this value by the actual measured

TABLE 20. Dry weights of wild mustard plants treated with metribuzin applied with the various nozzle tips.

Treatment[2]	Trial 1 Dry Weight[1] g/5 Plants	Trial 1 Dry Weight[1] % Reduction	Trial 2 Dry Weight[1] g/5 Plants	Trial 2 Dry Weight[1] % Reduction
1 Check	3.21 c	--	2.54 c	--
2 80015	2.17 ab	32	1.19 a	53
3 80015LP	1.98 a	38	1.01 a	60
4 80015LP (150 kPa)	2.29 b	29	1.25 a	51
5 TK 1.5	2.17 ab	32	1.34 ab	47
6 TK 0.75	2.09 ab	36	1.16 a	54
7 RA-2	2.26 b	30	1.65 b	35

[1]In each trial values followed by the same letter within a column are not significantly different (P = 0.10) according to Duncan's multiple range test.

[2]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at a pressure of 275 kPa.

amount of solution retained for that treatment.

With green foxtail, application of the dye solution with the 80015LP tip at 275 kPa and the TK 0.75 tip resulted in significantly larger amounts of actual solution retained compared to all other treatments (Table 21). The least amount of solution retained occurred with the 80015LP tip at 150 kPa and the flooding TK 1.5 nozzle tip. A similar trend occurred when actual amount retained/cm^2 was measured except that the treatments with both the 80015 and 80015LP at 150 kPa retained the least amount of solution.

In trial 1 when both retention values /gram and /cm^2 were adjusted, application with the flooding TK 0.75 resulted in significantly more solution being retained than from all other treatments. Based on green foxtail dry weight, application with the 80015LP at 150 kPa resulted in significantly less solution retained and based on leaf area the 80015LP at both pressures resulted in significantly less solution retained, when compared to all other treatments.

The retention ratio for the TK 0.75 nozzle tip was by far the highest while application with the 80015LP at 150 kPa resulted in the lowest ratio. Ratios for all the other treatments were similar.

In the second trial with green foxtail, similar results were obtained (Table 21). Based on actual amount of solution retained/gram and /cm^2, applications with the 80015LP at 275 kPa and TK 0.75 nozzle tips resulted in the largest amount of solution retained, with the 80015LP at 275 kPa retaining significantly more solution than all other treatments. When retention/gram and /cm^2 were corrected for volume, the application with the TK 0.75 nozzle resulted in significantly more solution retained than with all other treatments. The lowest retention values resulted from

TABLE 21. Actual and adjusted amounts of solution retained on green foxtail plants and retention ratios.

Treatment[1]	Solution retained/g dry weight[2] (microliters)		Solution retained/cm^2 [2] (microliters)		Retention Ratio[3]
	Actual	Adjusted	Actual	Adjusted	(1×10^{-5})
Trial 1					
1 Check	--	--	--	--	--
2 80015	226 b	228 b	0.36 b	0.36 b	13
3 80015LP	413 a	175 b	0.79 a	0.34 c	12
4 80015LP (150 kPa)	198 b	117 c	0.36 b	0.21 c	8
5 TK 1.5	205 b	209 b	0.37 b	0.38 b	14
6 TK 0.75	464 a	483 a	0.87 a	0.90 a	32
7 RA-2	210 b	200 b	0.42 b	0.40 b	14
Trial 2					
1 Check	--	--	--	--	--
2 80015	184 c	186 b	0.32 c	0.32 b	7
3 80015LP	321 a	144 cd	0.71 a	0.32 b	7
4 80015LP (150 kPa)	179 c	106 d	0.30 c	0.17 c	5
5 TK 1.5	155 c	158 bc	0.32 c	0.33 b	7
6 TK 0.75	254 b	264 a	0.52 b	0.54 a	10
7 RA-2	149 c	141 cd	0.30 c	0.29 b	6

[1] Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

[2] For each experiment, within each column values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[3] Ratios are determined by dividing the average volume of solution retained by 10 plants by the volume applied.

application with the 80015LP at the low pressure.

In the second trial retention ratios were smaller than in the first trial. This was due to the green foxtail plants being smaller in the second trial although they were in the same leaf stage as in the first trial when treated. The highest retention ratio occurred with the TK 0.75 tip while the lowest occurred with the 80015LP at 150 kPa and the RA-2 tips.

Wild oat plants retained much less dye solution (Table 22) than the green foxtail plants as indicated by actual and adjusted amounts of solution retained on retention ratios. In the first trial, actual retention measurements/gram and /cm^2 were significantly higher when the dye solution was applied with the RA-2 tip. The next highest amounts of solution retained occurred when the wild oat plants were sprayed with the flooding TK 0.75 tip and 80015LP at 275 kPa. Based upon actual solution retained/gram, application with the flat fan 80015LP at 150 kPa resulted in significantly less solution retained compared to all other treatments. Actual retention/cm^2 measurements showed that spraying with the TK 1.5 tip and 80015LP tip at 150 kPa resulted in the lowest levels of retention.

When retention measurements/gram were adjusted in the first trial the RA-2 nozzle resulted in significantly higher amounts of solution retained than all treatments except treatment 6 (Table 22). Lowest retention values occurred with the 80015LP at both the high and low pressure. Application with the RA-2 and TK 0.75 nozzles resulted in significantly higher volumes retained when measurements were based on leaf area, while application with the 80015LP tip at both pressures again resulted in significant lower levels of retention than all other treatments.

In the first trial retention ratios were highest for the RA-2 and TK 0.75 nozzles while application of the spray solution with the 80015LP

TABLE 22. Actual and adjusted amounts of solution retained on wild oat plants and retention ratios.

Treatment[1]	Solution retained/g dry weight[2] (microliters)		Solution retained/cm^2 [2] (microliters)		Retention ratio[3]
	Actual	Adjusted	Actual	Adjusted	(1×10^{-5})
Trial 1					
1 Check	--	--	--	--	--
2 80015	40 b	40 bc	0.11 bc	0.11 b	4.6
3 80015LP	47 b	20 de	0.13 bc	0.05 c	2.1
4 80015LP (150 kPa)	22 c	13 e	0.06 d	0.03 c	1.4
5 TK 1.5	35 b	31 cd	0.09 cd	0.09 b	3.7
6 TK 0.75	47 b	51 ab	0.15 b	0.16 a	5.7
7 RA-2	62 a	58 a	0.19 a	0.18 a	7.1
Trial 2					
1 Check	--	--	--	--	--
2 80015	22 bc	22 b	0.05 b	0.05 b	2.5
3 80015LP	55 a	23 b	0.13 a	0.06 b	2.8
4 80015LP (150 kPa)	28 bc	16 b	0.04 b	0.02 b	1.5
5 TK 1.5	14 c	14 b	0.03 b	0.03 b	1.6
6 TK 0.75	27 bc	25 ab	0.05 b	0.05 b	2.5
7 RA-2	38 b	36 a	0.10 a	0.09 a	4.3

[1]Treatment number 4 was applied at a pressure of 150 kPa; all other treatments were applied at 275 kPa.

[2]For each experiment, within each column values followed by the same letter are not significantly different (P = 0.10) according to Duncan's multiple range test.

[3]Ratios are determined by dividing the average volume of solution retained per 7 plants by the volume applied.

nozzles at both pressures resulted in the lowest values.

In the second trial on wild oats measurements of actual solution retained/gram showed that the 80015LP at 275 kPa retained significantly more solution than all other treatments (Table 22). The second highest amount retained occurred following application with the RA-2 tip. Application of the dye solution with the TK 1.5 nozzle resulted in the least amount of solution retained. Actual retention/cm^2 on wild oat leaves was significantly higher with the nozzles in treatments 3 and 7. All other treatments resulted in comparatively lower levels of retention.

Adjusted levels of retention in trial 2 showed that application of the dye solution with the RA-2 tip resulted in significantly more solution being retained compared to treatment with all other nozzles except the TK 0.75 when measurements were based upon wild oat dry weights. Treatments 4 and 5 retained the least amount of solution. Solution retained/cm^2 was significantly higher with the RA-2 nozzle. Significant differences did not occur with the other treatments but the lowest adjusted levels of retention resulted from the LP tip at 150 kPa and the larger TK 1.5 floodjet nozzle.

Retention ratios were somewhat smaller in the second trial, although wild oat leaf areas were similar in both trials. As in the first trial, the highest ratio occurred with the RA-2 nozzle. Similar ratios occurred with the nozzles in treatments 2, 3 and 6 while application with the 80015LP at 150 kPa and the TK 1.5 resulted in the lowest ratios.

Water Droplet Contact Angle Measurements

Contact angles were measured on leaves of wild oats, green foxtail, and wild buckwheat. Attempts were made to measure contact angles on leaves of wild mustard, but due to the abundance of hairs on the leaf surface it was impossible to obtain consistent values.

The contact angles measured on the wild oat and green foxtail leaves were considerably higher than those measured on wild buckwheat leaves (Table 23). With all measurements except on leaves of wild buckwheat grown in the growth room contact angles increased with leaf stage and leaf number.

Contact angles on wild oat leaves were larger on plants grown in the growth room compared to plants grown outside at all leaf stages except the fourth. With green foxtail and wild buckwheat the opposite effect occurred. Contact angles measured on outdoor-grown green foxtail were larger with all leaves except the first, while with all wild buckwheat leaves, contact angles were larger on plants grown outdoors.

With all plants the differences between the lowest contact angle and highest contact angle measured was greatest for the plants grown outside.

TABLE 23. Water droplet contact angle measurements on leaves of wild oats, green foxtail and wild buckwheat.

	Leaf stage	Leaf	Plants Grown in the Growth Room		Plants Grown Outside	
			Contact angle (degrees)	Standard deviation	Contact angle (degrees)	Standard deviation
Wild Oats	2½	1st	147	4.8	128	5.8
	2½	2nd	149	9.5	127	5.2
	4½	3rd	146	6.0	144	6.6
	4½	4th	151	8.4	153	7.2
Green Foxtail	2	1st	141	5.8	135	7.7
	3	2nd	143	5.4	148	5.0
	4	3rd	139	5.7	146	5.8
	4½	4th	145	5.2	148	4.7
Wild Buckwheat	2	1st	56	7.1	66	6.6
	3	2nd	48	4.5	71	4.0
	4	3rd	49	9.9	76	10.0
	4	4th	51	5.8	79	9.7

DISCUSSION

Field Experiments

Since the same amount of herbicide was applied to each plot in the field experiments, large differences between treatments were not expected. In studies of this type uniform weed populations are important to minimize variability and to show significant differences between treatments. Weather conditions during the growing season of 1979 and 1980 were very different (Appendix Tables 1 and 2) and this is reflected in the weed populations present in the two years. In 1979 good moisture conditions occurred in the spring and weed populations were generally uniform and more than adequate for assessing herbicide performance except for wild oats in the diclofop methyl and difenzoquat experiments. In 1980 weed populations in all experiments were variable. This was due to the extremely dry weather conditions in the spring and early summer of 1980. Differences in crop yields and levels of weed control between times of application and treatments were not always statistically significant even though in some cases these differences were quite large.

With each chemical the treatments were applied at an early and late leaf stage of the susceptible weeds. The chemicals propanil, diclofop methyl, bromoxynil and metribuzin would normally be expected to perform the best in controlling susceptible weeds when application is at an early leaf stage. Generally this did occur except in three cases. The first exception was when propanil was applied to green foxtail in 1979 (Table 7). Hunter (1980) reports that control of green foxtail with propanil at a rate of 1.0 kg/ha is significantly better at the two-leaf stage than the four-leaf stage. In 1979, the treatments at the late application (three- to five-leaf stage) reduced green foxtail densities by an average of 6% more than the early treatments (two- to three-leaf stage). Control based on dry weight was similar with the early and late treatments averaging 69% and 66% control, respectively. This unexpected response could be attributed to weather conditions at the time of spraying (Table 2). RH was substantially higher and temperature slightly higher at the late date. Propanil is a contact type herbicide and as reported by Muzik (1976) the phytotoxic effect of contact herbicides increases as temperature and RH increase.

The other two exceptions involved metribuzin applied to broadleaf weeds in 1979 (Table 16) and diclofop methyl applied to green foxtail in 1980 (Table 11). In both these cases weather conditions did differ between early and late application dates, but the effect of weather conditions is less clear. In the metribuzin experiment in 1979, at the early application date temperature and wind velocity were lower but the RH was substantially higher than at the late application date (Table 2). From these results it would seem that metribuzin activity is enhanced by warm and dry conditions. In the diclofop methyl experiment in 1980 temperatures were higher and wind velocity and RH lower at the early treatment date (Appendix Table 1). The explanation of why diclofop methyl performed better at the late treatment date may relate to the higher RH which could influence the uptake characteristics. High humidity at the time of treatment could slow evaporative loss of the spray from the leaf surface and enhance cuticular penetration. Laboratory studies have confirmed that uptake of many herbicides, including a number of wild oat herbicides, is enhanced under conditions of high humidity (Sharma et al. 1976; Miller et al. 1978). Control of wild oats with difenzoquat is best when the plants are at the five-leaf stage (Miller et al. 1978). As expected late applications of difenzoquat provided the highest levels of wild oat control. When wild oat dry weights were measured, the late application resulted in an average of 99% control while the early application resulted in 92% control (Table 13). However, the data on wild oat counts showed that difenzoquat applied at the late date resulted in significantly better wild oat control (98% vs 87%).

As mentioned earlier, in each of the field experiments the same amount of active ingredient was applied in roughly equivalent volumes (110 L/ha) to all plots except the weedy control, with the only difference being the way in which the spray was delivered onto the target plants. The differences in delivery of the spray solution are attributable to the various nozzle types which have different droplet size distributions and spray patterns. Each of these factors could have an effect on herbicide efficacy.

In a comparison of the flat fan nozzles, the droplet size distributions of the 80015 and 80015LP at 275 kPa are similar (Appendix Figures 1 and 2), with the conventional 80015 and 80015LP having volume median diameters (VMD) of 370 μm and 375 μm, respectively. The VMD of the 80015LP at 150 kPa (Table 1) is larger than that of the 80015 and 80015LP at the high pressure. At the lower pressure the VMD of the 80015LP is 410 μm.

The droplet size distributions of the flooding nozzles vary considerably (Appendix Figure 3). The spray pattern of the TK 1.5 contains larger droplets with a VMD of 400 μm compared to the smaller TK 0.75

which has a VMD of 300 μm. The reported VMD of the Raindrop RA-2 is 330 μm (Table 1) but from observing the spray pattern of the RA-2 this figure seems misleading. With all other nozzle tips individual droplets were difficult to observe due to their small size but with the RA-2 nozzle the droplets were easily seen and probably were larger than the VMD figure provided by the manufacturer would suggest.

From the literature it is well established that droplet size is a critical factor in the performance of herbicidal sprays (McKinlay _et al_. 1972), but has a greater effect at low volumes than at high volumes of application (Ennis _et al_. 1962; Ayres and Merritt 1977, 1978; Wilson and Taylor 1978). Ashford (1974) compared the effect of 2,4-D applied in 100 μm and 200 μm droplets and reports that under field conditions herbicide efficacy was not necessarily increased when droplet size was decreased. He cited the reason as being that under field conditions the 100 μm droplets are more readily deflected away from the target by air currents. However, in the nozzle efficacy experiments conducted at Graysville in 1979 and 1980, droplet sizes of 100 μm or less only account for less than 2% of the spray solution with the 80015, 80015LP and flooding nozzle tips (Appendix Figures 1, 2 and 3). Although droplet size distribution information is unavailable for the RA-2 it is most likely that the percentage of droplets below 100 μm is also very low. It would, therefore, be expected that moderate air currents would not have much effect on performance of these nozzles.

From 1973 to 1976, the Saskatchewan Research Council carried out a series of deposit pattern studies with 80 degree flat fan, flooding and Raindrop nozzle tips and determined the coefficient of variation (CV) for each of the nozzle types (data unpublished). The CV gives an indication of the uniformity of spray deposition. As the CV value increases the uniformity of the amount of spray deposited across the width of the pattern decreases. A CV of 20% indicates that 1/6 of the area sprayed receives less than 80% of the spray volume, while a CV of 50% indicates that 1/6 of the area sprayed gets less than 50% of the average spray volume.

Tests on the flat fan 8002 nozzle which is similar to the 80015 showed that it has a CV of 19% at 200 kPa while the 8002LP at 100 kPa has a CV of 20%. It would be expected that these CV's would be similar to the CV's of the 80015 at 275 kPa and 80015LP at 150 kPa since the nozzles are of similar design. No information was available on LP nozzles applied at a high pressure.

The flooding TK 0.75 nozzle was tested by the Saskatchewan Research Council at 200 kPa and showed a CV of 28%. This indicates that both the flooding nozzles (TK 0.75 and TK 1.5) in the experiments reported here probably have higher CV's than the flat fan nozzle tips. CV determinations of the Raindrop nozzle (type not specified) show them to be very high, averaging 50%. Although the type was not specified in the work reported by the Saskatchewan Research Council it would seem likely that RA-2 CV would be high.

Information on how spray pattern CV affects nozzle performance in the field is not available, but it might be expected that high CV's would result in poor nozzle performance. With a high CV certain areas along the width of the spray pattern would receive less herbicide and control of susceptible weeds would be reduced in these areas because of the irregular spray pattern.

In the experiments conducted at Graysville all treatments were applied at approximately 110 L/ha. This is considered to be a fairly high volume and as reported earlier droplet size was generally less critical in herbicide performance at high volumes. Differences in nozzle performance may be partly due to differences in droplet size distribution but probably is also greatly influenced by the degree of uniformity of the spray pattern.

With all herbicides tested, application with the flooding TK 0.75 with the overlapping pattern, the 80015LP at 275 kPa, and the conventional flat fan 80015 nozzle tips generally resulted in high levels of weed control in both years. Of these nozzles the TK 0.75 and the 80015LP at 275 kPa performed the best followed closely by the conventional 80015 flat fan tip.

The TK 0.75 nozzle performed well in all experiments except when diclofop methyl was applied to green foxtail in 1979. The 80015LP at 275 kPa also performed well in all experiments except when bromoxynil was applied to a mixed population of broadleaf weeds at the late application date in 1980 (Table 14). The performance of the conventional 80015 was somewhat less consistent than the other two tips. For the most part, results were good except in the following three cases: (1) when propanil was applied to green foxtail in 1979 (Table 7), (2) when diclofop methyl was applied to green foxtail plants in 1979 (Table 9), and (3) when metribuzin was applied to broadleaf weeds in 1979 (Table 16).

The 80015LP at 150 kPa ranked slightly below the 80015LP at 275 kPa, 80015 and TK 0.75 tips. Herbicide application with this nozzle resulted in a high level of weed control only on four occasions. These were, (1) when green foxtail was sprayed with diclofop methyl in 1980 (Table

11), (2) when wild oats were treated with difenzoquat in 1980 (Table 13), (3) when broadleaf weeds were treated with bromoxynil in 1979 and at the late treatment date in 1980 (Table 4), and (4) when broadleaf weeds were sprayed with metribuzin in 1979 and 1980 (Table 16). It should be pointed out, however, that the results in the difenzoquat and metribuzin experiments in 1980 were confounded by poor and variable weed populations and that for the most part, control was excellent with all treatments, with no tip resulting in clearly superior results.

Application of all herbicides with both the flooding TK 1.5 and RA-2 nozzles consistently resulted in the poorest levels of weed control when compared to the other nozzles tested. On occasion each of these nozzles performed as well as the other nozzles but this was the exception rather than the rule.

Generally, the performance of the flat fan nozzles was similar. But in comparing the percent control values in all experiments the 80015LP at 275 kPa performed the best. The next best was the conventional flat fan (80015) and the least satisfactory was the 80015LP at 150 kPa. From the coefficient of variation information discussed previously, performance of the 80015 and 80015LP would be expected to be similar, although information for LP nozzles at a high pressure is unavailable. From the information available, the only differences between the nozzles would be in droplet size. The VMD's of the nozzles follow closely to the levels of performance. The least satisfactory nozzle was the 80015LP at 150 kPa which has the largest VMD (Table 1). The slightly better performance of the 80015LP at 275 kPa could possibly have been due to an improvement in spray pattern or to smaller droplets but no information is available to support this contention.

The TK 0.75 with the overlapping spray pattern performed similarly to the 80015LP at 275 kPa when percent reductions in weed dry weights and densities are compared. When compared to the larger flooding tip (TK 1.5), the performance of the TK 0.75 was superior. Both the TK 1.5 and TK 0.75 would probably have similar CV's (reported to be 28%). Mounting the TK 0.75 nozzles on the sprayer boom so the patterns overlap would improve its pattern uniformity compared to the TK 1.5 where no overlapping occurred. The TK 1.5 produces large droplets with a VMD of 400 μm, while the TK 0.75 produces considerably smaller droplets with a VMD of 300 μm (Table 1). The superior performance of the TK 0.75 nozzle could be attributed to both an improved spray pattern due to the overlapping and the smaller droplet size produced. The improved spray pattern probably is the major factor. Crop canopy penetration would also be improved with the overlapping pattern since the spray is originating from opposite directions.

The RA-2 tip produces a spray pattern with a very high CV of approximately 50%. This is most probably the major reason for its poor performance. It was also observed that the RA-2 nozzle produces a sizable number of large droplets. Because of the large droplets the possibility of droplet bounce and run-off would be increased as reported by Brunskill (1956), and Johnstone (1973). Penetration through the crop canopy and onto the target weeds would also be hindered by the large droplets. The number of droplets over a given area would be less than when droplets are smaller increasing the probability of reduced interception by the weeds. These confounding factors along with the high CV would be responsible for the poor performance of the RA-2 nozzle in the field experiments.

It was expected that differences between nozzle type would become more apparent when application was made at suboptimal leaf stages of the susceptible plants, and under environmental conditions which were not favorable for maximum herbicide effectiveness. But time by treatment interactions did not occur with all experiments and where they did occur, differences in nozzle performance were not necessarily more apparent at the suboptimal leaf stages.

An important environmental condition that can influence the effectiveness of a spray application is wind velocity. In both years at all spraying times wind conditions were ideal (Tables 2 and 3). The highest wind velocity recorded was 13 kPh which is well within the range of safety. Spraying in higher winds of up to 20 kPh would affect the performance of the various nozzles due to spray drift and pattern distortion. Drift potential would be highest for the 80015, 80015LP at 275 kPa and TK 0.75 and lowest for the low pressure (LP) nozzle at 150 kPa, TK 1.5 and RA-2 nozzle tips. Under high wind conditions it might be expected that performance of the 80015, 80015LP at 275 kPa and TK 0.75 would be reduced although the anticipated reduction in performance of the TK 0.75 might be less than for the others because of the lower boom height (Table 2) which would help to minimize the drift hazard. Schafer and Stobbe (1972) found that the low profile TeeJet 650067 (a standard TeeJet 65006 but at a lower boom height) and the TK 0.75 performed well when barban was applied to wild oats under conditions of high wind. The improved performance was attributed to the lower boom height.

The herbicides propanil and bromoxynil are contact herbicides, while diclofop methyl, difenzoquat, and metribuzin can be classified as translocated herbicides, but with all herbicides nozzle performance was similar. This does not conform with the findings by Ayres and Merritt (1977) who found that translocated herbicides tend to perform better when applied in smaller droplet sizes (150 μm) while contact herbicides result in more effective control with a larger droplet size. But the experiments by Ayres and Merritt (1977) were conducted at low volumes of 5 and 15 L/ha with uniform droplets, whereas the experiments in this study are sprayed at volumes of approximately 110 L/ha with nozzles producing droplets of various sizes. This reinforces the fact that the effect of droplet size is minimal and that the differences in weed control between nozzles found in these experiments are probably due to a large extent to differences in spray pattern.

In those trials where a time interaction occurred with either crop dry weights or grain yields higher yields occurred when the chemicals were applied at the early date. This result can be directly attributed to early removal of weed competition from the crop.

The trends in weed control between the treatments did not correspond to final grain yields in 1979 or crop dry weight in 1980. It is possible that differences in weed control between the treatments were not large enough to affect yield, and that other factors such as different moisture levels across the experimental area had a greater influence on yields. This was especially true in 1980 when significant differences between crop dry weight only occurred on two occasions.

Laboratory Experiments

Nozzle Efficacy Experiments

In the nozzle efficacy experiments the differences in levels of weed control between treatments were not large. This would be expected since applications were made at ED_{50} rates under stable environmental conditions. Furthermore, in these experiments the chemicals were sprayed directly onto the weeds without the influence of a crop canopy covering. Differences between nozzles in the ability of the spray to penetrate into the crop canopy as influenced by spray pattern or droplet size would, therefore, be eliminated.

Generally in the growth room experiments greatest dry weight reductions occurred when the chemicals were applied with the 80015, 80015LP at 275 kPa and TK 0.75 nozzles. On most occasions application with the 80015LP at 150 kPa and RA-2 nozzles resulted in the poorest levels of control. The RA-2 tip performed well only on one occasion and that was in the first trial when diclofop methyl was applied to wild oats. For the most part, control with the TK 1.5 was adequate and the performance of this nozzle usually ranked between the best and the worst.

The trends in nozzle performance in the laboratory experiments resemble the results found in the field studies except that the 80015LP at 150 kPa did not perform as well and the TK 1.5 performed somewhat better in the laboratory experiments.

A possible explanation why the 80015LP at 150 kPa performed poorly in the laboratory may be found in the results reported by Reipma (1960). He showed that the ratio of volume retained and applied decreases as the volume median diameter of the spray increases. Similar observations were recorded by Lake and Taylor (1974) who found that as spray volume increased large droplets reached maximum retention values at lower volumes than did smaller droplets. In the laboratory the 80015LP at 150 kPa produced a volume of 186 L/ha compared to approximately 110 L/ha in the field. The 80015LP at 150 kPa, having a large VMD of 400 μm combined with the high volume, would result in the less active ingredient being retained than in the field. Evidence of this effect is clearly seen with the adjusted retention values and retention ratios on Tables 21 and 22. The 80015LP at 150 kPa consistently has the lowest adjusted retention values and retention ratios.

With the 80015LP at 275 kPa the high volume (258 L/ha) apparently had less of an effect on performance than it did at 150 kPa as shown in the nozzle efficacy experiments where weed control levels were high, and in the retention studies where actual retention and retention ratio values were higher than the LP nozzle used at 150 kPa. The better performance of the LP nozzle at the higher pressure can be attributed to the smaller VMD (375 μm) (Table 1).

With the 80015, TK 1.5, TK 0.75 and RA-2 nozzles, volumes of output were similar (Table 6). The only differences between the nozzles would be in droplet size and pattern uniformity. As stated earlier, the effect of droplet size on the performance of herbicides is less critical at high volumes (Ennis et al. 1962; Ayres and Merritt 1977, 1978; Wilson and Taylor 1978). But the TK 0.75 and 80015 which both have smaller VMD's than the TK 1.5 and RA-2 did perform better; although performance was only marginally better than the TK 1.5. The good performance of the 80015 can probably be attributed to both droplet size and to low pattern CV. As discussed in the section on field experiments both the VMD and CV of the 80015 spray are lower than those of the TK 1.5 and RA-2. As pointed out earlier, the reported VMD for the RA-2 seems erroneous upon observation of the spray pattern. The TK 0.75 which has a smaller VMD (Table 1) but a higher CV than the conventional 80015, performed better in all experiments except when the contact herbicide propanil was applied to green foxtail. The slightly better performance of the 80015 in the propanil experiment could be ascribed to the lower CV or possibly the larger droplet size produced. Douglas (1969) and Ayres and Merritt (1977) showed that contact herbicides perform better when applied as large droplets. But the better performance of the TK 0.75 in the diclofop methyl and metribuzin experiments might not be expected solely on the basis of differences in CV since the CV of the TK 0.75 is 28% which is higher than that of the 80015 (20%). Therefore, in these cases pattern uniformity must play a less prominent role and droplet size must be the major factor.

The Floodjet TK 0.75 performed better than the larger Floodjet TK 1.5. In the cabinet sprayer, with the TK 0.75 the overlapping pattern used in the field was simulated by making two passes with the nozzle over the plants. With each pass the plants were positioned directly under the middle of the pattern. The TK 0.75 spray produces a VMD of 300 μm whereas the TK 1.5 produces a VMD of 400 μm. The results of the nozzle efficacy experiments show that in all cases except where the contact herbicide propanil was applied to green foxtail application with the TK 0.75 resulted in larger dry weight reductions than the TK 1.5. As mentioned previously when comparing the performance of the TK 0.75 to the standard 80015, this exception may be explained by the findings of Douglas (1969) and Ayres and Merritt (1974) who report that contact herbicides tend to perform better when applied in larger droplet sizes. In contrast, the better performance of the TK 0.75 with the translocated herbicides, diclofop methyl and metribuzin supports the findings of Behrens (1957), Ennis and Williamson (1963) and McKinlay et al. (1972) who report that translocated herbicides perform better when applied in small droplets.

Referring to the retention data (Tables 21 and 22) application with the TK 0.75 did result in higher retention values than application with the TK 1.5 with both wild oats and green foxtail. From these results, one might expect that wild control would be better with the TK 0.75 since more herbicide is available for activity. As mentioned previously this did occur with diclofop methyl and metribuzin but not propanil. The enhanced activity of propanil due to the larger droplet sizes produced by the TK 1.5 must have been high enough to compensate for the differences in retention.

Application with the RA-2 in the growth room experiments consistently resulted in low levels of weed control in all experiments. The reported VMD of this nozzle is 330 μm; however, droplets in the range of 500 μm to 1000 μm can be observed in the spray. The reported CV of Raindrop nozzles is approximately 50% which is higher than all other nozzles. The combination of high CV and large droplet size would explain, in part, the poor performance of this nozzle. However, this is somewhat comfounded by the results of the retention study which show that the RA-2 treatment only resulted in relatively low levels of retention in the second trial when green foxtail plants were sprayed (Table 21). Possibly due to the placement of plants in the spray cabinet the effect of the high CV is minimized. From the observations of Brunskill (1956) and Johnstone (1973) retention would be expected to be reduced since large droplets tend to bounce and run off the leaf surface more readily than small droplets. The possible reasons for this anamoly will be discussed further in the next section.

Retention Study

Green foxtail and wild oat leaves were chosen for these experiments since they both have low leaf wettabilities. With low wettabilities it is probable that retention differences between nozzles would be more readily observed.

Green foxtail leaves retained much more solution than wild oat leaves. Retention ratios (Tables 21 and 22) were also higher in the green foxtail experiment except on one occasion where the retention ratio of the RA-2 in the second green foxtail trial was lower than in both wild oat trials. From the wettabilities of green foxtail and wild oat leaves as dictated by contact angle measurements (Table 23), one would expect that retention/gram dry weight and /cm^2 and the retention ratios would be similar for the two species. The reason why they are not similar has to do with the leaf orientation of the plants at the time of treatment. All three leaves of the green foxtail plants were positioned horizontally while the leaves of the two-leaf stage wild oat plants were positioned vertically. The vertical position of the wild oat leaves would, in effect, reduce the projected leaf area and the amount of spray actually hitting the leaf would be smaller than if the leaf was horizontal. The wild oat leaf angles were approximately 70-80 degrees from the horizontal and as reported by Hibbitt (1969) and Lake (1977), retention decreases as wild oat leaf angle increases from the horizontal. Hibbitt (1969) attributed this to increased droplet bounce and run-off.

The remainder of the discussion on retention differences between treatments will center on the adjusted retention volumes unless otherwise indicated. These values depict a more realistic view of what the differences in retention between treatments are, since the values represent the amount retained as if the treatments were applied in equal volumes of 110 L/ha. The retention ratios in Tables 21 and 22 which are closely related to the adjusted values were included in the tables to give a clearer picture of retention relationships between the treatments.

In both green foxtail trials, based on amount of solution retained/ g dry weight and /cm^2 the TK 0.75 nozzle resulted in the highest levels of retention. In the first trial the lowest levels of retention resulted from application with the 80015LP at 150 kPa while the nozzles used to apply treatments 2, 3, 5 and 7 resulted in similar retention values. In the second trial similar retention values occurred with the nozzles used to apply treatments 2, 3, 5 and 7. As in the first trial application with the 80015LP at 150 kPa resulted in the lowest amounts of solution retained.

In both trials retention of the spray solution on wild oat plants was highest after application with the RA-2 tip. The 80015LP at 150 kPa consistently resulted in the lowest retention values. In the first trial application with the TK 0.75 resulted in higher retention values than all nozzles except the RA-2 while in the second trial it performed similarly to the nozzles in treatments 2 and 3 and better than the nozzles in treatments 4 and 5. In the first trial the 80015 and TK 1.5 performed better than the 80015LP at 275 kPa, while in the second trial all three nozzles performed similarly.

Reimpa (1960) showed that the ratio between volumes retained and applied decreases with an increase in the droplet median diameter. Brunskill (1956), Furmidge (1962b), Johnstone (1973) and Lake (1977) showed that retention of a spray solution was highest when the spray was applied in small droplets. From these results one would expect that the nozzles in this experiment with the smallest droplet size would have the highest retention values.

The TK 0.75 nozzle resulted in the highest retention values in the green foxtail experiment and second highest in the wild oat experiment.

The good performance of this nozzle can be attributed to droplet size since it produces the smallest VMD of all nozzles tested. The other flooding tip, the TK 1.5, produces a similar pattern to the TK 0.75 but has a higher VMD (Table 1). This is reflected in the lower retention values compared to the TK 0.75.

Both the 80015 and TK 1.5 produce similar VMD's being 370 μm and 400 μm, respectively. With green foxtail, adjusted retention values and retention ratios were similar for both tips, but with wild oats somewhat higher levels of retention occurred with the 80015, These results would indicate that the high angles of the wild oat leaves had a greater effect in decreasing levels of retention with the TK 1.5 nozzle. This result could possibly be attributed to the difference in droplet size between these nozzles, although the difference is small.

Lake and Taylor (1974) showed that as the spray volume increased, larger amounts of solution were retained with smaller droplets compared to larger droplets. Evidence of this type of result can be seen in a comparison of the 80015LP applied at 275 kPa and 150 kPa. This nozzle at both pressures delivered the highest volumes of solution (Table 6). Measurements of actual amounts of solution retained with wild oats and green foxtail (Tables 21 and 22) showed that the 80015LP at 275 kPa resulted in the highest retention values, as would be expected, but with the 80015LP at 150 kPa the amount of solution retained was similar to the other treatments which were sprayed at considerably lower volumes (Table 6). The low levels of retention with the 80015LP at 150 kPa are reflected in low adjusted values and retention ratios. The poor retention values of the 80015LP at 150 kPa which has a VMD of 410 μm compared to the 80015LP at 275 kPa which has a VMD of 375 μm is most likely attributable to the difference in VMD's between the nozzles.

The RA-2 nozzle resulted in retention values similar to all others except the TK 0.75 in the green foxtail experiment, and in the wild oat experiment had the highest retention values. These results would not be expected since this nozzle produces large droplets. Since the droplets of the RA-2 are large, one droplet being retained on the leaf surface in one particular area would have the same effect of a number of small droplets being retained over a larger area of the leaf. Upon observation of the plants after spraying with the dye solution, application with the RA-2 resulted in spray deposits occurring sporadically over the leaf surface. With the other nozzles the spray solution was spread evenly over the whole surface. The retention experiments show that the application with the RA-2 did result in high retention values compared to other treatments but do not relay the fact that spray distribution was sporadic. The effect of uneven spray solution with the RA-2 is reflected in the poor weed control results which occurred when chemicals were applied with the RA-2 nozzle. The RA-2 nozzle producing the highest retention values on wild oats could possibly have to do with the way the spray is delivered from the nozzle. The spray leaves the orifice of the RA-2 in a wide cone shaped pattern. This means that the droplets are moving outward in all directions. A certain percentage of the droplets are moving horizontally while falling. Droplets moving in this fashion would have a better chance of contacting the vertical leaf surface of the wild oats than droplets dropping with little horizontal movement. With the other nozzles the spray moves mainly in a downward direction, therefore, having less chance of hitting the vertical leaves. This may explain why application with the RA-2 resulted in high retention values in wild oats, a situation which would be analogous to the improved spray coverage obtained when conventional nozzles are directed 45 degrees forward to improve the activity of numerous wild oat herbicides by increasing the amount deposited on the leaf blades and sheaths.

Where a large number of droplets hit the wild oat leaves it was observed that some must have rolled down the leaf into the leaf axil and accumulated. Applying a wild oat herbicide with the RA-2 nozzle to two-leaf stage wild oat plants may result in good levels of control since Coupland et al. (1978) showed that the accumulation of the herbicide in the leaf axil may result in increased herbicide efficacy.

Water Droplet Contact Angle Measurements

Contact angles were measured on plants grown both indoors in the growth chamber and outdoors in the field to see if differences in wettability occurred due to environment. With wild oats, large differences between plants grown in the growth room and outside only occurred with the first and second leaves. From this you would expect that wild oat plants at the 2 1/2-leaf stage would be more easily wettable when grown outside. With green foxtail plants differences in contact angles between plants grown outside and in the growth room differed an average of only 2 degrees, therefore, wettabilities would be similar. With all leaves of wild buckwheat, contact angles of plants grown outside were about 19 degrees higher than of plants grown in the growth room. Therefore, plants grown indoors are much more wettable.

Wild oat and green foxtail plants established similar contact angles, therefore these plants should have similar wettability. In the retention studies discussed previously retention was different because of the positioning of the leaves. But if both wild oat and green foxtail leaves were positioned horizontally you would expect retention values of the two species to be similar. Wild buckwheat leaves are considerably more wettable than both wild oat and green foxtail leaves. Wild buckwheat leaves might be expected to have much higher retention ratios than both wild oat and green foxtail leaves but these were not measured.

Since the contact angles of wild buckwheat leaves are below 90 degrees, surface wax is not considered a prominent feature in governing wettability (Holloway 1970). Wild oat and green foxtail leaves exhibit contact angles of greater than 110 degrees which implies that surface wax as well as surface roughness are prominent features governing wettability (Challen 1960, 1962; Fernandes 1965; Holloway 1970). The rough surface of wild oat and green foxtail leaves caused by the parallel veination and wax deposition, therefore play an important part in the high contact angles which were measured.

Holloway (1969b) recorded similar observations between contact angles of broadleaf and grass plants. For example, on leaves of *Hordeum vulgare* contact angles of 165 degrees were measured while on leaves of *Polygonum persicaria* smaller angles of 82 degrees were recorded.

These studies basically show that as expected wettability characteristics do differ between plant species. These wettability characteristics would probably have only minimal effects on retention of herbicidal sprays due to the addition of surfactants and wetting agents. Attempts were made to measure contact angles of a drop of water mixed with a commercial diclofop solution. With all three species used in this experiment, the droplet once placed on the leaf quickly flattened and spread over the leaf surface.

SUMMARY AND CONCLUSIONS

In the field experiments the effects of nozzle type on the efficacy of propanil, diclofop methyl, difenzoquat, bromoxynil and metribuzin were similar. The differences in performance between the nozzles can be attributed largely to differences in spray pattern uniformity. As a rule, the nozzles which produced the most uniform spray pattern resulted in the highest levels of weed control.

Differences in levels of weed control resulting from the different nozzle tips generally were not reflected in differences in crop yields in either 1979 or 1980. This was especially evident in 1980 where weed populations were extremely low.

When timing of application had an effect on level of weed control, the highest levels of control occurred when treatments were applied at the most optimal leaf stage of the weeds, except on three occasions. As explained previously in the Discussion, on each of these occasions weather conditions may have exerted an overriding effect on herbicide activity. Where timing of application had an effect on crop yield, the early applications resulted in the highest yields. This was attributed to an early removal of weed competition from the plots.

As happened in the field trials the standard flat fan 80015, 80015LP at 275 kPa and TK 0.75 nozzles performed the best in the laboratory nozzle efficacy experiments. In comparison to the field results, the 80015LP at 150 kPa performed relatively poorer and the flooding TK 1.5 performed relatively better. As in the field experiments, the RA-2 tip generally resulted in the poorest level of weed control. Due to the method of herbicide application in the cabinet sprayer, the effect of different spray pattern uniformities between the nozzles was minimized. The differences in levels of weed control between the treatments were therefore largely attributed to differences in droplet size. Generally, application with the nozzles which produced the smallest droplet sizes resulted in the highest levels of weed control.

The results of the retention studies carried out on wild oats and green foxtail contributed to a better understanding of the reasons why certain nozzles performed better than others. For example, application of the dye solution with the 80015LP at 150 kPa resulted in the smallest amount of solution being retained. Correspondingly, in the nozzle efficacy experiments carried out in the laboratory, dry weight reductions were the least with the 80015LP at 150 kPa. The retention studies confirmed that droplet size does have an effect upon spray retention. Generally, retention was highest with the nozzles producing the smallest droplets. The effect of droplet size on retention is especially evident at high volumes, as seen in a comparison of the 80015LP applied at 275 kPa and 150 kPa. Both nozzles produced high volumes of output but due to the larger droplet sizes produced by the 80015LP at 150 kPa compared to the same nozzle at 275 kPa retention of the spray solution at the lower pressure on both wild oats and green foxtail was considerably lower.

The contact angle studies showed that the wettability of green foxtail and wild oat leaves is considerably less than of wild buckwheat leaves. The high contact angles recorded on the wild oat and green foxtail leaves were a result of the combined effect of surface wax and leaf roughness (Challen 1960, 1962; Fernandes 1965; Holloway 1970). The smooth surface of wild buckwheat leaves, combined with a negligible effect of surface wax, resulted in the low contact angles (Holloway 1970).

As mentioned previously, the recorded differences in wettability would not have much effect on herbicidal activity in the field due to the additional wetting agents and surfactants included in commercial formulations. The only possibility where differences in wettability would have an effect would be in situations where plant leaves are orientated differently. Examples of this were reported by Hibbitt (1969) and Sharma et al. (1978). They found that more effective control of wild oats without injury to flax could be achieved by herbicide application at a later leaf stage of the wild oats. At a later leaf stage the more wettable wild oat leaves are positioned horizontally, exposing more area for herbicide contact; while the water repellant flax leaves tend to hang down allowing for greater droplet bounce and run-off. The significance of leaf orientation, was illustrated in the retention studies with wild oats, where retention values were low due to the vertical positioning of the leaves.

These studies show that spray pattern uniformity is the major factor influencing herbicide efficacy in the field. Due to the differences in uniformity the effect of droplet size was hard to distinguish. Herbicide application in the laboratory tended to minimize differences in pattern uniformity due to the application method, therefore the differences in performance between nozzles under laboratory conditions can be attributed mostly to differences in droplet size. The retention studies provided an understanding why certain treatments performed better than others. This was especially illustrated in the cases of the 80015LP at 150 kPa and the RA-2 nozzles.

From the results of these studies, the following recommendations could be made. If a farmer intends to use a flat fan nozzle, he would be well advised to use the conventional flat fan. If a flat fan LP nozzle was used the best performance would result if it was used at a higher pressure than normally recommended. When using flooding type nozzles, they should be spaced so that the patterns overlap to improve pattern uniformity. Postemergence applications with the RA-2 nozzle would not be advisable. It should be pointed out that the above recommendations are based on results where applications were made under ideal wind conditions. Under windy conditions it would be advisable to use a flooding nozzle with the overlapping pattern since Schafer and Stobbe (1972) showed a lower boom height resulted in less herbicide drift.

The above recommendations are based on observations of weed control. The results of field applications with the various nozzle tips show that in many cases yield increases would not be expected if the recommended nozzle treatments were used. However, the extra measure of control attained by using these nozzles would result in less weeds producing fewer seeds, and over a number of years could result in lower weed populations. With lower weed populations yields may increase and the amount of herbicide needed for control may be less.

Recommendations for Future Research

Future investigations into the effects of application techniques on herbicide efficacy probably should focus on CDA (Controlled Droplet Application). With a CDA system, droplet size distribution can be closely regulated. Numerous studies have been carried out with CDA units (O'Keeffe *et al*. 1976; Cussans and Taylor 1976; Wilson 1976; Grier and Reed 1980). Generally, the results show that in most instances application of herbicides with the CDA system is equally effective as application with conventional hydraulic nozzles. The major problems associated with the CDA applicators are pattern uneveness (Lake _et al._ 1976), design of the system and conversion of conventional ground sprayers to accept the units (Grier and Reed 1980). Once these problem areas are solved and a greater understanding of how droplet size affects performance of various herbicides in the field is achieved, CDA application may provide an acceptable alternative to herbicide application and undoubtedly will be the subject of intensive research in the next decade.

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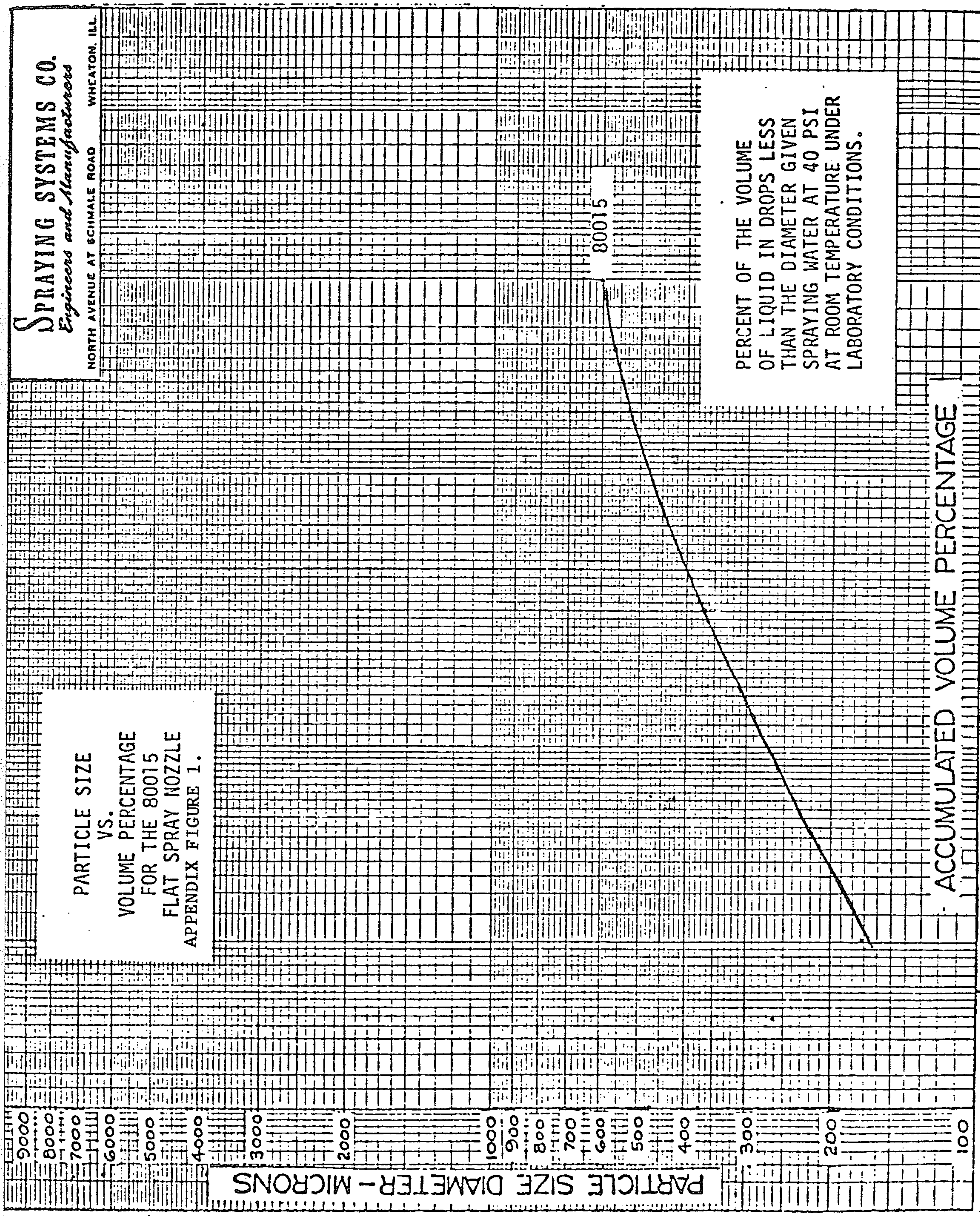
APPENDIX

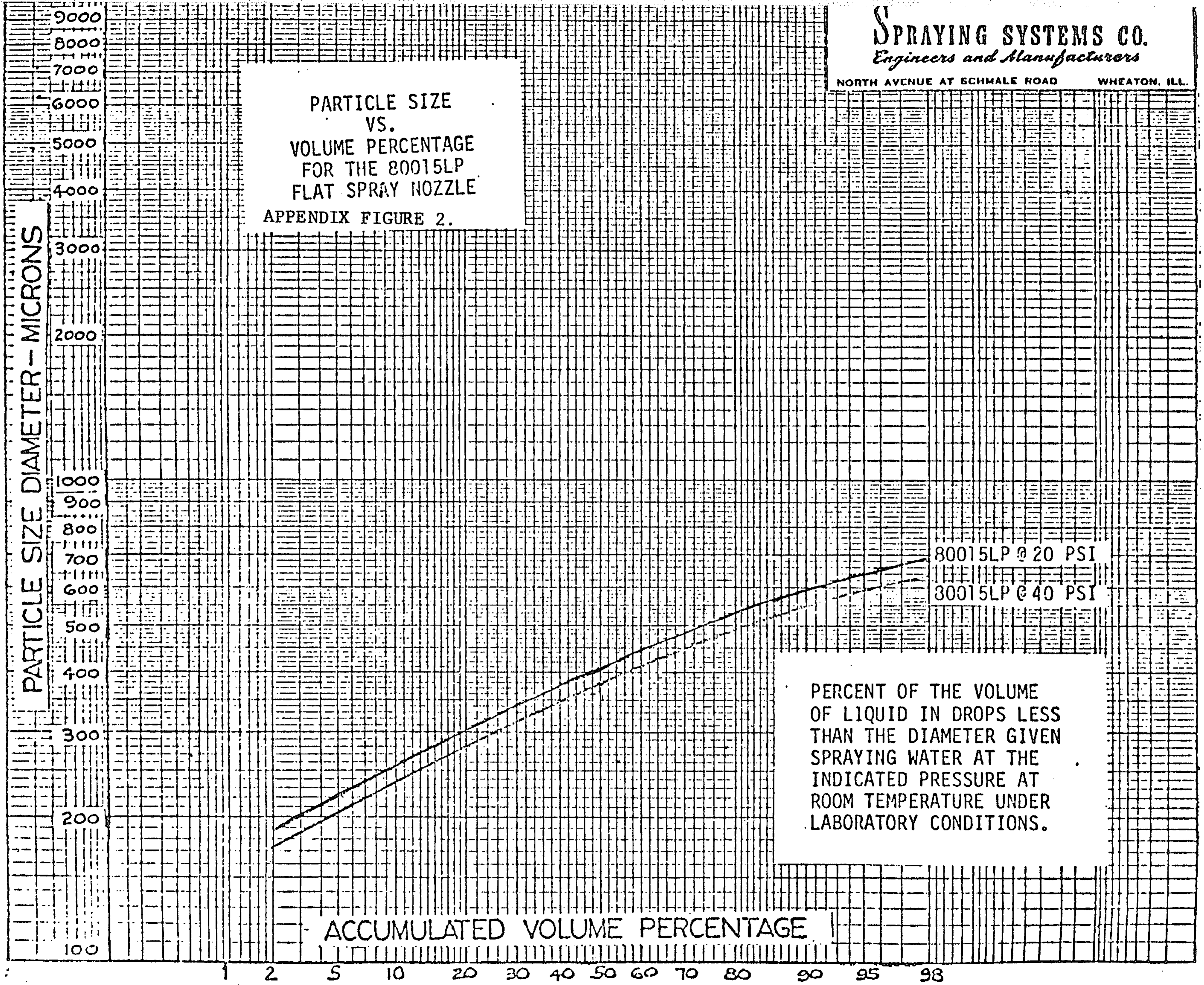
APPENDIX TABLE 1. 1979 Weather data.

Date	May			June			July			August			September		
	Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C	
	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.
1		12.0	- 1.5		17.0	3.0		27.0	12.0		30.0	10.5		23.0	15.0
2		6.0	- 2.0		22.5	5.0		26.5	14.0		26.0	15.0		16.0	12.0
3		5.5	- 4.5		26.0	8.0	2.8	26.5	14.5		24.0	10.0	0.8	21.0	11.0
4		5.0	- 5.0	7.6	19.0	7.0		30.5	7.5		22.0	10.0		22.5	12.0
5		6.5	- 4.5		25.0	6.0		29.0	9.5		22.0	8.0		25.0	
6		6.0	- 4.0	1.8	25.0	7.0		29.0	11.0	26.4	27.0	10.5		15.5	6.0
7		7.0	0.0		16.0	5.0		24.0	10.5		27.0	13.5		18.0	2.5
8		6.0	- 1.5		20.0	4.5		33.0	12.0		25.0	8.0		25.0	3.0
9		6.5	- 3.0		22.0	6.0		32.0	14.0		24.5	9.0		19.5	6.0
10		6.0	- 2.5		23.0	7.0		33.0	15.0		22.0	11.0		16.0	8.0
11		6.0	- 3.5	6.6	26.0	4.0		33.0	14.5		26.0	7.0		20.0	9.0
12		16.0	- 3.0		30.0	6.0		32.0	17.0	0.2	24.0	9.0		15.0	8.0
13		13.5	- 2.0		38.0	10.5	1.0	28.5	15.0	trace	15.5	6.5		14.0	5.0
14		14.0	0.0	0.2	29.0	13.0		25.0	12.0		19.0	4.5		22.5	0.0
15		18.5	- 3.0		24.5	7.0		21.5	12.5		23.0	2.0		26.5	2.5
16		29.0	- 1.0		25.0	5.0	2.5	25.5	10.0		25.0	3.5		35.0	8.5
17		20.0	5.0		26.5	3.0		29.5	11.0		29.0	9.0		23.5	16.0
18		11.0	2.5		28.0	5.0		32.0	15.0		30.0	11.5		16.0	7.0
19		10.0	- 3.0		22.0	7.0		30.5	16.0		30.0	12.0		26.0	6.0
20		5.5	- 1.5	33.0	17.0	11.0		34.0	16.0		30.0	10.5		16.5	6.0
21		20.0	2.5	12.7	12.0	7.5		29.0	17.0		22.0	11.0		20.0	1.5
22		19.5	4.0		19.0	6.0		31.5	13.0		23.0	12.5		15.0	7.5
23		16.0	3.0		23.0	4.5	15.2	27.5	15.0	trace	17.0	11.0	12.7	18.5	3.0
24		26.0	2.0		27.5	5.0	1.3	27.0	12.5	2.8	25.0	16.0		20.0	4.0
25	10.2	24.0	3.5		24.0	4.0	10.9	24.0	13.0		23.0	6.0		22.5	8.0
26		26.0	10.0		26.0	11.0		24.0	10.0		24.5	7.0	3.0	23.5	5.0
27		23.5	5.0		29.0	9.0		27.0	11.5		28.0	6.0		15.5	6.0
28		29.0	6.0	4.8	27.5	10.5		29.5	14.0	0.2	29.5	7.0		14.0	5.0
29	4.8	19.0	9.0		30.0	14.0		26.0	12.0	0.2	21.0	11.5		17.5	5.0
30	5.6	11.0	6.0		29.5	12.0		22.0	15.0		25.0	4.0		20.5	1.5
31		16.0	3.0					26.0	9.0	5.1	25.0	5.0			
	20.6	14.3	0.5	66.7	24.4	7.1	33.7	28.2	12.9	34.9	24.7	8.7	16.5	20.1	6.6

APPENDIX TABLE 2. 1980 Weather data.

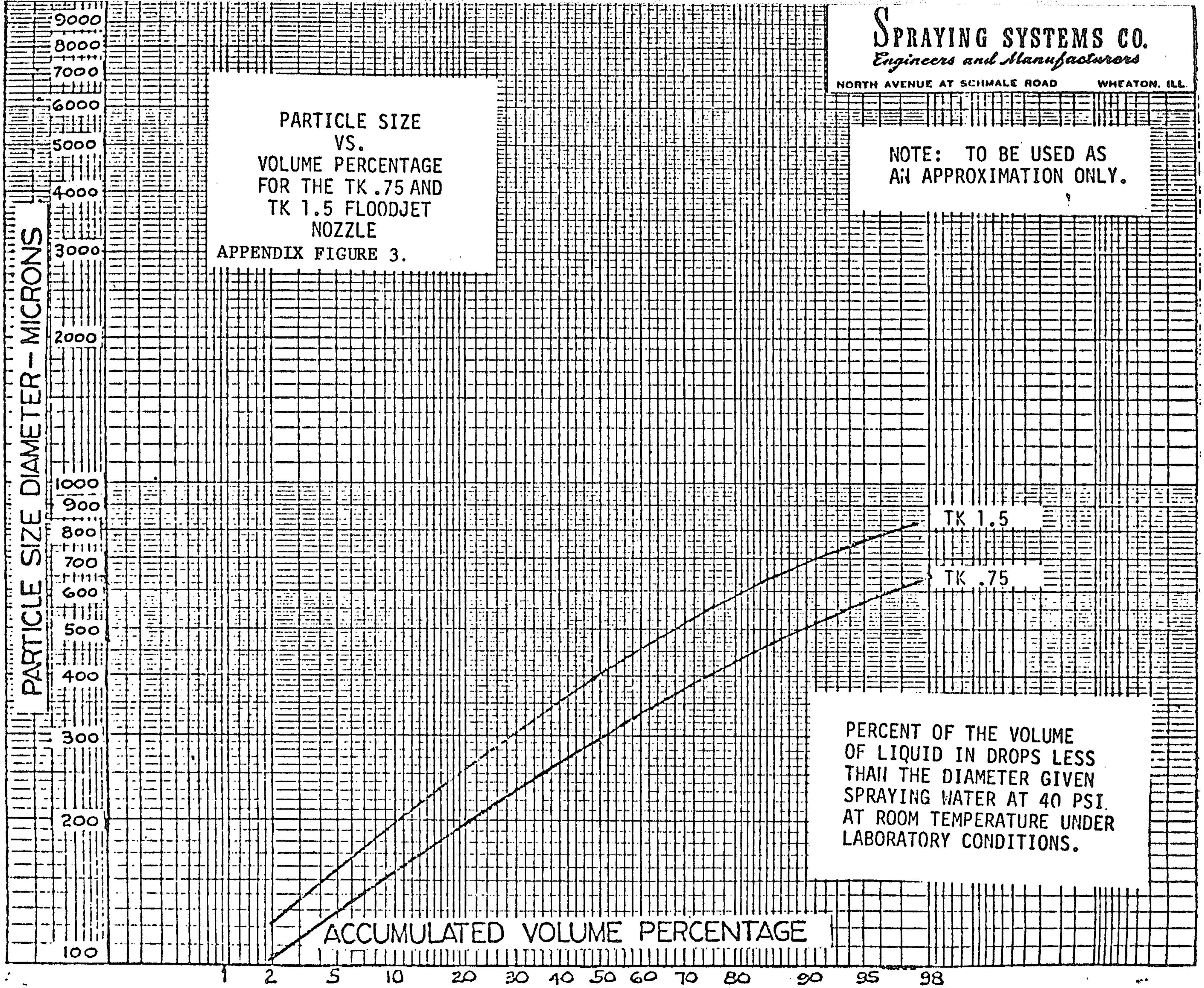
Date	May			June			July			August			September		
	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.
1		29.5	3.0		17.5	6.0		23.0	8.0		28.0	14.0		21.2	7.2
2		30.5	5.0		20.5	1.0		31.0	11.0		25.2	8.5	0.25	24.5	6.0
3		33.0	8.0		25.0	3.0		30.0	12.0	16.7	25.0	7.0	1.22	26.5	14.5
4		27.0	9.0	3.0	28.2	6.2	1.0	20.0	13.0	3.5	20.2	9.8	0.12	21.0	11.5
5		22.0	7.0		27.8	14.5		27.0	9.0	3.2	23.5	12.0		25.0	8.0
6		9.5	- 1.0		23.0	11.0		29.2	11.2		24.5	10.0		32.0	6.0
7		10.0	- 0.5		18.0	5.0	4.7	26.0	15.0		25.4	12.5	3.00	36.0	8.0
8		17.0	- 3.0		24.8	6.0		29.0	20.0		23.2	12.0	3.50	23.0	15.4
9		19.0	- 2.5		27.8	8.5		34.0	13.4		22.5	8.2		20.5	7.5
10		10.5	- 0.5		29.4	6.0		33.2	17.6	3.0	22.8	10.4		27.4	7.5
11		14.5	1.0		36.0	6.0	5.0	30.8	18.0	0.5	24.0	9.0		22.4	4.5
12		10.0	4.0	0.7	26.0	14.5		30.2	16.0		26.5	10.2	7.00	13.8	6.2
13		11.0	- 1.5	1.0	27.0	12.0	6.0	36.0	16.2	0.5	24.5	13.5		19.5	5.8
14		17.0	- 1.5		22.0	9.0	2.2	25.5	17.0		26.0	11.0		20.5	2.0
15		23.0	- 5.0		23.0	3.0		26.0	14.6		26.4	8.2		18.0	5.2
16		27.4	0.0		27.0	3.5	8.5	26.2	16.0		16.5	8.8	2.50	13.0	4.0
17		27.0	4.2	0.7	22.0	7.0	0.7	26.5	14.0		30.5	11.5	8.00	6.0	3.0
18		27.0	8.5		22.2	8.0		26.0	13.5	9.7	27.2	8.2	8.00	11.5	-2.0
19		34.0	8.0		25.0	4.5		23.0	11.0		31.2	9.0	7.00	7.0	-2.0
20		33.5	11.2		29.0	8.0		23.0	11.2	6.7	22.2	16.0		13.4	2.0
21		37.2	14.5		30.2	12.5	2.5	22.5	13.5	6.0	22.4	15.0	16.00	14.5	4.5
22		39.5	15.0		36.0	13.0		28.5	11.5		22.5	9.4		10.5	5.0
23		36.0	20.0	1.0	26.2	14.8		33.0	12.8		24.0	10.0	3.0	8.2	1.0
24		34.4	13.0		30.5	15.0		28.0	14.0		31.0	10.0		10.0	4.0
25	5.0	34.5	11.5		26.0	2.4		23.4	7.0		20.0	12.4		8.5	3.0
26		33.0	14.0		19.0	8.0		28.0	8.2		20.0	5.0			
27	0.2	33.0	14.4	1.0	19.0	8.5		28.5	10.0		22.5	2.0			
28	2.0	29.8	14.6	0.7	18.8	10.0		28.6	13.0	1.2	22.5	2.5			
29		26.0	14.5	11.0	24.2	10.4		32.5	10.0	3.2	21.0	11.0			
30		21.0	6.0	44.0	28.0	12.0		29.0	13.0		22.0	9.0			
31	1.5	22.0	5.0				1.0	28.8	14.5		21.0	5.0			
	8.7	25.1	6.3	63.1	25.3	8.3	31.6	27.9		51.2	24.0	9.7	59.6	18.1	5.5


SPRAYING SYSTEMS CO.
Engineers and Manufacturers
NORTH AVENUE AT SCHMALE ROAD WHEATON, ILL.
PARTICLE SIZE
VS.
VOLUME PERCENTAGE
FOR THE 80015
FLAT SPRAY NOZZLE
APPENDIX FIGURE 1.
PERCENT OF THE VOLUME
OF LIQUID IN DROPS LESS
THAN THE DIAMETER GIVEN
SPRAYING WATER AT 40 PSI
AT ROOM TEMPERATURE UNDER
LABORATORY CONDITIONS.
80015
ACCUMULATED VOLUME PERCENTAGE
1 2 5 10 20 30 40 50 60 70 80 90 95 98
PARTICLE SIZE DIAMETER-MICRONS
100 200 300 400 500 600 700 800 900 1000 2000 3000 4000 5000 6000 7000 8000 9000



PARTICLE SIZE
VS.
VOLUME PERCENTAGE
FOR THE 80015LP
FLAT SPRAY NOZZLE

APPENDIX FIGURE 2.



PARTICLE SIZE
VS.
VOLUME PERCENTAGE
FOR THE TK .75 AND
TK 1.5 FLOODJET
NOZZLE

APPENDIX FIGURE 3.