DESIGN AND EVALUATION OF A TWO-FLUID SUBSURFACE JET INJECTOR

BY

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TWO-FLUID SUBSURFACE

JET INJECTOR

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TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The use of agricultural chemicals has become a key link in modern agricultural production. The performance of many agricultural chemicals, especially herbicides, can be remarkably altered by their distribution in soil and depth of the incorporation. Therefore, for effective results, many pesticides should be evenly incorporated in the soil. There are many kinds of agricultural implements used for incorporation. However, most implements currently being used to incorporate pesticides were designed primarily for tillage and later adapted for incorporation of pesticides applied prior to incorporation.

The use of tillage implements for pesticide incorporation has disadvantages. These include incorporating the plant residue into the soil and increasing trips across over field. This will result in increased soil loss from water and wind erosion and a loss of soil moisture. Another is the potential drift of pesticide sprays during application. The drift problem typically involves the movement of only minute quantities of pesticides out of the treatment area, however some could present a serious hazard to people, livestock, wildlife or agricultural crops. New equipment, therefore, needs to be designed especially for soil incorporation of chemicals.

The subsurface jet injector (Solie et al., 1983) is such a new piece of equipment. It was constructed to incorporate herbicides by jetting them up into soil passing over the blades of a sweep plow. Water was used as the herbicide carrier. Herbicide solution jets penetrated up into the soil, through nozzles mounted on the top of a manifold attached behind the sweep blade support, distributing herbicide in the soil layer to control weeds. Meanwhile, most of the crop residues remained on the soil surface to protect the soil from erosion and to conserve soil moisture. Using such a subsurface jet injector could eliminate the drift problem, and make it possible to apply agricultural chemicals at any suitable time regardless of the wind conditions. Problems associated with the machine were high carrier volume requirements and inadequate penetration of herbicides for weed control. The machine needed modifications to overcome these problems.

Objectives

The objectives of this research are:

1. To design the distribution system of the subsurface jet injector using two-fluid atomization and air jets for penetration.
2. Evaluate and compare the weed control using the two-fluid subsurface jet injector versus an "S"

tine field cultivator.

3. Evaluate the uniformity of the distribution of herbicides applied by the two-fluid subsurface jet injector.

CHAPTER II

LITERATURE REVIEW

Subsurface Injection of Herbicide

Certain pesticides must be incorporated into the soil to be effective. Depth and uniformity of incorporation are extremely important both from the standpoint of weed control and crop injury. There are many ways to mix or inject herbicides into soil. Subsurface herbicide injectors were introduced to apply a uniform band of herbicide beneath the soil surface. The devices can be categorized under two general headings: injection in a layer and injection in a line. The first subsurface application of herbicides was in a layer (Figure 1). Wooten and McWhorter (1961) mounted

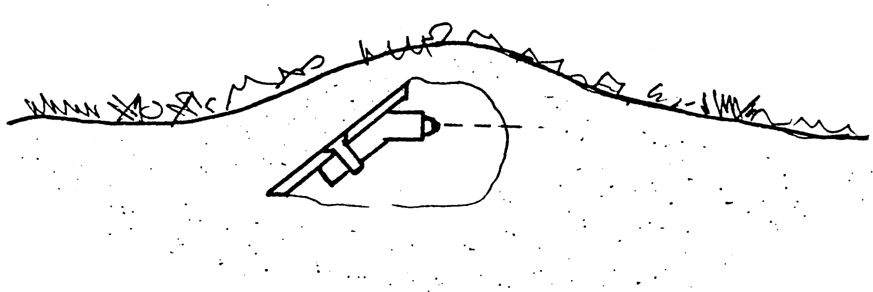

Figure 1. Injection Herbicide in a Layer

agricultural spray nozzles behind or under blades to spray herbicides in a layer into cavities formed by the sweeps. When operated within 5 cm of the surface, these sweeps could control weeds nearly as well as double tandem disk mixing.

Development of an injector planter for planting on beds and precisely placing herbicides was reported by Davis et al. (1975). Satisfactory weed control was achieved by placing a layer of either trifluralin (α,α,α-trifluro-2,6-dinitro-N,N-dipropyl-p-toluidine), fluometuron (1,1-dimethyl-3-(α,α,α-trifluoro-m-tolyl)urea) or both herbicides at a depth of approximately 1.9 cm. However, the injected layer of trifluralin caused some early cotton stunting.

Garner and Davis (1978) combined a sweep with a planting unit to accurately control sweep operating depth. Work by Collier et al. (1978) showed that placement of crop seed in the herbicides layer increased crop injury. Garner (1978) also indicated that crop injury was greater when cold, wet conditions followed planting.

Injection in parallel lines is another way to incorporate herbicides into soil. Hauser et al. (1966) injected herbicides through nozzles mounted behind knives. Rolling coulters cut residue ahead of the knives. Physical limitations of this equipment prevented application in lines less than 7.5 cm apart. Only the more volatile herbicides (i.e., thiocarbamates) controlled weeds when applied with this equipment.

Attempts have been made to inject herbicides into undisturbed soil with high pressure jets. Fenster (1962) reported injecting trifluralin into soil in parallel lines spaced 5 cm apart at 1400 kPa. Penetration ranged from 1 to 2 cm. Spacing was too wide for adequate weed control.

Solie et al. (1981) designed and field tested a subsurface jet injection sweep which used water as the herbicide carrier (Figure 2). Jet spacings of 2 to 4 cm

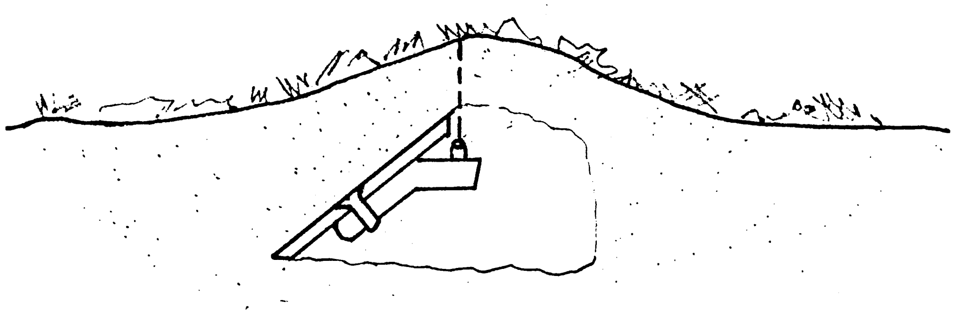

Figure 2. Subsurface jet Injection of Herbicide

were tested. It was found that the closest jet spacing resulted in the best weed control. Although the subsurface herbicide injection treatments controlled weeds as well as the surface applied and double disk incorporated treatments, the problem with the approach was obtaining adequate penetration without using an excessively large volume of water.

In order to determine whether fluid jets can be successfully used to incorporate herbicides, jet penetration distance must be predictable and experiments conducted to determine if herbicides could control weeds when jetted into soil in parallel lines. A mathematical theory to predict penetration of armor plate by high speed metallic jets was developed by Evans and Pack (1951). Their theory also predicted that soil depth penetration would be directly proportional to the square root of the operating pressure. Based on their theory, Huang and Tayaputch (1973) successfully designed a fluid injection spot and furrow opener for transplanting tobacco [Nicotiana tabacum (L.)] seedlings. Solie and Wittmuss (1983) developed a theory to predict the penetration distance of fluid jets into disturbed soil in place and into soil passing over a blade. It was reported that penetration distance depended on jet length, active or passive soil failure, fluid and soil density, soil strength, and secondary penetration. Fluorescent tracer tests confirmed aspects of their theory. Their theory provided a foundation for designing the subsurface jet injector.

Evaluation of Soil-Chemical Incorporation

Matthews (1967) used a chloride tracer technique to evaluate herbicide incorporation tools. Sodium (or potassium) chloride was sprayed on the soil surface and incorporated by various tools. Soil samples were then obtained and analyzed for chloride. The analysis was accurate, simple to run in the laboratory and provided a quantitative evaluation throughout the incorporation profile. It was also reported that the samples might be dried and stored for analysis, whenever it was convenient.

James and Wilkins (1964) used a fluorescent dye as the tracer material and then took pictures of the tracer incorporated soil profiles at night (under ultraviolet light). Visual judgement on the distribution patterns of plotted diagrams or pictures gave a qualitative assessment of the incorporation pattern, and by that means, the mixing efficiency of various tillage patterns were studied.

Staniland (1961) conducted several studies using iron filings and fluorescent dye as tracer materials. Soil cores were taken and divided into sections representative of various depth. Recovered iron filing weights and the counts of dye particles (with aid of a binocular microscope and an ultraviolet lamp) were used as an indication of the amount of chemicals in the soil. The method was tedious.

Read et al. (1968) recovered tracer materials from sample extracts and analyzed them by fluorometry and gas chromatography. A quantitative assessment of the uniformity of incorporation was achieved. However, the extraction processes involved several steps and were very slow and time consuming; full recovery of tracer was not possible; analyzing equipment was expensive; and the number of samples were limited.

The use of radioisotope tracer by James and Wilkins (1964) provided a quantitative method for incorporation studies, but its use required specialized equipment and trained personnel, and the number of samples had to be limited.

Lal and Reed (1977) reported that a radioactive tracer and granules (0.2% uranine dye--sodium fluorescein) were used to study the mixing characteristics of various tillage implements. Incorporation of granules or liquid was carried out just after the application or simultaneously with the application. Soil samples were taken immediately after incorporation and then analyzed for both vertical and lateral distribution. Analyzing equipment was expensive and the rate of recovery for both granular and liquid was low.

Collier et al. (1981) introduced a fluorescent photography technique for a quantitative analysis of soil applied chemicals. They compared emitted light intensity from dye incorporated soil samples with that of calibration samples of known tracer dye concentrations. Separate calibration curves had to be established for different types of soil and for different moisture contents. Analysis of the matrix of the soil cross section resulted in a quantitative assessment of the quality of incorporation.

Salyani and Bowen (1983) reported on the use of a microcomputer aided digitizing technique for evaluation of soil amendment incorporation. The technique involved the preparation of fluorescent dyed sand particles to be used as tracer material. They developed equipment (1985, a) to take complete cross sections of soil profiles (19 mm thick, 787 mm wide, and 508 mm deep). They also developed a criterion (Salyani and Bowen, 1985, b) for evaluation of quality of dispersions. The equipment and the criterion in conjunction with each other provided an accurate and reliable means for a quantitative assessment of soil incorporated. The dyed sand, however, can not be used to measure the distribution of liquid penetration by a subsurface jet injector.

CHAPTER III

TWO-FLUID MANIFOLD SUBSURFACE JET INJECTOR

Introduction

When water was used as the herbicide carrier and injected through the distribution system of the subsurface jet injector, the jet injector was called a one-fluid jet injector. Problems with this approach included obtaining adequate penetration and the need for large volumes of water. For a two-fluid jet injector, air is employed as the herbicide carrier. The mechanism of atomization is the high-velocity air creating high frictional forces over liquid surface. This causes liquid disintegration into spray droplets (Masters, 1982). By that means, finer droplets of herbicides could be produced, and, potentially, more efficient weed control could be obtained with a much lower volume of liquid.

Two versions of jet injector were designed with two fluid atomization and air as the herbicide carrier. These jet injectors are the manifold jet injector and the venturi bundled tube jet injector. The manifold jet injection system was constructed with a single tapered manifold and a remotely located atomizer. The second version of the injector used a multitube distributor with a venturi atomizer connected directly to the tube bundle.

Two-fluid Atomization

Atomization, in which a compressible fluid such as air is employed to disintegrate a liquid jet, is termed two-fluid atomization (Marshall, 1954). A two-fluid atomization device utilizes the kinetic energy of a high-velocity air flow for atomization (Figure 3). Breakup of the liquid can

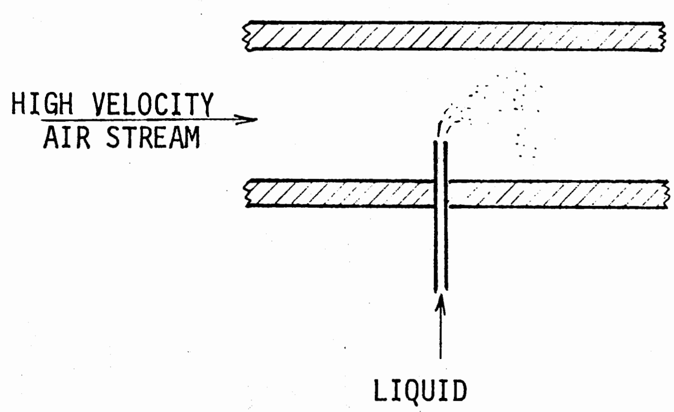

Figure 3. Two-fluid Atomization

be considered to occur in two phases (Masters, 1982). The first phase involves the tearing of the liquid into filaments and large droplets. The second phase completes the atomization by breaking these liquid forms into smaller and smaller droplets. The entire process is influenced by the magnitude of the liquid properties: surface tension, density, and viscosity; and the air flow properties of velocity and density. A high relative velocity between liquid and air must be generated so that the liquid is subjected to optimum frictional conditions. As the velocity of the air is increased over that of the liquid at the point of contact, more and more kinetic energy is available, thus finer and finer atomization results.

The principal effect of atomization is to produce a high-ratio of surface to mass in the liquid phase, resulting in very high evaporation rates. The two-fluid atomization systems can produce very fine sprays in which the diameter of a droplet can reach as small as 2 microns (Marshall, 1954). However, a large amount of energy is required per unit of surface area created.

When a liquid jet is disintegrated by air, the velocity of the air must be high relative to the liquid at the point where it encounters the liquid jet. Thus, the two-fluid atomizer generally discharges the atomized spray over a considerable distance before the momentum of the atomizing fluid becomes dissipated or transferred to surroundings. The spray from a two-fluid atomizer, therefore, has a tendency to penetrate a great distance. This is favorable for herbicide incorporation by subsurface jet injection.

Prediction of Jet Penetration Distance

To design the subsurface jet injector to incorporate herbicides or other chemicals into the soil, jet penetration distance must be predicted. The jet penetration distance can be predicted using the theory developed by Solie and Wittmuss (1983):

$$P = \frac{L}{\tan\theta}\left(\frac{\lambda \rho_j}{\rho_t}\right)^{1/2} R_p + S \qquad (1)$$

where P is penetration distance,

L is the jet length,

θ is the angle of the failure plane with respect to the vertical axis,

λ = 2 for fragment jets,

ρ_j = jet density,

ρ_t = target density,

R_p is defined as the reduction in penetration distance, and

S is the secondary penetration term.

Jet length L can be determined by

$$L = V_j * t \qquad (2)$$

where V_j is the jet velocity and t is the time the jet acts at any point. Jet velocity was calculated using Bernoulli's equation:

$$V_j = C_v\sqrt{\frac{2P_r}{\rho_j}} \quad (3)$$

where C_v is the velocity coefficient of the orifice and P_r is the pressure.

Jet velocity also can be calculated from the fluid flow rate:

$$V_j = C_c^2 * Q/A \quad (4)$$

where C_c is the coefficient of contraction of the nozzle orifice or tube outlet; Q is the measured fluid flow rate; and A is the inside area of the distribution tube or nozzle orifice.

Time a jet acts at a point is:

$$t = C_c * D_o/V_g \quad (5)$$

where C_c=1.0 assuming no contraction for the tube outlet; D_o is the tube inside diameter which was 1.65 mm; and V_g is the ground speed of the sweep.

The angle of the failure plane θ depends on soil type, particle size, particle distribution, and soil density. The value of θ equals $45^o - \Phi/2$ from the horizontal for active failure. The active failure occurred when fluid is jetted up into the soil passing over a sweep blade, such as the case in subsurface jet injector. Φ is defined as the angle of internal friction, which depends upon soil properties. Solie and Wittmuss (1983) reported that the angle of internal friction, ϕ, of an air dry Judson silt loam (3.6%

moisture content) with 0.92 g/cm^3 density was approximately 54^o. For active soil failure, $\theta = 18^o$.

Reduction in penetration distance R_p is a function of soil type, soil density, and soil moisture content. An equation to calculate R_p was developed for a Judson silt loam with soil moisture greater than 14.2 and less than 23.2 percent (Solie and Wittmuss, 1983). Since the equation was for a special soil type, and R_p remains to be determined for other types of soil, a value of 1.0 for R_p was used to design the two-fluid subsurface jet injector.

Solie and Wittmuss (1983) observed that the secondary penetration occurred as energy imparted by the jet to the face of the cut was dissipated after the jet ceases to act at that point. However, the secondary penetration was found relatively small compared to the total penetration distance and thus could be neglected.

To design a subsurface jet injector, jet penetration distance is specified, then the nozzle orifice size and the required fluid flow rate can be determined by using the jet penetration distance prediction theory (Solie and Wittmus, 1983). To predict the jet penetration distances, the fluid flow rate and the nozzle orifice are determined and the penetration distances calculated from the theory.

Manifold Jet Injector

The manifold jet injector was the first system designed and tested. The system consisted of jet injection manifolds mounted on five sweeps. The manifolds were constructed of 0.95 cm inside diameter copper tubing which was tapered and mounted to the trailing edge of a standard 60°, 50.8 cm sweep. Separate manifolds were attached to each wing of the sweeps (Figure 4). Twelve 2.29 mm diameter orifices, spaced

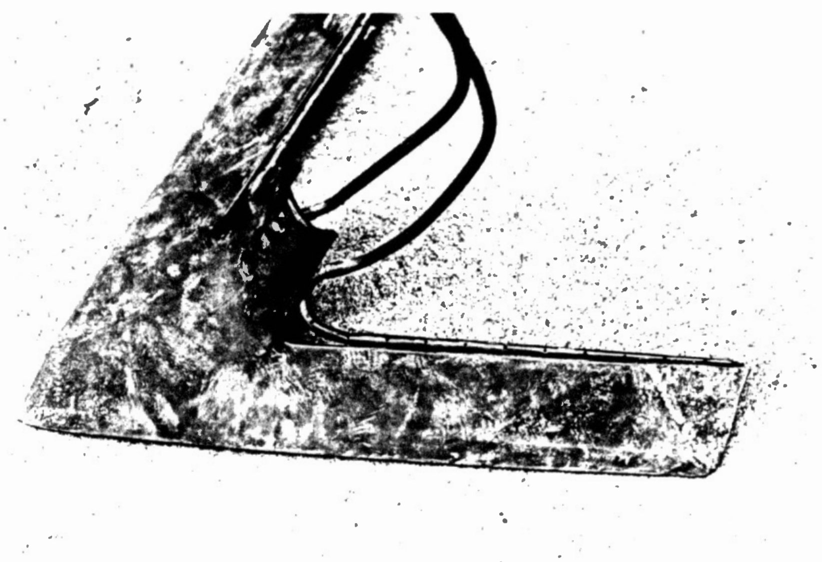

Figure 4. Sweep and Manifolds

3 cm apart along the tube, were drilled vertically on the top of each manifold (Figure 5).* This gave 1.5 cm

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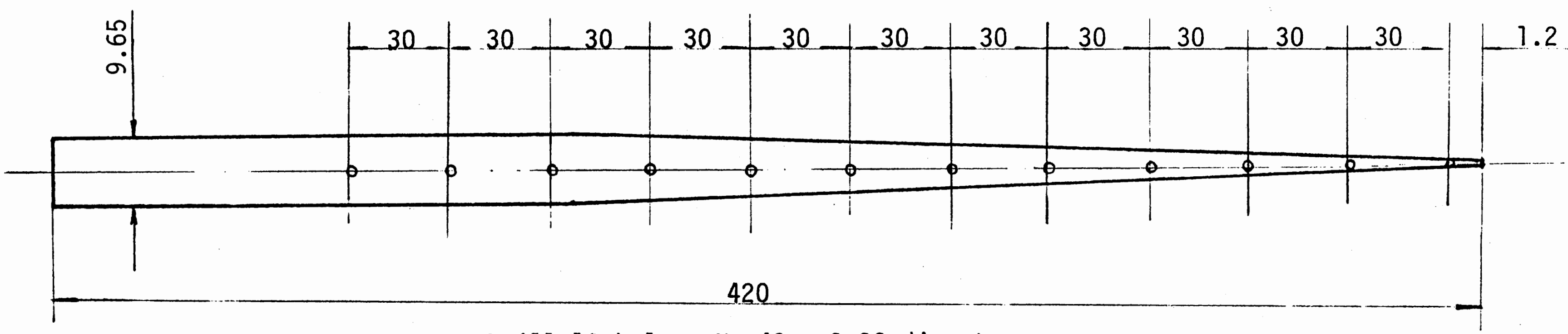
* The manifold was initially designed by Kelvin Self, research engineer, Department of Agricultural Engineering, Oklahoma state University.

NOTE: All dimensions in mm.



Drill 12 holes, No 43 - 2.29 diameter

Figure 5. Tapered Distribution Manifold for the Manifold Jet Injector

lateral spacing of the liquid jets, which was less than the maximum allowable spacing of 2 cm to produce the best weed control (Solie et al., 1981). The manifold inlets extended upward directly behind the sweep shanks and were connected to the outlets of spray atomizers. A separate atomizer was provide for each manifold.

The jet penetration prediction theory (Solie and Wittmuss, 1983) was used to determine the required air flow rate and select an air blower. To use the theory, herbicide jet penetration, P, must be specified. The depth of herbicide incorporation may vary depending on the kind of weed to be controlled. For effective control, the herbicide must come in contact with weeds that are germinating and emerging, usually the upper 2.5 to 7.5 cm of soil. It was, therefore, decided to specify P as 3.5 cm.

After the jet penetration distance, P, was specified, the jet length was calculated to be 23.4 cm using equation (1). Values of variables used were $\theta=180$, $\lambda=2$, $\rho_j=1.18$ kg/m^3, $\rho_t=1000$ kg/m^3, $R_p=1.0$ and $S=0$. Sweep operating speed was specified as 8 km/h. The time the jet acted at any point computed to equal 0.00103 s. The jet velocity was determined to be 227 m/s. Since there were five sweeps, two manifolds on each sweep and twelve orifices on each manifold, there were a total of 120 orifices. By employing equation (4), the required air flow rate was determined to be 404 m^3/h.

A Sutorbilt Series F Blower (5HVF), manufactured by

Fuller Company, Compton, California, was selected to supply the high-velocity, high-pressure air required for atomizing the herbicide solution. The positive displacement blower has two rotors, and each rotor has two lobes. Operating at a speed of 2300 rpm against a pressure of 163 kPa, the blower delivered air up to 440 m^3/h. The air lines were made of 12.7 mm Gates Econo Flex (Denver, Colorado) hose, which can withstand a maximum pressure of 1380 kPa. A one cylinder 16 horsepower gasoline engine (Model K341S, manufactured by Kohler Company, Kohler, Wisconsin) was used as the power supply for the air blower.

A modified Spraying Systems (Wheaton, Illinois) air jet atomizer was used to atomize the liquid. Modifications consisted of replacing the jet anvil and stepped turbulence chamber with a straight bored atomizing chamber to minimize machining and increase flow rate (Figure 7 and Figure 8). The herbicide solution was injected, through a nozzle orifice, into the high-velocity air stream flowing through the atomizing chamber. The nozzle orifice had a diameter of 0.305 mm and was equipped with a needle to clean out the orifice to keep it from clogging. The liquid was filtered through 80 mesh screens and conveyed to the nozzle orifice by air pressure. A piston type air compressor was used to supply pressure for the liquid. Herbicide solution was carried in a 15 L tank mounted on the sweep plow. The injection system was designed to operate with a liquid pressure of 310 kPa.

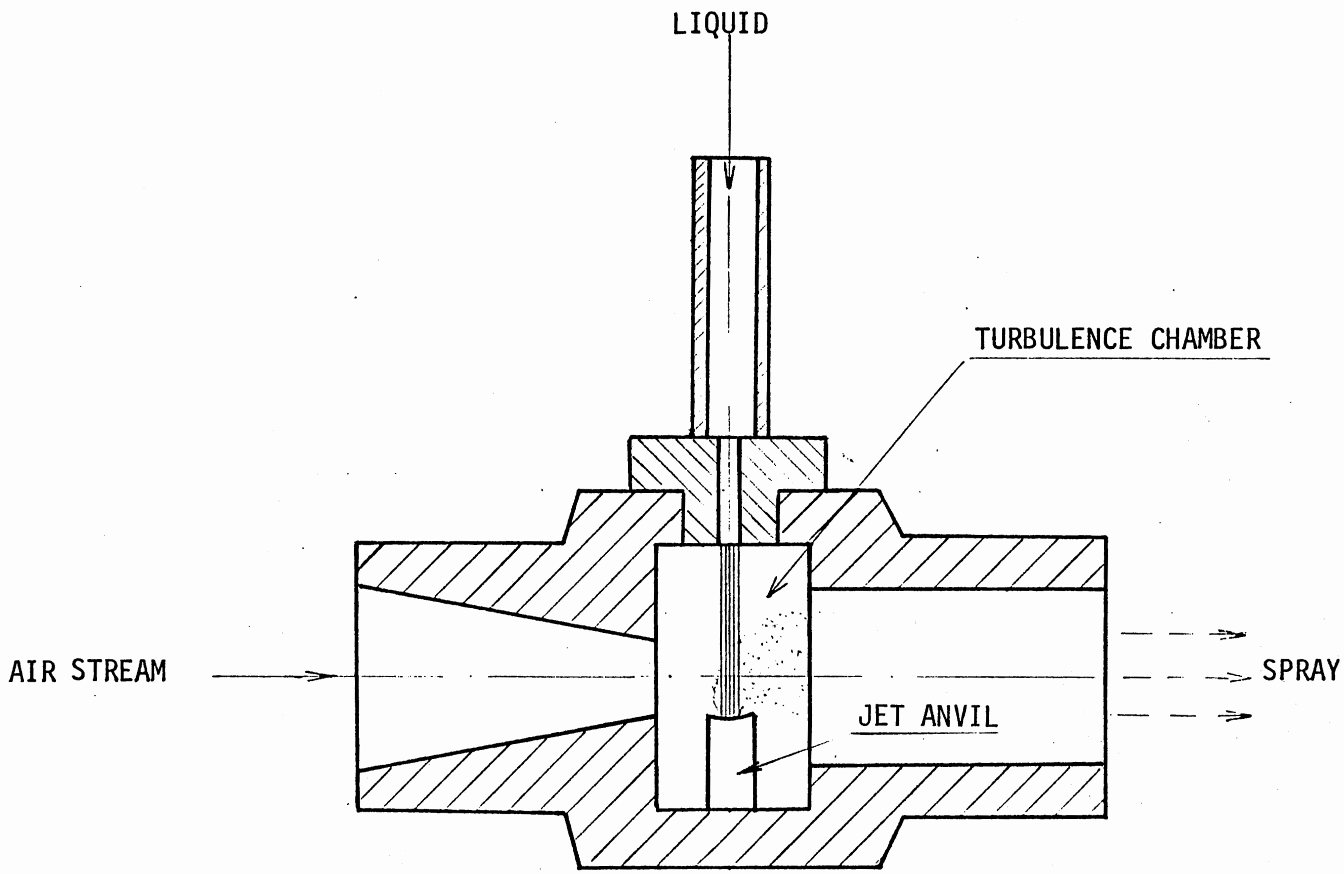


Figure 6. Spraying Systems Air Jet Atomizer

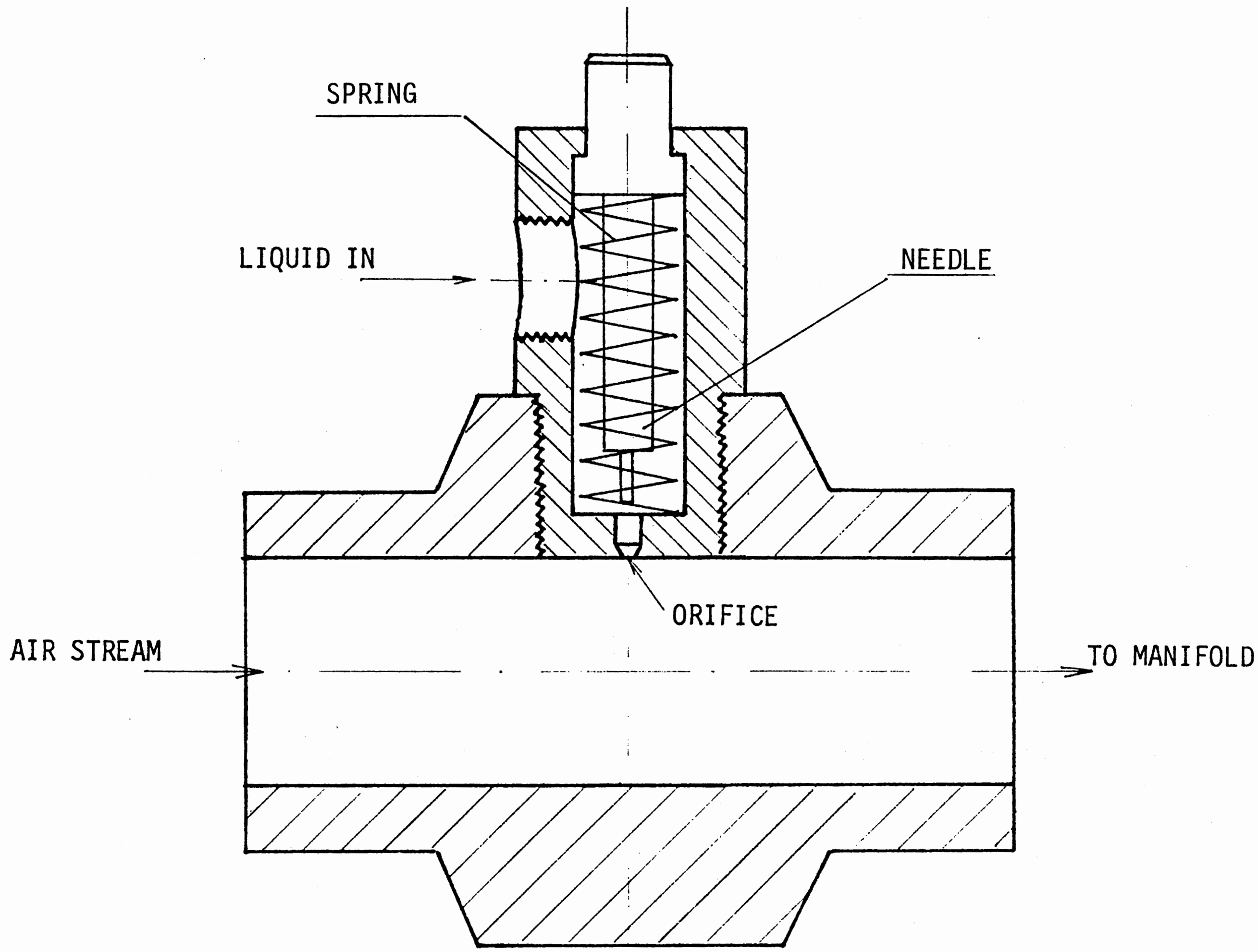


Figure 7. Modified Spraying Atomizer

A rubber shield was mounted above the manifolds to deflect jets of herbicide penetrating through the soil and to deflect the herbicide jets when the injection system was operated above ground (Figure 8).

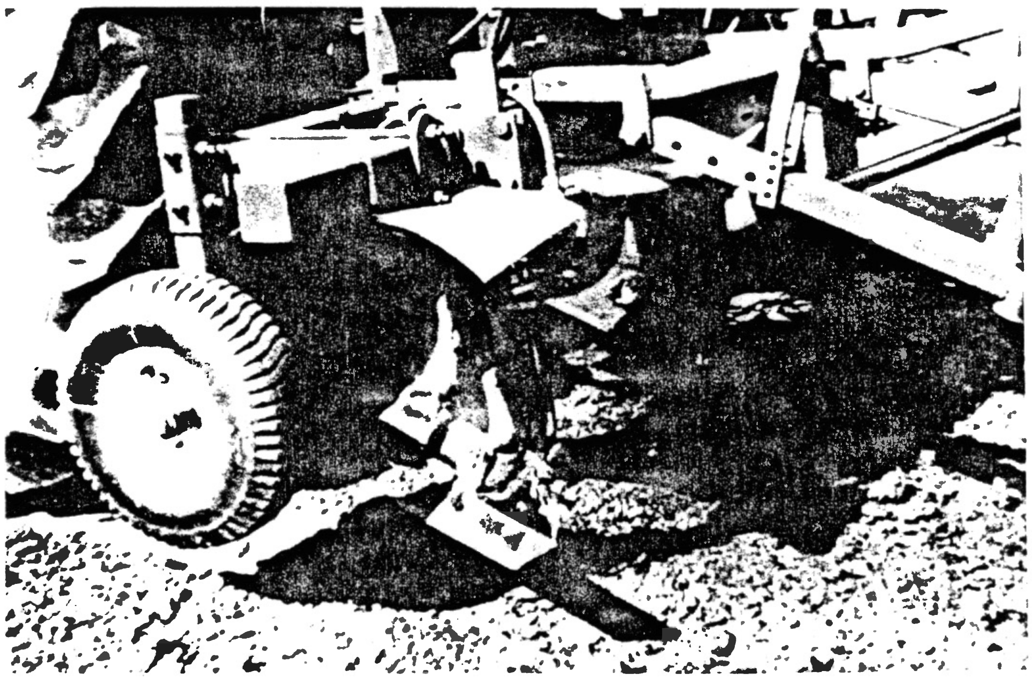


Figure 8. Subsurface Jet Injector Operating above Ground with Deflecting Shield

Methods and Procedure

To evaluate performance of the manifold jet injector, a field experiment was conducted to measure weed control and the effect on stands of Austrian winter peas of three herbicides. The experiment was carried out on September 9, 1986 and established at the Lake Carl Blackwell Research Area, Payne County, Oklahoma.

Two jet injection treatments and one "S" tine field cultivator treatment were included in the experiment. Herbicides were applied through the manifold jet injector at air pressure 163 kPa and solution pressure 310 kPa. The herbicide solution application rate was 65.5 L/ha. The sweeps were operated 3.8 cm and 6.4 cm deep at 8.0 km/h. The two jet injection treatments were compared with surface applied herbicide incorporation by two passes with an "S" tine field cultivator. The herbicide solution was applied at 187.1 L/ha with a plot sprayer for the "S" tine treatment.

The "S" tine field cultivator was equipped with spring tines with 10 cm shovels spaced 10 cm apart. A double rolling basket harrow was attached behind the cultivator to give additional incorporation of herbicide. The "S" tine cultivator was operated approximately 5 cm deep at 8.0 km/h.

Three herbicides, each at two rates, and a no herbicide check were applied to the experiment. Trifluralin (α,α,α-trifluro-2,6-dinitro-N,N-dipropyl-p-toluidine) was applied at 0.56 and 0.84 kg/ha; triallate (S-(2,3,3-trichloroallyl)diisopropylthiocarbamate) was applied at 1.68 and 2.24 kg/ha; and metribuzin (4 amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one) was applied at 0.56 and 1.12 kg/ha. Trifluralin, triallate and metribuzin were chosen because they are all widely used as preemergence or preplant herbicides. Metribuzin is highly soluble. Triallate has a high vapor pressure and diffuses readily though the soil. Trifluralin must be placed above and in the vicinity of the weed to be effective because it is nearly immobile in the soil (Ross and Lembi, 1985). Therefore, trifluralin and triallate require incorporation into the soil immediately after application.

All herbicides were injected or incorporated as a tank mix preplant. Check plots, on which no herbicides were used, were included in the experiment. Since the no herbicide checks were applied to each incorporation method treatment, a total of 3 check treatments and 12 plots existed in the experiment.

A randomized complete block design was employed, each block containing 21 treatments replicated four times. The experiment was blocked by slope and type of soil. See Appendix A for an outline of the experimental design and block randomization.

Plots were 21 m long and 3 m wide. All plots were tilled with an "S" tine field cultivator prior to herbicide incorporation to destroy weeds.

Rox Orange forage sorghum (Sorghum biocolor(L.) Moench) was broadcast by hand in all plots at about 16.8 kg/ha prior to herbicide application and mixed into the soil by one pass of the "S" tine field cultivator. Since Rox Orange sorghum is difficult to control, planting it assured ample presence and a uniform distribution of a challenge species that would test the weed control capacities of the two-fluid subsurface jet injector.

Herbicides were injected with the manifold subsurface jet injector or incorporated by two passes with the "S" tine field cultivator.

Austrian winter field peas (Pisum sativum spp. arvense L. Poir) was planted 2 cm deep at 67.25 kg/ha after herbicide application using a Crust Buster hoe drill with 25 cm row spacing.

The experiment site was mapped as a Port loam soil with 1-3% slope (Gray and Nance, 1978). However, a soil texture analysis conducted by the Agronomic Service Laboratory, Agronomy Department, Oklahoma State University, reported that the soil contained 32% clay, 50% silt and 18% sand. Thus it would be classified as a clay loam soil by the U. S. Department of Agriculture textural classification chart (Schwab et al., 1966). The soil condition was fine intermixed with some clods, and was dry on the surface at herbicide application.

The effect of herbicide placement on the Austrian winter field peas was determined by counting established plants in one meter of row in each plot seven weeks after planting (Appendix B).

As a measure of herbicide distribution, Rox Orange forage sorghum was harvested from a 1.0 m^2 area in the center of each plot on October 28, 1986. The sorghum was dried at approximately 50°C for 48 hours and then weighed (Appendix C). The sorghum dry weight data was analyzed by using the Statistical Analysis System (SAS, 1979) on an IBM 3081D mainframe computer, and treatment means were compared by using the Duncan's New Multiple Range Test at the 0.05 significant level (Steel and Torrie, 1980).

Results and Discussion

Analysis of winter peas stand data collected seven weeks after planting revealed that peas stands in the plots where the herbicide was incorporated with the subsurface manifold jet injector were not significantly different from stands where the herbicide was incorporated by two passes with the "S" tine cultivator (Table 1).

The analysis of variance for the winter peas stand data (Table 1) showed that block effects are significant at the 5 percent level. This indicates that the precision of the experiment was increased by use of the randomized complete block design. However, none of the herbicide treatments affected emergence of the peas.

The analysis of variance for the sorghum dry weight (Table 3) indicated that the treatment (PR>F=0.0001) was highly significant. Therefore, the treatments were further broken down into incorporation method, herbicide, and application rate and reanalyzed. Significant incorporation method (PR>F=0.0511), herbicide (PR>F=0.0001) and application rate (PR>F=0.0641) effects were found. Since

TABLE 1

ANALYSIS OF VARIANCE FOR WINTER PEAS STANDS
MANIFOLD JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	71	2259.65278		
Block	3	629.15278	8.17	0.0002
Treatment	17	321.90278	0.74	0.7501
Method	2	11.19444	0.16	0.8560
Herbicide	2	9.19444	0.13	0.8800
Rate	1	162.63889	1.13	0.3508
Method*Herbicide	4	0.68056	0.02	0.8910
Method*Rate	2	63.19444	0.88	0.4204
Herbicide*Rate	2	24.19444	0.34	0.7153
Method*Herb*Rate	4	50.80556	0.35	0.8402
Error	51	1038.59722		

TABLE 2

DUNCAN'S NEW MULTIPLE RANGE TEST FOR WINTER PEAS STANDS, MANIFOLD JET INJECTOR EXPERIMENT

Treatments			Stand Means (Plants/m row)	Grouping**
Method*	Herbicide	Rate		
Check			27	A
Injector 3.8	trifluralin	L	29	A
Injector 3.8	trifluralin	H	27	A
Injector 6.4	trifluralin	L	26	A
Injector 6.4	trifluralin	H	30	A
"S" tine	trifluralin	L	28	A
"S" tine	trifluralin	H	25	A
Injector 3.8	triallate	L	28	A
Injector 3.8	triallate	H	25	A
Injector 6.4	triallate	L	24	A
Injector 6.4	triallate	H	26	A
"S" tine	triallate	L	29	A
"S" tine	triallate	H	24	A
Injector 3.8	metribuzin	L	25	A
Injector 3.8	metribuzin	H	26	A
Injector 6.4	metribuzin	L	27	A
Injector 6.4	metribuzin	H	29	A
"S" tine	metribuzin	L	29	A
"S" tine	metribuzin	H	31	A

* Injector 3.8 and injector 6.4 denote that the jet injector operated 3.8 and 6.4 cm deep, respectively.

**Means with the same letter are not significant different at the 5 percent level.

TABLE 3

ANALYSIS OF VARIANCE FOR SORGHUM DRY WEIGHT
MANIFOLD JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	71	183868.38713		
Block	3	7812.00493	2.71	0.0546
Treatment	17	127071.48431	7.78	0.0001
Method	2	6615.54170	3.14	0.0511
Herbicide	2	97321.97101	46.26	0.0001
Rate	1	9960.47871	2.37	0.0641
Method*Herbicide	4	1347.75667	1.28	0.2626
Method*Rate	2	4892.43145	2.33	0.1074
Herbicide*Rate	2	2775.40778	1.32	0.2758
Method*Herb*Rate	4	4157.89699	0.99	0.4218
Error	51	48984.89790		

TABLE 4

DUNCAN'S NEW MULTIPLE RANGE TEST FOR SORGHUM DRY WEIGHT, MANIFOLD JET INJECTOR EXPERIMENT

Treatments			Sorghum Dry Weights (g)	Grouping*
Method	Herbicide	Rate		
Check			109.33	A B
Injector 3.8	trifluralin	L	33.99	E F G
Injector 3.8	trifluralin	H	15.89	F G
Injector 6.4	trifluralin	L	24.25	E F G
Injector 6.4	trifluralin	H	23.27	E F G
"S" tine	trifluralin	L	6.38	G
"S" tine	trifluralin	H	9.25	F G
Injector 3.8	triallate	L	118.65	A B
Injector 3.8	triallate	H	115.03	A B
Injector 6.4	triallate	L	93.36	A B C D
Injector 6.4	triallate	H	98.54	A B C
"S" tine	triallate	L	52.96	E F D
"S" tine	triallate	H	65.36	E C D
Injector 3.8	metribuzin	L	116.65	A B
Injector 3.8	metribuzin	H	66.15	E C D
Injector 6.4	metribuzin	L	136.58	A
Injector 6.4	metribuzin	H	84.04	C D
"S" tine	metribuzin	L	89.99	B C D
"S" tine	metribuzin	H	117.34	A B

* Means with the same letter are not significantly different at the 5 percent level.

all the interactions were not significant, it was concluded that the variables under consideration acted independently of each other. The sorghum dry weights averaged over levels of herbicide and application rate were appropriate and the best estimates of the common differences of the incorporation method.

To determine where the differences lay, ANOVA with a Means Duncan (SAS, 1979) was run with check plots excluded. The result indicated that early season sorghum control with the jet injection treatments was poorer than with the "S" tine incorporation treatment (Table 5). Table 6 revealed that trifluralin gave the best weed control among the three herbicides. Only trifluralin was labeled to control sorghum with the rates used in this experiment. Table 7 showed that there was no significant difference between the application rates.

Analysis of the sorghum dry weight data from only the trifluralin treatments indicated that incorporation method (PR>F=0.0568) did affect sorghum growth (Table 8). Further analysis of incorporarion method effects, with check plots included, showed that injection of trifluralin reduced sorghum weights to a level not significantly different from the "S" tine cultivator (Table 9). The jet injection and "S" tine treatments all presented significantly better weed control than the no herbicide check.

Since great variability existed among the no herbicide check treatments in different blocks and plots (see Appendix

TABLE 5

EFFECT OF METHOD ON SORGHUM DRY WEIGHT
MANIFOLD JET INJECTOR EXPERIMENT*

Incorporation Method	Sorghum Dry Weight (g)	Grouping**
Injector 3.8	77.718	A
Injector 6.4	76.676	A
"S" tine	56.833	B

* Effect of incorporation method was averaged over herbicide and application rate for he four replications.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

TABLE 6

EFFECT OF HERBICIDE ON SORGHUM DRY WEIGHT
MANIFOLD JET INJECTOR EXPERIMENT*

Herbicide	Sorghum Dry Weight (g)	Grouping**
Trifluralin	18.831	B
Triallate	90.653	A
Metribuzin	101.794	A

* Effect of herbicide was averaged over incorporation method and application rate for the four replications.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

TABLE 7

EFFECT OF APPLICATION RATE ON SORGHUM DRY WEIGHT
MANIFOLD JET INJECTION EXPERIMENT*

Application Rate	Sorghum Dry Weight (g)	Grouping**
Low	74.752	A
High	66.099	A

* Effect of application rate was averaged over incorporation method and herbicide for the four replications.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

TABLE 8

ANALYSIS OF VARIANCE FOR SORGHUM DRY WEIGHT
WITH TRIFLURALIN ONLY, MANIFOLD
JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	23	6022.5529		
Block	3	1694.4898	3.86	0.0315
Treatment	5	2130.6236	2.91	0.0496
Method	2	1460.9568	3.38	0.0568
Rate	1	173.7202	0.80	0.3819
Method*Rate	2	495.9466	1.15	0.3398
Error	15	2197.4394		

TABLE 9

DUNCAN'S NEW MULTIPLE RANGE TEST FOR SORGHUM
DRY WEIGHT WITH TRIFLURALIN, MANIFOLD
JET INJECTOR EXPERIMENT

Treatments		Sorghum Dry Weights (g)	Grouping*
Method	Rate		
Check		93.01	A
Injector 3.8	L	33.94	B
Injector 3.8	H	15.89	B
Injector 6.4	L	24.25	B
Injector 6.4	H	23.27	B
'S' Tine	L	6.38	B
'S' Tine	H	9.25	B

* Means with the same letter are not significantly difference at the 5 percent level.

C), the precision of the analysis could be significantly increased when the check treatments were removed from the data set. An analysis of variance of location of checks within blocks and among blocks indicated that position within blocks was not a significant factor affecting variability. With check treatment removed, the jet injection treatments provided poorer weed control than the "S" tine treatment at 5 percent significant level using Duncan's New Multiple Range Test (Table 10).

Observations were made on the weed control by all jet injection treatments. It was found that more sorghum grew along the tracks of the sweep shanks than that of the sweep wings where the manifolds were attached and the soil was treated by herbicides. Further observations on sorghum root growth revealed that the seeds germinated only in the upper 2-3 cm soil and roots grew horizontally in that region. That means the air jets containing herbicides did not penetrated up to the soil surface and the upper 2-3 cm of soil was left to be untreated by herbicides where the sorghum could germinate and grow.

However, the weed control was also not uniform across the region of the herbicides treated in each plot. The liquid flow rates of each orifice on selected manifolds were measured volumetrically using a graduated cylinder and a stop watch (see Table 11). The result showed that the distribution of flow rates was not even. Large difference existed from orifice to orifice along the manifolds. The

TABLE 10

EFFECT OF METHOD ON SORGHUM DRY WEIGHT WITH TRIFLURALIN ONLY, MANIFOLD JET INJECTOR EXPERIMENT*

Incorporation Method	Sorghum Dry Weight (g)	Grouping**
Injector 3.8	24.915	A
Injector 6.4	23.761	A
"S" tine	7.817	B

* Effect of incorporation method was averaged over application rate for the four replications and the check treatment was removed from the data set.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

TABLE 12

THE LIQUID FLOW RATE TEST
OF MANIFOLD ORIFICES

Orifice*	Liquid flow rate (ml/min.)			
	Sweep #2 (Right Side)	Sweep #3 (Left Side)	Sweep #4 (Right side)	Sweep #4 (Left Side)
1	12	9	13	8.5
2	24	28	23	22
3	26	13	25	23
4	11	5	10	15
5	4	2.5	9	17
6	1	3	2	5
7	4	7	1	5
8	1	6	1.5	7.5
9	1.5	8	3	5
10	2	7.5	2	4
11	2.5	4	2.5	5
12	0.5	2	1	2
Means	7.5	7.9	7.8	9.9
Std.	9.03	7.05	8.59	7.36
Variance	81.48	49.77	73.70	54.13
C.V. (%)	121.02	89.11	110.78	74.19

* The orifice number begins from the inlet of the manifolds to the closed end.

uneven distribution of herbicide along the manifolds probably caused the nonuniform weed control across each plot in the field test.

One factor affecting the distribution of herbicide was the friction loss. The rate of energy loss due to pipe friction varies with discharge and hence varies along the length of pipe and with the pipe diameter. The flow rate through the orifices will also vary. The flow will reduce approximately uniformly to zero at the closed end of the pipe, i.e. increase at every orifice from the closed end. If the Hazen-Williams equation is used, the pipe friction loss h_f will be given by:

$$h_f=F*L*[V/0.849*C_{HW}*(D/2)^{0.63}]^{1.852} \qquad (6)$$

where L is the length of the manifold,

V is the average velocity of flow at the feed tube,

D is the diameter of the manifold , and

C_{HW} is the Hazen-Williams coefficient, and is accepted as constant for any pipe. Here a value of 140 for C_{HW} is adopted. The value of factor F is dependent upon the number of orifices. From the Hazen-Williams equation, it is found that the pipe friction loss h_f is proportional to the pipe length L and inversely proportional to the pipe diameter. This result can cause more liquid to be ejected from orifices near the manifold inlet.

Another reason for uneven distribution from orifices in the manifold is the flow inertial force. Since air and liquid have different densities and thus different inertial forces, the bending of the air stream as it exited the manifold caused separation of the liquid from air. The inertial force makes the liquid flow rate from the second and the third orifices on each manifold much greater than that of other orifices.

In addition to the friction loss and the flow inertial force, surface tension force also plays an important role in the atomization of herbicide in the manifold subsurface jet injector. Droplet size varies directly with feed liquid surface tension. Moreover, the surface tension force will make the atomized liquid coalesce more easily. Since the spray atomizers were remotely located from the manifolds and the manifolds were tapered and bent, the atomized herbicide droplets had to travel large distances and go around bends before they were injected through the orifices on the manifold. While traveling the large distance between the atomizer and orifice, droplets collided and coalesced. This problem was compounded as droplets traveled around bends. There, centrifugal force concentrated droplets on the outside of the bend, increasing the probability of collision. Coalescing of liquid droplets contributed the uneven distribution of herbicide in the manifold subsurface jet injector.

In spite of these problems, the manifold two-fluid subsurface jet injector successfully solved the problem of excessive use of the large carrier volume requirements associated with the one-fluid subsurface jet injector.

CHAPTER IV

VENTURI BUNDLED TUBE JET INJECTOR

Introduction

Although the two-fluid manifold subsurface jet injector solved the problem of the need for large volumes of water as a herbicide carrier, and showed great potential for use as a herbicide incorporation tool, both field and laboratory experiments indicated that the distribution of herbicide in the manifold jet injector was nonuniform, and thus the soil-chemical incorporation of the manifold system was not as good as two pass incorporation with an "S" tine field cultivator. It was, therefore, necessary to improve the distribution system. The concept of the venturi bundle tube jet injector was developed to overcome the problems associated with the manifold distribution system.

Venturi Bundled Tube Jet Injector

The venturi bundled tube jet injector was designed to provide effective disintegration and uniform distribution of the liquid. In the venturi jet atomizer, the herbicide solution was injected radially, at the venturi throat, through nozzle orifices, into the high-velocity air stream.

The venturi, with throat diameter of 0.635 cm, was introduced to accelerate the air and reduce the pressure at the throat. The normal shock wave and violent turbulence formed after the throat should increase energy transfer from the high-velocity air to the liquid jet (Marshall, 1954). Thus improved atomization of the herbicide solution would be expected compared with the straight atomizing chamber used in the manifold jet injector.

To reduce the effect of friction losses, inertial effects, and coalescing of droplets, each manifold was replaced by a bundle of 12 individual tubes, with inside diameter of 1.65 mm. Each tube replaced one manifold orifice (Figure 9).

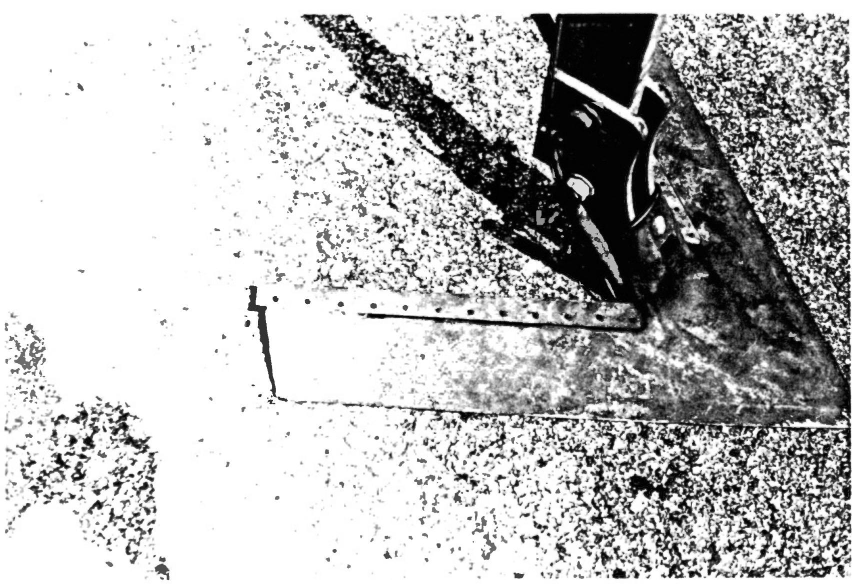


Figure 9. Sweep and Distribution Tubes

In order to lessen the influence of liquid surface tension and prevent the atomized herbicide from coalescing back to large droplets, the venturi atomizer was connected directly to the inlet of the tube bundle and mounted below the sweep blades. The single 90° bend of each tube was made immediately before outlet to minimize the coalescing of the spray droplets. The air supply lines were connected to the inlets of the venturi atomizer. The venturi atomizing body, air and liquid supply lines, and spray outlet tubes were covered by a protective steel guard to keep them from being damaged by soil. The arrangement is shown in Figure 10 and Figure 11.

Figure 10. Sweep, Venturi Atomizer, Tube Bundle and Protective Guard

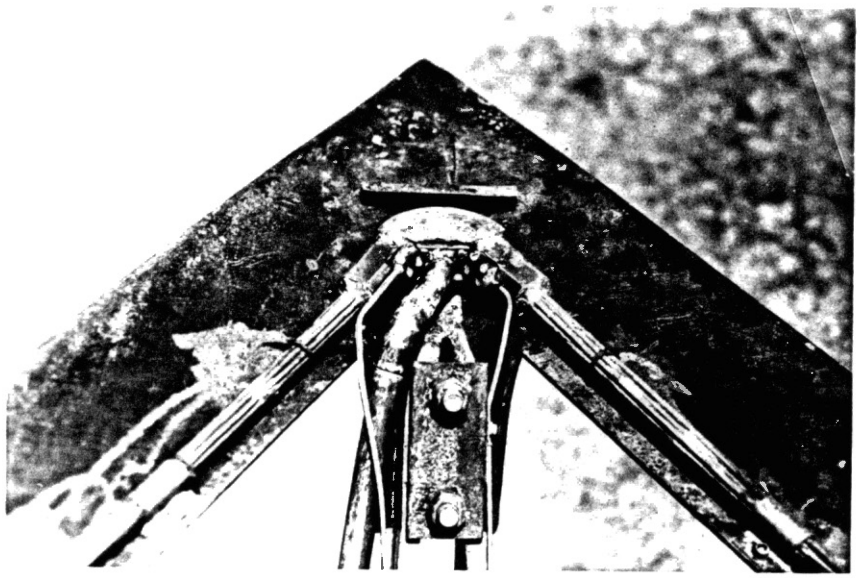


Figure 11. Venturi Atomizer, Tube Bundle, Air and Liquid Lines Mounted below the Sweep Blade

Initially a venturi with one nozzle orifice was built and tested. The desired uniformity of the liquid distribution was not achieved. The amount of water collected from different tubes in the tube bundle varied from 0.5 to 12.5 ml/min, with a coefficient of variation of 103.3 percent (Table 12).

A second venturi was then designed with two orifices located 180° apart at the venturi throat (Figure 12). The venturi atomizing body was constructed of brass, with different air stream inlet and outlet transitions. The inlet transition consisted of a nonuniform convex surface, and the outlet transition was beveled to a 9 degree angle.

TABLE 12

THE FLOW RATE TEST OF ONE NOZZLE ORIFICE VENTURI BUNDLED TUBE JET INJECTOR

Tube #	Outlet Pressure (kPa)	Air Flow rate (m^3/h)	Liquid Flow rate (ml/min)
1	166.82	1.954	1.5
2	162.69	1.869	12.5
3	175.79	2.379	1.0
4	164.76	1.869	1.0
5	173.72	2.294	3.5
6	165.45	1.835	4.5
7	166.82	1.869	0.5
8	170.96	2.073	1.0
9	166.82	1.954	6.5
10	166.82	1.869	2.5
11	163.38	1.699	3.5
12	164.76	1.699	1.5
Mean	167.40	1.864	3.29
Std.	4.05	0.323	3.40
Variance	16.40	0.104	11.57
C.V. (%)	2.42	10.76	103.32

Notes: 1. The tube order number is accorded with the tube length. 1 is the shortest tube and 12 the longest tube.

2. The upstream air pressure was approximately 200 kPa, and the liquid pressure was 275 kPa.

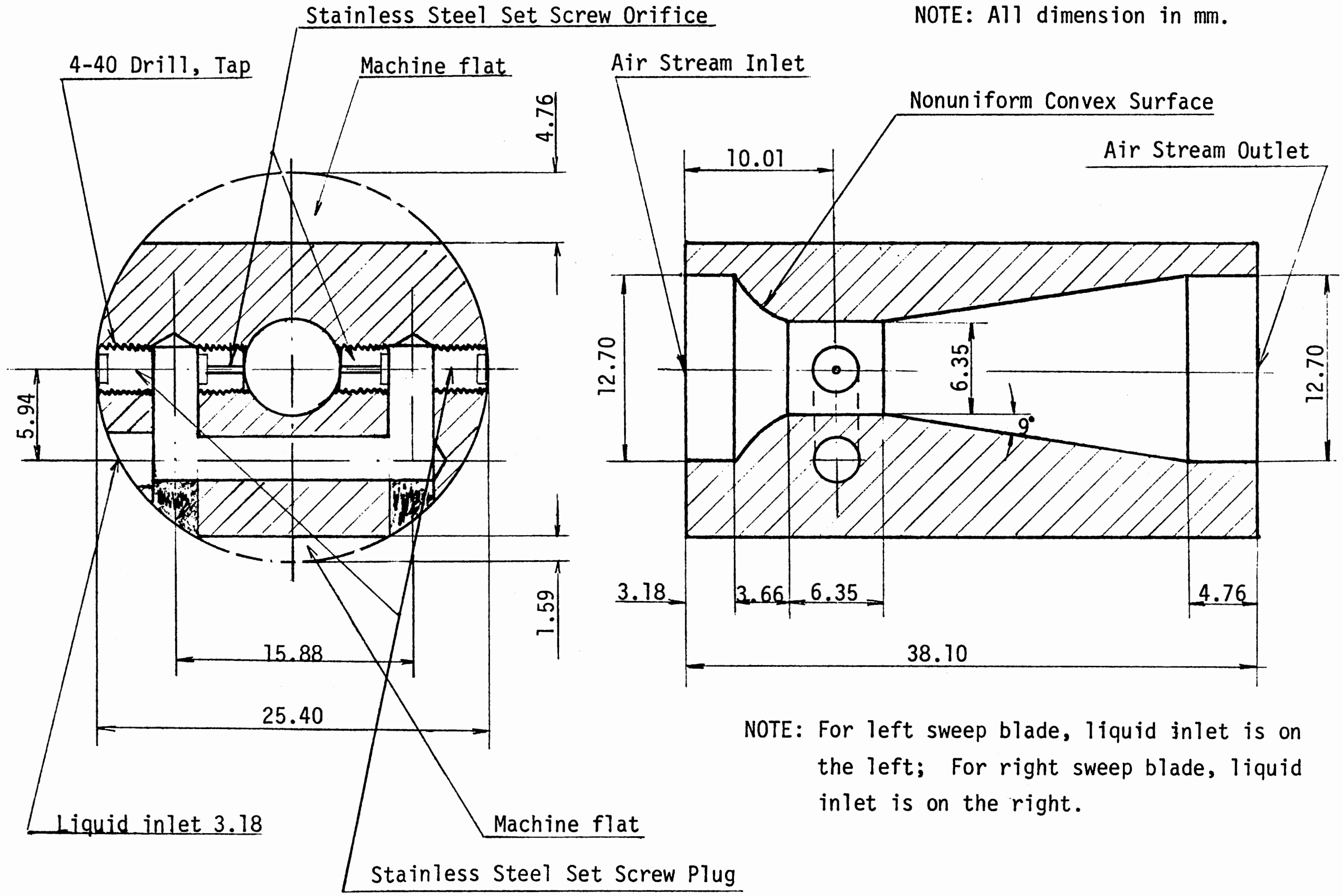


Figure 12. Venturi Atomizing Body, Venturi Throat and Nozzle Orifices

The inlet was counterbored to permit insertion of the air inlet tube, and the outlet was counterbored for insertion of the distribution bundle tubes. The bundled distribution tubes and the air stream inlet tube were lead soldered into the venturi. A 3.18 mm hole was bored radially and tapped through the throat of the venturi. Two nozzle orifices were inserted into this gallery. The orifices were constructed from stainless steel set screws by drilling one hole axially through each screw. Two stainless steel set screws were used to close this gallery and were removed to access the orifices. A second gallery was bored parallel to the orifice gallery and served as the liquid inlet. Two galleries were drilled perpendicularly to the orifice and inlet galleries to connect them. The connection gallery openings were blocked by silver soldering brass plugs. The venturi atomizing body was machined flat on the top and bottom to fit under the sweep.

The smaller the liquid jet diameter, the finer droplets of liquid (Marshall, 1954). An orifice diameter of 0.305 mm was initially tried. Serious plugging problems were encountered. Therefore, orifices with diameter 0.406 mm, were used to minimize plugging.

The feed system required separate control of both the liquid and air supply. The liquid was conveyed to the venturi nozzle orifices by compressed air which was provided by a piston type air pump mounted on a tractor. The solution was filtered through a 80 mesh screen. Air pressure was controlled by a regulator. Liquid pressure for the two-fluid atomization system was 275 kPa. The maximum pressure of the air stream was about 200 kPa measured at the blower outlet.

The Sutorbilt Series F Blower (5HVF) used with the manifold jet injector was used to provide the compressed air for the venturi atomizer. The air lines were made of 16 mm NAPA (Denver, Colorado) high pressure hose. To meet the high energy requirements of the two-fluid atomization device, a two cylinder 24 horsepower Kohler (Kohler, Wisconsin) gasoline engine, model K735, which has a maximum speed of 3600 rpm, was used as the power supply.

The uniformity of the distribution of the venturi bundled tube jet injector was much improved compared with the manifold jet injector (Table 13). With the two orifice venturi, the range of liquid flow rate was from 3.5 to 7.0 ml/min. with a coefficient of variation of 21.06 percent. The variation in the liquid flow rate resulted from the arrangement of the tube bundle. It was found that more liquid was ejected from the inside tubes than the outside ones in the tube bundle.

Field Experiment

Methods and Procedure

In order to evaluate the performance of the venturi bundled tube jet injector, a field experiment, similar to

TABLE 13

THE FLOW RATE TEST OF TWO NOZZLE ORIFICE VENTURI BUNDLED TUBE JET INJECTOR

Tube #	Outlet Pressure (kPa)	Air Flow rate (m^3/h)	Liquid Flow rate (ml/min)
1	157.86	2.124	4.5
2	163.38	2.209	6.0
3	159.93	1.954	6.0
4	163.38	2.124	5.0
5	159.93	1.920	3.5
6	166.82	1.954	7.0
7	170.27	1.869	4.5
8	170.96	1.988	3.5
9	170.27	1.954	6.5
10	168.89	1.699	5.0
11	170.27	1.869	5.5
12	171.65	1.869	5.5
Mean	166.14	1.961	5.21
Std.	4.99	0.139	1.10
Variance	24.86	0.019	1.20
C.V. (%)	3.00	7.07	21.06

Notes:
1. The tube order number is accorded with the tube length. 1 is the shortest tube and 12 the longest tube.
2. The air upstream pressure was approximately 200 kPa, and the liquid pressure was 275 kPa.

that used to evaluate the manifold jet injector, was conducted at the Agronomy Research Station, Stillwater, Oklahoma, on November 17, 1987.

Two jet injection treatments and one "S" tine field cultivator treatment were included in the experiment. Trifluralin at 0.56 and 0.84 kg/ha, triallate at 1.68 and 2.24 kg/ha, and metribuzin at 0.56 and 1.12 kg/ha were applied to the experiment. The herbicides were injected with the venturi bundled tube jet injector or incorporated by two passes with an "S" tine field cultivator. Check plots with no herbicide were included in the experiment.

A randomized complete block design was used, with 21 treatments and four replications. Each plot was 11 m long and 2.4 m wide. All plots were tilled several times prior to herbicide incorporation with moldboard plows, disk harrow and field cultivator.

Italiap ryegrass (Lolium multiflorum) was broadcasted by hand at about 15 kg/ha prior to herbicide application and mixed into the soil by one pass of the "S" tine field cultivator. Chisholm wheat (Triticum aestivum L.) and OK oats (Avena sativa) were planted after herbicide application. A Crust Buster hoe drill with 25 cm row spacing was used to plant the crops. Chisholm wheat was planted at 72 kg/ha, and Ok oats at 50 kg/ha. Both crops were planted 2 cm deep.

The experiment was established on a soil mapped as a Port silt loam soil, occasionally flooded (Gray and Nance, 1981). However, a soil particle size analysis, conducted by the Agronomic Service Laboratory, Agronomy Department, Oklahoma State University, indicated that the soil was a clay loam with 32% clay, 41% silt and 28% sand. The moisture content of the soil was high at herbicide application.

The oats and grass died or failed to emerge because of the severe cold weather in the winter of 1987. Wheat was planted initially to determine the effect of herbicides on crop injury. However, the data were used for measuring the weed control because of the lack of weeds.

On April 20, 1988, wheat forage was harvested from a 0.9 by 0.5 m^2 area of each plot in replications 2, 3 and 4. Replication 1 of the triallate and metribuzin treatments was discarded because of ponded rainfall drowning the wheat in these plots. Width of the harvest area was across the chemical application band of one sweep of the venturi bundled tube jet injector. The wheat was dried for 48 hours at approximately 50°C and then weighed (Appendix D).

Analysis and Discussion

Analysis of variance for the wheat dry weight data for block two, three and four (Table 15) showed herbicide (PR>F=0.0002) was highly significant. All other factors and interactions were not significant at 5 percent level. A Duncan's New Multiple Range Test was used to determine the differences among the herbicide treatments (Table 16). The

TABLE 14

ANALYSIS OF VARIANCE FOR WHEAT DRY WEIGHT WITH ALL HERBICIDES FOR BLOCK 2, 3 & 4 ONLY, VENTURI BUNDLED TUBE JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	53	13935.35668		
Block	2	1606.64723	5.10	0.0100
Treatment	17	6723.00768	1.97	0.0427
Method	2	328.26268	0.82	0.4488
Herbicide	2	4516.18606	11.27	0.0002
Rate	1	233.66720	1.17	0.2873
Method*Herbicide	4	1089.36919	1.36	0.2673
Machine*Rate	2	144.96944	0.36	0.6989
Herbicide*Rate	2	24.13339	0.06	0.9416
Method*Herb*Rate	4	386.41912	0.48	0.7486
Error	34	6390.38104		

TABLE 15

EFFECT OF HERBICIDE ON WHEAT DRY WEIGHT WITH THREE BLOCKS, VENTURI BUNDLED TUBE JET INJECTOR EXPERIMENT*

Herbicide	Wheat Dry Weight (g)	Grouping**
Trifluralin	7.191	A
Triallate	19.149	B
Metribuzin	29.574	C

* Effect of herbicide was averaged over incorporation method and application rate for the three replications.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

wheat dry weights were averaged over levels of incorporation method and application rate to obtain a more precise estimate. The result indicated that trifluralin treatments presented the best control, and triallate treatments gave better control than metribuzin treatments. All of three herbicides can injure wheat. However, trifluralin will normally produce the greatest injury.

To investigate the effect of incorporation method on the wheat dry weights at different levels of herbicide, the data from plots treated with each herbicide were analyzed separately.

All four block data included, the analysis of variance of data from trifluralin treatment plots (Table 16) showed that incorporation method, but not application rate, effected wheat growth. There were no incorporation method and application rate interaction. With the no herbicide check treatments included in the analysis, the Duncan's New Multiple Range Test (Table 17) revealed no significant differences among the incorporation methods. The venturi bundled tube jet injector and the "S" tine treatments all provided significantly better control than the no herbicide check treatments.

However, with the check treatment removed, The DUNCAN Means (Table 18) showed that the venturi bundled tube jet injector treatments gave significantly poorer control than the "S" tine treatment.

With triallate and metribuzin, both the analyses of

TABLE 16

ANALYSIS OF VARIANCE FOR WHEAT DRY WEIGHT WITH TRIFLURALIN ONLY FOR FOUR BLOCKS, VENTURI BUNDLED TUBE JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	23	1526.5337		
Block	3	243.6657	1.76	0.1934
Treatment	5	614.2110	2.42	0.0758
Method	2	469.1744	4.63	0.0239
Rate	1	28.0152	0.55	0.4668
Method*Rate	2	117.0214	1.15	0.3375
Error	15	668.6570		

TABLE 17

DUNCAN'S NEW MULTIPLE RANGE TEST FOR WHEAT DRY WEIGHT WITH TRIFLURALIN ONLY FOR FOUR BLOCKS, VENTURI BUNDLED TUBE JET INJECTOR EXPERIMENT

Treatments		Wheat Dry	Grouping*
Method	Rate	Weights (g)	
Check		47.75	A
Injector 3.8	L	12.92	B
Injector 3.8	H	4.85	B
Injector 6.4	L	9.71	B
Injector 6.4	H	12.26	B
"S" tine	L	1.22	B
"S" tine	H	0.25	B

* Means with the same letter are not significantly different at the 5 percent level.

TABLE 18

EFFECT OF METHOD ON WHEAT DRY WEIGHT WITH TRIFLURALIN ONLY FOR FOUR BLOCKS, VENTURI BUNDLED TUBE JET INJECTOR EXPERIMENTS*

Incorporation Method	Wheat Dry Weight (g)	Grouping**
Injector 3.8	10.982	A
Injector 6.4	8.886	A
"S" tine	0.732	B

* Effect of method was averaged over application rate for the four replications, and the check treatments were removed from the data set.

**Means with the same letter are not significantly different at the 5 percent level as indicated by Duncan's New Multiple Range Test.

variance (Table 19 & 20) indicated that incorporation method had no significant effects on the wheat dry weight.

Like the manifold jet injector experiment, more wheat forage was observed along the tracks of the sweep shanks for the jet injection treatments in the venturi bundled tube jet injector experiment. It was also found that wheat roots grew horizontally in the upper 2-3 cm soil region. However, the control was much better in the region of the sweep wings compared with the manifold jet injector experiment.

Tracer Test of Soil Incorporation

Methods and Procedure

A fluorescent tracer test was carried out to determine how far air jets with herbicide penetrated up into soil passing over the sweep blades. Four jet injector treatments and an "S" tine field cultivator with two passes treatment were included in the experiment. The injector sweeps were operated at 3.8 and 6.4 cm deep. When operating 3.8 cm deep, the sweep ground speed was 7.5 km/h. At the 6.4 cm depth, three different operating speeds, 4.5, 6.4 and 7.5 km/h, were tested. The "S" tine field cultivator was operated 5 cm deep at 7.5 km/h.

The literature review disclosed that fluorescent tracer offered a quick, easy, inexpensive, and accurate procedure to evaluate chemical incorporation of the subsurface jet injector. A low cost brand of fluorescent pigment (Day-Glo

TABLE 19

ANALYSIS OF VARIANCE FOR WHEAT DRY WEIGHT
WITH TRIALLATE FOR BLOCK 2, 3 & 4
ONLY, VENTURI BUNDLED TUBE
JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	17	2141.7297		
Block	2	243.6657	1.76	0.1934
Treatment	5	373.0636	0.51	0.7664
Method	2	285.7870	0.97	0.4071
Rate	1	55.0201	0.37	0.5526
Method*Rate	2	32.2565	0.11	0.8972
Error	10	1768.6661		

TABLE 20

ANALYSIS OF VARIANCE FOR WHEAT DRY WEIGHT
WITH METRIBUZIN FOR BLOCK 2, 3 & 4
ONLY, VENTURI BUNDLED TUBE
JET INJECTOR EXPERIMENT

Source	DF	Sum of Squares	F Value	PR>F
Total	17	5874.2250		
Block	2	2911.9410	5.79	0.0174
Treatment	5	1272.7158	0.66	0.6579
Method	2	736.9222	0.96	0.4101
Rate	1	163.3829	0.43	0.5262
Method*Rate	2	372.4107	0.49	0.6269
Error	10	4601.5092		

Saturn Yellow AX 17-N, manufactured by Day-Glo Color Corp., Cleveland, Ohio) was used as the tracer material. The insoluble fluorescent tracer was suspended in water at a rate of 10 g/L. A non-ionic surfactant, TRITON AG-98 spreader activator, manufactured by Rohm and Haas Company, Philadelphia, Pennsylvania, was added at a rate of 6 ml/L to water to help hold the tracer in suspension. Density of the tracer suspension was 1.00 g/cm^3.

The tracer was injected into the soil through the venturi bundled tube distribution system, or sprayed on the soil surface and incorporated by two passes with the "S" tine cultivator. For jet injector treatments, the application rates of the tracer solution were 110 L/ha at 4.5 km/h, 76 L/ha at 6.4 km/h and 65.5 L/ha at 7.5 km/h. The application rate for "S" tine treatment was about 235 L/ha.

The test was conducted at the same location as the experiment used to evaluate the performance of the venturi bundled tube jet injector. Soil moisture content and bulk density were measured after tracer application, averaged 13.3 percent (Appendix E) and about 1.0 g/cm^3 wet basis, respectively.

Three soil sampling boxes were built for soil sampling across the 46 cm width of application of one sweep of the subsurface jet injector. The boxes were constructed 46 cm long, 32 cm wide and 15 cm high with one 46 cm side open, and were made of 16 gauge steel sheet. A 9.5 mm threaded rod was bolted on the open side of the box to make it rigid (Figure 13).

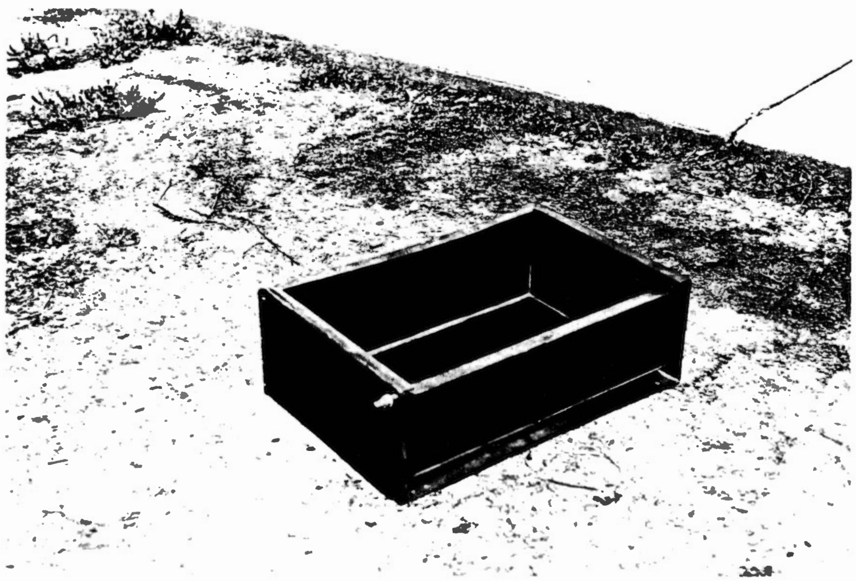


Figure 13. Soil Sampling Box and Soil-cutting Blade

Soil samples were taken immediately after the tracer application. Three samples along the line of travel were selected for each treatment. Wheel tracks were avoided when collecting the samples. A 40 by 11.5 cm^2 soil-cutting blade was manually pressed vertically into the soil. The soil was removed from one side of the blade with a shovel, the sampling box was placed into the hole. The sample box was then driven horizontally into the soil from that side by using sledge hammer until the sample box was full of soil. The blade was removed and inserted in the open side of the sampling box to cut and retain the soil. The soil samples were transported to the Agricultural Engineering Laboratory Annex where jet penetration distances were measured or tracer distributions photographed under ultraviolet light.

The light source was two 40 watt ultraviolet tubes Model F40T12/BLB, manufactured by General Electric Company, Cleveland, Ohio. A Minolta 35 mm AF camera Model Maxxum 7000, manufactured by Minolta Camera Co., Ltd., Osaka, Japan, was employed for photographing the tracer distributions. The camera was equipped with a autofocus wide angle macro lens, AF 28-85. To photograph fluorescence, two filter are necessary. One is UV filter (model Haze 1, manufactured by Tiffen Manufacturing Corp., Hauppauge, New York) which absorbs ultraviolet light and passes fluorescent visible light to be record by film. Another is FL-D filter (Tiffen Manufacturing Corp.) which allows proper color rendition under fluorescent lighting to produce good pictures. The photographic film used was Ektachrome ISO 400 film, manufactured by Eastman Kodak Company, Rochester, New York. The film was exposed 20, 30 and 40 seconds. It was found that the exposure of 30 seconds gave the best result.

Attempts were made to photograph distribution of the fluorescent tracer both by the venturi bundled tube jet injector and by the "S" tine field cultivator. However, the attempt to photograph the distribution of the fluorescent tracer by the venturi bundled tube jet injector did not succeed, because the concentration of the tracer in the soil by the venturi bundled tube jet injector was too low to be photographed under the ultraviolet light. Therefore, only the distribution of the fluorescent tracer by the "S" tine cultivator was photographed.

The jet penetration distances for venturi bundled tube jet injection treatments were measured under the ultraviolet light. The soil sample was shaved from the open side of the sample box, and the soil face was examined. It was observed that individual fluorescent tracer spots appeared to be randomly distributed in the soil. The distance from the sweep operating depth to the observed highest tracer spot was measured as the maximum jet penetration distance. After the first measurement, the soil was shaved again, and another measurement was taken. This was repeated until twenty measurements were taken for each soil sample. The tracer jet penetration distance data of the venturi bundled tube jet injection treatments were presented in Appendix F.

Results and Discussion

The penetration distance of fluorescent tracer was quite variable for all venturi bundled tube jet injection treatments. To obtain an accurate result, the jet penetration distances were averaged over the three samples and 60 observations for each treatment. When the sweeps operated 3.8 cm depth at a speed of 7.5 km/h, the average maximum penetration distance was 31.9 mm with a range from 24 to 42 mm and a standard deviation of 4.6 mm. When the sweeps operated 6.4 cm depth at speed of 4.6 km/h, penetration distances ranged from 26 to about 64 mm, and the mean maximum jet penetration distances of the tracer was 45.2 mm with a standard deviation of 8.8 mm. At 6.4 cm depth and 6.4 km/h operating speed, the penetration distance range was from 21 to 57 mm, and the average maximum penetration distance of the tracer was 38.8 mm with a standard deviation of 9.1 mm. For 6.4 cm depth and 7.5 km/h speed, a mean maximum penetration of the tracer of 36.3 mm with the standard deviation of 7.8 mm was obtained.

The average measured maximum penetration distances of tracer were compared with the predicted distances obtained by the theory developed by Solie and Wittmuss (1983). Jet penetration distances were calculated for ground speeds of 4.5, 6.4 and 7.5 Km/h. The predicted penetration distances were 64, 45 and 39 mm at speed of 4.5, 6.4, and 7.5 km/h, respectively.

95% confidence intervals of the mean maximum jet penetration distances were constructed for the three operating speeds with 6.4 cm depth. The result indicated that at the operating speed of 7.5 km/h, the predicted penetration distance nearly fell within the 95% confidence interval and lay close to the maximum value (Figure 14). However, the measured maximum penetration distances ranged

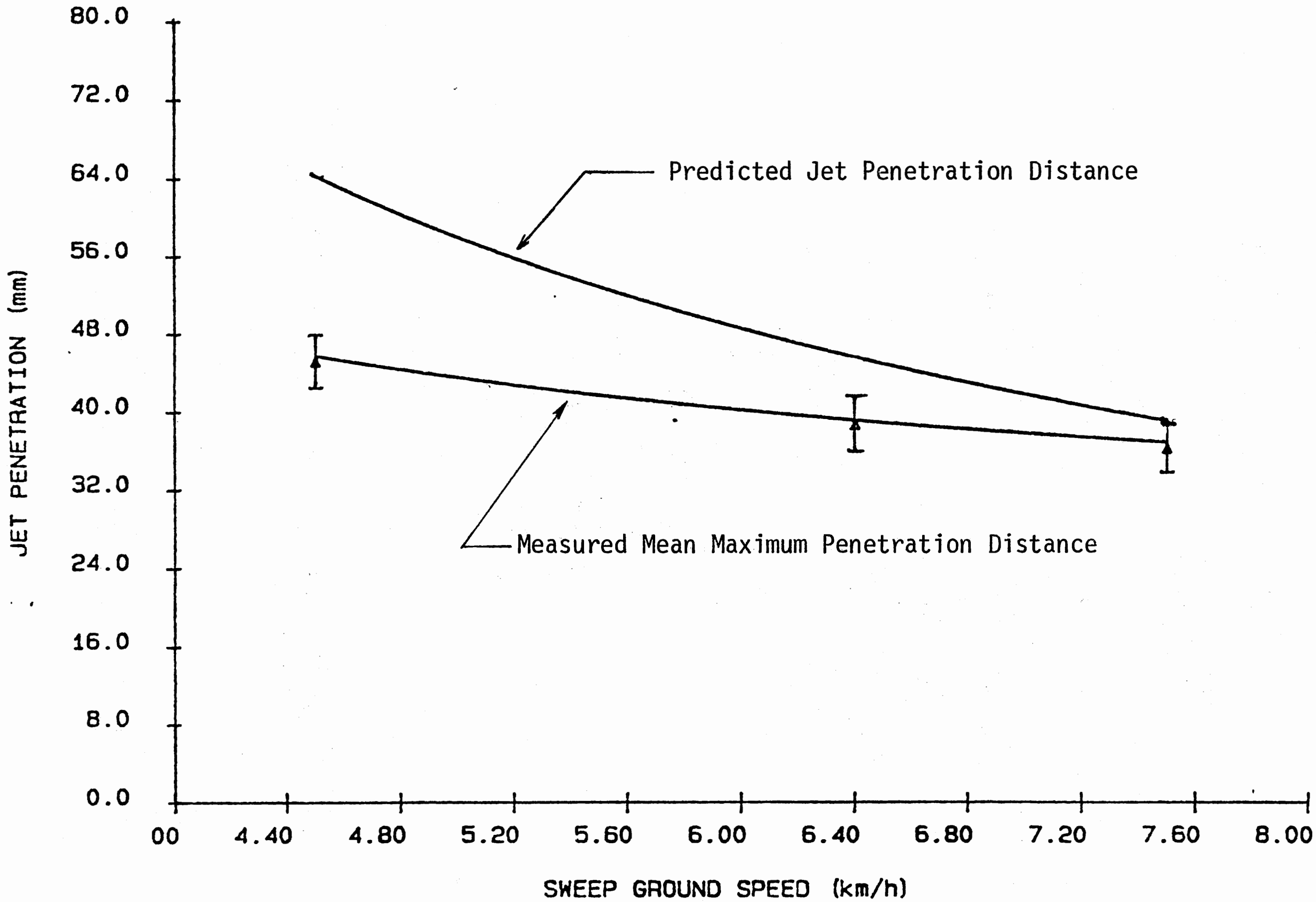


Figure 14. Mean Maximum Penetration Distances and 95% Confidence Intervals, Theoretical Prediction of Jet Penetration Distances

as high as 60 mm which was greater than the predicted value.

Average maximum jet penetration distance was inversely proportional to the sweep ground speed. A graph was constructed to show the relation of the jet penetration distances and the sweep ground speed, the 95 percent confidence intervals about the mean maximum penetration and the predicted distances (Figure 14).

The difference between the predicted jet penetration distances and the experimentally obtained average maximum penetration distances can be reduced with data on the value of reduction in penetration distance R_p and the angle of the failure plane with respect the vertical axis for the soil classification in the experiment. It can be concluded the theory of jet penetration (Solie and Wittmuss, 1983) provides a criterion on which to design subsurface jet injector to jet herbicides or other chemical into the soil, provided the required information, such as soil type, soil density and moisture content.

It was also found from the tracer jet measurement that at regular sweep operating speed of 7.5 km/h, the mean maximum penetration distance was 38.8 mm. The jets penetrated about 2/3 the distance to the surface leaving about 2 cm of untreated soil in which weed could germinate. Observed sorghum root growth and germination depth in the manifold jet injector experiment, as well as the observed wheat root growth and germination depth in the venturi bundled tube jet injector weed control experiment, confirms the existence of this 2 cm untreated zone. This contributed to the slightly poorer weed control of the venturi bundled tube jet injector.

In addition to the measurements of the maximum jet penetration distances, photographs of the fluorescent tracer with two pass "S" tine cultivator incorporation were taken under the ultraviolet light (Figure 15). The distribution

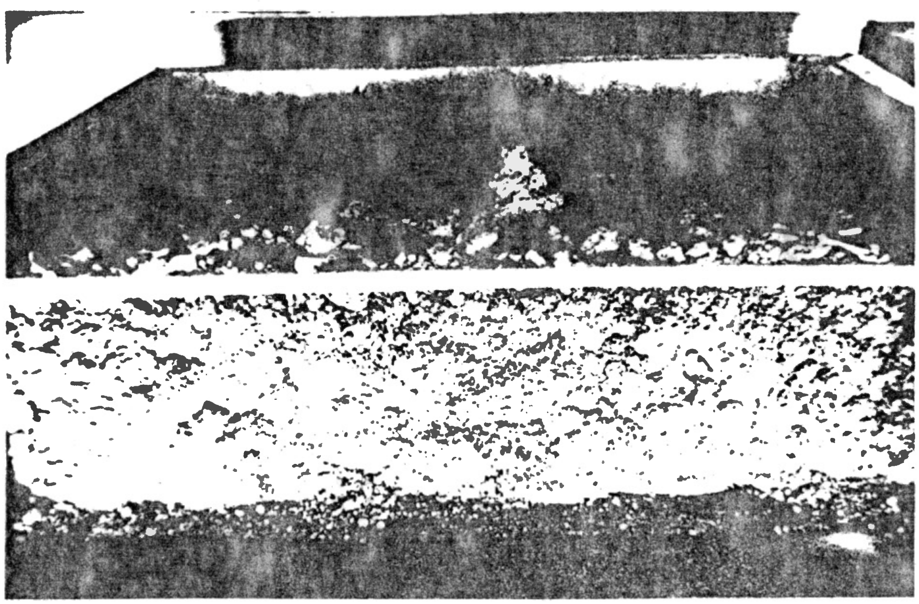


Figure 15. Distribution of Soil-incorporation of the Two Pass "S" Tine Cultivator

of the incorporation by the venturi bundle tube jet injector treatments appeared to be nearly as uniform as the "S" tine in region where jets penetrated.

Serious plugging problems occurred with the venturi bundled tube jet injector. Since the venturi atomizing body was made of brass, the consequent oxidation and scaling of the brass caused the clogging of nozzle orifices. Cleaning of the inlet solution tubes and venturi atomizer with acid eliminated the plugging problem for a time. However, failure to flush the atomizer with acid prior to operation caused the venturi nozzle orifices to plug quickly. The plugging problem did result in the nonuniform distribution of herbicide and thus the poor weed control.

Though these problems existed, the distribution of the venturi bundled tube jet injector was much improved compared with the manifold jet injector. The design penetration of herbicide was achieved with the two-fluid subsurface jet injector. However, using two-fluid atomization and air jet for penetration requires large amount of power since the efficiency of the two-fluid atomization is relatively low. This will make the operating cost with the two-fluid subsurface jet injector excessively high.

Further research is needed to overcome the problems with the two-fluid jet injector.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Two versions of the two-fluid subsurface jet injector were designed, constructed and tested. Both injectors used air jets for herbicide penetration. The manifold jet injector was the first version to be designed, built, and evaluated. The injector was constructed of tapered copper manifolds mounted on five standard 50.8 cm sweeps, with the atomizer located remote from the sweep. A field experiment indicated that the manifold jet injector herbicide treatments did not control weeds as well as two pass incorporation with an "S" tine field cultivator. Liquid (herbicide) distribution through the manifold orifices was not uniform. This may cause the unsatisfactory weed control obtained with the manifold jet injector.

The venturi bundled tube jet injector was the second version of injector to be designed and tested. The system used a bundle of twelve 1.65 mm individual tubes to replace each manifold. The tube bundles were directly connected to the outlet of the two-fluid venturi atomizer. The venturi was introduced to accelerate the air flow and reduce the pressure at the venturi throat so that more kinetic energy was available to disintegrate herbicide liquid jets, and thus produce finer droplets of herbicide solution. A laboratory flow rate test indicated that the uniformity of the liquid distribution was much better than with the manifold jet injector.

A field experiment was conducted to evaluate the effect weed control of applying herbicide with the venturi bundled tube jet injector. The venturi bundled tube jet injector treatment could control weeds nearly as well as the two pass incorporation with an "S" tine field cultivator, although the statistical analysis indicated that the venturi bundled tube jet injector provided slightly poorer weed control.

Fluorescent tracer test was conducted to examine and measure the jet penetration distance with the venturi bundled tube jet injector. Mean maximum penetration distances and 95 percent confidence intervals were calculated for different sweep ground speeds and compared with the predicted jet penetration by using the theory developed by Solie and Wittmuss (1983). Theoretically predicted penetration distance at the sweep ground speed of 7.5 km/h was very close to the measured maximum penetration distance confidence interval.

Conclusions

Conclusions derived from this research are:

1. Both the two-fluid manifold jet injector and the

venturi bundled tube jet injector provided slightly but significantly poorer weed control than the two pass herbicide incorporation with an "S" tine field cultivator.

2. The design jet penetration distance was achieved with the both two-fluid subsurface jet injectors. However, an untreated zone existed at the soil surface where weed seeds could germinate.
3. The distribution of incorporation by the venturi bundled tube jet injector was nearly as uniform as that achieved by the two passes with the "S" tine field cultivator in the region where jets penetrated.
4. The jet penetration prediction theory developed by Solie and Wittmuss (1983) could predict the jet penetration distances of the subsurface jet injector quite accurately if the necessary data on the soil properties are available.

Recommendations

The following recommendations are made for further work to overcome several problems with the design of the injector, and to improve the weed control:

1. New liquid jet injector orifices need to be designed in order to solve the plugging problem associated with the venturi bundled tube jet injector.

2. Redesign the turbulence chamber and use more venturi nozzle orifices at the venturi throat to force more materials to the outside tubes in the distribution tube bundles and improve the uniformity of herbicide distribution.
3. Use a wider sweep so that it is possible to mount a larger venturi atomizer below the sweep blades.
4. New atomization device needs to developed to solve the large power requirement problems with the two-fluid atomization.
5. Further work is needed to investigate the soil properties for accurate prediction of jet penetration distances.

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APPENDIXES

APPENDIX A

EXPERIMENT DESIGN

EXPERIMENT DESIGN

#	Incorporation Method*	Herbicide	Rate (L/ha)	Block # I	II	III	IV
				Plot #			
1	Injector 3.8	check	0.00	01	21	12	19
2	Injector 3.8	trifluralin	0.56	02	14	19	06
3	Injector 6.4	trifluralin	0.56	03	03	21	12
4	"S" tine	trifluralin	0.56	04	20	06	10
5	Injector 3.8	trifluralin	0.84	05	15	03	20
6	Injector 6.4	trifluralin	0.84	06	07	04	14
7	"S" tine	trifluralin	0.84	07	18	17	17
8	Injector 3.8	triallate	1.68	08	06	11	13
9	Injector 6.4	triallate	1.68	09	04	16	05
10	"S" tine	triallate	1.68	10	11	14	09
11	Injector 6.4	check	0.00	11	02	10	02
12	Injector 3.8	triallate	2.24	12	10	08	03
13	Injector 6.4	triallate	2.24	13	13	02	08
14	"S" tine	triallate	2.24	14	08	01	11
15	Injector 3.8	metribuzin	0.56	15	12	07	16
16	Injector 6.4	metribuzin	0.56	16	19	15	04
17	"S" tine	metribuzin	0.56	17	01	13	07
18	Injector 3.8	metribuzin	1.12	18	05	09	18
19	Injector 6.4	metribuzin	1.12	19	09	18	21
20	"S" tine	metribuzin	1.12	20	17	20	01
21	"S" tine	check	0.00	21	16	05	15

* Injector 3.8 and injector 6.4 denote that the subsurface jet injector operated 3.8 and 6.4 cm deep, respectively.

APPENDIX B

STAND COUNTS FOR WINTER PEAS, 7 WEEKS AFTER PLANTING, MANIFOLD JET INJECTOR EXPERIMENT

STAND COUNTS FOR WINTER PEAS, 7 WEEKS AFTER PLANTING, MANIFOLD JET INJECTOR EXPERIMENT

#	Incorporation Method	Herbicide	Rate (L/ha)	stands (Plants/m row) Block # I	II	III	IV
1	Injector 3.8	check	0.00				
2	Injector 3.8	trifluralin	0.56	31	37	27	20
3	Injector 6.4	trifluralin	0.56	30	27	26	21
4	"S" tine	trifluralin	0.56	32	28	32	21
5	Injector 3.8	trifluralin	0.84	43	21	24	19
6	Injector 6.4	trifluralin	0.84	32	23	34	29
7	"S" tine	trifluralin	0.84	29	30	18	22
8	Injector 3.8	triallate	1.68	30	32	27	23
9	Injector 6.4	triallate	1.68	28	30	20	19
10	"S" tine	triallate	1.68	35	38	25	19
11	Injector 6.4	check	0.00				
12	Injector 3.8	triallate	2.24	31	37	26	25
13	Injector 6.4	triallate	2.24	24	29	28	22
14	"S" tine	triallate	2.24	27	19	26	25
15	Injector 3.8	metribuzin	0.56	19	29	24	26
16	Injector 6.4	metribuzin	0.56	30	25	29	23
17	"S" tine	metribuzin	0.56	40	23	29	25
18	Injector 3.8	metribuzin	1.12	33	32	18	20
19	Injector 6.4	metribuzin	1.12	28	34	28	26
20	"S" tine	metribuzin	1.12	38	27	25	35
21	"S" tine	check	0.00				

APPENDIX C

SORGHUM DRY WEIGHT DATA, MANIFOLD JET INJECTOR EXPERIMENT

SORGHUM DRY WEIGHT DATA, MANIFOLD
JET INJECTOR EXPERIMENT

#	Incorporation Method	Herb.	Rate (L/ha)	Block # I	II	III	IV
				Sorghum dry weight (g)			
1	Injector 3.8	check	0.00	26.84	136.62	139.05	16.60
2	Injector 3.8	Trifl.	0.56	11.16	50.24	56.38	17.97
3	Injector 6.4	Trifl.	0.56	5.00	12.45	52.76	26.78
4	"S" tine	Trifl.	0.56	1.90	0.01	16.40	7.21
5	Injector 3.8	Trifl.	0.84	8.68	31.34	18.69	4.86
6	Injector 6.4	Trifl.	0.84	19.23	29.25	20.99	23.63
7	"S" tine	Trifl.	0.84	0.13	25.51	7.62	3.76
8	Injector 3.8	Trial.	1.68	159.76	121.89	109.77	83.18
9	Injector 6.4	Trial.	1.68	88.43	77.14	99.75	108.14
10	"S" tine	Trial.	1.68	72.78	76.08	27.30	35.70
11	Injector 6.4	check	0.00	103.11	62.59	66.37	188.55
12	Injector 3.8	Trial.	2.24	91.99	148.24	97.94	121.94
13	Injector 6.4	Trial.	2.24	147.03	90.31	88.64	68.20
14	"S" tine	Trial.	2.24	57.32	107.41	81.51	15.22
15	Injector 3.8	Metri.	0.56	89.36	188.52	111.31	77.41
16	Injector 6.4	Metri.	0.56	82.73	159.57	118.20	185.83
17	"S" tine	Metri.	0.56	131.85	34.34	107.90	85.91
18	Injector 3.8	Metri.	1.12	75.14	91.68	68.16	29.63
19	Injector 6.4	Metri.	1.12	49.65	120.78	156.74	9.00
20	"S" tine	Metri.	1.12	152.24	123.90	118.10	75.12
21	"S" tine	check	0.00	205.93	138.66	97.61	140.17

APPENDIX D

WHEAT DRY WEIGHT DATA, VENTURI BUNDLED TUBE JET INJECTOR WEED CONTROL EXPERIMENT

WHEAT DRY WEIGHT DATA, VENTURI BUNDLED TUBE JET INJECTOR WEED CONTROL EXPERIMENT

#	Incorporation Method	Herb.	Rate (L/ha)	Block # I	II	III	IV
				Wheat dry weight (g)			
1	Injector 3.8	check	0.00	68.23	65.32	13.97	43.49
2	Injector 3.8	trifl.	0.56	5.80	37.08	2.06	6.74
3	Injector 6.4	trifl.	0.56	10.10	11.45	6.17	11.11
4	"S" tine	trifl.	0.56	1.44	0.00	3.28	0.14
5	Injector 3.8	trifl.	0.84	4.06	8.23	6.99	0.13
6	Injector 6.4	trifl.	0.84	13.01	16.92	6.34	12.76
7	"S" tine	trifl.	0.84	0.97	0.00	0.03	0.00
8	Injector 3.8	trial.	1.68	2.13	25.95	9.35	18.51
9	Injector 6.4	trial.	1.68	0.00	36.36	5.09	39.34
10	"S" tine	trial.	1.68	2.70	8.96	16.94	27.58
11	Injector 6.4	check	0.00	1.67	24.98	15.97	75.74
12	Injector 3.8	trial.	2.24	1.81	20.31	1.86	32.39
13	Injector 6.4	trial.	2.24	0.00	14.77	34.21	17.12
14	"S" tine	trial.	2.24	0.00	8.60	16.90	10.45
15	Injector 3.8	metri.	0.56	7.38	56.43	30.90	43.95
16	Injector 6.4	metri.	0.56	2.57	35.69	7.89	34.78
17	"S" tine	metri.	0.56	12.15	21.13	14.01	48.50
18	Injector 3.8	metri.	1.12	0.00	47.24	3.67	36.74
19	Injector 6.4	metri.	1.12	0.00	32.28	5.10	10.63
20	"S" tine	metri.	1.12	4.50	10.32	26.63	66.40
21	"S" tine	check	0.00	7.57	56.44	33.83	35.63

APPENDIX E

SOIL MOISTURE CONTENT ANALYSIS,

VENTURI BUNDLED TUBE JET

INJECTOR FLUORESCENT

TRACER EXPERIMENT

SOIL MOISTURE CONTENT ANALYSIS, VENTURI BUNDLED TUBE JET INJECTOR FLUORESCENT TRACER EXPERIMENT

Sample Content* #	Mass (gms) Wet	Mass (gms) Dry	% Moisture (Dry Wt. Basis)
1	220.80	193.85	13.90
2	193.78	176.34	9.89
3	174.00	154.51	12.61
4	193.52	164.67	17.52
5	181.34	156.87	15.60
6	185.36	167.50	10.66
7	204.92	187.52	9.28
8	248.95	216.48	15.00
9	182.17	159.68	14.08
10	274.90	214.10	14.02
11	265.60	228.70	16.13
12	241.66	204.28	18.30
	Average Moisture Content		13.92

* After oven drying for 48 hours at 120°C.

APPENDIX F

MEASURED PENETRATION DISTANCE DATA WITH THE VENTURI BUNDLED TUBE JET INJECTOR

MEASURED PENETRATION DISTANCES (mm)
WITH THE VENTURI BUNDLED TUBE
JET INJECTOR OPERATING
3.8 CM AT 7.5 KM/H

Observation #	Sample #1	Sample #2	Sample #3
1	29	25	27
2	26	30	31
3	33	28	34
4	37	35	37
5	41	29	29
6	32	32	39
7	27	26	33
8	29	33	36
9	31	40	35
10	26	35	37
11	24	28	24
12	35	34	38
13	40	39	29
14	31	34	38
15	26	31	27
16	27	27	35
17	33	42	31
18	34	35	26
19	29	32	29
20	36	29	28
Means	31.3	32.2	32.2
Std.	4.8	4.6	4.6
Variance	23.3	21.7	21.3
C.V. (%)	15.4	14.5	14.4

MEASURED PENETRATION DISTANCES (mm)
WITH THE VENTURI BUNDLED TUBE
JET INJECTOR OPERATING
6.4 CM AT 4.5 KM/H

Observation #	Sample #1	Sample #2	Sample #3
1	51	36	53
2	62	41	57
3	34	55	38
4	45	39	26
5	36	38	45
6	65	35	34
7	50	47	52
8	46	33	41
9	45	48	39
10	40	42	54
11	48	51	40
12	65	37	36
13	40	52	55
14	62	45	29
15	54	46	49
16	55	32	46
17	37	54	37
18	47	34	42
19	48	49	48
20	52	43	51
Means	49.1	42.9	43.6
Std.	9.4	7.2	8.8
Variance	88.0	52.5	77.8
C.V. (%)	19.1	16.9	20.2

MEASURED PENETRATION DISTANCES (mm)
WITH THE VENTURI BUNDLED TUBE
JET INJECTOR OPERATING
6.4 CM AT 6.4 KM/H

Observation #	Sample #1	Sample #2	Sample #3
1	28	44	36
2	42	21	46
3	34	32	32
4	24	31	34
5	36	28	30
6	39	44	26
7	29	39	36
8	47	34	27
9	38	52	34
10	47	39	44
11	53	48	46
12	48	28	27
13	25	36	35
14	51	31	39
15	33	50	42
16	44	42	50
17	57	45	40
18	47	41	30
19	42	26	57
20	55	32	52
Means	41.0	37.2	38.2
Std.	9.9	8.6	8.8
Variance	98.6	73.5	78.1
C.V. (%)	24.2	23.1	23.2

MEASURED PENETRATION DISTANCES (mm)
WITH THE VENTURI BUNDLED TUBE
JET INJECTOR OPERATING
6.4 CM AT 7.5 KM/H

Observation #	Sample #1	Sample #2	Sample #3
1	32	35	31
2	28	46	60
3	34	35	27
4	38	36	28
5	29	33	30
6	24	45	40
7	32	40	32
8	47	43	33
9	21	35	28
10	44	45	41
11	47	38	39
12	29	39	40
13	31	31	37
14	49	34	39
15	33	29	35
16	24	37	53
17	50	28	28
18	40	37	44
19	43	26	46
20	31	28	39
Means	35.3	36.0	37.5
Std.	8.9	5.9	8.7
Variance	79.0	34.7	75.2
C.V. (%)	25.2	16.4	23.1

VITA

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