Design and Evaluation of Liquid Swine Manure Injectors for Potato Nutrient Placement

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ABSTRACT

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A project was developed to determine the feasibility of using liquid hog manure as a nutrient source (Nitrogen) for the potato crop. A survey of liquid hog manure storage facilities on Prince Edward Island (P.E.I.) provided a sampling technique and the range of nutrients found on hog farms. It was concluded from the data that there were large differences between farms and on farm manure sampling was required to determine accurate nutrient applications. An infrastructure was designed, constructed and tested for storage, handling and the application of liquid hog manure at the Harrington Research Farm, Crops and Livestock Research Centre, Charlottetown, P.E.I. Data from the first of two three year experiments determined that the placement of liquid hog manure under the sown potato row and beside the row (0.23 m) provided yields better than manure placed between the sown rows. These yields were not different for the extra Nitrogen fertilizer treatment. The second field experiment examined the placement of liquid hog manure by various injector designs between the rows after the potato crop was planted. Potato tuber yield data over the three years indicated no differences among injector design nor between the injector treatments and the treatment which received the extra Nitrogen fertilizer. Over both experiments there was a decline in the severity of Rhizoctonia (*Rhizoctonia solani*) in one year for plots receiving manure compared to those which received only inorganic fertilizer. There were no differences in the incidence or severity of scab (*Streptomyces scabies*) over the study. In general liquid manure can be used as nutrient source for the potato crop on P.E.I.

RÉSUMÈ

Un projet fut conçu pour déterminer la faisabilité d'utiliser le lisier de porcs comme source d'azote (de nutriments) pour la culture de la patate. Un sondage fut effectué chez les fermes porcines de l'Ile du Prince Edouard (IPE) pour analyser la teneur en éléments des lisiers en entreposage. Les résultats ont démontré que la teneur en éléments des lisiers variait d'une ferme à l'autre et que la moyenne provinciale ne pouvait pas être utilisée pour établir la valeur fertilisante des lisiers pour une ferme en particulier. Un système fut aussi conçu pour le stockage et la reprise des lisiers à la ferme expérimentale de Harrington, de Centre de Recherche en Culture et Productions Animales d'Agriculture et Agro-Alimentaire Canada à Charlottetown, IPE. Le premier de deux essais de trois ans visait à déterminer si le positionnement du lisier de porcs, entre les rangs de patates, pouvait influencer le rendement. Cet essai démontrait qu'il était préférable de positionner le lisier sous le rang ou à 0.23 m à coté des rangs sans avoir d'effet sur le rendement. L'essai démontrait aussi que le lisier pouvait fournir autant d'azote que les engrais minéraux. Le deuxième essai de trois ans examinait l'effet du placement du lisier de porcs en utilisant plusieurs genres d'injecteur conçu pour placer le lisier entre les rangs de patates. Le rendement en patate n'a pas été supérieur pour aucun des injecteurs il fut le même que celui des parcelles recevant de l'azote sous forme minérale. Pour ces deux essais de trois ans, l'incidence de la maladie Rhizoctonia a diminué pendant un an, pour les parcelles recevant des lisiers de porcs, et en comparaison avec les parcelles recevant des engrais minéraux. Aucun des traitements influençait l'incidence de la gale pendant les trois années d'étude. En générale, l'étude a démontré que le lisier de porcs peut être utilisé comme source d'azote pour la culture de la patate sur l'IPE.

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Chapter 7

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1.1 Introduction

Prince Edward Island is a small province on Canada's east coast. It has a land area of 400,000 ha of which 300,000 are considered to be arable and is referred to as "The Garden of the Gulf." The major agricultural sectors on Prince Edward Island include the potato industry, the dairy industry, the hog industry and the beef industry. Perhaps the most striking on Prince Edward Island is how these sectors are not distinct but are intertwined and dependent on each other for long term stability.

The hog industry on Prince Edward Island is not large by North American standards but does own and operates its own slaughter plant where approximately 185,000 market hogs are processed annually. The hog industry on Prince Edward Island is land based, that is to say that most farms grow all their own feed components. The crop rotation is barley/soybeans or wheat/soybeans. This provides the major feeder ration of barley/roasted full fat soybeans, and a sow ration of barley/wheat/roasted full fat soybeans. Prince Edward Island's self sufficiency in grains and soybeans is achieved with 55,000 and 8,000 ha respectively.

The potato industry on Prince Edward Island provides the major cash cropping operation. The potato acreage has been climbing steadily since 1986 from 26,000 ha to 35,000 ha in 1993. It is projected that the 1995 cropping season will go over the 40,000 hectare mark. This may be due to the increase in processing capacity brought about by the addition of the new McCain's Food Plant and the high farm value of the crop that has averaged $4000 per ha over the last ten years with a high of $5700 in 1989. The most common rotation is potatoes, small grain under seeded to forage and a year of hay or forage.

The dairy sector on Prince Edward Island consists of 540 small production units of 30 to 50 cows generally run by a single family. Beef operations are similarly small with 50 to 100 feeders. These are a forage based system with concentrates fed to maintain high production. Beef cattle are also fed cull potatoes and potato wastes from processing plants. Therefore it is not uncommon to find potato and beef operations linked.

The base of these sectors leads to their interdependence. Thus, the grain and forage produced in the potato rotation are used by the hog, dairy and beef sectors. In many cases on Prince Edward Island, this goes one step further in that fields are traded or shared. For example, a hog farmer will crop the fields for the potato grower when grain is grown in rotation and under-seed the field to a forage crop. In the forage year a dairy of beef farmer might take a cut of hay or silage before the forage is left to grow as a green manure for the following potato crop. Hog and dairy farmers will, in return, give fields to the potato grower. The above outlines the general case and many variations on this theme can be found.

This sharing of the land base naturally leads to a sharing of other resources. Potato growers enjoy the benefits of manure applied prior to the small grain crops in the rotation. Some potato farmers will purchase manure from hog farmers and have it spread on the forage crop in the rotation.

For the hog grower, it is recognized that manure is a cost of doing business. Liquid hog manure is a low value product with high storage and application costs. Manure usage on Prince Edward Island hog farms is presently confined to on farm cropping systems and feed production. The majority of manure is surface spread and incorporated with a disc harrow. Application windows include early spring applications (May first to May fifteenth) prior to the small grain crop, later in the spring (May twentieth to June fifth) prior to the soybean crop and fall applications (October first to freeze up) on any ground which may be cropped the following spring. Thus, it is possible for ground to receive a double application annually. Because the windows of application for the hog farmer are very limited especially in the spring, they lead to delayed planting and reduced yields of barley and soybeans. Small grains are low nutrient users compared to other crops and soybeans do not require the nitrogen applied though they will use it instead of fixing it from the atmosphere.

The direct application of manure to the potato crop offers a new application window with many advantages. Potatoes are a high value crop requiring large nutrient inputs to achieve maximum production. On Prince Edward Island all the fertilizer is applied pre-plant and/or banded at planting time. The high value of the crop insures that the crop will be fertilized for maximum production every year. The amounts vary depending on variety and the previous crop. In the case of Russet Burbank a high yielding late processing variety, fertilizer rates of 200 kg/ha of nitrogen, phosphorus and potash (1200 kg/ha 17-17-17) are required for maximum yields. If only half this requirement were from manure, a 3000 tonne storage could be spread on only 45 ha of potatoes. Manure could be applied after the crop is planted, in June after the spring planting rush, resulting in a wider application window. Injection of manure between the potato rows would eliminate odour problems created during land spreading. Other possible benefits might include improved soil conditions with the addition of organic matter leading to easier cultivating and harvesting.

Thus, the emphasis of this work is to take present manure usage one step further and have the liquid hog manure applied directly as a nutrient source in the potato producing year. This ties in with existing programs at the Charlottetown Research Centre which are examining the effects of previous crop and fertilization practices on nitrogen utilization and leaching losses, prior to, during and after the potato crop. It is therefore proposed to examine application equipment and windows which will allow the potato grower to apply liquid manure to the growing potato crop. This practice would make better use of manure, improve soil conditions and reduce nutrient losses.

1.2 Nature of the Problem

Manure has been used for many years as a nutrient source for many crops in fact before the advent of inorganic fertilizers it was one of the few nutrient sources. The advent of inorganic fertilizers has greatly intensified crop production practices and the farm landscape to single enterprise operations, such as "potato farms", "hog operations", "dairy producers", thus leading to a reduction in the number of mixed farms. These single enterprise operations, on the crop side, are dependent on large inputs of inorganic fertilizers since organic sources are not available from their farm operations. On the other side animal production units have grown in size. More efficient on farm systems have been developed for manure handling and in the case of hog and dairy farms the new systems have moved from solid handling to liquid manure systems. To quote from the introduction, Prince Edward Island has the advantage in that our single enterprises are inter-mixed in terms of location and land use. The problem is that historically manure used as nutrient source for the potato crop was as a solid and was broadcast spread prior to planting. Liquid manure is also broadcast spread thus the window of application is very narrow for manure applied in either form. Spreading manure prior to the planting of the crop might causes delays which are unacceptable to the potato farmer. Expertise and equipment are not available to use injected liquid hog manure as a nutrient source after the potato crop has been planted.

1.3 Objectives

The objectives of this work include compiling and reviewing the previous research work done on; i) manure injection technology, ii) crop performance data relative to injected manure, iii) changes in soils due to liquid manure injection and iv) root development and measurement in situ conditions.

The second objective is to field sample various liquid hog manure storage facilities on Prince Edward Island with subsequent nutrient analysis to determine the nutrient status of liquid manure stored on Prince Edward Island.

A third objective is to design and assemble a liquid manure storage facility at the Charlottetown Research Centre for the receiving, mixing and tanker filling. The design will be followed by the purchasing and calibration of the field application equipment and the conducting of a preliminary field experiment to verify the above designs.

The final objective is to design field experiments which will allow the study of the effects or benefits of liquid hog manure injection into the soil for the fertilization of a potato crop. Primary to this objective, is to examine the factors which maybe considered in the field experiments and deciding on those which can be controlled in the field and of those which are best to examine first and will produce meaningful results.

1.4 Hypothesis

Liquid hog manure is a natural source of nutrients required for crop growth, and the potato crop requires large quantities of nutrients for maximum economic production. The hypotheses of this work are two fold: 1. That injector design has a significant effect on liquid manure placement in the soil, and 2. That liquid manure placement location in the soil has a significant effect on nutrient utilization by the potato crop.

1.5 Scope of the Work

The scope of this work will cover a literature review of topics outlined above, manure nutrient status on Prince Edward Island farms, storage and application equipment and selection and calibration, and two field experiments to establish 1) The nutrient availability of liquid hog manure placement relative to distance from the sown row, and 2) The effect of injector design on manure placement in the soil, subsequent nutrient movement and crop nutrient utilization. Work will be limited to one long season potato variety and will be conducted on small experimental field plots. Liquid hog manure will be provided by a single source and applied at one rate and at a single time during the growing season. Crop nutrient status will be determined by petiole nitrogen measurements.

CHAPTER 2 LITERATURE REVIEW

2.1 Background

Tunney (1981) presents an overview on the fertilizer value of livestock wastes. He noted that the most accepted way to "dispose" of livestock waste was land application. Hall (1986b) presented the benefits and constraints of manure injection.

Table 2.1 The benefits and constraints of soil injection.

Benefits	Constraints
Runoff control	Soil type
Odour control	Soil moisture
Visual aesthetics	Sward damage
Pathogens buried	Weather dependent
No crop taint	Uneven growth
Soil loosening	Stony soil
Improved nutrient management	Higher power requirement
Operational flexibility	Operational complexity

(Hall 1986b)

For purposes of this review, all of these topics will not be covered. This is not to say that we will not benefit nor be limited by the constraints. We will most certainly benefit from the reduction in odour, reduced surface runoff, improved soil loosening and improved operation flexibility. Much of this is proven technology and answers can be obtained from other researchers.

In considering the use of liquid hog manure as a nutrient source for potatoes, we will be most concerned with the design of the manure delivery system and the crop response to the delivered manure.

2.2 Manure and Potatoes

Very little data exist on the use of manure in potato production. Widdowson et al. (1974) relates on experiments conducted in England where various farmyard manure rates were surface applied and incorporated to different depths and compared and combined with fertilizer treatments. The best potato yields were from the highest level of inorganic fertilizers incorporated to the deepest depth. Second to this was where a combination of farmyard manure and fertilizer were incorporated to a shallow depth. This data suggests that there are possible advantages for combined applications of nutrients from both manures and fertilizers but that placement of each in the soil is important.

2.3 Design of Liquid Manure Injectors

Negi et al. (1976b), based on work at the Macdonald Campus of McGill University, (Montreal, Canada), reported on the development of mechanization for the injection of liquid wastes into agricultural soils. It is clear, based on the literature, that this document has become the basis for work from that time forward. Of the 20 or so papers published since then, 11 have been by the same authors or authors working at the same institutions and the vast majority of other papers all reference this work.

This 111 page publication covers the engineering and soils criteria used in the design of liquid slurry injecting tools. Equations were developed for application rates, volumes to be injected, soil pore space required, draft forces for various designs, operating depths, experimental procedures and field verification. Results present optimization for design, depth, draft forces, and volumes of slurry which may be injected by each configuration. Two publications follow this, Negi et al. (1976a) and Negi et al. (1978), which condense various aspects of this original work.

Following on from this work, Godwin et al. (1985) at Silsoe College, England reported on the use of winged tine designs for the injection of liquid sewage sludges into grasslands. They concluded that winged tines allow for a shallower depth of operation while still allowing for adequate volumes of slurry injection. Hann et al. (1987) discussed further work on the design of injection tines. They suggested that the injection tine have a rake angle of 105 degrees and added loaded press-wheels to close the slot and push the grass sod back in place. Also that deep injection depths under dry conditions reduced root damage and the use of an umbilical hose injection system improved trafficablity. Work reported by Warner and Godwin (1988) stated that for injection design purposes, sewage sludge and agricultural slurries were similar. Results reported in this paper were similar to those of Hann et al. (1987).

Godwin et al. (1990) put forward a comparison of an umbilical hose system versus a conventional tanker system. Their conclusions were that the umbilical hose system reduced the injection power requirement by 25 to 50 percent over the tanker mounted system. Net fuel required was reduced by 20 to 30 percent. Increased trafficability meant more field work days and greater work rates in fields larger than 10 hectares thus resulting in a requirement for less on farm manure storage due to earlier and more frequent spreading. The cost of the umbilical system was 20 percent more than that of the conventional surface application systems. Warner et al. (1990) followed this research with a paper which dealt with the economic analysis of slurry treatment and spreading systems for odour control. Conclusions from this paper were that injection costs were 1 to 2 British Pounds/m^3 higher than surface spreading but when compared to other odour control methods (aeration or anaerobic digestion), were 1 to 1.5 British Pounds/m^3 less. At higher daily rates of production (>10 m^3) umbilical hose systems were cheaper than tanker systems. Finally Warner et al. (1991) looked at injection wing design and rake angles to reduce soil disturbance when injecting into grassland conditions. They suggested that a cutting disk in front and a press wheel behind will reduce the amount of soil disturbance during injection.

Feldman and Thuns (1976) at Ottawa, Canada were also working on manure injection. They developed a three tine injection system, front mounted frame which did not inject into the wheel tracks of the tanker but rather injected on only one side of each corn row. The unit required 85-90 horse power to pull it through the field. Feldman and Compton (1981) reported on work to modify this tanker arrangement for sod application where the unit was reduced to two rows and had a cutting coulter and dual press wheels were added.

In New Zealand, Choudhary et al. (1988) looked at the shallow injection of animal slurries and blood from the killing plants. Their design was based on small inverted-T shaped openers set at close spacings. Rates could be adjusted from 30 to 50 m^3 per ha with a gravity fed system.

In Quebec, Canada, Lague et al. (1986) and Lague (1991) designed a gravity fed shallow tine injection system. This system provided delivery rates of over

100 tonnes/ha. This machine was designed to handle liquid manures with a solid content as high as 10 percent.

In Japan, Nambu and Gemma (1981) worked on a roto-tiller type incorporation device. This device was used to inject both cattle and swine liquid wastes at rates up to 162 tonnes/ha.

Safley et al. (1982) in North Carolina, USA developed a plot scale manure injection spreader. This spreader featured a hydraulic drive, positive displacement pump and a self weighting system to accurately control and measure applications to each treatment plot.

Finally on the aspect of design, Marshall (1991) defined shallow injection as 50 mm (2 inches) and deep injection as 150 mm (6 inches). He discussed the commercial machines which are available and new systems including the umbilical hose system. The merits of these systems have been discussed in the earlier reviews.

Summary and Conclusions

The above review covers work done on the design and testing of liquid slurry injectors. Most of this is based on work by Negi et al. (1976b) conducted at the Macdonald Campus of McGill University (Montreal, Canada). This review should provide a suitable background when considering the engineering and soils aspects of the mechanical design.

Further to this, the following points should be considered:

1) Manure combined with fertilizer may provide the best results.

2) Manure location in the soil (depth) may be a factor in the production equation.

3) The design should have a sweep style injector to ensure enough void space.

4) Depth control wheels or slot closing wheels can be added to the injector system to add precision to the depth of deposition and to close the injection slot.

2.4 Crop Responses and Soil Effects of Injected Liquid Slurries

Literature on manure injection is somewhat limited. The major areas studied are corn in the United States and Canada, and grasslands in the United Kingdom and grassland and row crops in Europe. For purposes of this discussion, the following definitions for injection depth will be used; shallow injection will be 50 mm (2 inches) and deep injection will be 150 mm (6 inches)(Marshall 1991). Negi et al. (1976b) discussed injector design and defined the two basic injector types as the chisel, narrow point or knife which injected the manure in a vertical band and the sweep or winged type injectors places the manure into a horizontal band.

Safley et al. (1981) showed that liquid swine manure injected early in spring at 168 kg/ha of nitrogen produced corn grain yields equal to those obtained by using similar nitrogen rates of ammonium nitrate.

Sutton et al. (1982) looked at the effect of manure injection and broadcast application methods and rates on the corn crop response and the soil parameters. Their application rates were in excess of crop requirement for N, P, and K. Their experiments were conducted on a silty loam soil. Manure injection increased corn yields by 2130 kg/ha averaged over the length of their study as compared to broadcast methods at similar application rates. They noted increases in soil levels of NO_3, NH_4, P, and K over the soil profile and were more affected by application method than by application rate. They noted that over the course of their study that there were increasing levels of P and K regardless of the application method. Method of application did affect where, in the soil profile, these nutrients accumulated. Mid summer application times showed higher accumulations of NO_3 and K levels when compared to fall measurement times. They attributed this to the leaching of these nutrients.

Safley et al. (1989) conducted an experiment which examined four factors related to manure injection in corn silage production. They compared: 1) Chisel versus sweeps, 2) High versus low application rates, 3) Spring versus fall application times, 4) Wide spacings of 0.96 m versus narrow spacings at 0.48 m; with a fertilizer check treatment. All their treatments were preplant, not injected as a side-dressing. The formula used for available nitrogen was 100 percent of the ammonium nitrogen plus 30 percent of the organic nitrogen. In year one (1985) of their study, the four way interaction was significant. In 1986 only some of the main effects were significant. In 1987 a number of their two way interactions were significant. In their abstract they dealt only with the recoverable nitrogen from the top 300 mm of soil, rather than crop yields. In the results section, yield data is discussed by year. In 1985 the results were jumbled due to the four way interaction. In 1986 they stated the following effects were noted for crop yield:

Chisel > Sweeps

High rates > Low rates

Narrow spacing > Wide spacing

In 1987, the above was true but only for the fall treatments, not for the spring applied treatments, again this serves to highlight the extent of the significant interactions involved in manure injection research.

Beauchamp (1983) examined the effects of nitrogen source (urea, anhydrous ammonia and liquid cattle manure), application time (preplant versus side-dress) and application methods (surface spread, incorporated, and injected) on the corn crop. As in the case of Safley et al. (1989), Beauchamp found a number of interactions to be significant. First was the year by nitrogen source, second was the year by nitrogen rate and third was the nitrogen rate by nitrogen source. These interactions serve to highlight the effect which seasons (years) have on the response of various nitrogen materials. Beauchamp's study highlighted the fact that each nitrogen source had a different nitrogen delivery system. Beauchamp concluded with a discussion on liquid manure- plant available nitrogen. He suggested that the lower response curve for manure was due to the fact that only about 50 percent of the total nitrogen might be available for crop growth. His rationale for liquid beef manure is as follows:

Manure (200 units)

/ \

Organic N (100 units) | Ammonium N (100 units)

/ \ / \

Mineralized N	Residual N	Volatilization	Ammonia N
(20 units)	(80 units)	(25 units)	(75 units)

Total plant available Nitrogen 20 + 75 = 95 units

This division of nitrogen agrees with the available nitrogen calculations from the field studies he conducted.

Sawyer, Schmitt, Hoeff, Siemens and Vandeholm at the University of Illinois published five papers between 1990 and 1992 dealing with various aspects of liquid beef manure injection and corn production.

Sawyer and Hoeff (1990a) discussed a laboratory experiment designed to examine the effects on soil properties and corn rooting of a simulated knife injected liquid beef manure. They were particularly interested in the nitrogen reactions in and around the injection slot and whether concentrations of the nitrogen compounds were sufficiently high to inhibit root growth. They measured redox potential, pH, soil moisture, NH_4-N, NH_3-N, NO_2-N, and root distribution.

Soil chemical properties were significantly changed at the 38 mm distance from the band but not at the 77 mm distance after seven days. There were significant changes in soil redox potential in the band, to the side, below the band but not over the band. At 14 days, the 38 mm beside the seed measurements were returning to the three inch values. pH values closely paralleled the Eh value discussed above. Soil moistures were also very high in the manure zone.

NH_4-N levels remained high in the zone of application for 28 days after application. Nitrification started between the 14th and the 21th day with increasing levels of NO_3-N and NO_2-N being detached. They stated that chemical changes in and near the injected manure appeared similar to those caused by aeration of the manure.

Corn seeds were planted over the injected row, the same time as the manure placement took place. Root observation indicated no root growth into or below the manure band till 26 days after planting. Deficiency symptoms for nitrogen and phosphorus were noted from 13 days to 23 days after application. These disappeared at 27 days.

Sawyer and Hoeft (1990b) conducted a more detailed greenhouse study of liquid beef manure placement methods with treatments of (knife versus sweep), incubation temperatures of (8.9, 15.5, and 22.2 °C) 21 days prior the corn planting and a fertilizer control. The authors noted a significant reduction in corn growth with all treatments except for the highest incubation temperature of 22.2 °C and the sweep injection method of application. A number of soil properties (redox potential, pH, Mn, NH_4, NO_3, and NO_2) were measured as well as results paralleled those of plant yield.

Sawyer et al. (1990) discussed the effects on soil properties as a result of field injected beef manure. The authors used both sweep and knife types of injectors. After injection, the plots were double disced to a depth of 100-to 120 mm. Corn was planted 2 weeks after application. Soil was sampled in a grid pattern both vertically and horizontally around the manure slot at 1 to 2 week intervals after planting in the first year and only in the centre in subsequent years. In 1985, NH_4 disappearance was rapid with the sweep applicator, after 32 days. With the knife application, high levels of NH_3 were noted for at least 29 days after application. No root growth into the manure placement zone was observed 51 days after application. In the case of the sweep injection levels were high for NH_3 (aq) only 7 to 19 days after application.

Sawyer et al. (1991) conducted field studies on the corn crop. Experiment one had knifed manure treatments with corn planted over the slot, and varying distances away from the slot. Highest corn yields were recorded for seeds planted over the slots with yields decreasing slowly to 84% with placement away to a distance of 0.76 m from the seed. The average yield loss over the two years was 0.53 percent for each 25.4 mm the manure band was moved away from the seed row. These losses were in part due to a lack of nitrogen availability. Corn planted over the row allowed the roots to grow around the manure band in the soil.

In experiment two, manure was knife or sweep (0.61 m wide) injected, or broadcast and incorporated. There were two rates of additional nitrogen (0 and 180 kg/ha) applied as a split plot treatment over the top. Also manure was applied with and without nitrogen inhibitors. Over the four years of the experiment no manure treatments out yielded the control with 180 kg/ha.

Response to manure treatments varied depending on the year with the knife being significantly lower in 1984, and the sweep and broadcast being significantly lower in 1986.

Schmitt et al. (1992) looked at the effect of time and manure rate on the soil chemical properties as they related to poor corn production. As rates of manure increased, there was a linear trend to increasing NH_4-N and the root toxic conditions remained longer in the soil.

Patni and Culley (1989) applied liquid cattle manure to corn by fall broadcast and plow-down, preplant broadcast and disc, side-dress by injection and side-dress by surface application. There were no responses due to manure applications. The authors suggest that this was likely due to residual nitrogen from the previous alfalfa crop.

Wolt et al. (1984) in Tennessee examined the effects of time of liquid swine manure injection on the yield and nutrient content of silage corn. Manure was injected monthly from September to May. Only March applications produced yields comparable to those obtained with inorganic fertilizers. The authors noted that cold temperatures, for five days after injection, lowered crop responses to manure applications.

Lamb and VanRoestel (1994) published the results of a two year field test on liquid swine manure injection for corn in Nova Scotia. Results indicated that manure injection (split pre-plant incorporated and side-dress) out yielded pre-plant incorporated application in one of the two years. Over the two years of the study the split application of manure maintained yields which were equal to those of the fertilizer treatments.

Westerman et al. (1983) conducted a survey across 22 states in the US. They were seeking to determine the perceived harmful effects with the application of manures at agronomic rates. Two conclusions in particular were; that they noted poor crop performance with injected manures, and that the most important area of further research was in the time and rate of applications for optimal crop production.

Comfort et al. (1987) examined manure injection compared to equal quantities of inorganic fertilizers at the same rates for N, P, and K taking into account the availabilities of the above nutrients in the manure. Of concern to them was the build up of soil levels of these nutrients over the three years of the study. They conducted their experiments on three soil types, a loamy fine sand, and two different silt loams. They did not give a description of the injector used only to say that the manure was injected 130 to 220 mm below the soil surface. In the case of the nitrogen additions, the authors noted that there was a large fraction of the manure nitrogen that was unaccounted for at the end of the three year study as compared to that of the inorganic nitrogen fertilizers (ammonium nitrate and diammonium phosphate). Comfort et al. (1987) attributed this to the loss of nitrogen due to denitrification as a result of anaerobic conditions in the manure bands. They also stated that a small part may be due to the manure nitrogen in the organic form in the soil. They note very little build up of either phosphorus or potash from organic or other sources.

Motavalli et al. (1989) reported on the first year nutrient availability for the above study. In general there was less nutrient availability from the manure additions as compared with the fertilization applications. The authors did note the considerable differences between the site year combinations in there nutrient yield data with ranges for N, P, and K being 12 to 63 percent, 12 to 89 percent and 24 to 153 percent respectively. The authors suggest that simple tests may not be sufficient to predict performance from manure sources of nutrients.

Summary

The area of soil and crop responses to manure injection into the soil are complicated and intermixed. It is difficult to separate them in that the manure is in the soil and what happens to the nutrients determines how the crop responds. From the above discussion, the following points must be taken into account in the design of any field experiments involving manure injection.

First, it would appear that when you place the manure, how you place the manure, and where you place the manure have effects on the nutrient availability and possible toxic effects on the growing crop. Second, when comparing manure treatments with each other and fertilizer check treatments multiple interactions between factors occur. For this reason one should avoid multi-factor experiments (more than two factors) until some of the basic questions have been answered. Third, given that most experimenters found that there are year interactions with most factors the experiment should have three years of field data in-order to get a clearer picture of the main effects. Fourth, some authors noted the effect of previous legume crop on nitrogen availability. Thus if nitrogen is one of the nutrients you are considering one should avoid previous legume crops until other factors have been established. Fifth, a number of authors have indicated that the shape of the manure band (vertical versus horizontal) in the soil has an effect on nutrient availability.

2.5 Root Growth, Root Measurement and the Potato Crop

For the purposes of this discussion, potato rooting may be divided into two areas: 1) General root growth and 2) The measurement of root distribution. Linford and McDole (1977) described the Russet Burbank potato as a typical vegetable crop in that it has a shallow rooting system. This variety of potato has a lower efficiency in recovering applied fertilizer nutrients and water than plants with a more fibrous root system. Thus, a number of questions are raised with regards to the use of injected liquid hog manure as a nutrient source for the potato crop. These include the placement of manure nutrients in relation to the root system development, the movement of nutrients due to cultivation and hilling practices, and the movement of the nutrients due to leaching. These in-turn beg the question as to whether the placement of manure causes changes in the rooting pattern and subsequent improvements nutrient and water uptake by the potato crop.

Root measurement techniques

Many approaches to root measurement may be taken. These are broken down into the following, pot or root box studies, field pits with on site measurements, observation wells in the field, and field sampling with subsequent laboratory analysis.

A number of experiments on root development have taken place in pot studies in greenhouses or growth chambers. These studies have the advantages of being able to control some of the environmental conditions, and one is able to recover most of the roots since they are located in a confined space. This highlights the major disadvantage in that the roots quickly reach the outside of the pot and thus bias the study. Root boxes have also been used to examine rooting patterns, these also may be kept in growth chambers or greenhouses. They are a non-destructive method of looking at root development patterns over time but the glass face also alters the pattern as the plant develops (Petitte and Ormrod 1988, Swiezynski et al. 1978, Cao and Tibbitts 1992).

The second method involves the excavation of observation pits dug in the field. In the case of Durrant et al. (1973) and Fulton (1970), these are installed prior to the planting with a glass face sealed to keep light out during non-observation periods, this may also be referred to as an in-field root box. In the second case, a pit is dug after the crop is growing. In the case of the potato crop, the pit is perpendicular to the row (Linford and McDole 1977). A pit is dug and the face is examined for root locations. In some cases counts are made and root diameters are recorded for each position in the field. Another approach is to square the face and excavate in a short distance exposing short lengths of roots. These are then recorded, transferred to a plastic sheet or photographed for later analysis (Boone et al. 1978).

Observation wells are glass tubes which are placed in the ground early in the growing season. They are sealed to keep light out during the growing season. Small fibre optic lenses are fed down the tubes during the growing season to examine root intersections with the sides of the tubes. These may be manually recorded or captured on video tape for later analysis (Parker et al. 1991).

Perhaps the most common method of field observation is to collect soil and root samples from the field, store them in cold rooms, separate the roots from the soil and measure root lengths. Field sampling may take many forms from digging up the entire plant, building square or rectangular samplers to take cross-sectional samples, soil augers to sample various depths or soil cores to various depths. Sampling whole plants has the advantage in that the entire root system may be inspected. The problem is that a large amount of soil is involved, separation is time consuming, thus only a few selected plants may be done (DeRoo and Waggoner 1961).

Taking square or rectangular samples allows the researcher to look at a cross-section from the rooting profile. The sample maybe left intact and done all at once or divided and handled section by section.

Soil cores or auger samples allow more samples to be collected and depending on the diameter, may be smaller in volume than other sampling procedures. In the case of a grass or grain crop, the sampling is in a random pattern. In the case of a row crop such as potatoes or corn, a systematic pattern across and down the row is the preferred option. Below are a number of patterns researchers have choose for sampling potato rows.

Three methods of separating roots from soil have been employed. One is to manually sort through the soil mass by hand and remove the root samples. Two is to wash the soil of the roots with water over a fine sieve. Third is to dry the samples and sieve them to separate the soil and roots (Lesczynski and Tanner 1976).

Lesczynski and Tanner (1976) describe the core method shown in Figure 2.1. The pattern was 100 mm between cores across the row and over the plant and directly between the plants in the row. The sample core was 70 mm in diameter and taken at 100 mm depth intervals. The cores were 85 mm in length for a sample volume of 0.327 m^3. Samples were processed by air drying to 4% and dry sieved. Root lengths were calculated by the line intersect method described in Newman (1966).

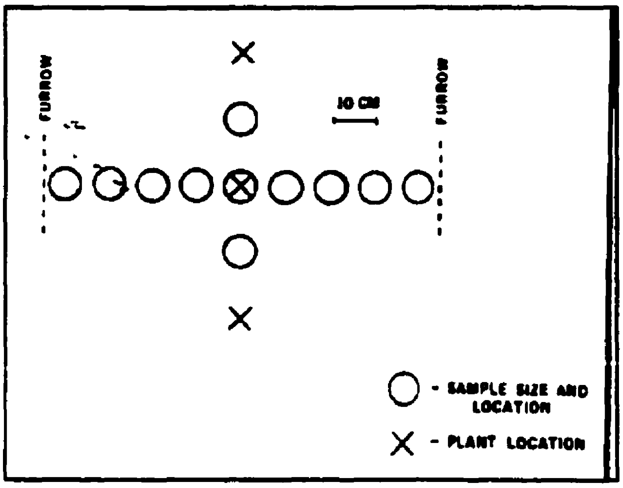

Figure 2.1 Root system sampling pattern, top view. Lesczynski and Tanner (1976)

Ibrahim and Miller (1989) used a bucket auger 72 mm in diameter to sample to a depth of one meter in 150 mm intervals. They sampled in only one position in the center of the row directly between two plants. They stored the samples at 4°C and used a washing procedure to separate the roots from the soil.

Vos and Groenwold (1986) indicated the need for a systematic sampling pattern for row crops such as potatoes. The pattern they chose is shown in

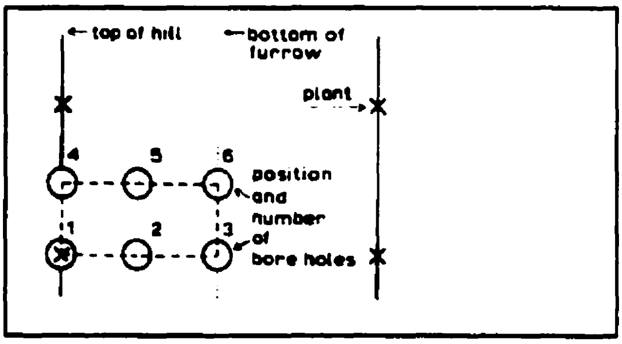

Figure 2.2 Schematic representation of the pattern of root sampling, showing the number of bore holes and their position relative to the plants. The dashed area represents the smallest land area containing all possible systematic variation caused by the planting pattern (top view). Vos and Groenwold(1986)

Figure 2.2. Samples were taken with a 70 mm diameter soil auger and the vertical profile was divided into 100 mm sections. The authors developed the following equation to compile the data:

$$\text{Mean} = (((p1 + p2)/2 + (p2 + p3)/2)/2 + ((p4 + p5)/2 + (p5 + p6)/2)/2)/2 \quad (1)$$

or

$$\text{Mean} = (p1 + 2p2 + p3 + p4 + 2p5 + p6)/8$$

Where px is the position in the row where the roots were sampled.

The purpose of the equation was to develop a measure for a single potato plant, by assigning higher weightings to areas where two plants contribute to the roots collected in a given sample.

In year two of the Vos and Groenwold (1986) study a rectangular box sampler was constructed to sample a 70 mm slice across the furrow to a depth equal to the bottom of the furrow (Figure 2.3). In this case the samples were sectioned, stored at -20°C and later removed from storage and separated. Roots were recovered using a dispersion method with oxalic acid.

Figure 2.3 (a) Schematic representation of the sampler used in 1983 to cut out slices of hills. The division into subsamples A-F is indicated, as well as the relative sizes of the subsamples. (b) The device to record the shape of the hills. The freely movable, vertical pegs were calibrated (cm-scale) and their heights above the vertical bar of the frame were recorded. These readings were used to calculate the volumes of the subsamples A, B, C, D, E and F. Vos and Groenwoild (1986)

Two other methods using radio-active tracers have been described. Sen Tran and Giroux (1991) used labelled ^{15}N to determine nitrogen uptake and partitioning by the potato plant. Roots were recovered during the growing season and nitrogen ^{15}N contents were determined. Saoud et al. (1992) also studied the nitrogen uptake and efficiency of the potato crop using ^{15}N nitrogen. Swaminathan and Verma (1997) injected ^{32}P phosphoreus into an above ground plant stem. Experiments were conducted in pots and soil cores were taken and analyzed for ^{32}P content to determine root growth in the soil.

Image analysis of extracted roots

Root measurements have been of interest since the study of plants and cultivation. Many early methods involved the digging of pits and manually examining the excavated surface. For the purpose of this discussion, the Newman (1966) study will be used to described the development of new method which allowed the estimation of root length. Roots were separated from the soil and floated on a dish where the roots were dispersed. The water was then removed and the dish placed under a microscope. A straight line on the eye piece of known length was randomly positioned over the roots and the number of intersections (N) between the straight line and the root hairs were counted. The length of straight (H) lines is calculated from the number of times the eye piece is moved. The area (A) is that which contains to roots on the dish. The method was called line intercept and an estimated root length can be determined by the following equation:

$$R = Pi * N * A/2H \quad (2)$$

Where: R = The total length of roots in mm

Pi = 3.1417

N = The number of intersections

A = The area of the rectangle containing the roots mm^2

H = The total length of straight lines mm

Much of the work on root measurements which follows in the literature uses this technique to determine root lengths.

Potato root development

The potato is a shallow rooted crop. Studies have been conducted over the years examining the root system and the parameters which affect its development. An examination of the literature suggests that the major contributing factors affecting the development of potato crop root systems are soil compaction, soil moisture levels, nutrient placement in the soil, varietal differences and soil pathogens present.

Soil compaction

Unger and Kaspar (1994) in a paper titled "Soil Compaction and Root Growth: A Review" set an excellent background for the discussion of potato crop root systems. In reviewing the literature they made the following observations. First that when soil strength reaches a critical level, root growth and development is restricted to the point where plant growth, nutrient uptake and yield may be affected. This may be the result of natural or induced soil compaction. Second, generally the whole root system is not adversely affected by soil compaction, thus compensatory growth may take place changing root distribution in the soil.

Third, even when root development is compromised weather conditions, and general fertility may allow no changes in crop production (yield).

Boone et al. (1985) summarized a series of experiments examining the relationships between soil physical properties and the potato root development under differing soils and soil conditions in the Netherlands. In the case of dry soil conditions the plow pans acted as a absolute barrier to root penetration. In a wet year on the same soil there was some root penetration into and through the plow pan. In both years the authors considered mechanical impedance as the main deterrent to root growth into the plow pan and the sub-soil below. The authors also noted that removal of the plow pan had only a small influence on root development into the soil. They suggest that the lack of improvement in root development was due to the nature of the sub-soil in also preventing deeper root development.

Van Loon and Bouma (1978) reported on the plant and yield responses to the experiments conducted by Boone et al. (1985). The authors stated that soil compaction reduced early plant and root development. This subsequently led to large reductions in marketable yield but not necessarily total yield. Difference in yield were attributable to more small tubers and mis-shaped tubes in the soil compaction treatments.

DeRoo and Waggoner (1961) reported on plot experiments in which the plow pan and sub-soil were manually broken up prior to planting. In their experiments they were able to encourage root growth into the deeper profile. Bulk density readings of 1.16 t/m^3 and cone penetrometer reading confirmed the loosening effects. They concluded that mechanical impedance was the principle cause of the lack of root penetration. In commercial potato fields, the differential distribution of root structures was related to the compaction created in the traffic furrow.

Ibrahim and Miller (1989) were interested in the effects of subsoiling and in-row subsoiling on potato and corn crop development under various irrigation schedules. On the sand soil, tuber yield was not affected by subsoiling unless irrigation frequency was reduced from daily to a four day period. Subsoiling did however increase the percent of U.S. #1 tubers under both irrigation strategies especially under the longer interval times. The authors overall conclusion was that subsoiling was not beneficial if irrigation (soil moisture) was adequate.

Linford and McDole (1977) went into a number of commercial potato fields to examine rooting patterns and soil compacted layers. In most of the fields, compacted zones existed and reduced or stopped root penetration deeper into the soil. Removal of these layers could be achieved using a ripper with a shank spacing of 0.46 m and operating at a depth of 0.31 to 0.46 m deep. Perhaps most important the authors discovered that even though there was a lack of root penetration, yields were not affected if the plants were not stressed during the growing season. In ripped fields, the authors noted deeper rooting systems and plants which were more stress resistant.

Soil moisture

The discussion on soil compaction is often linked to studies of soil moisture. This is also true of other parameters in that they are seldom studied as a single entity.

Ibrahim and Miller (1989) studied irrigation frequency and subsoiling to conclude that increasing irrigation frequency from a four day to one day interval prevented moisture stress and allowed for maximum marketable yields.

Fulton (1970) and Durrant et al. (1973) examined the potato crop's ability to remove water from the soil. Fulton compared the potato crop to corn and tomatoes. From his observations, he concluded that the potato crop had a lower capacity for water absorption, thus; most of the potato root system had to have access to low water tension soil in-order to avoid water stress under maximum growing conditions. Durrant et al. (1973) compared moisture removal rates by sugar beets, potatoes and barley under field conditions by measuring soil moisture profiles. The authors discovered that over the growing season, potatoes extracted less moisture than the other two crops especially below the 0.6 m depth.

Singh and Struchtemeyer (1976) and Fatemy and Evans (1986) conducted pot experiments examining moisture stress and other related factors. Singh and Struchtemeyer (1976) were interested in the effects of plant anatomy. With increased moisture stress, the plants developed larger water carrying structures in both the stems and roots. Fatemy and Evans (1986) on the other hand were interested in the relationship between moisture stress and nematode infection. They noted that as plants were moisture stressed, the shoot to roots ratio was reduced and more roots developed. When nematode infection was superimposed, the root system became larger but water and nutrient carrying efficiency decreased as a result of the infection.

It is clear from the above discussion that the potato crop is not one of the best plant types for water removal. This is in great part due to the shallow nature of the root system and in part to the poorer moisture up take capacity of the plant. Remedial actions such as subsoiling will help reduce moisture stress in some cases by breaking hard pans and allowing deeper root penetration.

Nutrient placement effects on root development

DeRoo and Waggoner (1961) looked at the deep placement of fertilizer or the placement of fertilizer in the upper layer of the loosened subsoil. In comparison to loosening alone, they detected no greater root development resulting from the placement of the fertilizer. The authors were unable to explain the lack of additional root development in the enriched soil.

Summary

In the discussion on potato root development and measurement we may make the following conclusions. The potato crop is considered to have a shallow rooting system. Soil compaction often further restricts root growth to the upper layers of the soil. For these reasons the crop is easily subjected to moisture stress and thus responded well to irrigation.

In sampling for root development in the potato crop a systematic system should be used due to the row placement of the crop. This systematic procedure should be kept in mind as one develops sampling procedures for other aspects of potato crop production.

Connecting Text Chapter 2 to Chapter 3

As a starting point for work with liquid hog manure, a survey of manure storage facilities and manure nutrient content on P.E.I. was conducted. Manure was characterized for nutrient content and the results are presented in Chapter 3. I wish to acknowledge the assistance of Dr. John MacLeod in preparation of the manuscript and Christina Stewart and Lloyd Kerry in sample collection and analysis. This paper has been published in Canadian Agricultural Engineering 39(1)043-048.

CHAPTER 3 NUTRIENT CHARACTERIZATION OF STORED LIQUID HOG MANURE

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3.1 Abstract

Liquid swine manure from eight Prince Edward Island concrete storage facilities was sampled at three depths in the fall of 1992. Samples were analyzed for dry matter (DM), NH_4^+-N, P, K, Ca, Mg, S, Cu, Zn, Mn, Fe, and B. Dry matter content and most nutrient concentrations declined as sampling depth increased except K and B which had the highest concentration at the mid depth. Samples taken from the mid depth generally represented the average manure nutrient concentrations in the storage. There were significant differences between farms on a volume basis for all parameters except P, Mg, Zn, Mn and Fe and on a DM basis except for NH_4^+-N, Mg, and Mn. High manure Cu concentrations on some farms suggests that Cu toxicity problems could occur over time with high annual application rates on low pH soils. A regression analysis of the nutrient concentrations against DM indicated that P, Ca, Mg, S, Mn, and Fe could be predicted if DM content were known but DM content was not helpful in predicting NH_4^+-N, Zn, K, B, or Cu.

3.2 Introduction

Swine manure chemical characteristics are generally expressed in terms of maximum, minimum, average and, in some cases, standard deviation values (Tunney and Molloy 1975, Beauchamp 1983, Fraser 1985, Collins et al. 1988, and Kumar et al. 1990). These characteristics vary widely, often by a factor of 3 to 4 times. Animal diet, animal age, type of storage, manure handling system and water content are possible sources of this variation (Beauchamp 1983; Tunney 1980).

Less information on the micro-nutrient content of swine manures is available. Zublena et al. (1990) provided information on concentrations of micro-nutrients for liquid hog manure. Maschhoff and Muehling (1985) and the ASAE Yearbook (1990) list amounts of micro-nutrients produced per animal unit but do not refer to the concentration of micro-nutrients in the stored manure.

Overcash et al. (1983a) discussed the qualities of manure produced by various livestock sectors, including both macro- and micro-nutrients based on animal production units. Overcash et al. (1983b) discuss the land-limiting constituent (LLC) approach for maximum manure application rates. This approach is based on crop nutrient removal rates, nutrient losses, and the ability of the soil to assimilate nutrients over time. Christie (1990) examined micro-nutrient build-up on a clay loam soil, over a 19-year manure application experiment. He determined that Cu levels were within 86% of the soil's allowable maximum after 19 years of manure applications of 200 $m^3ha^{-1}year^{-1}$ on low pH soils.

With the introduction of storage structures of known geometry, systematic sampling can provide farmers and researchers with a means of determining manure nutrient concentrations. This would provide an improved method for making comparisons of manure handling systems and their influence on manure nutrient concentrations. This system of systematic sampling could provide the farmer with a pre-spring estimate of the manure nutrient concentrations and amounts. The objectives of this study were to select suitable equipment, develop on farm procedures for the systematic sampling of stored liquid swine manure and characterize the stored manure of a number of Prince Edward Island hog farms.

3.3 Materials and Methods

Manure storage facilities on eight hog farms were sampled in the fall of 1992. A list of swine production facilities was obtained from the P.E.I. Hog Commodity Marketing Board and eight farms were selected at random from each county across the Island. The nutrient concentrations of manure in various concrete storage structures were characterized by sampling manure at different depths down the side of each storage structure. Each storage was sampled at three depths, shallow (0.5 meters from the top of the storage), mid (the centre of the storage) and deep (0.5 meters from the bottom of the storage). Samples were taken from near the edge of each storage and were replicated twice for a total of six samples per storage.

For the purposes of this study an ISCO 3700 Automatic Sampler Model Number 68-3700-001 (ISCO Corp., Lincoln, Nebraska) was selected. The unit has built-in software which controls a peristaltic pump and allows for sample line purging and measured volume sampling. It also produces an output report of the sample number, date and time. The unit contains a 175 mm long strainer with 7 mm inlets. These units are designed for waste water sampling, are weather protected and have an internal power supply. This sampler has 24, 500 ml bottles, thus allowing four farms to be sampled into one tray.

A sectioned rod, marked in half meter intervals was constructed and used to measure the depth of the storage pit. The rod with the strainer and connecting tube was lowered into the storage and samples taken at the predetermined depths.

Chemical analysis

For NH_4^+ analysis, liquid manure samples were agitated and a 50 ml subsample was collected and centrifuged. A 1:10 dilution was prepared in duplicate for each centrifuged sample. The AOAC approved determination of NH_4^+ as outlined in Industrial Method No. 825-87T of the Technicon Traacs 800 Auto Analyzer manual (Bran + Luebbe Analyzing Technology Inc. 1987) was used to determine the NH_4^+ levels directly from each prepared sample.

For dry matter (DM) determination, a 20g subsample was collected in a tared crucible from the agitated liquid manure sample. The crucibles were placed in a laboratory oven at 80 C. for 24 hours. The oven-dried samples were placed in a desiccator until they had cooled to room temperature after which they were reweighed. The DM was then calculated by difference.

Other macro-nutrients and micro-nutrients were determined by Inductively Coupled Argon Plasma Spectrophotometry (ICAP). Oven-dried samples were placed in a cold muffle furnace and ashed for 3.5 hours at 500 C. The contents of the crucibles were cooled, treated with 5 ml of 2N HCl, transferred to a 50 ml centrifuge tube and diluted to 50 ml with distilled water. Samples were agitated and centrifuged and two ICAP analyses were performed on each sample. ICAP results provided values for P, K, Ca, Mg, S, Cu, Zn, Mn, Fe and B.

Analysis of variance was conducted to determine differences between storages (main plots) and sampling depth (sub-plots). Regression analysis was conducted to determine the relationship between DM and the nutrient concentrations of the manure, and testing whether the slope (b) or y-intercept (a) was significantly different from zero.

$$[c] = a + b * DM$$

Where $[c]$ = Nutrient concentration

a = Y-intercept

b = Slope

DM = Dry matter

The analysis was conducted using Genstat V (1987).

3.4 Results and Discussion

Sampling depths

For the eight storage facilities the DM, NH_4^+-N, S, and B concentrations on a volume basis did not vary significantly with sampling depth (Table 3.1). Phosphorus, Ca, Mg, Cu, Zn, Mn, and Fe concentrations declined as sampling depth increased, while K concentration increased. The sample taken from the mid depth corresponded well with the average concentration across the storage (Table 3.1).

Between storage variations

Across all farms in this study, concentrations of DM, NH_4^+-N, K, Ca, S, Cu, and B on a volume basis varied significantly, while P, Mg, Zn, Mn, and Fe concentrations did not differ (Table 3.2). Most nutrient concentrations on a DM basis varied significantly among farms except NH_4^+-N, Mg, and Mn (Table 3.3). This suggests that differences in concentrations are not simply dilution effects from varying amounts of water use but are due to differences in feeding and other management practices.

A comparison of results from other studies indicates that macro-nutrients levels in Prince Edward Island stored swine manure were similar to those of other regions in Canada, the United States and Europe. Average values from Prince Edward Island were very similar to those reported by Beauchamp (1983) in Ontario and Kumar et al. (1990) in the United States. The nutrient values from England reported by Tunney and Molloy (1975) were in line with readings from Prince Edward Island when one considered the more than two-fold difference in DM for the English manure.

Zublena et al. (1990) reported levels of secondary and micro-nutrients in liquid swine manure effluent of North Carolina. When compared to Prince Edward Island levels, Ca, Mg, S, Fe, Mn, Zn, and Cu were all within an order of magnitude. Boron was markedly different at 8.2 g/m^3 in North Carolina compared to 1.12 g/m^3 in Prince Edward Island. This was likely due to the use of rations based on grain produced on soils low in B (Gupta, 1971)

Copper levels among farms appeared to be divided between groups of low range of (3.75 g/m^3) and high (18.5 g/m^3) concentrations. This is possibly due to levels of Cu added to the ration for growth-promoting reasons (Pond and Maner 1984). Christie (1990) found that, based on annual swine manure application rates of 200 m^3/ha (manure Cu content ranged from 3.5 to 53.5 mg l$^{-1)}$ over a 19-year period, Cu levels in the clay loam soil were raised to 86% of the maximum allowable limit on a low pH soil. The higher Cu concentrations in the

Prince Edward Island manure were similar to those in the manure applied by Christie.

Nutrient concentrations versus dry matter content

In an attempt to use DM as a predictive tool, nutrient concentrations were regressed against the DM content of the manure (Table 3.4). The constant or y-intercept (a) was significantly different from zero for the highly soluble nutrients NH_4^+-N, K, and B suggesting that a portion of their nutrients was related to the liquid fraction and not the solid properties of the manure.

The slope coefficient was significant ($P<.01$) in all cases when concentrations were compared to the DM content of the manure (Table 3.4). Phosphorus, Ca, Mg, S, Mn, and Fe had reasonably good R^2 values suggesting these might be predicted if DM content of the manure were known. Ammonium nitrogen and Zn R^2 values were in the mid-range which would suggest dry matter could not be used as a predictive tool. The R^2 values (Table 3.4) for K, B, and Cu were low. In the case of the soluble nutrients K and B this could be due to the fraction of the nutrients in the liquid portion. In the case of Cu, it is due to the wide variations between storages as discussed earlier.

3.5 Conclusions

The waste water sampling equipment used in this study, an ISCO 3700 Automatic Sampler Model Number 68-3700-001, proved to be a valuable tool for consultants or researchers sampling manure slurries in concrete storages. A number of depths and locations could be quickly sampled and processed to get an accurate measure of nutrient concentrations in the manure storage.

Average nutrient concentrations for the swine slurries in Prince Edward Island manure storage facilities were within the range of those measured in other parts of Canada, the United States, and Europe. There were significant differences in DM and nutrient concentrations between storages; therefore for best nutrient utilization from land application, individual storage sampling is required. Among storage facilities, differences were found on both a volumetric and a dry matter basis, indicating that differences were due to more than just a dilution factor.

Although concentration differences were detected among depths of liquid manure storage facilities, in most cases sampling from the mid depth provided results that were representative of the storage.

High Cu levels in manure on some farms suggests Cu soil toxicity problems could occur if high annual application rates are used for a long time.

A regression analysis showed a relationship between DM and P, Ca, Mg, S, Mn, and Fe suggesting that these nutrients could perhaps be predicted from DM content. Ammonium nitrogen concentrations could not reliably be predicted from the dry matter content.

3.6 Acknowledgments

The authors wish to acknowledge the assistance of L. Kerry and D. Grimmett in the collecting and analysis of the manure samples.

3.7 References

ASAE 1990. ASAE D384.1. Manure production and characteristics. 463-465 In *ASAE Standards 1990*. 37th Edition. ASAE, 2950 Niles Road, St. Joseph, Michigan, 49085-9659, USA.

Beauchamp E.G. 1983. Manure for crop production. Publication Number 83-039. Agdex Number 100/538. Ontario Ministry of Agriculture and Food, Toronto, Canada.

Bran+Luebbe Analyzing Technology Inc., 1987. Elnsford, New York, USA. Technical Publication Number DSM-0005-00.4.

Christie P. 1990. Accumulation of potentially toxic metals in grassland from long-term slurry application. In *Fertilizer and the Environment.* 24-130 Edited by Merckx R., Vereecken H., and Vlassak K. Leuven University Press, Karkenstraat 3, B 3000 Leuven/Louvain, Belgium.

Collins E.R. Jr., T.A. Dillaha, F.B. Givens and C.D. Eddleton. 1988. Farm manure management planning for Virginia. ASAE Paper 88-2048. St. Joseph, MI:ASAE.

Fraser H. 1985. Manure characteristics. Publication Number 85-109. Agdex Number 538. Ontario Ministry of Agriculture and Food.

Genstat V 1987. Reference Manual Clarendon Press, Walton Street, Oxford, England.

Gupta U.C. 1971. Boron and Molybdenum nutrition of wheat, barley, and oats grown in Prince Edward Island soils. *Canadian Journal of Soil Science* 51:415-422.

Kumar D., C.D. Eddleton, E.R. Collins, and T.A. Dillaha. 1990. Characterization of manure nutrient values in Virginia. ASAE Paper Number 90-2024. St.Joseph, MI:ASAE.

Maschhoff K.D. and A.J. Muehling. 1985. Using nurse tankers to transport liquid manure to the field from a 650-sow farrow-to-finish operation. 55-62 In *Agricultural Waste Utilization and Management* Dec 16-17, 1985 By ASAE, 2950 Niles Road, St. Joseph, Michigan, USA.

Overcash M.R., F.J. Humenik, J.R. Miner. 1983a. *Livestock Waste Management. Volume I.* 180-248 CRC Press Inc, 2000 Corporate Blvk., N.W., Boca Raton, Florida, USA.

Overcash M.R., F.J. Humenik,and J.R. Miner. 1983b. *Livestock Waste Management. Volume II* 163-235 CRC Press Inc, 2000 Corporate Blvk., N.W., Boca Raton, Florida, USA.

Pond W.G., and J.H. Maner. 1984. *Swine Production and Nutrition.* 546-547. AVI Publishing Company, Inc. Westport, Connecticut, United States.

Tunney H. 1980. Fertilizer value of animal manures. *Farm and Food Research* 11(3)78-79.

Tunney H., and S. Molloy. 1975. Variations between farms in N, P, K, Mg and dry matter composition of cattle, pig and poultry manures. *Irish Journal of Agricultural Research* 14:71-79.

Zublena J.P., J.C. Barker and J.W. Parker. 1990. Swine manure as a fertilizer source. *Soil facts.* Publication Number AG-439-4. The North Carolina Agricultural Extension Service.

Table 3.1 Summary of nutrient concentrations for sampling depths reported on a volume basis, averaged over the eight farms.

	Sampling depths				
	Shallow	Mid	Deep	SED	Average Nutrient
Dry Matter kg/m^3	31.90	29.20	25.40	ns	28.8
Ammonium kg/m^3	3.31	3.69	3.59	ns	3.53
Phosphorus kg/m^3	0.94	0.76	0.59	.12 *	0.77
Potassium kg/m^3	1.52	1.72	1.67	.05 **	1.64
Calcium kg/m^3	0.86	0.71	0.56	.11 *	0.71
Magnesium kg/m^3	0.36	0.26	0.20	.05 *	0.27
Sulphur kg/m^3	0.32	0.30	0.28	ns	0.30
Copper g/m^3	12.6	12.2	8.12	1.4 **	11.0
Zinc g/m^3	39.9	29.7	23.9	4.9 *	31.2
Manganese g/m^3	14.0	10.9	8.46	1.9 *	11.1
Iron g/m^3	57.0	46.1	36.1	6.6 *	46.4
Boron g/m^3	1.11	1.16	1.08	ns	1.12

SED Standard error of the difference
* Significant at the 0.05 percent level
** Significant at the 0.01 percent level
Shallow- Sampled at 0.5 m from the storage surface
Mid- Sampled at the centre depth of the storage
Deep- Sampled at 0.5 m of the bottom of the storage

Table 3.2 Summary of nutrients for the farms sampled in the study reported on a volume basis averaged over depth.

	Farms in the survey								
Nutrients	1	2	3	4	5	6	7	8	SED
Dry matter kg/m^3	18.3	19.8	22.0	28.7	31.8	34.2	40.3	53.5	6.4 **
Ammonium kg/m^3	2.68	1.45	2.77	3.50	4.28	4.55	5.33	5.67	.30 **
Phosphorus kg/m^3	0.42	0.63	0.66	0.93	0.81	0.93	0.96	0.80	ns
Potassium kg/m^3	1.08	0.69	1.47	1.77	2.00	2.04	2.97	1.90	.10 **
Calcium kg/m^3	0.48	0.59	0.50	0.67	0.87	0.80	0.78	1.14	.20 *
Magnesium kg/m^3	0.17	0.23	0.26	0.31	0.25	0.33	0.26	0.36	ns
Sulphur kg/m^3	0.18	0.18	0.26	0.27	0.25	0.30	0.58	0.74	.42 **
Copper g/m^3	3.21	3.80	18.0	18.2	3.75	18.9	13.7	8.60	2.6 **
Zinc g/m^3	22.3	36.3	19.3	35.1	34.0	38.7	26.2	19.3	ns
Manganese g/m^3	6.52	9.97	9.55	12.5	12.0	13.2	14.2	14.1	ns
Iron g/m^3	32.8	34.2	42.1	49.9	54.4	63.5	49.8	45.7	ns
Boron g/m^3	0.49	0.48	1.12	1.08	2.03	1.11	2.36	0.67	.10 **

SED Standard error of the difference
* Significant at the 0.05 percent level
** Significant at the 0.01 percent level

Table 3.3 Summary of nutrients for the farms sampled in the study reported on a dry matter basis

	Farms in the survey								
Nutrients	1	2	3	4	5	6	7	8	SED
Dry matter kg/tonne	18.3	19.8	22.0	28.7	31.8	34.2	40.3	53.5	6.4 **
Ammonium kg/tonne	152	123	143	122	134	146	133	107	ns
Phosphorus kg/tonne	22.4	28.4	28.9	32.5	25.3	26.7	28.8	15.1	2.7 **
Potassium kg/tonne	61.5	61.3	75.8	61.8	62.7	64.9	73.7	35.3	16.7 **
Calcium kg/tonne	26.0	25.4	22.3	23.5	27.2	23.2	23.3	21.5	1.7 **
Magnesium kg/tonne	9.20	8.70	10.8	10.8	7.70	9.10	7.90	6.80	ns
Sulphur kg/tonne	9.90	11.7	11.9	9.30	7.70	9.40	14.4	13.9	.77 **
Copper g/tonne	173	195	731	636	118	565	342	166	48.3 **
Zinc g/tonne	1186	1639	778	1225	1067	1141	651	738	131 **
Manganese g/tonne	342	388	389	436	376	379	353	265	ns
Iron g/tonne	1753	1476	1755	1743	1704	1846	1237	870	145 **
Boron g/tonne	27.4	36.6	56.4	37.5	63.5	34.4	58.7	12.6	3.3 **

SED Standard error of the difference
* Significant at the 0.05 percent level
** Significant at the 0.01 percent level

Table 3.4 Summary of regression analysis -nutrients versus DM

Nutrients	Constant	Coefficient	R Squared	Variance
NH_4^+-N kg/m^3	1.597 **	0.0672**	0.45	34.54 **
Phosphorus kg/m^3	0.0078 ns	0.0024**	0.68	89.72 **
Potassium kg/m^3	0.0912 **	0.0025**	0.29	18.02 **
Calcium kg/m^3	-0.0019 ns	0.0025**	0.85	233.13 **
Magnesium kg/m^3	-0.0016 ns	0.001**	0.70	100.09 **
Sulphur kg/m^3	0.0001 ns	0.0011**	0.71	103.41 **
Copper g/m^3	3.95 ns	0.2448**	0.14	7.71 **
Zinc g/m^3	2.98 ns	0.977**	0.52	46.4 **
Manganese g/m^3	-0.14 ns	0.3906**	0.73	111.89 **
Iron g/m^3	9.04 ns	1.295**	0.61	67.15 **
Boron g/m^3	0.598 **	0.018**	0.14	7.69 **

ns Not significant
* Significant at the 0.05 percent level
** Significant at the 0.01 percent level

Connecting Text Chapter 3 to Chapter 4

Having determined the nutrient characteristics of liquid hog manure on P.E.I., it was necessary to assemble an infrastructure at the Harrington Research Farm, Crops and Livestock Research Centre, Charlottetown P.E.I. for the storage and application of liquid hog manure. The next Chapter outlines the storage and handling facilities developed along with the application equipment and calibrations. I wish to acknowledge Dr. Suzelle Barrington's assistance in preparing the manuscript and Lloyd Kerry for his technical assistance. This article is to be submitted to Canadian Agricultural Engineering for publication.

CHAPTER 4 LIQUID MANURE STORAGE AND APPLICATION EQUIPMENT DEVELOPMENT, CALIBRATION PROCEDURES AND FIELD VERIFICATION IN THE POTATO CROP

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4.1 Abstract

An infrastructure was developed and put in place at the Charlottetown Research Centre of Agriculture and Agri-food Canada to allow for field research on broadcast application and injection of liquid hog manure into potato crop production systems. The storage facility consisted of two up-right plastic tanks with a total volume of 40,000 l connected to a mixing pump. The field equipment included a 9100 l tanker with individually controlled injectors. Calibration procedures were developed for both broadcast and injection manure applications. A field preliminary experiment was conducted on the timing of liquid hog manure injection into the growing potato crop to verify the equipment selection. Results of the field experiment showed small differences in yield distribution but no differences in total yield of the potato crop. Neither scab (*Streptomyces scabies*) incidence nor severity were increased by manure injection treatments as compared to the fertilizer treatment. Successful completion of the preliminary field experiment validated the performance of the storage facility in terms of manure handling and mixing, and the field injection system in terms of calibration procedures and the ability to inject liquid hog manure into the potato crop at various grow stages.

4.2 Introduction

The Charlottetown Research Centre of Agriculture and Agri-food Canada located on Prince Edward Island has a mandate for research into various aspects of crop production pertaining to potatoes, cereals, protein crops and forages. The Centre does not have a swine facility on site to provide manure for crop production studies, so studies to this point have concerned themselves with the use of mainly inorganic fertilizers for crop production systems. This however is not the case on many farms on P.E.I., where on livestock operations, manure is an integral part of the production system. Also, the nature of farming on P.E.I. is such that land is often traded throughout the crop rotation between potato growers, hog farmers and dairy producers. This means that manure is not just used for the feed crop production but thus becomes part of the potato crop production system as well. At present manure is used on the other crops in the rotation not generally directly on the potato crop. Development of application strategies which would use manure directly on the potato crop would expand the use of manure to the potato crop which has a large nutrient requirement. One of the ways manure could be used in the potato production system would be to inject the liquid manure between the potato rows after the crop was planted. This procedure was untried but had advantages in that it expanded the windows of application for liquid manure from a short period in May before the crop was planted to the month of June when planting was finished and both the hog farmer and potato grower had more time. Injection also would reduce odours resulting from surface spreading and with the correct injector designs would allow the potato crop to make maximum use of the nutrients in the liquid manure.

Before any major field experiments could be put in place at the Charlottetown Research Centre, an infrastructure for manure handling had to be developed, application equipment purchased, modified and calibrated, and experimental field designs determined. This paper serves to describe this process, and the design rationale for these developments as a basis for further research work.

The objectives of this work were as follows:

1. To ensure a storage facility with sufficient capacity to meet the requirements for manure sampling, mixing, and ease of handling for liquid hog manure on a site close to the field experiments.
2. To develop calibration procedures for field application equipment.
3. To verify the design by conducting a preliminary field injection experiment with a potato crop, looking at crop damage and disease incidence (scab) (*Streptomyces scabies*) caused by manure injection and injection equipment at different times of application.
4. To determine in-field performance of the manure injection equipment.

Completion of these objectives were required before more detailed experiments could be conducted on in-field manure injection for potato production.

4.3 The Experimental Equipment

Design of the liquid manure storage facility

The information basis for the design of the storage facilities at the Charlottetown Research Centre was provided in Campbell et al. (1997), where the nutrient content of a number of liquid hog manure storage facilities located on P.E.I. were reported.

The first design consideration was that the storage have sufficient volume to allow the application of manure to a complete set of treatments before the storage had to be refilled. Thus only one nutrient sampling and calibration would be required and the same manure source used for the whole experiment. An individual plot area was considered to be .34 m^2, and given 4 replications and 10 treatments, the total area would be 0.136 ha. Allowing for calibration runs, plot run-in, and run-out distances, the area would double to 0.272 ha. An average liquid manure treatment would be in the order of 75,000 L/ha, thus one experiment would require a storage volume of 20,000 L and allowing for two experiments this volume would be doubled. The manure storage was also required to have its own transfer pump so that manure could be loaded, mixed and unload independent of the tractor and tanker.

Since it was not possible to buy one plastic tank with a capacity of 40,000 L, two tanks, of 21,000 L and 19,000 L were purchased and installed (Figure 4.1), thus two field experiments could be accommodated. The tanks were connected to a 3.5 kw electric pump by 100 mm diameter lines with quick connectors and valves to provide maximum flexibility and safety. The most important feature of the system is that manure mixing can take place in either tank before any moving, sampling or tanker filling operation thus preventing any settling of the solids at the bottom of the tank. The system allows incoming manure to be place in either tank, manure to be transferred from tank to tank, either tank to be mixed, and manure to be unloaded from either tank, as required.

4.4 Manure Application Equipment

The manure application equipment (Figure 4.2) was a tanker (Nuhn Industries Ltd., R.R.#1 Sebringville, Ontario, N0K-1X0) with a capacity of 9100 L, which corresponds to a small commercial tanker. The tanker has adjustable wheel spacing (2.28 m to 3.65 m centre to centre) to accommodate various plot widths as well as highway transportation. The tanker also has a removable injector assembly located at its rear. The injector assembly has adjustable tyne spacing and individual control valves for each injector. Nuhn Industries also added a flow meter (Signet flow gauge "Accum-U-Flo") which could be read in the tractor cab. The tractor was a Ford 7810 Model FR415LBC86970, with a synchronized transmission, four forward gears, two ranges, and Hi/Lo for a total of 16 forward speeds.

4.5 Calibration Procedure for a Broadcast Application

The calibration of the rate of liquid manure application involved the following consecutive steps. For the first step, the tanker was filled with water from an irrigation pump. The tanker pump was then run at various power take off (pto) speeds and the time to unload the tanker was recorded for each speed (Table 4.1). Tractor speeds were calculated on a separate measured flat track for each gear selection and engine rpm setting used above. Using these two values the application rates in L/ha in Table 4.1 were developed and used to determine the correct gear setting and tractor rpm for the appropriate application rate. The second method involved the use of the flow meter. While the filled tanker was being unloaded, the flow rates on the meter were recorded. These values were then compared to the full tank unloading figures. These measurements gave us the rate of manure applications for various tractor speeds and allowed us to verify the performance of the flow meter

As a final step, the tanker was taken to a local hog farm where it was filled from the manure storage with liquid swine manure. The tanker was then taken to the field where spread times and the width of spread were recorded for each load and pto setting. Flow meter reading could not be taken with the liquid swine manure as straw and other large pieces of material clogged the transducer. This allowed us to compare spreading performance of manure as compared to water.

In an attempt to determine the uniformity of spread, collection trays were placed in the field to collect the liquid discharge from the tanker. Visual observation of the collection procedure showed that some of the liquid which landed in the trays splashed out and some which landed outside the tray splashed in. It was therefore concluded that the data collected was unreliable. Further to this the spread pattern was controlled by an angled steel plate at the end of a 100 mm discharge pipe with no real adjustment. Thus it was decided to live with the pattern as long as the width was correct. Differences in the pattern may be compensated for with soil incorporation tools.

4.6 Calibration Procedure for the Injector Equipment

The manure injection system was supplied from Nuhn Industries (Figure 4.2). The system consists of a toolbar and injectors mounted behind the tanker. Injector spacing is variable or can be adjusted, and each injector supply line had a gate value installed to control the flow. The system was designed for a maximum of four injectors, but due to the 0.91 m row spacing in the potato crop, only three were required and the fourth line was closed.

For the calibration of the injectors, a system had to check for be developed for not only total injected manure, but also the distribution between the injectors. For this purpose three plastic tubs 1.09 meters in diameter were used to collect the output from each injector. The volume of liquid in each was determined by measuring the liquid height. This procedure was repeated and after each run, the liquid was returned to the manure tank using an electric sump pump. Gate values for each injector were opened 3.0, 3.5 and 4.0 turns. The delivery volume for each is given in Table 4.2. As can be seen from Table 4.2 the volumes delivered by the centre injector were slightly less than the outside two.

This was likely due to the design of the distribution box. Since we were already down to half turns on the gate values and the differences were small compared to overall delivery rates we did not attempt a finer adjustment. Given the nature of the equipment and the fact that half the centre injected band of manure and each of the outside bands fed a single row of potatoes, the system was balanced and should not compromise yields. As with the broadcast applications the tanker and injectors were taken to a local hog farm and field tests were run with the injectors in the soil and the times to unload were measured. Measurements of total in-soil injection corresponded to the plastic tub measurements given in Table 4.2. Using the speed data and delivery rates from the valve opening the delivery rates in l/ha were calculated and presented in Table 4.3.

4.7 Verification of Field Performance

The equipment described above was designed to conduct field experiments on liquid manure injection into the potato crop. At this point a number of questions remained and it was decided to conduct a preliminary field experiment to:

1. Test equipment performance in the field, as to whether the equipment could operate in the potato rows without destroying the planted crop and what type of experimental design would allow for the movement of equipment between plots.
2. Visually examine damage to the potato crop canopy caused by wheel traffic and the injection process.
3. Examine scab incidence on the variety Kennebec. It is considered by some researchers that there is a link between manure application and scab incidence in potatoes. It is clear that in some cases this is true, but there is no scientific explanation as to why. The variety Kennebec was chosen because it is

considered sensitive to the scab organism and would be a good indicator of scab infection.

4. Evaluate differences in potato crop performance in-terms of yield and quality characteristics.

4.8 Design of Field Experiment

A number of possible factors could be examined in the preliminary experiment, such as rates of application, injector design, and time of injection. For the purposes of the preliminary work, timing of injection seemed most appropriate. The times of injection were prior to crop emergence (early stage), after emergence in an approximately 100 mm high crop (middle stage), just prior to row closure (late stage) and a fertilizer check applied at the early stage. The liquid hog manure was injected at a rate of 40 tonne/ha (60 kg/ha of ammonium nitrogen). The measurement of ammonium nitrogen was used because it was easy to measure just prior to application and reflected the major portion of the manure nitrogen readily available to the crop. The injector sweep had a width of 200 mm and injected manure at a 100 mm depth. Inorganic nitrogen was applied at an equivalent rate to the fertilizer plot. These choices would allow the use of the equipment in the field with a growing potato crop at different stages, the examination of crop damage caused by the equipment as it traveled through the plots, and the development of skills in potato production.

The experimental design was four treatments by six replications organized in three blocks (Figure 4.3). The basic potato plot consisted of four rows of potatoes (spacing .91 meters) 3.65 meters by 9.1 meters in length. The pathways for this experiment were 12 meters to allow for maneuvering the tractor, tanker and injectors.

The potato crop was planted on June 6, 1994 using the variety Kennebec with a between row spacing of .91 meters and an in-row spacing of 300 mm. Weed control was pre-emerge with Sencor 75 df at 750 gm product per hectare. The crop was cultivated twice and hilled prior to canopy closure. Blight sprays were applied as required by the Provincial blight spray forecasts, in conditions of light infestation and dry weather on a two to three week schedule, during moist conditions the frequency could be once a week or shorter. The centre two rows of each plot were harvested separately on Oct. 12, 1995 and placed in storage. From the storage, the tubers were graded into 6 size classifications 0-45 gm, 45-50 gm, 50-55 gm, 55-60 gm, 60-65 gm, and over 65 gm which were weighted separately. A sub-sample was taken from each plot for specific gravity and scab disease rating. Data were analyzed using analysis of variance with Genstat (1987).

4.9 Results and Discussion

A few days before manure was to be applied to the plots,it was hauled from a near by farm and the storage tanks were filled (Figure 4.1). Mixing took place as each tank of manure was added to the storage. After filling the storage tanks, the mixing pump was run to mix the contents of the storage and five liquid manure samples were taken to the laboratory and analyzed for ammonium nitrogen (Campbell et. al 1997). This was then used to determine the application rate (l/ha) for the liquid manure under experimental conditions in the field. If the manure was in the tank for an extended period of time, the tanks were sampled again using the procedure outlined above, sampling was generally done a couple of days before field spreading. When time came to apply the manure to the plots the tank was again agitated, the tanker filled and taken to the field. At the storage facility the pump, hoses and hose quick connectors, valves and tanks allowed for manure handling as the system was designed. No changes were required during the course of the experiment.

Injection equipment performance in the field involved lining up the tractor, tanker and injectors at the top of the plot, lowering the injectors, engaging the tanker manure pump, opening the main valve and driving through the plot to inject the liquid manure. Given the size and length of the equipment care had to be taken that one was straight at the top of the plot and that one drove straight down the plot. For this reason the pathway width of 12 m was determined to be too narrow and it was suggested to widened this to 15 m for subsequent experiments. In general the equipment performed as expected, after each plot had manure injected, the rows and plants were examined to determine the extent to which damage occurred. During the first two dates there was little damage to the rows or plants as the injectors moved through the plots. On the last date the vines were closing over between the rows and there was some damage to the foliage due to the tractor wheels moving thorough the plots but not any worse than that of the spray tractor.

Figure 4.4 shows the yield distribution by size across treatments. Over the six size ranges there was no significant difference ($P<0.05$) in the first four yield ranges. At the size range 60-65 gm the early manure treatment yielded significantly ($P<0.05$) less than the other three treatments. At the size range >65 gm the middle stage injection treatment significantly ($P<0.05$) out yielded the early and late stage treatments but not the fertilizer check. Table 4.4 presents the harvest results, specific gravity and scab disease rating for the field experiment. Although there was a variation in total yield from 30.6 t/ha to 34.1

t/ha there was no significant ($P<0.05$) between treatments. As with total yield there were no significant differences ($P<0.05$) in specific gravity readings between treatments. The disease measurements made are divided into scab incidence (occurrence) and scab severity (amount). Although both showed some variation over treatments there was no significant difference ($P<0.05$) between treatments.

4.10 Conclusions

The major objective of this work was to develop an infrastructure which would allow for field studies on application strategies for liquid manure application in crop production systems. This was broken down further into the development of a storage facility, the selection and calibration of field application equipment, and the verification by conducting a preliminary field experiment.

The storage facility consisted of two plastic tanks (21,000 and 19000 l) connected to a 3.5 kw pump with 10 mm diameter hoses. The system allowed for the holding, mixing, sampling and unloading of either tank in the system. The storage facility allowed for the effective storage and handling of the liquid hog manure.

The field application equipment consisted of a 9100 l tanker with rear mounted injectors supplied by Nuhn Industries Ltd. Calibrations were successfully conducted for both broadcast and injection systems. In a preliminary field experiment the equipment performed as expected, the constraint being that the pathways were too narrow at 12 m and it is suggested that they be widened to 15 m for future experiments to allow for easier movement and setup prior to plot application.

A preliminary field experiment examining various times of manure injection in the growing potato crop was conducted. The experiment confirmed that the storage facility could store and provide the quantities of liquid manure required for a field experiment. The experiment also confirmed the field design (plot size and layout) with the only limitation being the pathway width as outlined above.

Results of the field experiment showed some small differences in yield distribution across size but the total yield was the same for all treatments. There was no difference in either scab severity or incidence across treatments in this study. Successful completion of the preliminary field experiment paves the way for more detailed field experiments using manure in various crop production systems.

4.11 References

Campbell A.J., J.A. MacLeod, C. Stewart. 1997. Nutrient Characterization of Stored Liquid Hog Manure. *Can. J. Agric. Engng.* 39(1):043-048.

Genstat V 1987. Reference Manual Clarendon Press, Walton Street, Oxford, England.

Table 4.1 Broadcast Application Rates of Liquid Hog Manure in Liters per Hectare

Tractor Gear	Range	RPM / L/MIN	1800 / 3370	1900 / 3596	2000 / 3846	2100 / 3954
1	L		88684	89900	87409	82375
1	H		64808	66593	66310	63774
2	L		60179	59933	60094	59909
2	H		46806	47316	48075	47071
3	L		44342	44950	46902	45977
3	H		34388	34577	34964	34684
4	L		33039	33296	33737	33508
4	H		25530	26058	26708	25675
5	L		25149	26058	26708	N/A
5	H		19824	19978	19230	N/A

Table 4.2 Manure deliver for Nuhn Injection System in L/min.

Valve Opening	Left Injector	Centre Injector	Right Injector	Average
3.0 turns	277	255	273	268
3.5 turns	320	303	320	314
4.0 turns	372	355	380	369

Data Collected in 1994.

Table 4.3 Injection Application Rates of Liquid Hog Manure in Liters per Hectare

Tractor		RPM	1900	1900	1900
Gear	Range	L/MIN	268	314	369
			3.0 turns	3.5 turns	4.0 turns
1	L		87931	103023	121069
1	H		65134	76314	89681
2	L		58621	68682	80713
2	H		46279	54223	63720
3	L		43965	51512	60534
3	H		33820	39624	46565
4	L		32567	38157	44840
4	H		25487	29862	35092
5	L		25487	29862	35092
5	H		19540	22894	26904

Table 4.4 Effect of Manure Application timing on Total Yield, Specific Gravity, and Scab Disease Rating for Kennebec Potatoes

	Early Applied Manure	Medium Applied Manure	Late Applied Manure	Fertilizer	
Total Yield Tonne/ha	30.60	34.08	31.65	33.84	n.s.
Specific Gravity	1.102	1.102	1.099	1.101	n.s.
Scab Incidence	4.83	5.17	5.33	4.83	n.s.
Scab Severity	0.75	0.83	1.25	1.08	n.s.

Non-Significant ($P<0.05$) Analysis of Variance

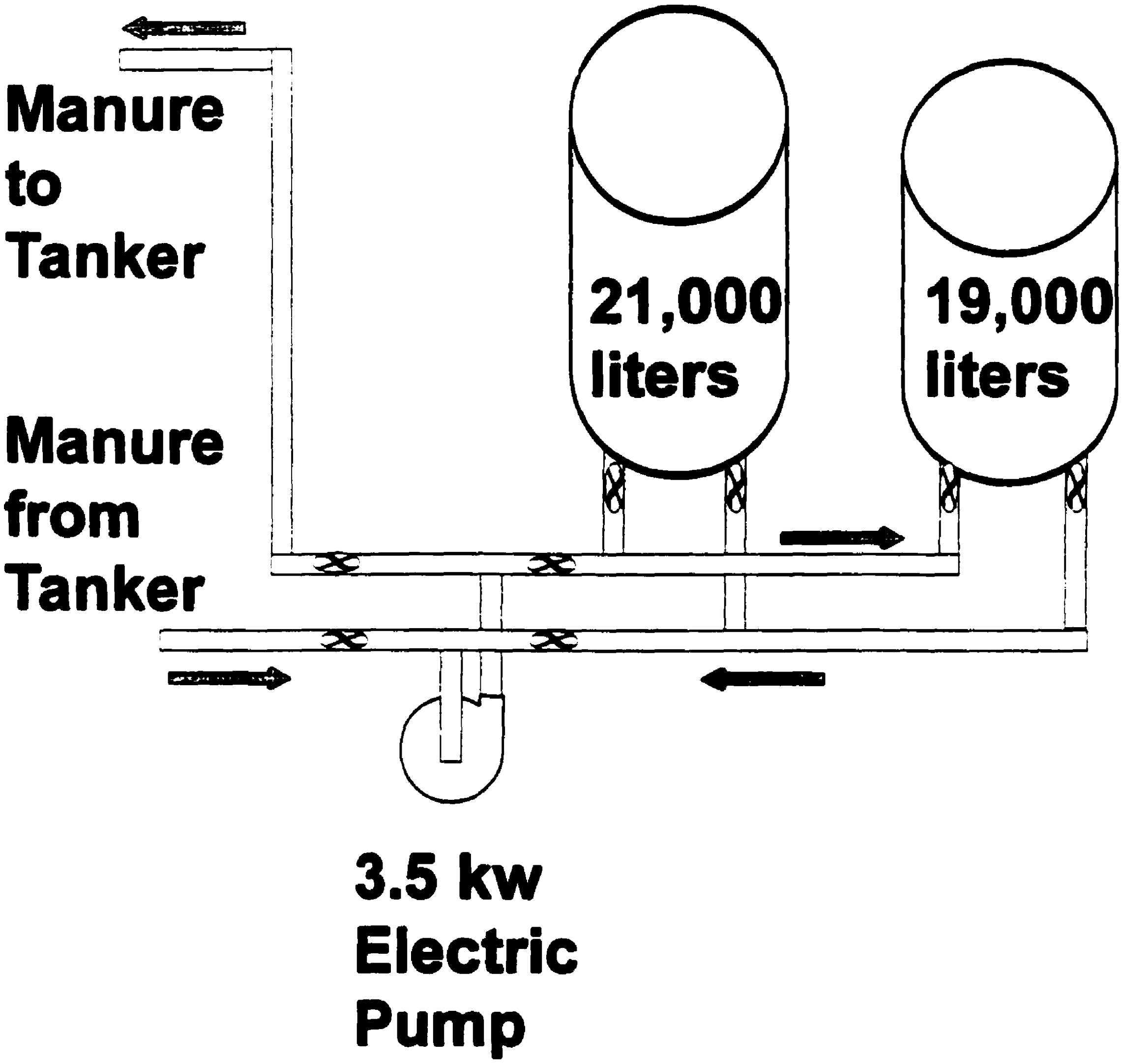

Figure 4.1 Manure Storage Facility

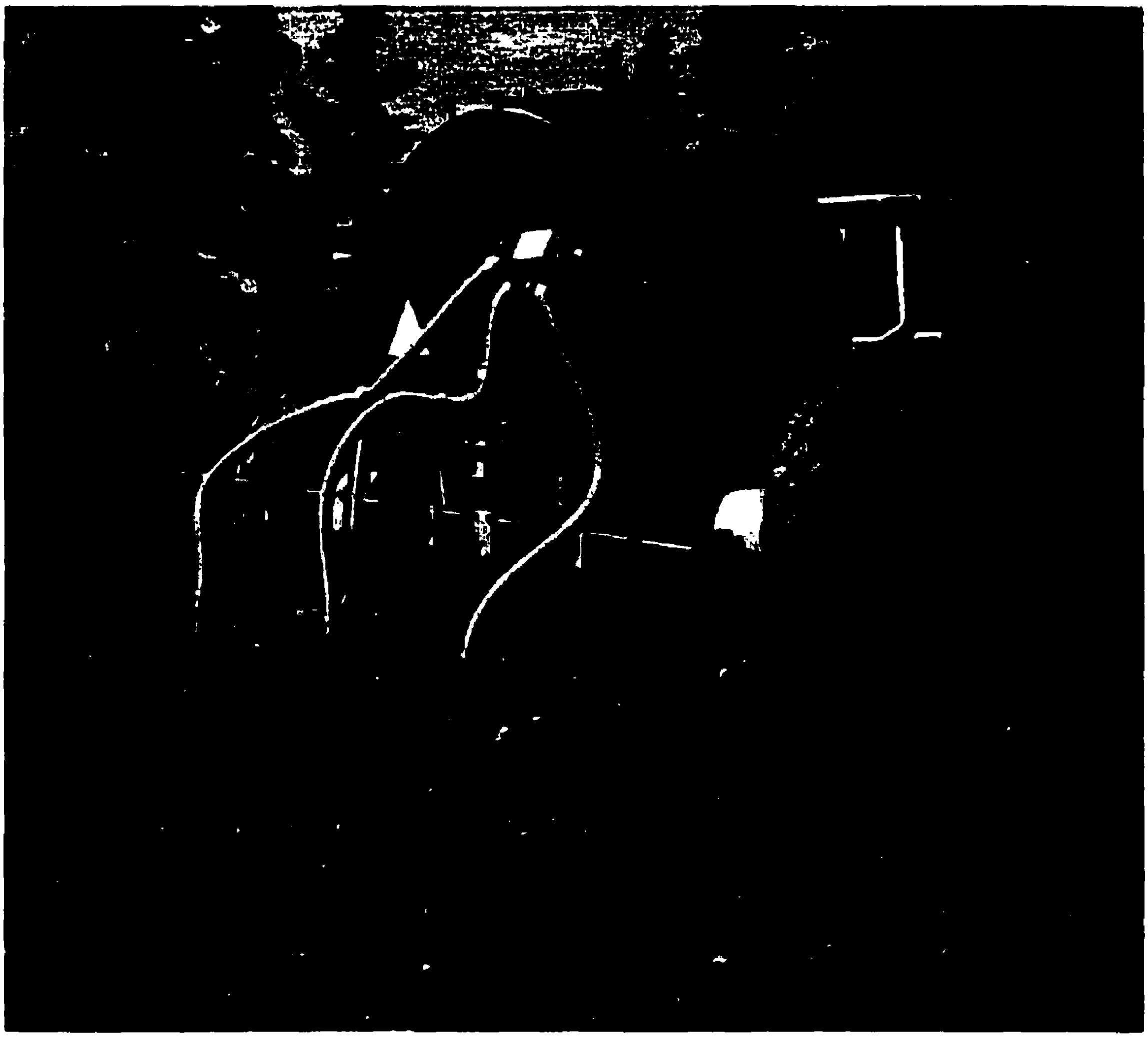

Figure 4.2 Nuhn Industries Ltd. Tanker and Manure Injectors

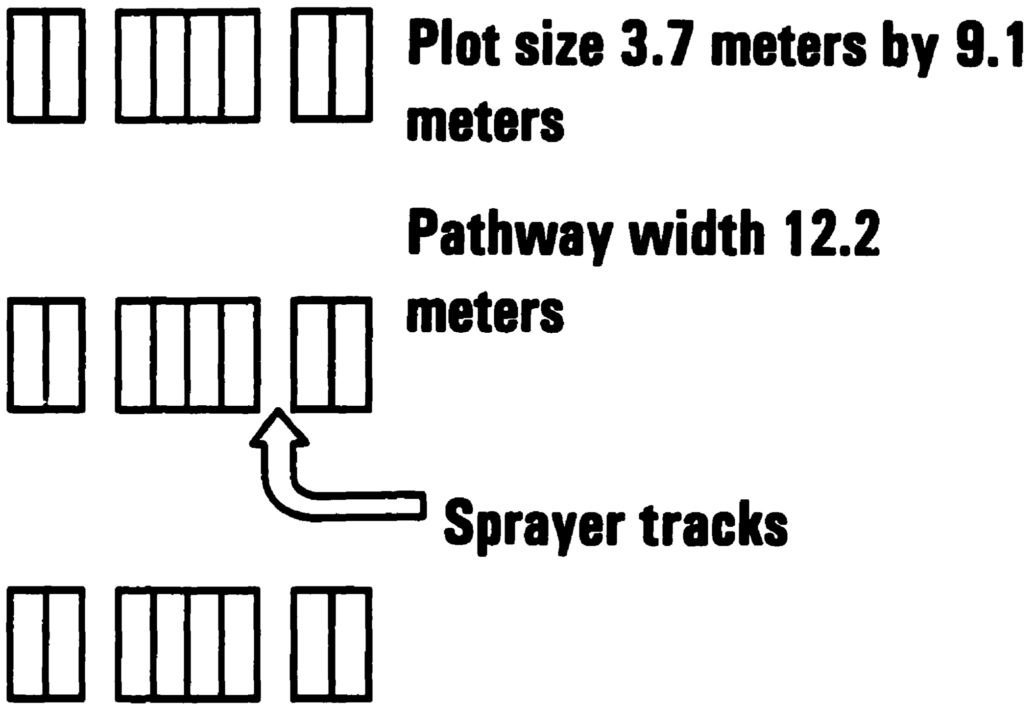

Figure 4.3 Field Plan

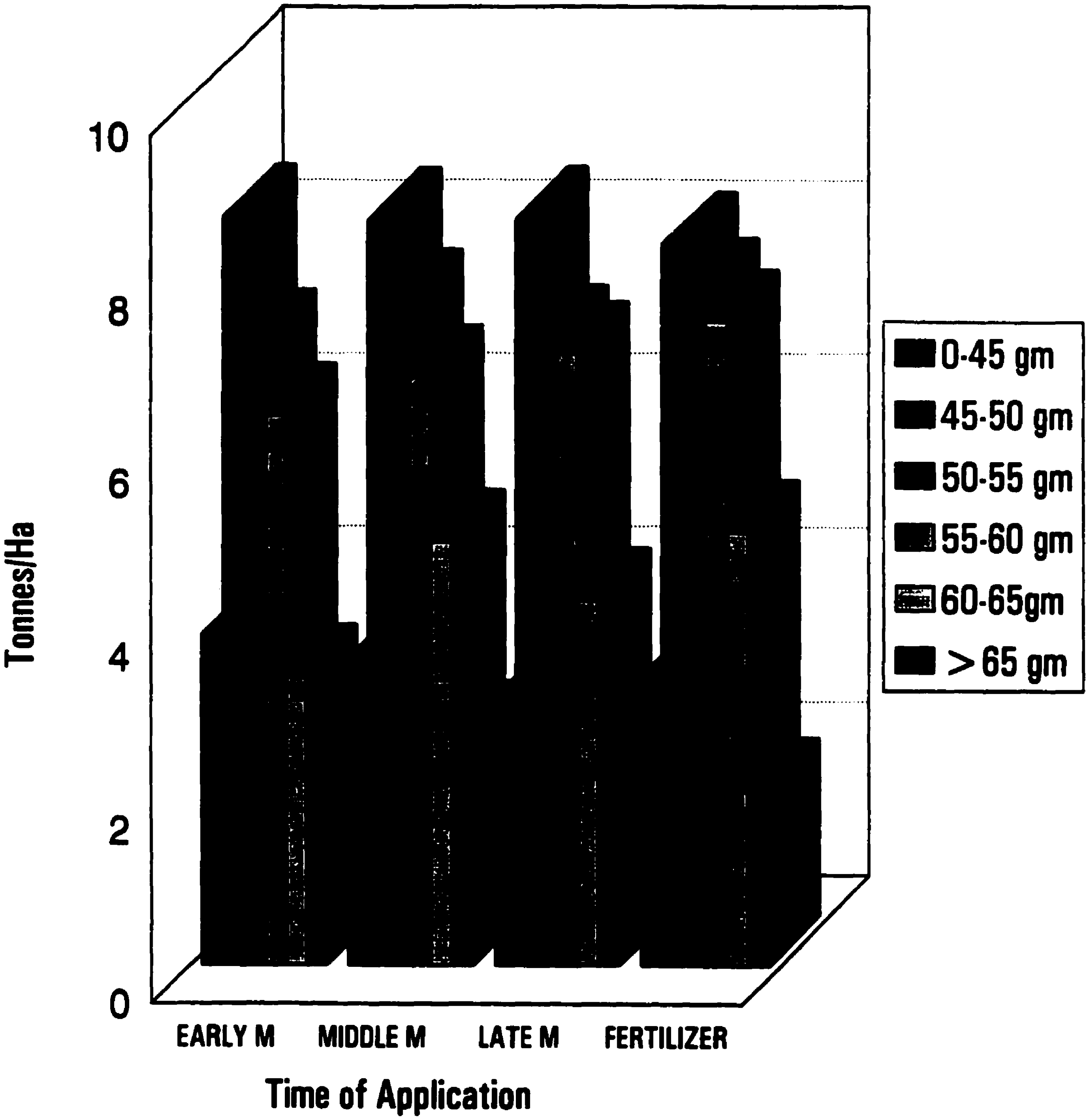

Figure 4.4 Effect of Manure Application Timing on Classification Yields of Kennebec Potatoes

Connecting Text Chapter 4 to Chapter 5

With the infrastructure in place at the Harrington Research Farm, Crops and Livestock Research Centre, Charlottetown P.E.I., two-three year field experiments were conducted. The next Chapter deals with the first which sought to establish whether manure position relative to the sown potato row was important to the nutrient uptake, crop yield and tuber diseases. The following paper presents this work. I wish to acknowledge the assistance of Dr. Suzelle Barrington in reviewing the manuscript, Dr. John MacLeod in discussions of the work and Lloyd Kerry for technical assistance in the field, with sample collection and analysis. This manuscript is to be submitted to the Canadian Journal of Plant Science.

CHAPTER 5 EFFECT OF MANURE PLACEMENT RELATIVE TO THE SOWN ROW ON NUTRIENT UTILIZATION BY THE POTATO CROP

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Contribution Charlottetown Research Centre

5.1 Abstract

A three year field experiment was established in 1995 to examine the effects of injected liquid hog manure placement relative to the sown potato row, and compare them to an extra Nitrogen fertilizer check and a no extra Nitrogen check. Manure was injected at 100 kg/ha of ammonium Nitrogen, which was the same as the extra Nitrogen check. Russet Burbank potatoes (*Solanum tuberosum L.*) were planted over the manure band, 0.23 m beside the manure band and 0.46 m away putting the manure band directly between the sown rows. Yield data over the three year period suggest that in general the plots receiving manure had yields equal to those which received the extra Nitrogen fertilizer. Yields across the three manure placement treatments showed the highest yields for manure placed under the row and beside the row compared to manure placed directly between the sown rows. In general, petiole differences paralleled yield differences when yield differences were large. When yield differences were smaller, petiole nitrate levels did not always reflect end of season potato market yields. Potato disease measurements over 1996 and 1997 indicated a reduction in the incidence of rhizoctonia (*Rhizoctonia solani*) in 1997 for the plots receiving manure compared to those which received only inorganic fertilizer. Over, the experiment there were no differences in scab (*Streptomyces scabies*) levels or in the specific gravity data between any of the treatments.

5.2 Introduction

Prince Edward Island (P.E.I.) is a small province on the east coast of Canada with 400,000 ha of arable land of which 45,000 ha are in potato production. The balance of arable land is used to grow small grains and oil seeds, forages and pasture. The unique feature of P.E.I. is that the farming operations are evenly dispersed thus potato farmers often have hog and dairy farmers as next door neighbors. This situation also leads to sharing or trading of land and other resources and thus the possibility of using hog manure as a nutrient sources for the potato crop. Traditional methods of manure utilization on the small grain crop would have the manure spread and incorporated prior to planting. Given the short growing season on P.E.I., time to spread manure is limited before the crop is planted and often results in delays in planting of spring crops. For reasons of timing, it was decided to investigate the injection of hog manure between rows of potatoes, after the crop was planted. This offered the benefits of not interfering with the potato farmers' planting operation, the hog farmer did not have to spread manure when he would be seeding his own crops, the potato crop is a very large nutrient user (200 kg Nitrogen, 200 kg Phosphorus and 200 kg Potassium per hectare), odour would be reduced and the dryer soil conditions in June would result in less soil compaction.

5.3 Literature Review

Very few data exist on the use of manure in potato production. Widdowson et al. (1974) relate on experiments conducted in England where various farmyard manure rates were surface applied and incorporated to different depths and compared and combined with fertilizer treatments. The best potato yields were from the highest level of inorganic fertilizers incorporated to the deepest depth. Second to this was where a combination of farmyard manure and fertilizer were incorporated to a shallow depth. These data suggest that there are possible advantages for combined applications of nutrients from both manures and fertilizers but that placement of each in the soil is important.

Most of the manure injection work conducted on a row crop has been on corn. Though the results are not directly transferable to the work with potatoes many of the ideas and approaches are of value.

Safley et al. (1989) conducted an experiment which examined four factors related to manure injector in corn silage production. They compared with a fertilizer check treatment: 1) Chisel versus sweeps, 2) High versus low application rates, 3) Spring versus fall application times, 4) Wide spacings of 0.96 m versus narrow spacings at 0.48 m. Four way interactions were some times significant with seasonal dependence.

Beauchamp (1983) examined the effects of Nitrogen source (urea, anhydrous ammonia and liquid cattle manure), application time (preplant versus side-dress) and application methods (surface spread, incorporated, and injected) on corn. As for Safley et al. (1989), Beauchamp found a number of interactions to be significant. First was the year by Nitrogen source, second was the year by Nitrogen rate and third was the Nitrogen rate by Nitrogen source. Therefore the seasons (years) have a significant effect on the response of various Nitrogen materials. Each Nitrogen source also had a different Nitrogen delivery system. Beauchamp concluded with a discussion on liquid manure-plant available Nitrogen. He suggested that the lower response curve for manure was due to the fact that only about 50 percent of the total Nitrogen might be available for crop growth. His rational for liquid beef manure is as follows:

Manure (200 units)

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Organic N (100 units) — Ammonium N (100 units)

Organic N (100 units)		Ammonium N (100 units)	
Mineralized N (20 units)	Residual N (80 units)	Volatilization (25 units)	Ammonia N (75 units)

Total plant available Nitrogen 20 +75 = 95 units

This division of Nitrogen agrees with the available Nitrogen calculations from the field studies conducted.

Sawyer et al. (1991) conducted field studies on corn. The experiment compared knifed manure treatments with corn planted over the slot, and planting distances increased away from the slot. Highest corn yields were recorded for seeds planted over the slots with yields decreasing slowly to 84% with manure placement away to a distance of 0.76 m from the seed. The average yield loss over the two years was 0.53 percent for each 25.4 mm the manure band moved away from the seed row. These losses were in part due to a lack of Nitrogen availability. Corn planted over the band of manure allowed the roots to grow around the soil manure band.

The area of soil and crop responses to manure injection are complicated and intermixed. It is difficult to separate them as the manure/soil interaction determines nutrient availability and crop response. From the above discussion, the following points are offered for consideration in the design of any field experiments involving manure injection:

1) Manure placement (how and where) has an effect on the nutrient availability and possible toxic effects on the growing crop; 2) when comparing manure treatments with each other and fertilizer check treatments, multiple interactions between factors occur. For this reason one should avoid multi-factor experiments (more than two factors) until some of the basic questions have been answered. 3) given that there are year interactions with most factors, the experiment should have three years of field data in-order to get a clearer picture of the main effects. 4) a previous legume crop can have an effect on Nitrogen availability (Patni and Culley 1989). Thus, if Nitrogen is one of the nutrients considered previous legume crops should be avoided until other factors have been established; 5) the shape of the manure band (vertical versus horizontal) in the soil has an effect on nutrient availability.

For the potato crop, the position of the manure band is one of the first questions to be answered. Thus the hypothesis of this study was whether the liquid manure placement location in the soil relative to the sown row has a significant effect on nutrient utilization by the potato crop.

The objective of this experiment is to examine the effect of manure placement relative to the seeded row on the potato crop nutrient utilization in terms of leaf petiole Nitrogen levels over the growing season, crop yield, specific gravity and disease incidence in the stored crop.

5.4 Materials and Methods

As for Sawyer et al. (1991), the closest placement of manure to the sown row is directly under it and the furthest away is half way between the rows. Splitting these two distances gives a middle treatment. In order to get the manure in the proper locations without disturbing the planted crop, the plots were marked for seeding and the manure injected in the correct positions a day prior to planting. The rate of injection was chosen as 100 kg/ha Nitrogen as ammonium in the liquid manure. This rate would provide a level of Nitrogen nutrient that would put potato crop yields on the steepest part of the response curve and thus provide the best comparison between treatments.

The injection of liquid hog manure was made using a 260 mm wide sweep (Figure 5.1), supplied by Nuhn Industries Ltd., R.R. #1 Sebringville, Ontario, Canada, N0K-1X0. The three manure treatments are shown in Figure 5.2 and are as follows: 1. Manure was injected directly under the row to be sown (under). 2. Manure was injected 0.23 m to one side of the row to be sown (beside). 3. Manure was injected 0.45 m to the side or centered between the sown rows (between). Manure injection treatments were applied one day prior to planting. Another fertilizer treatment received 100 kg/ha of Nitrogen as ammonium nitrate broadcast after the crop was planted before the first hilling operation. There was a check plot which received no additional Nitrogen fertilizer. All plots received 1000 kg/ha 5-20-20 banded at planting 50 mm below the set and 50 mm to either side of the seed row in 1995 and 1000 kg/ha of 2.5-20-20 in 1996 and 1997. Plots consisted of four rows for a width of 3.7 m and had a length of 9 m. The randomized complete block design consisted of five treatments in six replications arranged in 3 block (Figure 5.3).

The plots were sown each year using a two row commercial potato planter with the long season variety Russet Burbank (*Solanum tuberosum L.*) with a between row spacing of 0.91 m and an in-row spacing of 0.38 m (Table 5.1). Weed control was pre-emerge with Sencor 75 df at 750 g product per hectare. Cultivation and hilling operations were conducted as required. Blight sprays were applied as required by the Provincial blight forecasts. Insecticides were applied as insect numbers warranted through out the growing season.

Potato leaf petiole samples were taken at 2 week intervals starting from the canopy closure. Samples were collected from each plot by randomly taking 30, fourth leaf petioles from the center two rows of the potato plot. The samples were dried and stored for further analysis. Potato leaf petiole samples were dried, ground and analyzed for nitrate Nitrogen using the AOAC approved determination as outlined in Industrial Method No. 825-87T of the Technicon Traacs 800 Auto Analyzer manual (Bran+Luebbe Analyzing Technology Inc. 1987).

The center two rows of each plot were harvested by a single row harvester in the fall and each sample was placed in cold storage (Table 5.1). Potatoes were removed from storage and separated into 6 size classifications as follows: 0-45 g, 45-50 g, 50-55 g, 55-60 g, 60-65 g, and over 65 g. For the discussion of results, data were recombined to give smalls 0-50 g, market over 50 g and knobs as any misshaped tubers removed during grading.

After separation, sub-samples were taken from each size range and crop specific gravity was measured by weight in air versus water. Sub samples were returned to cold storage after the specific gravity measurements.

During the winter months samples were removed from storage and tubers were rated for both disease incidence and disease severity for rhizoctonia (*Rhizoctonia solani*) and scab (*Streptomyces scabies*).

Factors were analyzed using ANOVA in Genstat (1987) data are presented in tables with the standard error of the differences.

5.5 Results and Discussion

Since experiments were conducted on different sites in each of the years, data will be discussed by year. Yield data in t/ha has been broken down into marketable yields, smalls and knobs (Tables 5.2, 5.3, 5.4). In general yields from 1995 were much less than 1996 and 1997 due to the fact that 1995 was a dry season and moisture was the limiting factor in potato crop production.

Table 5.2 shows potato market yield data. In 1995, the Nitrogen check treatment and the under row placement of the manure were significantly better than the no extra Nitrogen check and the manure placement between the rows. Manure placement beside the row was significantly less than the extra Nitrogen check plot. In 1996, the no extra Nitrogen check yield was significantly less than all other treatments. Also the under row manure treatment was significantly less than the extra Nitrogen treatment. Market yields from 1997 confirmed that the no extra Nitrogen check was significantly less than all other treatments. The extra Nitrogen check and the placement in-between the rows were significantly less than the placement under and beside the rows. Over the three years plots with no extra Nitrogen yielded less than other treatments. Yields from the extra Nitrogen fertilizer plots, the manure placed under the row and the manure placed beside the row were similar over the three years. Yields of marketable tubers from plots with manure placed between the rows was less in two of the three years.

Due to the dry soil conditions in 1995, yields of small tubers were much higher than in the other two years (Table 5.3). There were no significant differences in small tuber yields between treatments in 1995 and 1996. In 1997, the no extra Nitrogen check had a significantly larger yield of small potatoes than other treatments.

Table 5.4 shows the yield of knobbed or misshapen potatoes for the three years. There were no significant differences among treatments in the first two years. In 1997, the no extra Nitrogen treatment had significantly fewer knobs than other treatments. This is not surprising since the market yields in this treatment were so much less than the others and the yield of small tubers was greater than in other treatments.

Seasonal measurements of leaf petiole nitrate levels provides a relative measure of the plants Nitrogen status over the growing season. Figure 4 shows curves for plant petiole levels for 1995 and values for the standard error of the difference for the curves in Figure 4, 5 and 6 are given in Table 5.7. The treatment receiving the extra Nitrogen had significantly higher nitrate petiole levels when compared to all treatments over all dates. Next highest were the manure placement under the row and the manure placed beside the row. On the first sample date, the between the row treatment and the no extra Nitrogen check were similar. Over the last four sampling dates, the manure placed between the row behaved the same as the other manure treatments. The 1995 petiole data, for date one, closely parallels that reported earlier in the yield data. Even though petiole nitrate levels in the between the row treatment was the same as other manured petiole levels for the later dates the yields at the end of the season were not as high.

As in 1995, 1996 petiole nitrate levels for the extra Nitrogen treatment were significantly higher than all other treatments across all dates (Figure 5). The no extra Nitrogen check was significantly less than all other treatments for the first three sample dates but not the last two. On the first two sample dates (day 48 and day 55) from planting, the manure under the row placement had nitrate levels significantly higher than the other manure treatments but was not different from the others over the last three sample dates. These changes in petiole nitrate levels were not reflected in yield differences for the manure treatments.

In 1997 (Figure 6) petiole nitrate levels were significantly higher for the three manure treatments over the other treatments over all dates. The extra Nitrogen treatment was significantly higher than the no extra Nitrogen check. The petiole nitrate levels for 1997 did not reflect the end of season yield differences between manure treatments.

Consistent over the three years, was the no extra check with the lowest petiole nitrate levels. In the first two years, petiole nitrate levels dropped as one would expect over the season. In year three, the manure and extra Nitrogen treatments has a slight increase on the third sampling and then dropped off. In years one and two, there was some separation between petiole nitrate levels on early samples but not late in the season for manure treatments. In the first two years, the extra Nitrogen treatment had the highest petiole nitrate levels, while in the third year, the three manure treatments were the highest.

Disease ratings for rhizoctonia and scab are presented in Tables 5.5 and 5.6 (data for 1995 not available). Over the two years and for both diseases, the only significant differences were for rhizoctonia in 1997 where the no extra Nitrogen and the extra Nitrogen check had a higher incidence compared to the manure treatments. The no extra Nitrogen treatment also had a significantly higher level of disease severity.

Specific gravity measurements showed no significant differences between any treatments in any of the three years (data not presented).

5.6 Conclusions

Data from the first two years suggests that the Nitrogen input from the manure applied was equal to that of the extra Nitrogen check. These results compare favorably to work by Beauchamp (1983) and Sawyer et al. (1991). In year three, 1997, the trend was reversed and two of the three manure treatments out yielded the extra Nitrogen check. This also agrees with data from Beauchamp (1983) and Sawyer et al. (1991) stating that there are often interactions over years; that manures and fertilizers do not have the same nutrient release curves and that these vary from year to year. Yield data for the three years, suggests that for the most part plots receiving manure had yields equal to those which received the extra Nitrogen fertilizers and were significantly better than the no extra Nitrogen checks. Comparing the three manure treatments, those which placed the manure closer to the sown row out yielded the treatment with manure placed between the sown rows. These results are similar in pattern to those of Sawyer et al. (1991) with corn.

Most petiole nitrate levels paralleled yield values in the three years. The exception being the last year when differences in yield between manure placement treatments were not reflected in petiole nitrate levels. Petiole differences paralleled yield differences when yield differences were large. When yield differences were smaller, petiole nitrate levels did not always reflect the end of season potato market yields.

Disease measurements over 1996 and 1997 showed a lower incidence of rhizoctonia in the manure treatments compared to those receiving fertilizer only. There was no increase in Scab where manure was injected into the plots.

5.7 Acknowledgments

The authors wish to acknowledge the technical assistance of Lloyd Kerry in the planning and planting of the plots, the collection and analysis of samples, yield and disease determinations of potato materials, and the data preparation.

5.8 References

Beauchamp E.C. 1983. Response of corn to Nitrogen in preplant and sidedress applications of liquid dairy cattle manure. Canadian Journal of Soil Science 63:377-386.

Bran+Luebbe Analyzing Technology Inc., 1987. Elnsford, New York, USA. Technical Publication Number DSM-0005-00.4.

Genstat V 1987. Reference Manual Clarendon Press, Walton Street, Oxford, England.

Patni N.K., J.L.B.,Culley ;1989. Corn silage yield, shallow groundwater quality and soil properties under different methods and times of manure application. Transactions of the ASAE 32(6)2123-2129

Safley Jr. L.M., P.W. Westerman and L.D. King. 1989. Effects of dairy manure application rate and timing, and injector spacing and type on corn silage production. Biological Wastes 28:203-216.

Sawyer J.E., M.A. Schmitt, R.G. Hoeft, J.C. Siemens, D.H. Vanderholm, 1991. Corn production associated with liquid beef manure application methods. Journal of Production Agriculture. 4(3)335-344.

Widdowson F.V. A. Penny, and R.C. Flint. 1974. Results from experiments measuring the effects of large amounts of fertilizer and of farmyard manure on main-crop potatoes grown in sandy soil at Woburn, Bedfordshire. Journal of Agricultural Science Cambridge 82:117-127.

Table 5.1 List of planting and harvest dates.

Year	Planting Date	Harvest Date
1995	June 07 (158)	Oct 16 (289)
1996	June 05 (157)	Oct 21 (285)
1997	June 10 (161)	Oct 10 (283)

Table 5.2 Market yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato Marketable Yield t/ha		
	1995	1996	1997
No extra Nitrogen	16.6	27.3	18.2
Extra Nitrogen	20.7	36.9	26.4
Manure placed under row	20.1	32.8	33.3
Manure place beside row	18.3	33.8	34.1
Manure placed between rows	17.3	34.2	25.1
SED	1.1	1.9	2.5
Significance Level	P<.01	P<.001	P<.001

SED Standard Error of the Difference

Table 5.3 Small yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato Small Yield t/ha		
	1995	1996	1997
No extra Nitrogen	15.1	5.2	6.0
Extra Nitrogen	13.4	4.0	4.3
Manure placed Under row	13.5	4.4	4.0
Manure place beside row	14.4	4.2	4.2
Manure placed between rows	13.9	4.4	3.7
SED	1.0	0.5	0.4
Significance level	n.s.	n.s.	P<.001

SED Standard Error of the Difference

Table 5.4 Knob yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato Knob Yield t/ha		
	1995	1996	1997
No extra Nitrogen	0.2	2.2	5.0
Extra Nitrogen	0.7	2.6	6.5
Manure placed under row	0.7	3.0	8.7
Manure place beside row	0.5	2.6	7.6
Manure placed between rows	0.3	2.6	8.6
SED	0.3	0.7	1.4
Significance level	n.s.	n.s.	P<.05

SED Standard Error of the Difference

Table 5.5 Disease rating for rhizoctonia incidence and severity.

	Potato Rhizoctonia Ratings			
	1996		1997	
	Incidence	Severity	Incidence	Severity
No extra Nitrogen	98.0	1.7	94.0	2.33
Extra Nitrogen	92.7	1.7	90.7	1.50
Manure placed under row	89.3	1.2	78.7	1.50
Manure place beside row	87.3	1.5	79.3	1.33
Manure placed between rows	91.3	1.2	72.0	1.17
SED	2.1	0.3	6.3	0.41
Significance level	n.s.	n.s.	$P<.05$	$P<.05$

SED Standard Error of the Difference

Table 5.6 Disease rating for scab incidence and severity.

	Potato Scab Ratings			
	1996		1997	
	Incidence	Severity	Incidence	Severity
No extra Nitrogen	2.7	0.8	2	0.17
Extra Nitrogen	2.7	0.3	0	0
Manure placed under row	4.7	0.8	0	0
Manure place beside row	0.0	0.0	0	0
Manure placed between rows	1.3	0.3	0	0
SED	2.2	0.5	1.3	0.1
Significance level	n.s.	n.s.	n.s.	n.s.

SED Standard Error of the Difference

Table 5.7 Standard error of the difference values for petiole nitrate-N data presented in Figures 5.4, 5.5 and 5.6.

	Date 1	Date 2	Date 3	Date 4	Date 5
1995	0.08	0.08	0.09	0.09	0.08
1996	0.09	0.1	0.1	0.09	0.08
1997	0.13	0.09	0.22	0.44	0.46

List of Figures.

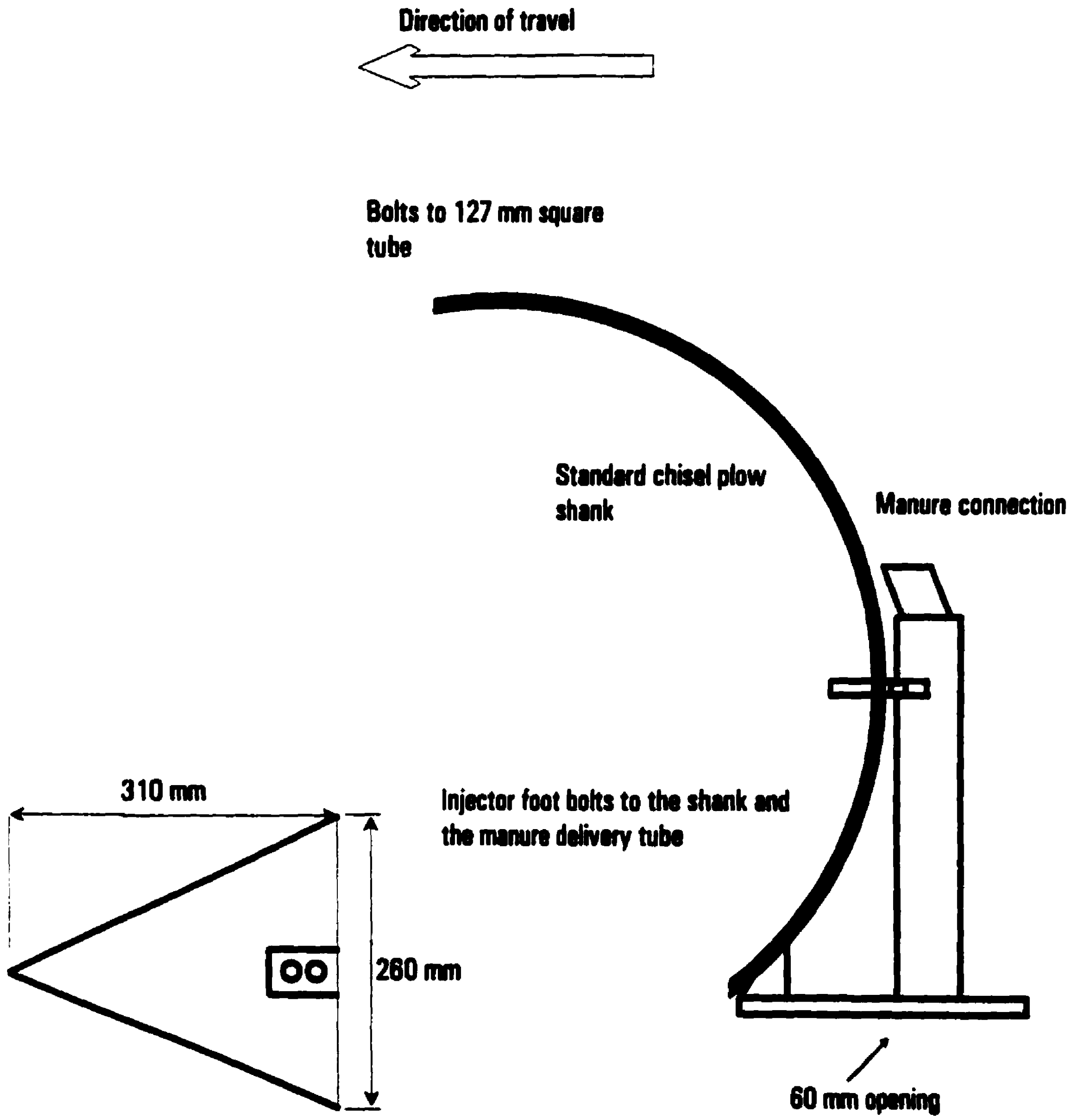

Figure 5.1 Configuration of Manure Injection Assembly Supplied by Nuhn Industries Ltd.

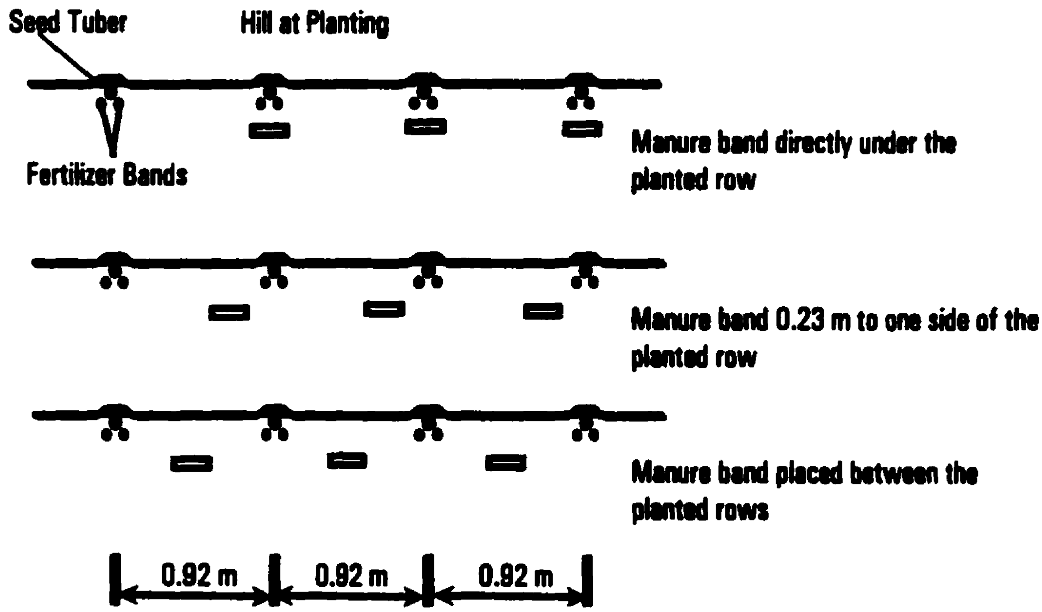

Figure 5.2 Placement of Manure Bands Relative to the Planted Row.

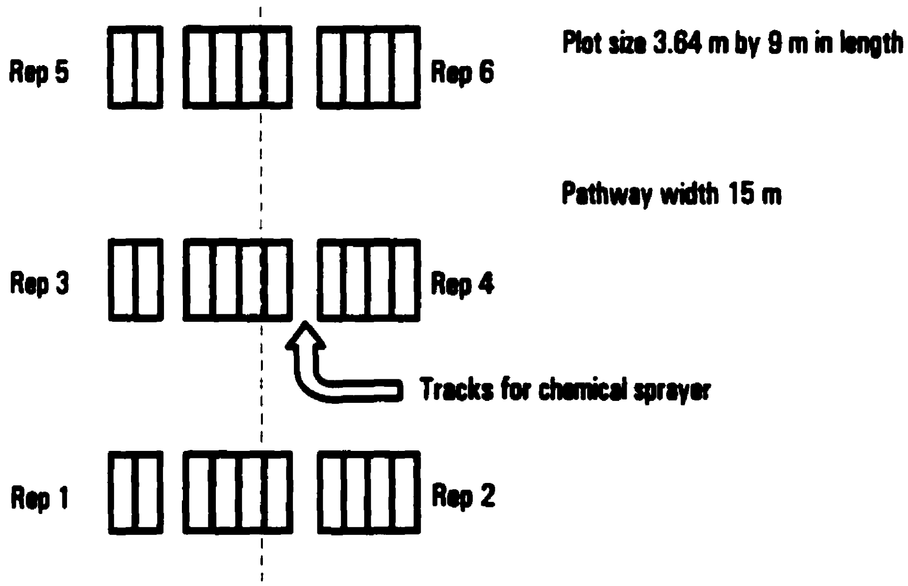

Figure 5.3 Field Plan with Five Treatments, in Six Replications in Three Blocks.

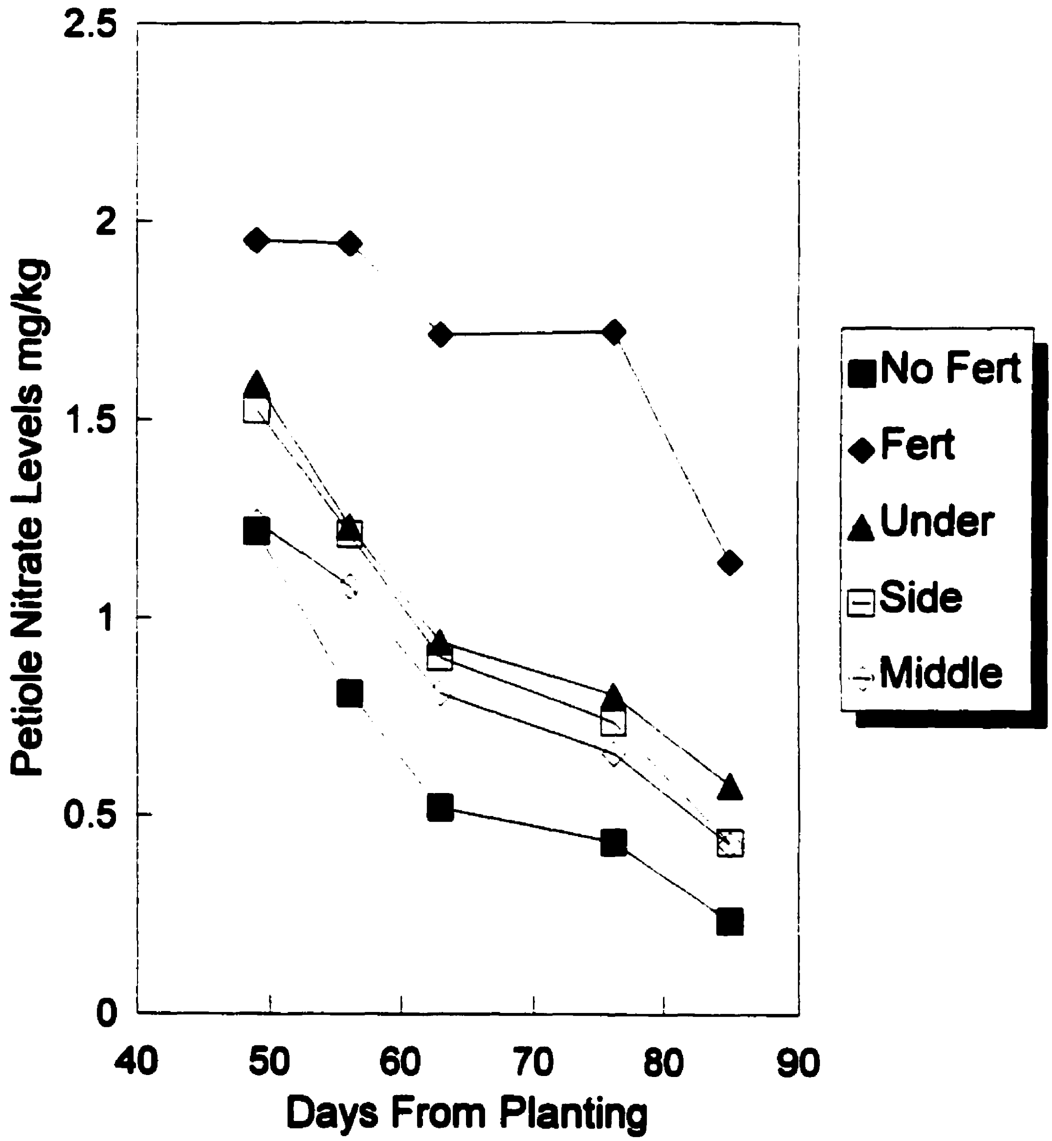

Figure 5.4 Potato leaf petiole levels for 1995.

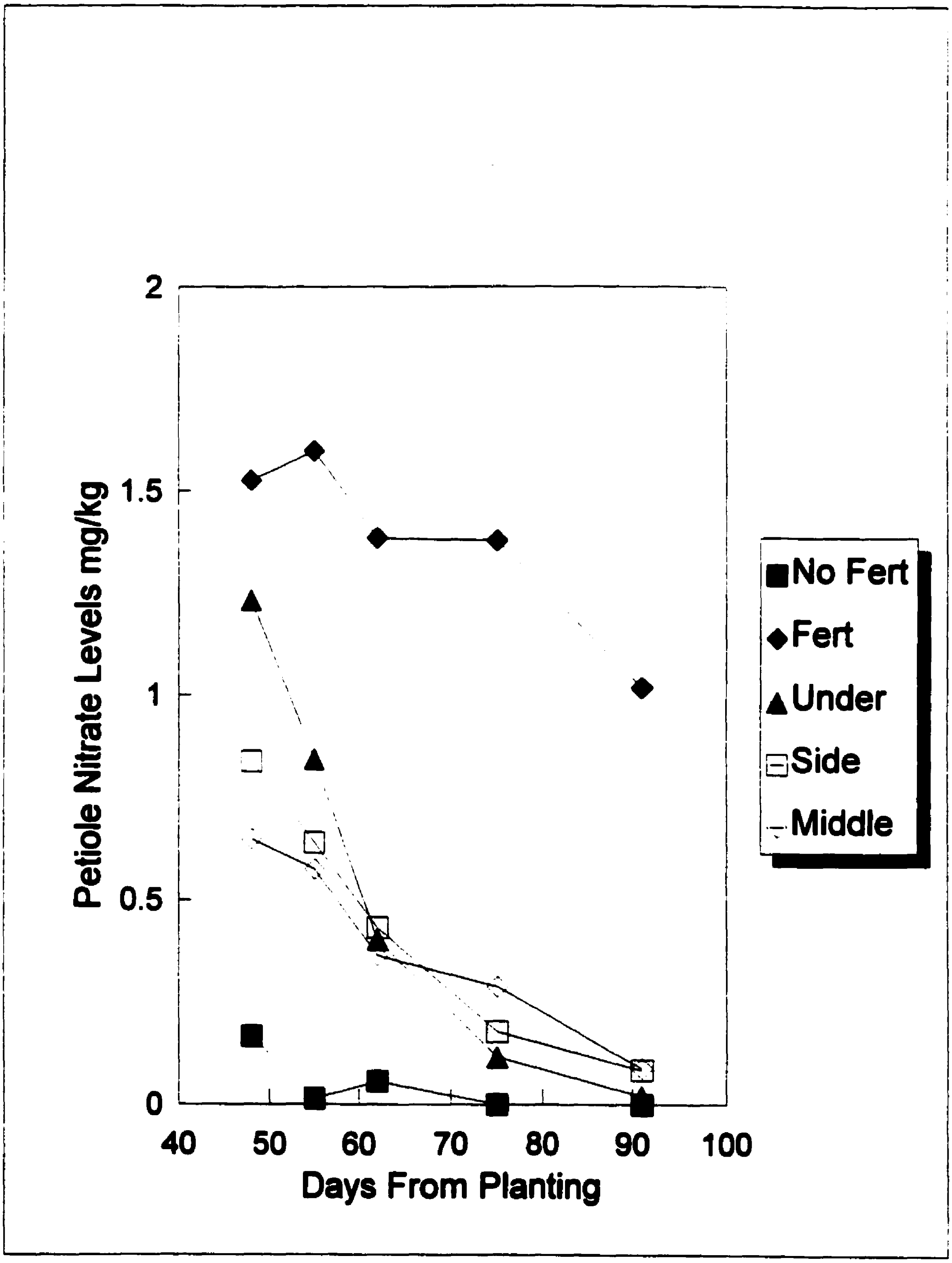

Figure 5.5 Potato leaf petiole levels for 1996.

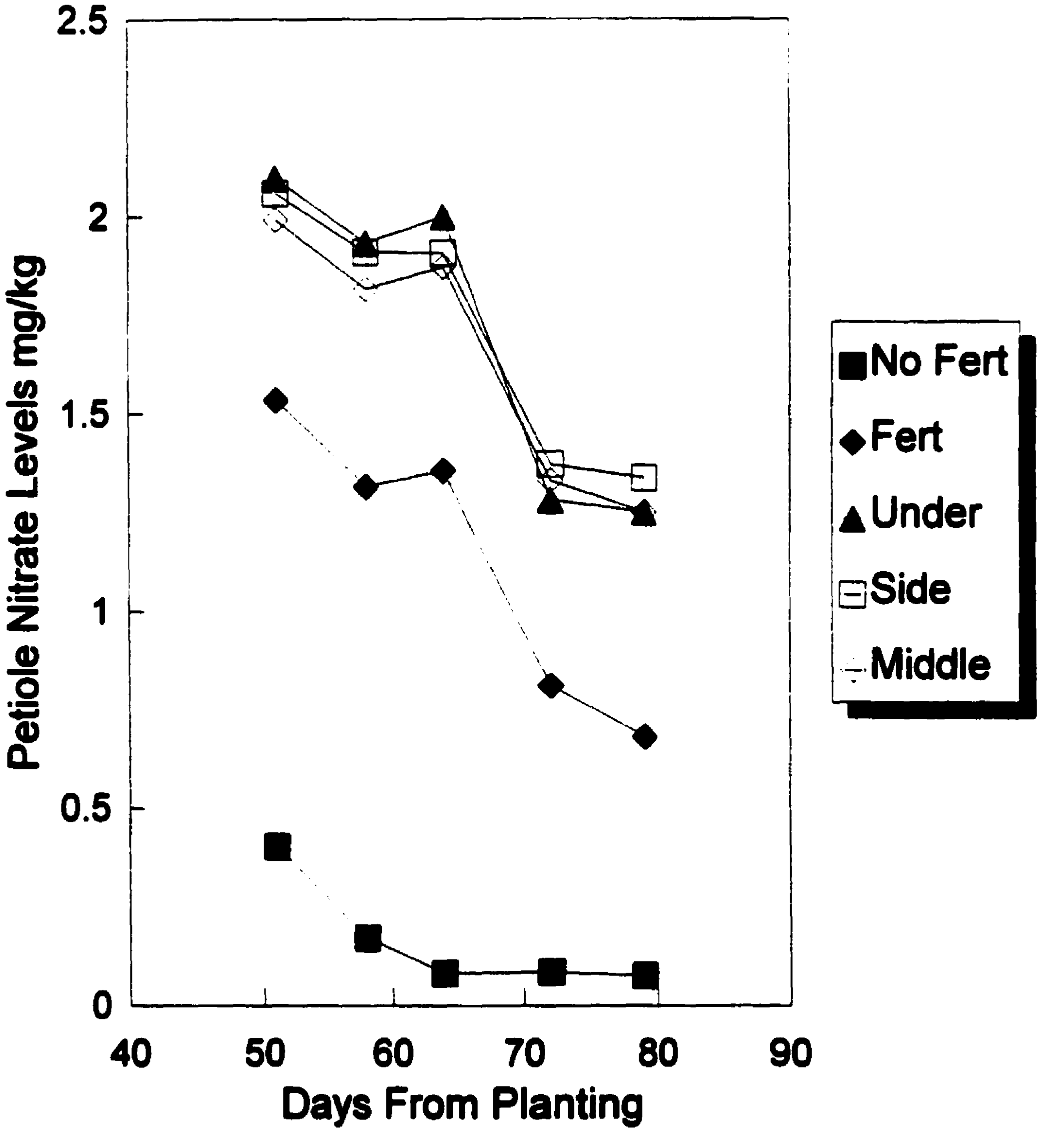

Figure 5.6 Potato leaf petiole levels for 1997.

Connecting Text Chapter 5 to Chapter 6

The next Chapter deals with the second three year experiment. In this experiment various liquid manure injector designs were developed and evaluated under field conditions in terms of nutrient uptake by the potato crop, crop yields and tuber diseases. I wish to acknowledge the assistance of Dr. Suzelle Barrington in reviewing the manuscript, Dr. John MacLeod in discussions of the work and Lloyd Kerry for technical assistance in the field, with sample collection and analysis. This manuscript is to be submitted to the Canadian Journal of Plant Science.

CHAPTER 6.0 DESIGN AND FIELD TESTING OF MANURE INJECTORS FOR LIQUID HOG MANURE INTO THE GROWING POTATO CROP.

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6.1 Abstract

A three year field experiment was established in 1995 to examine the effects of different liquid manure injectors on the placement of nutrients and the response of the potato crop compared to an extra Nitrogen fertilizer check and a no extra Nitrogen check. Russet Burbank potatoes (Solanum tuberosum L.) were planted and manure was later injected between the rows at a rate of 100 kg/ha Ammonium Nitrogen and the extra Nitrogen fertilizer was applied at the same time. Yield data over the three years indicated no differences among injector designs or compared to the extra Nitrogen fertilizer addition. Only in the third year was there a significant yield reduction for the no extra Nitrogen treatment. In general, petiole nitrate-N levels were lower in the no extra Nitrogen treatment than for all other treatments, in all years. The extra Nitrogen treatment gave the highest petiole nitrate-N levels in the second year. In the third year their was a separation on the last date when the deeper placed manure treatments had higher petiole nitrate-n levels compare to the shallow placed manure treatments. Potato disease measurements over 1996 and 1997 indicated a reduction in the incidence of rhizoctonia (*Rhizoctonia solani*) in 1997 for the plots receiving manure compared to those which received only inorganic fertilizer. Over the experiment there were no differences in scab (*Streptomyces scabies*) levels or in the potato specific gravity between any of the treatments.

6.2 Introduction

Prince Edward Island (P.E.I.) is a small province on the east coast of Canada with 400,000 ha of arable land. The major cash crop is potatoes on some 45,000 ha, with other areas cropped to small grains, oilseed crops, hay and pasture land. Although farm size and specialization continue to increase on

P.E.I., diversity remains in that operations of each type are mixed over the entire Island, with potato farms next door the hog farms next door to dairy farms. This arrangement of properties allows farmers to share and trade resources, primarily land but also manure as well. Traditional usage of manure is to apply it prior to planting the crop. On P.E.I., the short planting season means time to spread manure is limited and planting may have to be delayed to accommodate the manure application. An alternative would be to develop another strategy where the manure could be applied after planting. The potato crop would lend itself to this on P.E.I. because it is a large nutrient user and, being a row crop, would allow the manure to be injected between the rows after the crop is planted.

6.3 Literature Review

For the purposes of the this review, shallow injection will be defined as 50 mm (2 inches) and deep injection 150 mm (6 inches)(Marshall 1991). Injector styles are defined as; 1) Chisel, narrow or point which create a V shape or vertical band in the soil, or 2) Sweep or winged styles which place the manure in a horizontal band in the soil (Negi et al. 1976b).

The majority of work on manure injector design is based on research by Negi et al. (1976). The authors described the theory of liquid manure injection as pulling an injector through the soil to lift and loosen the soil thus increasing the pore space into which the manure is then injected.

Very few data exist on manure usage as nutrient source for the potato crop. Widdowson et al. (1974) suggest that there were advantages to using combined applications of both manure and inorganic fertilizers and that the placement of each in the soil was important. Most of the work on manure injection has been with the corn crop. Safley et al. (1981) showed that liquid swine manure injected early in the spring at 168 kg/ha of nitrogen produced corn grain yields equal to those obtained by using similar rates of ammonium nitrate fertilizer. Sutton et al (1982) noted an increase in corn yields for manure injected versus broadcast applications. In 1989, Safley et al. reported on a four factor experiment with corn silage which included style of injector, rates of application, timing of application and spacing of the injector tines. Over the three years of their study, they noted a number of interactions between factors and over years. In year one, their four way interaction was significant, in year two some of the main factors were significant and in year three a number of the two way interactions were significant. In the second, year they noted the chisel point was better than the sweep, the high rates were better than the low rates and the narrow tine spacing was better than the wide tine spacing. In year three, the results were the same for fall applied treatments but not spring injected manure.

A number of authors noted the adverse effects of manure injection on adjacent soil properties. Saywer and Hoeft (1990a) discussed a laboratory experiment with knife injected liquid beef manure and its effect on soil properties adjacent to the manure band and affects on corn seedling development. They notes that after seven days, soil chemical properties 38 mm from the band were altered but properties at 77 mm were not. At day 14, the 38 mm values were returning to the 77 mm levels. Corn seedling root observations indicated no root growth into or below the manure band till 26 days after planting. Sawyer and Hoeft (1990b) observed that higher soil temperatures after manure injection reduced the adverse effects of manure injected in laboratory studies.

In follow up experiments, Sawyer et al. (1990) noted that NH_3 levels were higher with knife injected liquid beef manure compared to sweep injected manure. In a subsequent field experiment (Sawyer et al. 1991), corn was planted over the manure band and at varying distances away from the band. Highest corn yields were from seeding directly over the band and decreasing corn yields were observed as one moved away from the banded manure. The Authors suggest that the seed planted over the row allowed the roots to grow around the manure band and thus make better use of the nutrients as the season progressed.

It would appear from the literature that conditions adverse to plant root growth exist in and around the manure band for sometime after injection into the soil. The length of time is dependent on the amount of manure injected, the shape of the manure band, the soil temperature, and the amount of soil aeration to convert ammonium to nitrates. Once soil conditions are favorable, root growth into the band can make use of the nutrients for crop growth.

Thus if one is interested in liquid manure injection into the potato crop, how and where the manure is placed is important to the potato crops subsequent nutrient usage. Also, in the case of the potato crop, the rows are cultivated and hilled after the manure is injected and this could affect aeration nutrient placement and subsequent crop utilization. Work described in Campbell et al. (1998) outlined the placement of liquid hog manure relative to the sown rows. Data from this work suggested that the closer to the sown row the manure is placed the better the crop performance. In terms of field scale operations, injection of liquid hog manure prior to planting is difficult due to difficulties in locating the two operations and due to the shortage of time in the spring planting season. Thus, from a practical point of view, it would be preferable to inject the manure after the crop is planted when more time is available and potato row positions are clearly marked in the field.

The objective of this experiment was to examine a number of injector designs to determine if design had an effect on nutrient uptake (petiole nitrate-N levels), crop yield or tuber diseases.

6.4 Materials and Methods

Based on the literature review, the design and selection of injectors and injection treatments are based on the following criteria.

1. Treatments were to consider equipment supplied by the manufacturer of the tanker (Campbell and Barrington 1998).
2. Treatments should take into account the effect of injection depth on performance of the injector designs.
3. The treatments should cover what is considered practical in terms of injection while not disturbing the sown crop.
4. The treatments should attempt to cover a range of possibilities from simple to more complex.

The treatment descriptions will start with common bases, all plots received 1000 kg/ha 5-20-20 banded at planting 50 mm below the set and 50 mm to either side of the seed row in 1995 and 1000 kg/ha of 2.5-20-20 in 1996 and 1997. An additional rate of 100 kg-N/ha was chosen as a fertility level which would place potato yields on the steepest part of the response curve. Thus the first two treatments were a no additional Nitrogen plot and a 100 kg/ha Nitrogen fertilizer treatment broadcast at the time of manure injection.

Treatments three and four considered the equipment supplied by the manufacturer. Figure 6.1 shows the basic design of the Nuhn injection system (Nuhn Industries Ltd., R.R. #1 Sebringville, Ontario, Canada, N0K-1X0) which consisted of a 50 mm wide chisel plow shank bolted to a 127 mm square tube. At the base of the shank, a manure delivery tube is attached to the rear of the shank. On the front of the shank, a 260 mm wide by 310 mm long sweep is attached as an opener to complete the injector foot. Treatment 3 involved operating the injector at a 150 mm depth and treatment 4 at a 76 mm depth.

Figure 6.2 shows the shoe design for treatments 5 and 6. The shape is the same as use in treatments 3 and 4 but the shoe is wider (420 mm) thus should produce a thinner and wider horizontal band thus moving the manure closer to the seed row. This cultivator shoe is commercially available and is bolted on the same shank and delivery tube supplied by the manufacturer. Again as above, treatment 5 was injected at 150 mm and treatment 6 at 76 mm.

Figure 6.3 shows the configuration for treatment 7. A narrow chisel plow point (60 mm wide and 250 mm long)was bolted to the chisel plow shank. The standard manure delivery tube at the rear was replaced by a straight pipe 60 mm in diameter with the back of the bottom end cut out to provide for manure delivery This narrow point was operated at a 150 mm depth. This was designed as an attempt to produce a narrow vertical band of manure directly between the sown rows.

Figure 6.4 shows the configuration for treatment 8 where the manure is delivered by 50 mm diameter ABS pipe to the soil surface in two bands beside the sown rows of potatoes. Behind this, the standard Nuhn injection shoe is pulled through the soil to move soil from between the rows to cover and incorporate the manure which has been spread on the soil surface. The attempt here is to use a simple system and have the manure incorporated near the soil surface.

Figure 6.5 shows the configuration for treatments 9 and 10. Here the manure flow is split and delivered to the soil in two bands 390 mm on center. The attempt here was to deliver the manure to the ends of the delivery shoe with the hope that more manure would be closer to the sown rows. As in previous cases, treatment 9 operated at the 150 mm depth and treatment 10 at the 75 mm depth.

Plots consisted of four rows for a width of 3.7 m and had a length of 9 m. The plots were sown each year using a two row commercial potato planter with the long season variety Russet Burbank (*Solanum tuberosum L.*) with a between row spacing of 0.91 m and an in-row spacing of 0.38 m. Sowing dates are given in Table 6.1. Weed control was pre-emerge with Sencor 75 df at 750 g product per hectare, cultivation and hilling operations were conducted as required. Blight sprays were applied as required by the Provincial blight forecasts. Insecticides were applied as insect numbers warranted through out the growing season.

Potato leaf petiole samples were taken at weekly intervals starting from the canopy closure. Samples were collected from each plot by randomly taking 30, fourth leaf petioles from the center two rows of the potato plot. The samples were dried and stored for further analysis. Petiole leaf samples were dried, ground and analyzed for nitrate Nitrogen using the AOAC approved determination as outlined in Industrial Method No. 825-87T of the Technicon

Traacs 800 Auto Analyzer manual (Bran+Luebbe Analyzing Technology Inc. 1987).

The center two rows of each plot were harvested by a single row harvester in the fall and each sample was placed in cold storage (dates in Table 6.1). Potatoes were removed from storage and separated into 6 size classifications as follows: 0-45 g, 45-50 g, 50-55 g, 55-60 g, 60-65 g, and over 65 g. For the discussion of results, data were recombined to give smalls 0-50 g, market over 50 g and knobs as any misshaped tubers removed during grading.

After separation, sub-samples were taken from each size range and crop specific gravity was measured by weight in air versus weight in water. Sub samples were returned to cold storage after the specific gravity measurements.

During the winter months, samples were removed from storage and were rated for both disease incidence and disease severity for rhizoctonia (*Rhizoctonia solani*) and scab (*Streptomyces scabies*).

The experimental design was a completely randomized block design with ten treatments and four replications. The field experiments were conducted in a different field in each year so data will be analyzed by year. All factors were analyzed using ANOVA in Genstat (1987).

6.5 Results and Discussion

Table 6.2 presents the market yields of potato tubers for 1995, 1996, and 1997. Due to the dry season in 1995 yields were less than in 1996 and 1997. In 1995 and 1996, there were no significant differences in market yields.

Market yields in 1997 were significantly less for the no extra nitrogen treatment compared to all others. There were no market yield differences among the other treatments. Tables 6.3 and 6.4 present data for yields of small tubers and the yields of knobs or misshapen tubers. There were no significant differences among treatments in any of the three years.

In summarizing the yield data, there was a significant difference only in 1997 where the no extra fertilizer treatment was less than all others. These results were in line with work by Campbell et al. (1998) in that the no extra Nitrogen treatments were lowest in yield in the last year. Campbell et al. (1998) showed that placement of manure under the sown row or close to it, was superior to liquid manure placed between the rows for potatoes. Safley et al. (1989) found that in some years the chisel point injector foot was superior to the sweep injector in terms of corn yields. Data from this experiment suggest that there were no differences in tuber yield due to the placement of nutrients by the different injector designs or operations. This is likely due to the large quantities of manure injected between the rows not forming distinct patterns and that further mixing occurred due to subsequent cultivation and hilling operations. Saywer and Hoeft (1990b) suggest a lag time between nitrates being available from injected manure treatments. This may also help to explain the lack of different responses to injection between the sown rows.

Figure 6.6 presents the data for the petiole-N levels for 1995, the standard error of the differences for the three years are presented in Table 6.7. The curves show a natural drop in levels over the season. Values for the no extra nitrogen treatment were low for all dates and this was significant over the last four dates. The extra nitrogen fertilizer treatment was generally highest but this was only significant at the last date indicating a better late season nitrogen supply.

Figure 6.7 presents data for the petiole-N levels for 1996. Most noticeable, the extra nitrogen fertilizer treatment is significantly better than all other treatments on all dates except the last one which was opposite to the year before. The no extra Nitrogen fertilizer treatment levels were significantly less than all manure treatments over the first three dates and less than most on the last two dates. Manure injection treatments were grouped together and followed the same pattern with the exception of the drop nozzle which started higher than all the others but then dropped quickly to be less by the last two sample dates.

Petiole nitrate-N levels for 1997 are presented in Figure 6.8. Similar to previous years, the no extra nitrogen treatment was significantly less than all other treatments over all dates. The curve shape for the other treatments is not typical of the normal declining values over the season. Some separation occurred on the last date where the three treatments, the standard Nuhn shoe, the wide shoe, and the split shoe that injected the manure at the 150 mm depth had higher nitrate petiole-N levels compared their respective shallow placement treatments. These were significant for the first two.

Over the three years, the no extra Nitrogen treatments had lower petiole-N levels that the treatments receiving the extra nitrogen. In year two, the extra nitrogen fertilizer treatment was higher than the manure treatments, and the point injector dropped on the last two sampling dates. In year three, the deep manure injection was better than the shallow on the last sampling date. These differences in petiole-Nitrate-N were only reflected in significant yield reductions for the no additional Nitrogen treatment in the last year of the study. Petiole nitrate-N levels reported in Campbell et al. (1998) also suggest differences in crop uptake due to manure placement. These differences could not be shown consistently for manure placed by differing injector designs, likely due to reasons outlined above for tuber yields.

Disease data from 1996 and 1997 concern (Table 6.5) Rhizoctonia incidence and severity. Noticeable is that in 1997 the treatments which received manure had significantly less Rhizoctonia severity than those which received only fertilizer. There were no significant differences in incidence in 1996 or in 1997. There were also no significant differences for incidence or severity of scab in either of the two years (Table 6.6).

Data were also collected for tuber specific gravity. There were no significant differences among treatments over any of the years (data not presented).

6.6 Conclusions

Over the three years of the study, there were no significant differences for tuber yield among liquid manure injector designs nor between the extra Nitrogen treatments and the manure injection treatments. Only in the third year did the no extra Nitrogen treatment have a significantly lower market yield of potato tubers.

Petiole nitrogen levels were significantly lower for the no extra nitrogen treatments for most dates over the three years. In year two, the extra nitrogen treatment was significantly better that all other treatments for most dates, this was not the case for year one and year three. There was little separation in petiole nitrate-N among manure injector designs over the three years of the study. The exceptions being in year two where the drop nozzle treatment started high and then quickly dropped off and year three where the deep placed manure treatments had higher petiole nitrate-N levels for the last sampling date.

In 1997 treatments which received manure had a lower rhizoctonia severity compared to those which received only fertilizers. There were no differences in scab levels of severity where manure was added to the plots.

6.7 Acknowledgments

The authors wish to acknowledge the technical assistance of Lloyd Kerry in the planning and planting of the plots, the collection and analysis of samples, yield and disease determinations of potato materials, and the data preparation.

6.8 References

Bran + Luebbe Analyzing Technology Inc., 1987. Elnsford, New York, USA. Technical Publication Number DSM-0005-00.4.

Campbell, A.J., S. Barrington, 1998. Liquid manure storage and application equipment development, calibration procedures and field verification in the potato crop. In press.

Campbell, A.J., S. Barrington, J.A. MacLeod, 1998. Effect of manure placement relative to the sown row on nutrient utilization by the potato crop. In Press.

Genstat V 1987. Reference Manual Clarendon Press, Walton Street, Oxford, England.

Marshall I. 1991. Going underground to solve a slurry worry. Power Farming July 26. pp24-26.

Negi S.C., E. McKyes, R.J., Godwin, J.R. Ogilvie. 1976. Development of mechanization for the efficient injection of liquid slurry wastes into agriculture soils. Report to Agriculture Canada Engineering Research Canada. DSS Contract RN:01843-5-0042, FC 1-1850-000-000-0414, Serial OSW5-0287.

Safley L.M. Jr., G.M. Lessman, J.D Wolt.,M.C. Smith. 1981. Comparison of corn yields between broadcast and injected applications of swine manure slurry. Proceedings of the 4th International Symposium on Livestock Waste, ASAE pp.178-180.

Safley Jr. L.M., P.W. Westerman and L.D. King. 1989. Effects of dairy manure application rate and timing, and injector spacing and type on corn silage production. Biological Wastes 28:203-216.

Sawyer J.E., R.G. Hoeft. 1990a. Effect of injected liquid beef manure on soil chemical properties and corn root distribution. Journal of Production Agriculture. 3:50-55

Sawyer J.E., R.G. Hoeft. 1990b. Greenhouse evaluation of simulated injected liquid beef manure. Agronomy Journal. 82:613-618.

Sawyer, J.E., M.A. Schmitt, and R.G. Hoeft. 1990. Inorganic nitrogen distribution and soil chemical transformations associated with injected liquid beef manure. Agronomy Journal. 82:963-969.

Sawyer J.E., M.A. Schmitt, R.G. Hoeft, J.C. Siemens, D.H. Vanderholm. 1991. Corn production associated with liquid beef manure application methods. Journal of Production Agriculture. 4(3)335-344.

Sutton A.L., D.W. Nelson, J.D. Hoff, V.B. Mayrose: 1982. Effect of injection and surface application of liquid swine manure on corn yield and soil composition. Journal Environmental Quality. 11:468-472

Widdowson F.V. A. Penny, and R.C. Flint. 1974. Results from experiments measuring the effects of large amounts of fertilizer and of farmyard manure on main-crop potatoes grown in sandy soil at Woburn, Bedfordshire. Journal of Agricultural Science Cambridge 82:117-127.

Table 6.1 List of planting, manure injection dates and harvest dates.

Year	Planting Date	Manure Injection Date	Harvest Date
1995	June 07 (158)	June 29 (180)	Oct 16 (289)
1996	June 05 (157)	June 20 (172)	Oct 21 (285)
1997	June 10 (161)	June 25 (176)	Oct 10 (283)

Table 6.2 Market yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato Marketable Yield t/ha		
	1995	1996	1997
No extra Nitrogen	18.2	23.5	13.3
Extra Nitrogen	20.5	32.9	24.9
Nuhn Sweep at 150 mm	20.9	27.9	28.4
Nuhn Sweep at 75 mm	18.1	30.4	24.1
Wide Sweep at 150 mm	20.1	30.4	25.7
Wide Sweep at 75 mm	19.5	31.4	26.5
Point injector	20.5	28.4	26.2
Drop nozzle and cover	22.8	29.7	24.7
Split Sweep at 150 mm	21.1	26.8	28.6
Split Sweep at 75 mm	21.4	30.8	27.3
SED	2.4	3.3	2.4
Significance level	n.s.	n.s.	$P<.001$

SED Standard error of the difference

Table 6.3 Small yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato Smalls Yield t/ha		
	1995	1996	1997
No extra Nitrogen	14.6	10.3	10.0
Extra Nitrogen	12.9	6.7	8.2
Nuhn Sweep at 150 mm	14.9	8.0	7.5
Nuhn Sweep at 75 mm	16.7	7.2	7.3
Wide Sweep at 150 mm	12.4	6.5	7.6
Wide Sweep at 75 mm	15.0	7.6	6.1
Point injector	15.0	7.6	7.0
Drop nozzle and cover	13.2	7.8	7.4
Split Sweep at 150 mm	14.7	5.4	7.5
Split Sweep at 75 mm	14.8	8.1	7.9
SED	1.6	1.1	1.0
Significance level	n.s.	n.s.	n.s

SED Standard error of the difference

Table 6.4 Knob yields for potato tubers harvested 1995, 1996, and 1997 in t/ha.

	Potato knob Yield t/ha		
	1995	1996	1997
No extra Nitrogen	0.7	1.4	4.3
Extra Nitrogen	0.4	1.8	6.1
Nuhn Sweep at 150 mm	0.6	1.6	7.7
Nuhn Sweep at 75 mm	0.2	3.8	8.2
Wide Sweep at 150 mm	0.9	2.9	7.7
Wide Sweep at 75 mm	0.4	2.2	8.4
Point injector	0.2	2.9	7.4
Drop nozzle and cover	0.6	2.5	7.9
Split Sweep at 150 mm	0.6	7.0	6.3
Split Sweep at 75 mm	0.7	2.4	7.4
SED	0.3	1.8	1.4
Significance level	n.s.	n.s.	n.s.

SED Standard error of the difference

Table 6.5 Disease rating for rhizoctonia incidence and severity.

	Potato Rhizoctonia Ratings			
	1996		1997	
	Incidence	Severity	Incidence	Severity
No extra Nitrogen	86.0	1.3	97.0	2.8
Extra Nitrogen	87.2	1.4	97.0	2.3
Nuhn Sweep at 150 mm	83.0	1.3	98.0	1.5
Nuhn Sweep at 75 mm	90.0	1.5	93.9	2.3
Wide Sweep at 150 mm	88.0	1.3	91.8	1.8
Wide Sweep at 75 mm	84.0	1.3	85.7	1.5
Point injector	89.0	1.8	97.0	1.8
Drop nozzle and cover	85.0	1.5	89.0	1.5
Split Sweep at 150 mm	89.0	1.5	93.0	1.5
Split Sweep at 75 mm	84.0	1.8	86.0	1.5
SED	8.5	0.4	5.4	0.4
Significance level	n.s.	n.s.	n.s.	$P<0.1$

SED Standard error of the difference

Table 6.6 Disease rating for scab incidence and severity.

	Potato Scab Ratings			
	1996		1997	
	Incidence	Severity	Incidence	Severity
No extra Nitrogen	0.0	0.0	0.0	0.0
Extra Nitrogen	2.3	0.2	0.0	0.0
Nuhn Sweep at 150 mm	2.0	0.8	2.0	0.3
Nuhn Sweep at 75 mm	2.0	0.3	0.0	0.0
Wide Sweep at 150 mm	2.0	0.3	0.0	0.0
Wide Sweep at 75 mm	2.0	0.3	0.0	0.0
Point injector	1.0	0.3	0.0	0.0
Drop nozzle and cover	2.0	0.8	0.0	0.0
Split Sweep at 150 mm	6.0	1.3	0.0	0.0
Split Sweep at 75 mm	2.0	0.5	0.0	0.0
SED	3.0	0.7	0.9	0.1
Significance level	n.s.	n.s.	n.s.	n.s.

SED Standard error of the difference

Table 6.7 Standard error of the difference values for petiole nitrate-n data presented in Figures 6.6, 6.7 and 6.8.

	Date 1	Date 2	Date 3	Date 4	Date 5
1995	0.15	0.20	0.20	0.21	0.16
1996	0.14	0.15	0.12	0.13	0.13
1997	0.15	0.19	0.20	0.21	0.19

List of Figures

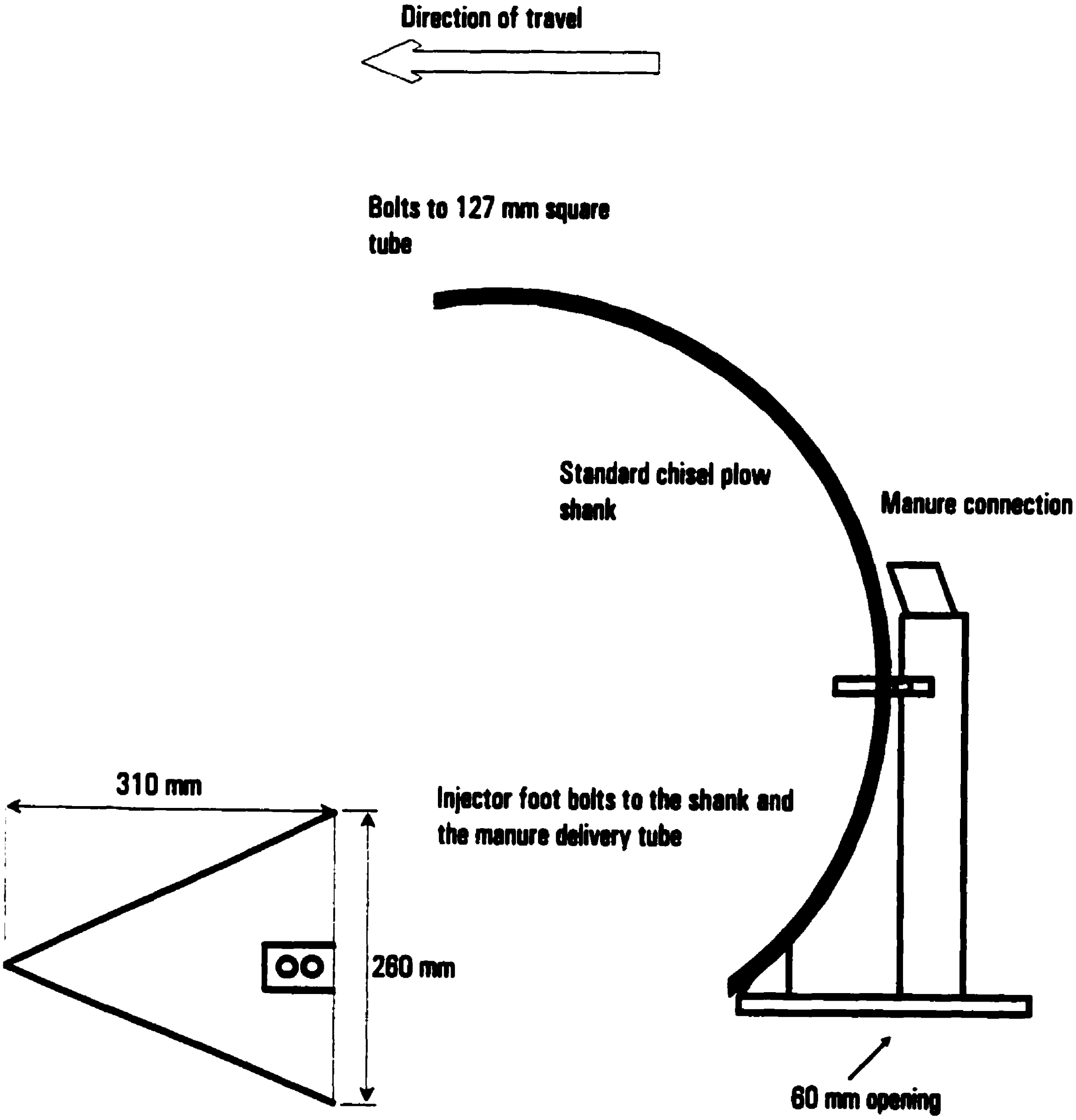

Figure 6.1 Configuration of manure injection assembly supplied by Nuhn Industries Ltd.

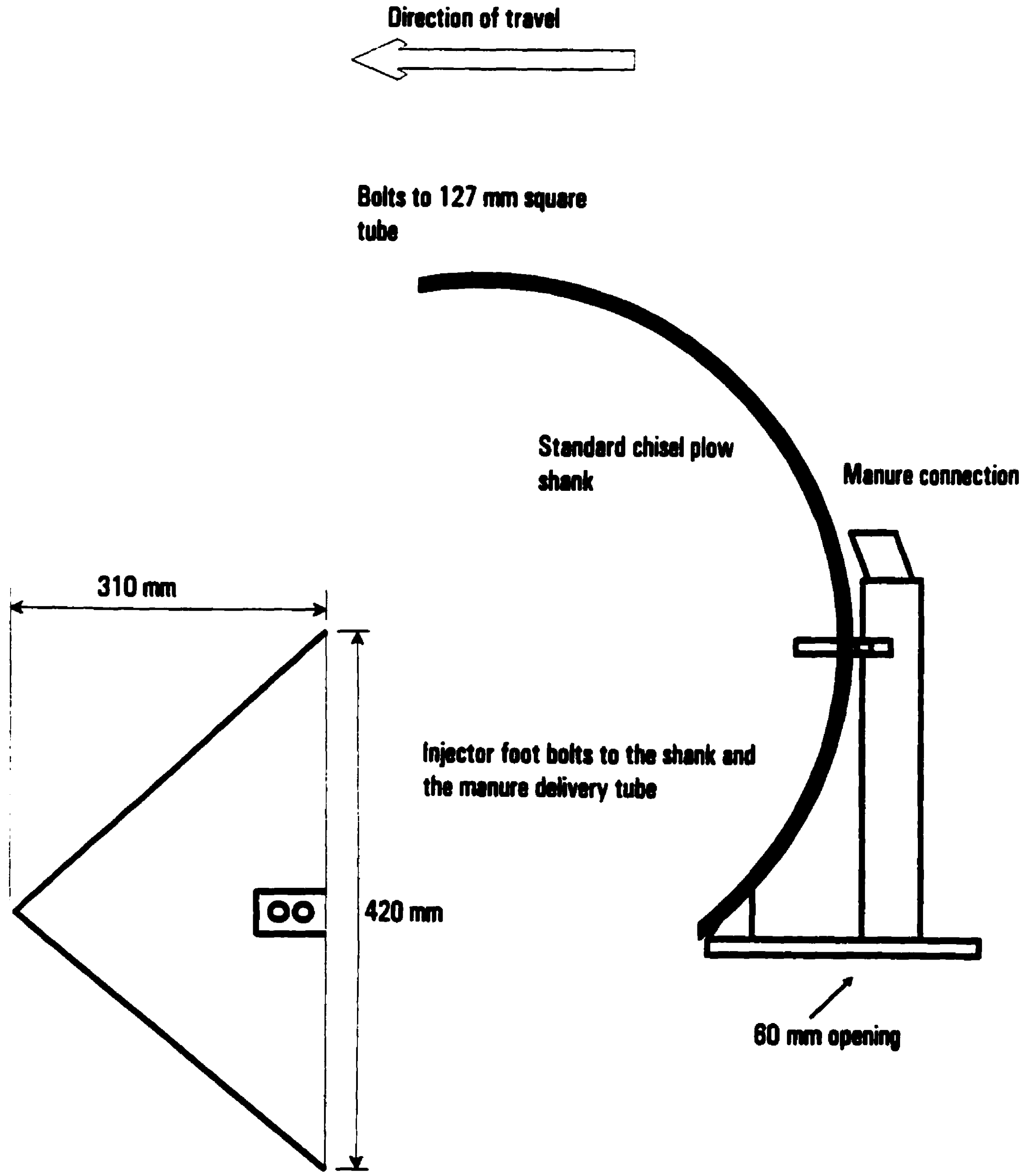

Figure 6.2 Configuration of the wide band manure injection foot bolted to the assembly supplied by Nuhn Industries Ltd.

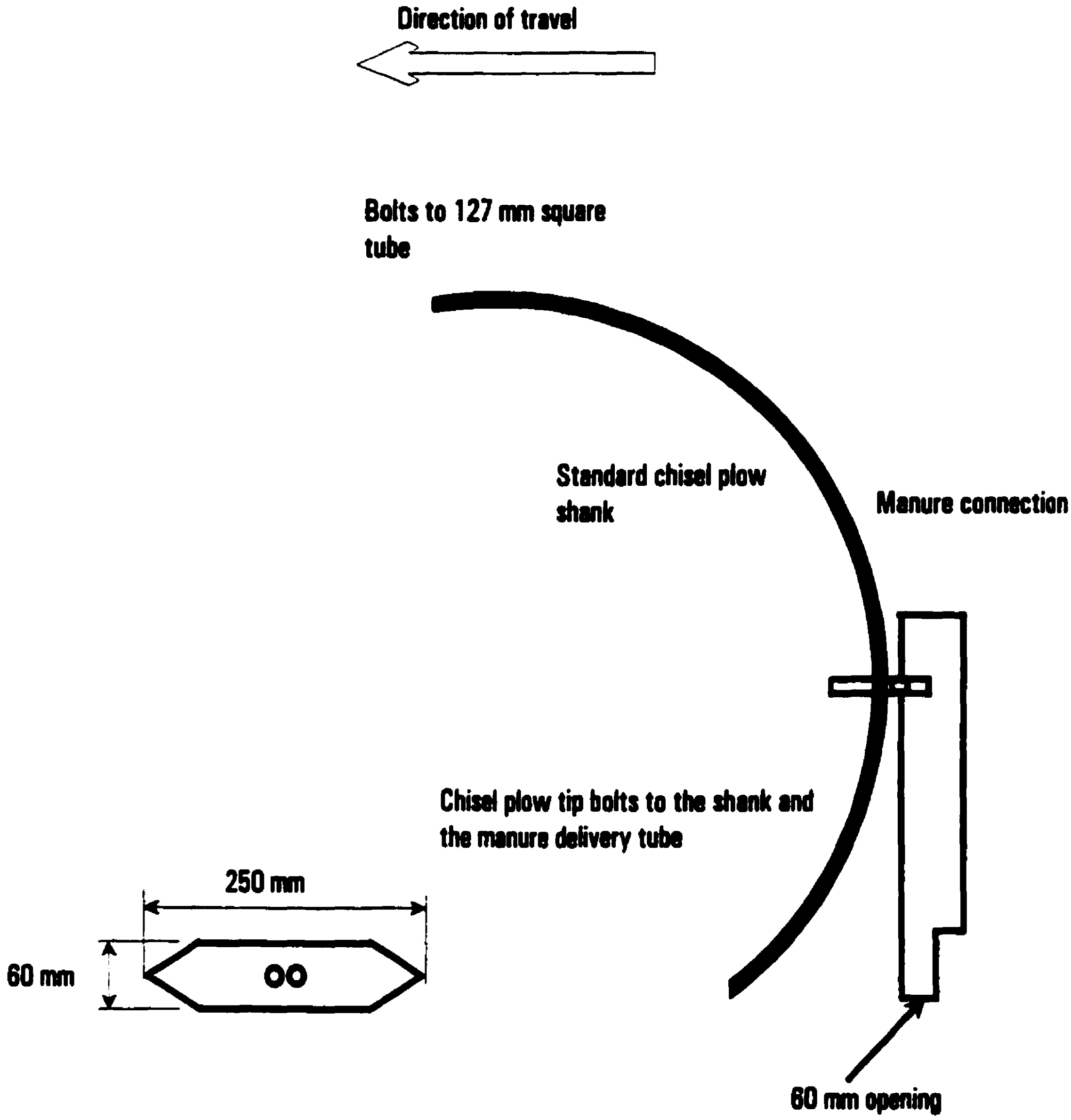

Figure 6.3 Configuration of the narrow point manure injection assembly bolted on the Nuhn injection system.

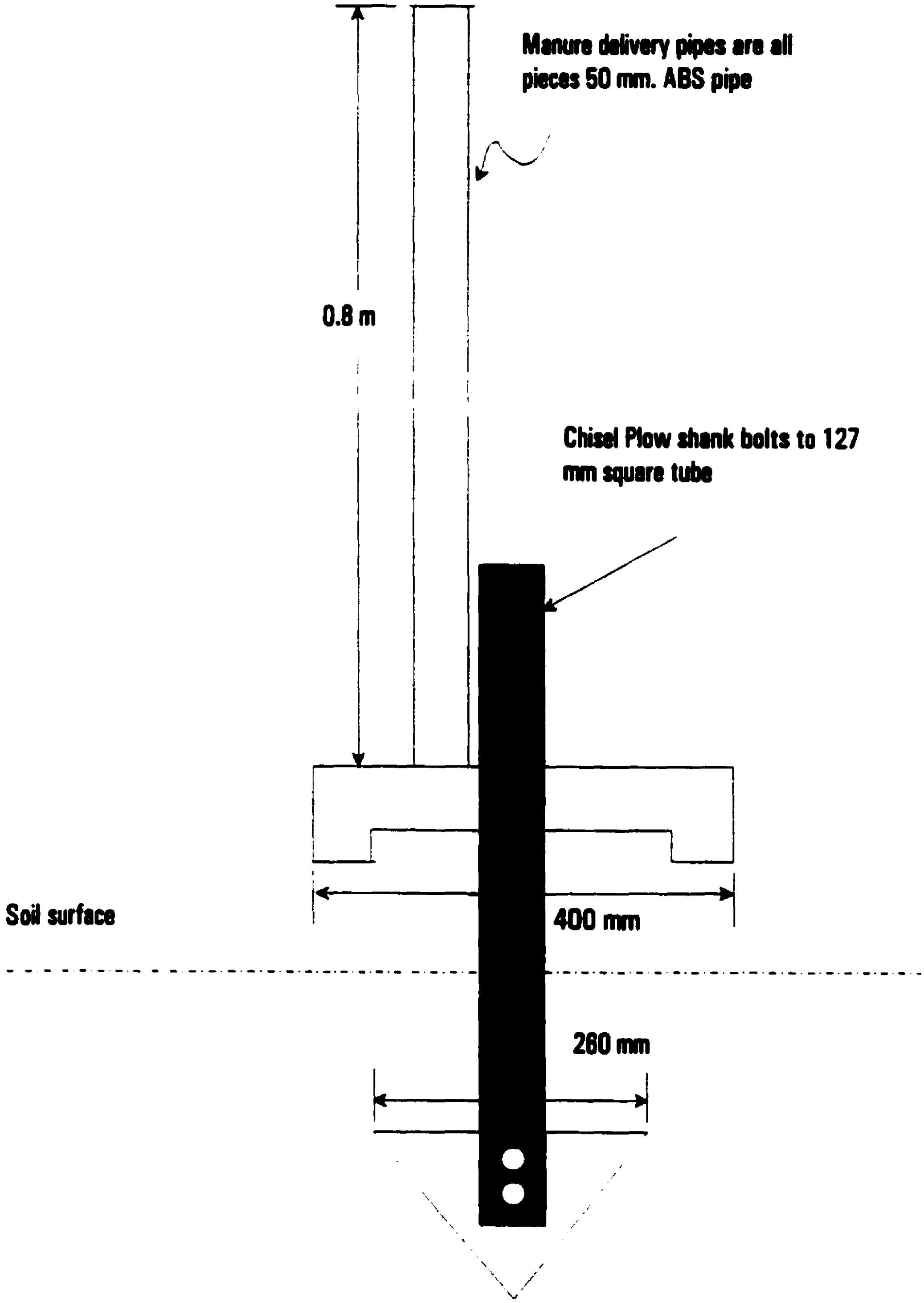

Figure 6.4 Manure flow is divided and spread on the soil surface beside the potato rows and incorporated by the standard injector foot supplied by Nuhn Industries Ltd.

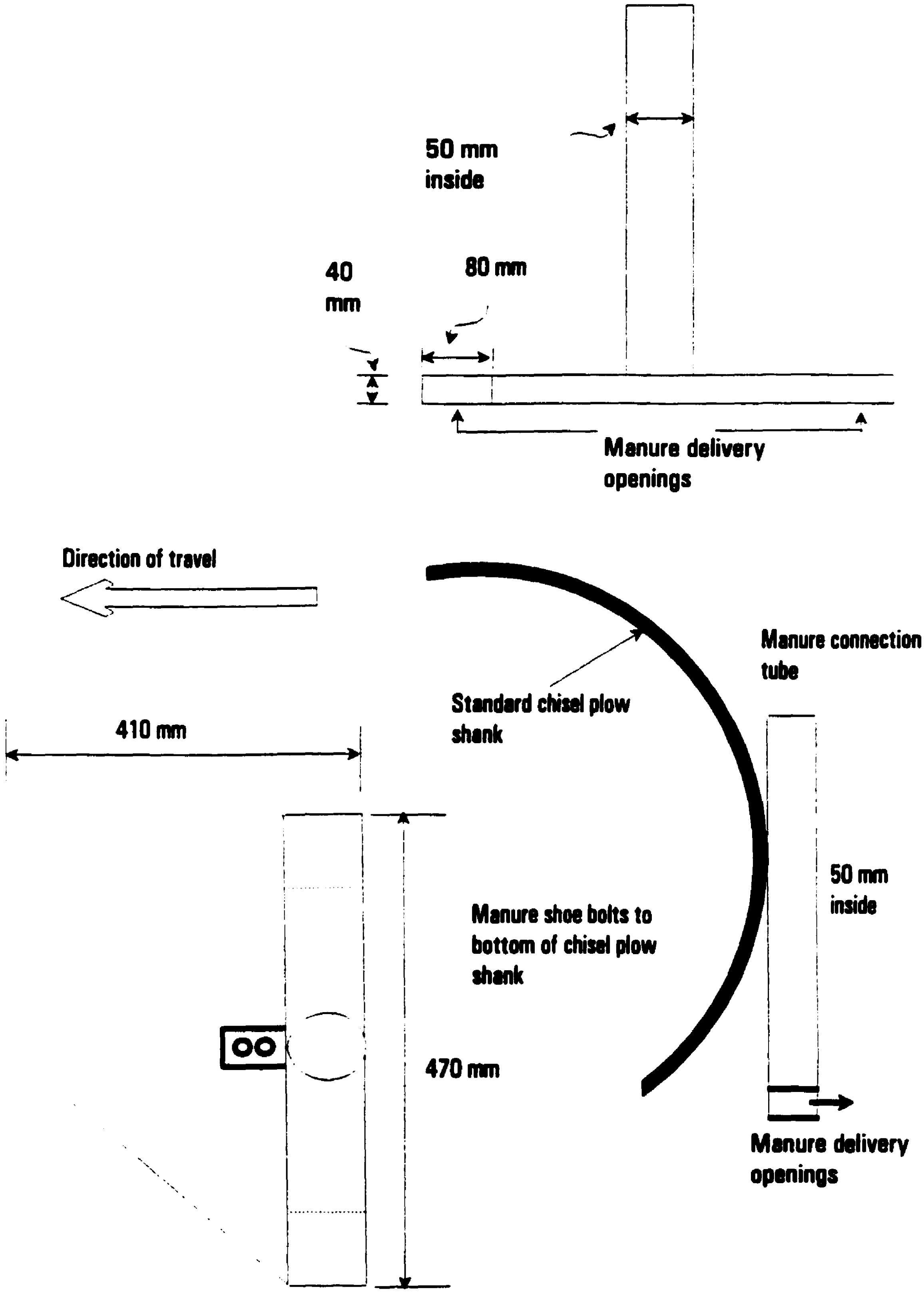

Figure 6.5 Configuration of manure injection assembly for treatments 9 and 10 to divide the flow and deliver the manure in two bands 390 mm on center.

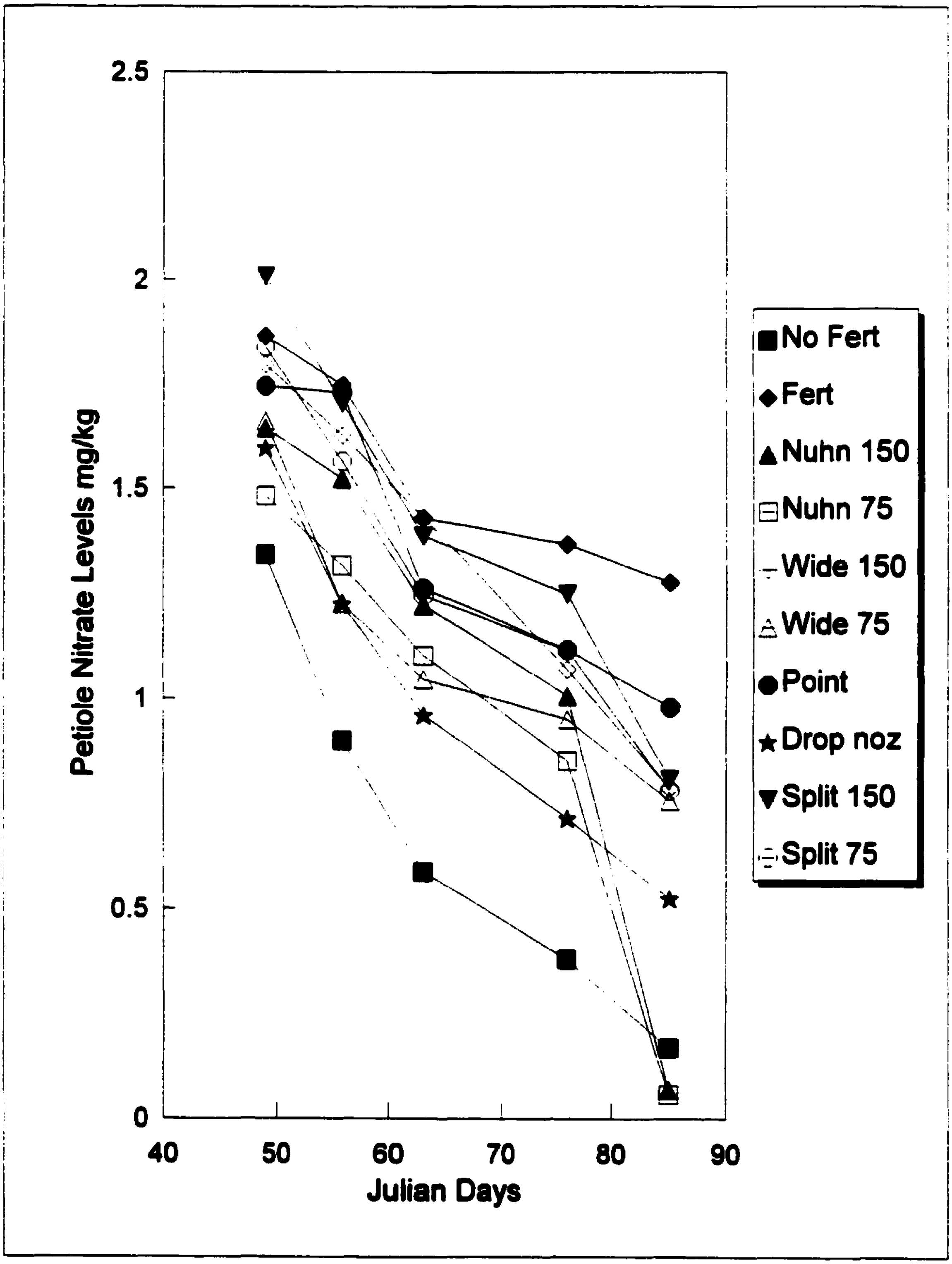

Figure 6.6 Petiole Nitrate-N Levels for 1995.

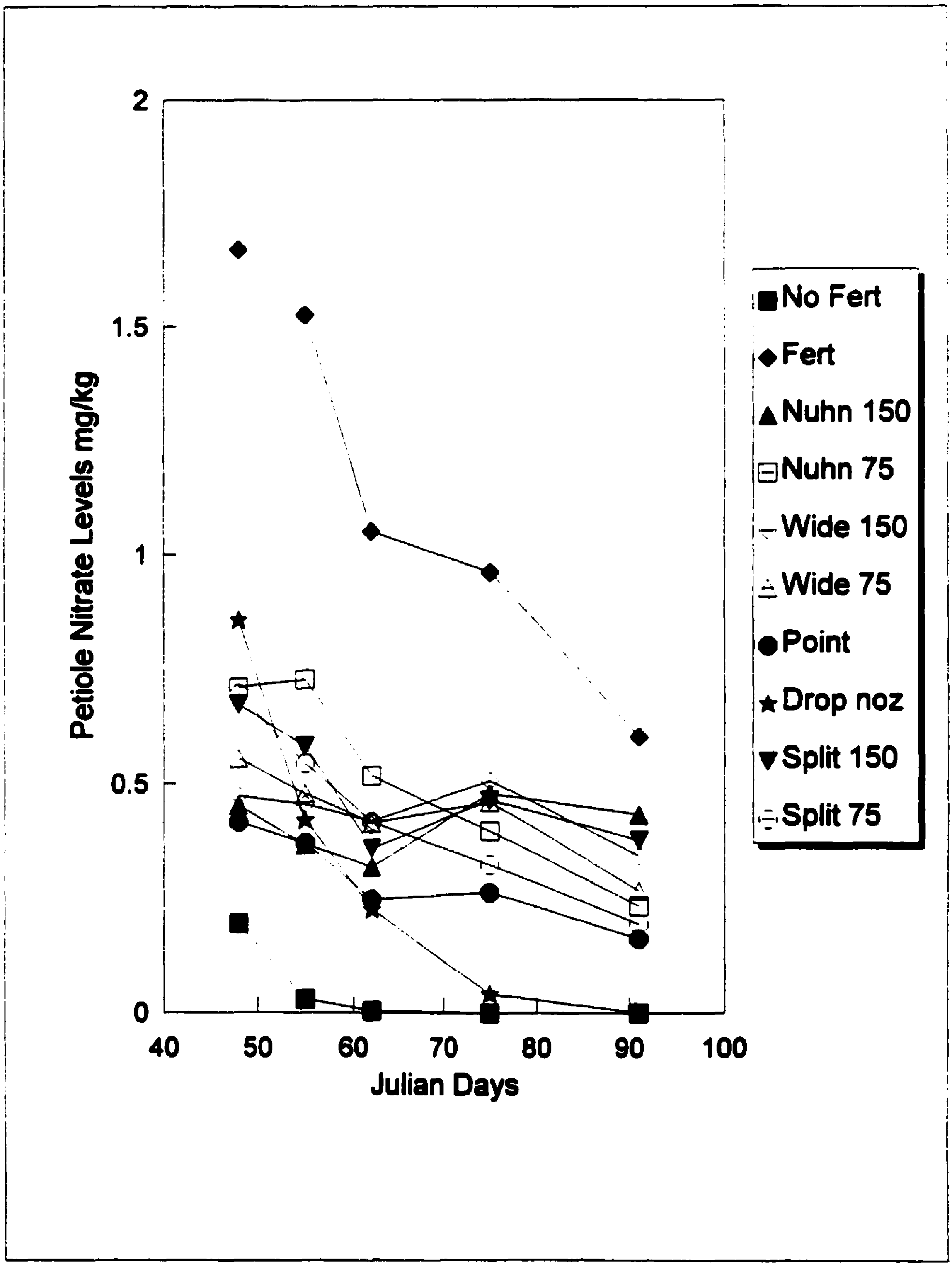

Figure 6.7 Petiole Nitrate-N Levels for 1996.

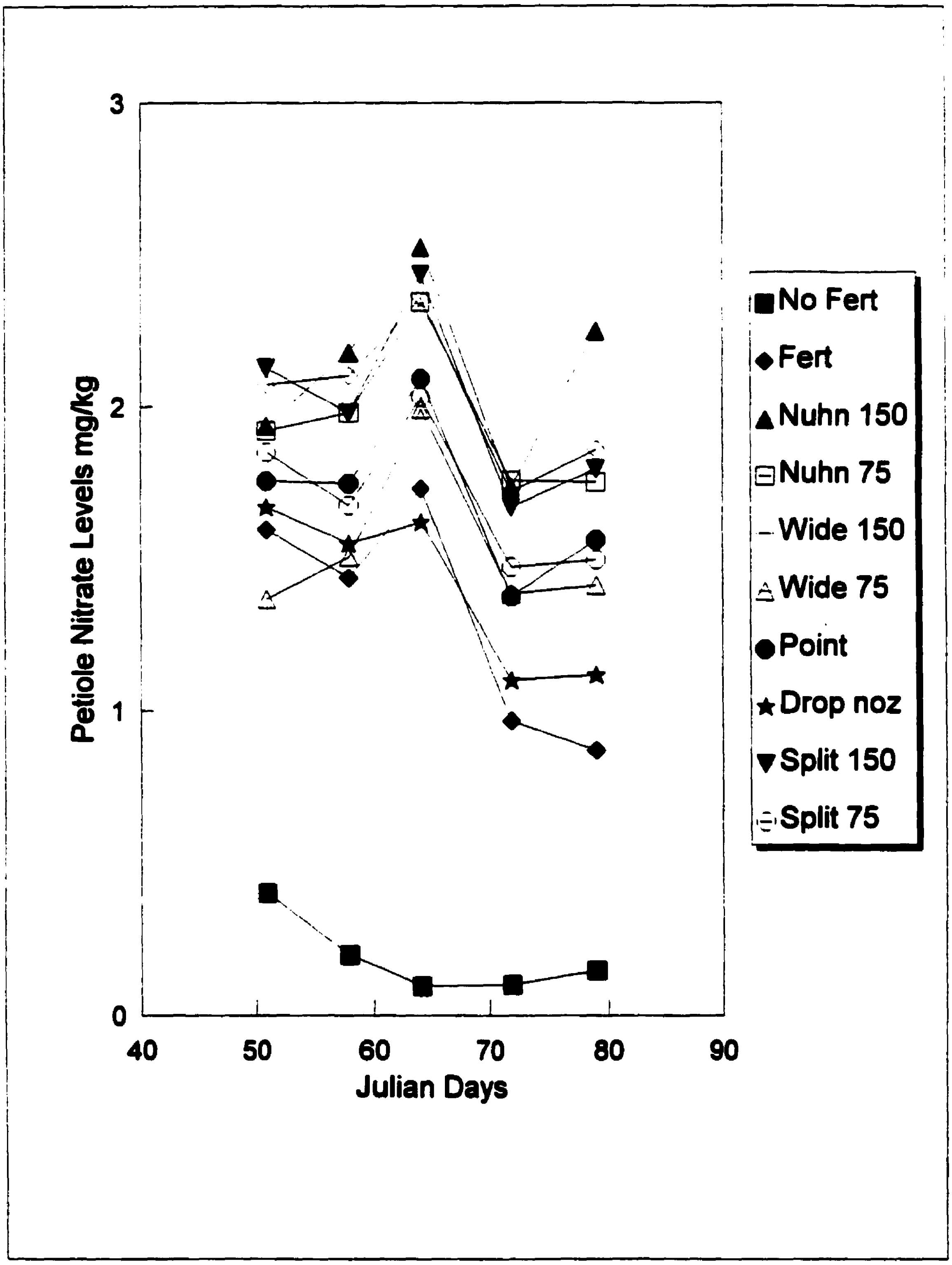

Figure 6.8 Petiole Nitrate-N Levels for 1997.

Connecting Text Chapter 6 to Chapter 7

This Chapter covers the development of a technique for determining potato root development. Samples were collected from selected treatments in the experiment outlined in Chapter 6 in 1996. The technique and data collected are presented in this Chapter. I wish to acknowledge the assistance of Dr. Suzelle Barrington in reviewing the manuscript and to Lloyd Kerry for technical assistance in the field and in sample collection and analysis. This paper is to be submitted to Canadian Agricultural Engineering.

7.1 Abstract

A technique was developed to determine differences in potato crop rooting development under field conditions using soil cores. A systematic sampling pattern was adopted from in which six positions were sampled for each plot. Soil cores were collected using 54.5 mm diameter by 460 mm long plastic tubes pushed into the ground by hand and to the plow depth. Tubes were cut to desired lengths, soil was removed and placed on separation screens under a rainfall simulator nozzle and soil was gently washed from the roots through the screens. Roots were then removed from the screens, oven dried and weighted to determine their dry weight. To verify the technique, a small portion of an existing field experiment was sampled in mid-August. Data collected indicated significant differences with plots receiving liquid hog manure having larger root masses than plots receiving inorganic fertilizer.

7.2 Introduction

Linford and McDole (1977) described the Russet Burbank potato as a typical vegetable crop in that it has a shallow rooting system. Thus the potato has a lower efficiency in recovering applied fertilizer nutrients and water than plants with a more fibrous root system. An examination of the literature suggests that the major contributing factors affecting the development of potato crop root systems are soil compaction, soil moisture levels, nutrient placement in the soil, varietal differences and soil pathogens present. DeRoo and Waggoner (1961) looked at the deep placement of fertilizer or the placement of fertilizer in the loosened subsoil. In comparison to loosening alone, they detected no greater root development resulting from the placement of the fertilizer. The authors were unable to explain the lack of additional root development in the enriched soil.

In considering the placement of liquid hog manure as a nutrient source the study, of rooting and root development in the potato crop was logical in that the roots are the interface between the potato crop, the soil and thus the nutrients in the hog manure. A number of questions are raised with regards to root development and the use of injected liquid hog manure as a nutrient source for the potato crop. These include the placement of manure nutrients and their relationship to the root system, the movement of nutrients due to cultivation and hilling practices, and the movement of the nutrients due to leaching. The placement of manure requires investigations as to its effects on rooting development and rooting patterns and the subsequent improvements on nutrient and water utilization by the potato crop.

A review of the literature uncovered many methods of root measurement in the field ranging from soil pits to soil core sampling to clear tubes with video cameras. Given the number of plots in field studies, a soil coring approach appeared to be the most practical alternative. It was felt that soil pits would cause too much disturbance to the plots and clear tubes installed in the field presented problems for cultivating and hilling operations. The problems with the soil coring technique was the need to develop an efficient system. Thus the objective of this work was to develop an efficient methodology for the collection, separation and measurement of the potato root system development.

7.3 Material and methods

The development of an efficient method of a root measurement technique can be broken down into three components. The first is infield sampling, the second is the soil root separation, and third is the measurement of the root system.

The field sampling procedure consisted of a) locating the samples and b) developing the method of root sample collection. Examination of the literature strongly suggested that for row crops like potatoes a systematic sampling procedure should be used. The arrangement for sample position chosen for our study was that described by Vos and Groenwold (1986) (Figure 7.1). To accomplish sample collection in the field, 54.5 mm diameter by 460 mm long plastic tubes were selected. These were labeled then pushed into the soil by hand in the pattern outlined by Vos and Groenwold. The authors developed the following equation to compile the data:

$$\text{Mean} = (((p1 + p2)/2 + (p2 + p3)/2)/2 + ((p4 + p5)/2 + (p5 + p6)/2)/2)/2 \quad (1)$$

or

$$\text{Mean} = (p1 + 2p2 + p3 + p4 + 2p5 + p6)/8$$

Figure 7.1 shows the six px sample positions either in the row beside the row or between the rows for plant location and between the plants where the roots were collected.

The purpose of the equation was to develop a measure for a single potato plant, by assigning higher weighting to areas where two plants contribute to the roots collected in a given sample.

Since we were dealing with tilled soil, the procedure of pushing the tubes by hand allowed sampling to the plowpan depth. Data from Boone et al. (1985) suggested that there was little root penetration into the plowpan and lower layers. This procedure required about 5 minutes per plot for two persons, thus a reasonable number of treatments could be sampled in an afternoon: 10 treatments over 4 replication or 40 plots, can be sampled in 3 hours and 20 minutes if each plot takes 5 minutes. Samples were then moved to the cold room for short term storage.

The separation assembly consisted of a 6 by 6 grid system of small square boxes (150 mm by 150 mm). The assembly was constructed with 2 by 4 lumber on edge with a nylon screen (2.0 mm^2 mesh) attached to bottom (Figure 7.2). One meter above the boxes, a single 12.7 mm rainfall simulator nozzle (Tossell et al. 1990) was positioned and water from a standard tap was used as supply. From the storage, each plastic core with soil was cut in measured lengths using a commercial metal cutting chop saw with a metal cutting blade. Soil was removed from the plastic liner and placed in the individual boxes and the rainfall simulator was run for 24 to 36 hours. At the end of this time, most soil had been washed through the screen. Stones and other material were manually separated from the roots which were then moved to a cold room for storage.

When all samples had been separated, they were oven dried for 24 hours at 70° C and weighed to determine root mass in each sample. The core volumes were calculated and the root densities are presented as mg/cm^3. An image analysis technique could also be used to calculate root length in the sample, but this technique was not available at the time of this work.

In order to field test the root measurement system, 6 treatments over two replications of an existing field experiment were sampled on August 19, 1996. The complete details of the experiment are given in Campbell et al. 1998. In general, the experiment was designed to evaluate different injector designs used to inject liquid hog manure into the potato crop after it was planted. All treatments received 25 kg/ha nitrogen, 200 kg/ha phosphorus and 200 kg/ha potassium in two fertilizer bands below and to one side of the potato seed piece. Treatment one, not given any additional nitrogen, was the check plot (trt1). The fertilizer check had 100 kg/ha of nitrogen as ammonium nitrate fertilizer, broadcasted at the time of manure injection (trt2). Manure treatments involved the injection of liquid hog manure at a rate to give 100 kg/ha of nitrogen in the ammonium form, between the potato rows, after the crop was planted. Manure was injected using a 260 mm wide sweep injector foot (supplied by Nuhn Industries Ltd., R.R.#1 Sebringville, Ontario, N0K-1X0) at two depths 75 and 150 mm (trt3 and trt4 in Figure 7.3). A second injection treatment using a 470 mm wide sweep injector foot with manure delivered by a 40 mm by 80 mm opening at the ends of the sweep (Figure 7.4) was operated at the same two depths as trt3 and trt4 (trt5 and trt6). Thus the experimental design of the root sampling study was 6 treatments over two replications for a total of 12 plots.

The data from the root measurements were analyzed using ANOVA in Genstat 1987. This procedure tested the effects of liquid hog manure placement on mean root density

7.4 Results and discussion

Table 7.1 indicates that depth had the highest variance value. The data indicate that there was a significant difference between the 0.06 mg/cm^3 root density in the shallow samples and 0.1 mg/cm^3 in the deeper soil layers. Since there were no significant interactions, the effect was consistent across all positions and treatments.

Second in the significance table was the effect of sample position. The data presented in Figure 7.5 corresponds to the sample positions in Figure 7.1. The pattern matches what was expected in that the highest root densities were scored at P1 over the plant location and root densities were reduced as one moved away to position P6.

Third in level of significance was the effect of treatment (Table 7.2). The lowest values for root density were for the treatments receiving the inorganic fertilizer, the 100 kg/ha of nitrogen fertilizer followed by the no nitrogen check. Manure treatments had significantly more roots but were not different from each other. A similar pattern was shown in the weighted root density calculation based on Vos and Groenwold 1986. Since there were no interactions between treatments and either position or depth, the effects were consistent across these two factors. Root expansion and density increase in the manure treatments could be due to the general enrichment of the soil due to the manure additions.

7.5 Conclusions

The development of a complete root sampling procedure consisted of three phases or steps, field sampling, soil/root separation and root measurement. A rapid field sampling procedure was developed using 54 mm plastic tubes pushed into the ground by hand. The sampling pattern used in this study was that developed by Vos and Groenwold (1986). The sample tubes were cut into desired lengths, soil cores were removed and placed on the separation screen assembly where the rainfall simulator applied an even rainfall, washing the soil from the roots through the screens. Roots were removed from the screens, oven dried and weighed. Though not providing as much information as root length and diameter measurements using computer image analysis, the weighing procedure was rapid, simple to use and provided good comparative results.

Data collected from the small field trial clearly demonstrated the success of the technique, showing significant differences in depth of sampling, position of sampling and treatments.

Treatment differences suggest that the plots receiving manure had significantly higher root densities than those which received only inorganic fertilizers.

7.6 Acknowledgments

The authors wish to acknowledge the assistance of Lloyd Kerry in the design and construction of some of the test equipment, in field sampling the plots and his work in running the root separation procedure, weighting of samples and compilation of the data.

7.7 References

Boone F.R., L.A.J. De Smet, C.D. Van Loon. 1985. The effect of a ploughpan in marine loam soils on potato growth. 1. Physical properties and rooting patterns. Potato Research. 28:295-314.

Campbell, A.J., S. Barrington, J.A. MacLeod. 1998 Design and field testing of manure injectors for liquid hog manure into the growing potato crop. In press.

De Roo H.C., P.E. Waggoner. 1961. Root development of Potatoes. Agronomy Journal. 53:15-17

Genstat V 1987. Reference Manual Clarendon Press, Waston Street, Oxford, England.

Linford K., R.E. McDole. 1977. Survey to investigate potato rooting in southern Idaho soils. Proceedings 28th Annual Fertilizer Conf. Pacific Northwest, Twin Falls, Idaho, July 12-14, 1977. pp109-114.

Tossell R.W., G.J. Wall, W.T. Dickinson, R.P. Rudra, P.H. Groenevelt. 1990. The Guelph rainfall simulator II: Part 1-Simulated rainfall characteristics. Canadian Journal of Agricultural Engineering 32:205-213.

Vos J., J. Groenwold. 1986. Root growth of potato crops on a marine-clay soil. Plant and Soil 94(1):17-33.

Table 7.1 Significance of data from the ANOVA analysis for the root densities measured mg/cm ^{3}.

Factor	d.f.	Variance	Significance
Treatments	5	3.55	**
Position	5	7.73	**
Depth	5	14.67	**

There were no significant interactions in this analysis.

** significant at P<.001

Table 7.2 The effect of manure injection treatments on root density.

Treatments	Mean Root Densities mg/cm^3
Trt 1. No additional nitrogen	0.064
Trt 2. 100 kg/ha nitrogen	0.043
Trt 3. Standard Nuhn at 75 mm deep	0.084
Trt 4. Standard Nuhn at 150 mm deep	0.111
Trt 5. Split injection at 75 mm deep	0.098
Trt 6. Split injection at 150 mm deep	0.081
Standard error of the difference	0.018

List of Figures

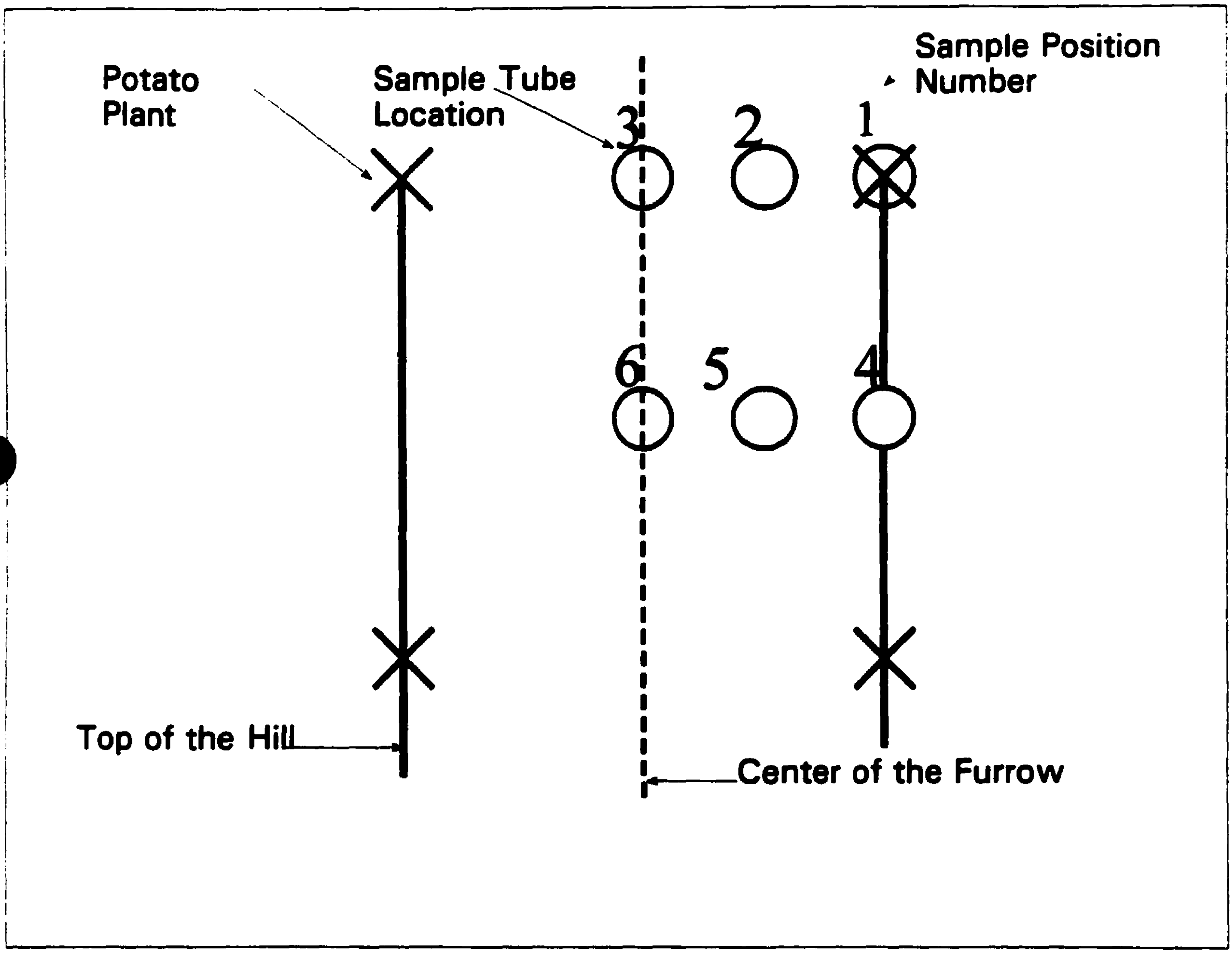

Figure 7.1 Position of core sample locations relative to the potato rows in the field.

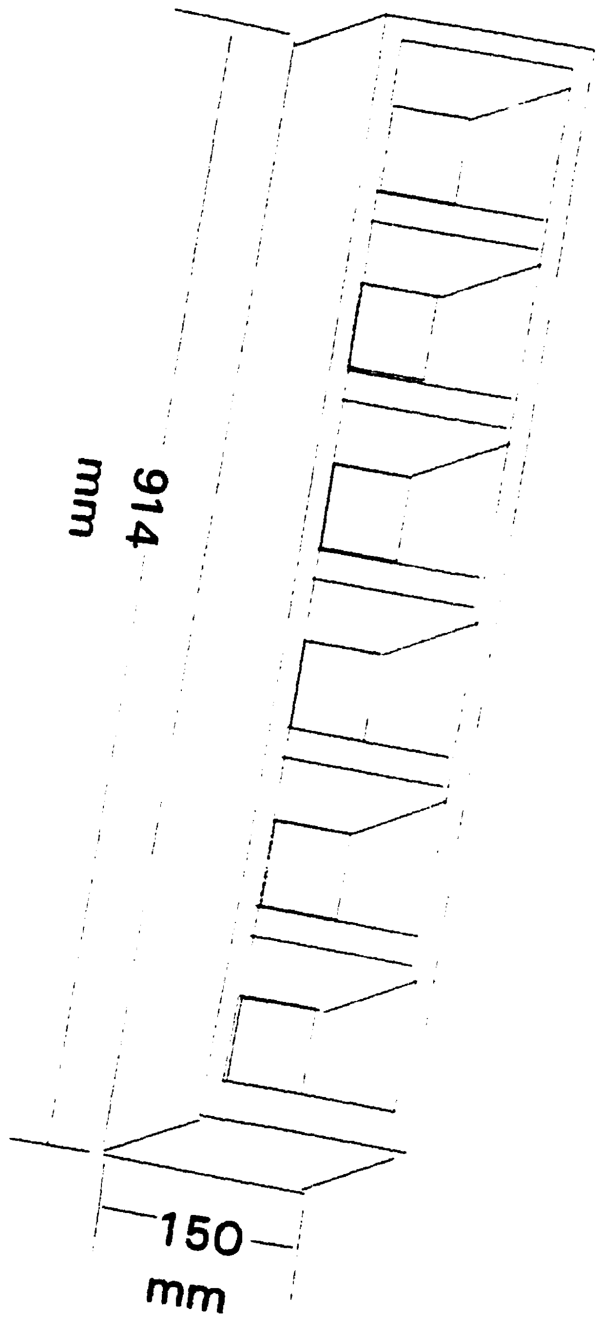

Figure 7.2 Diagram of the root soil separation boxes.

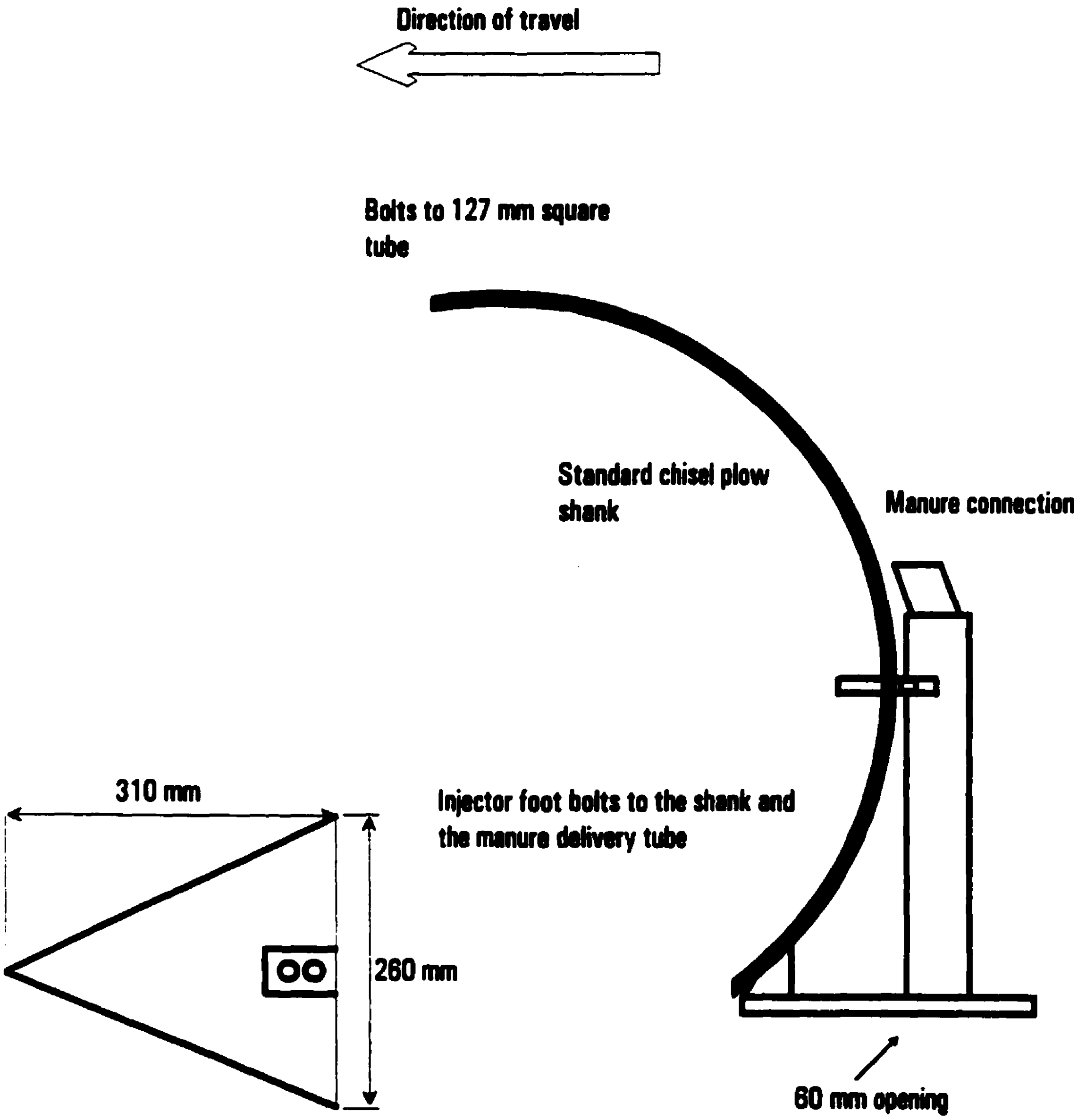

Figure 7.3 Nuhn industries standard injector design supplied with the tanker and injection system.

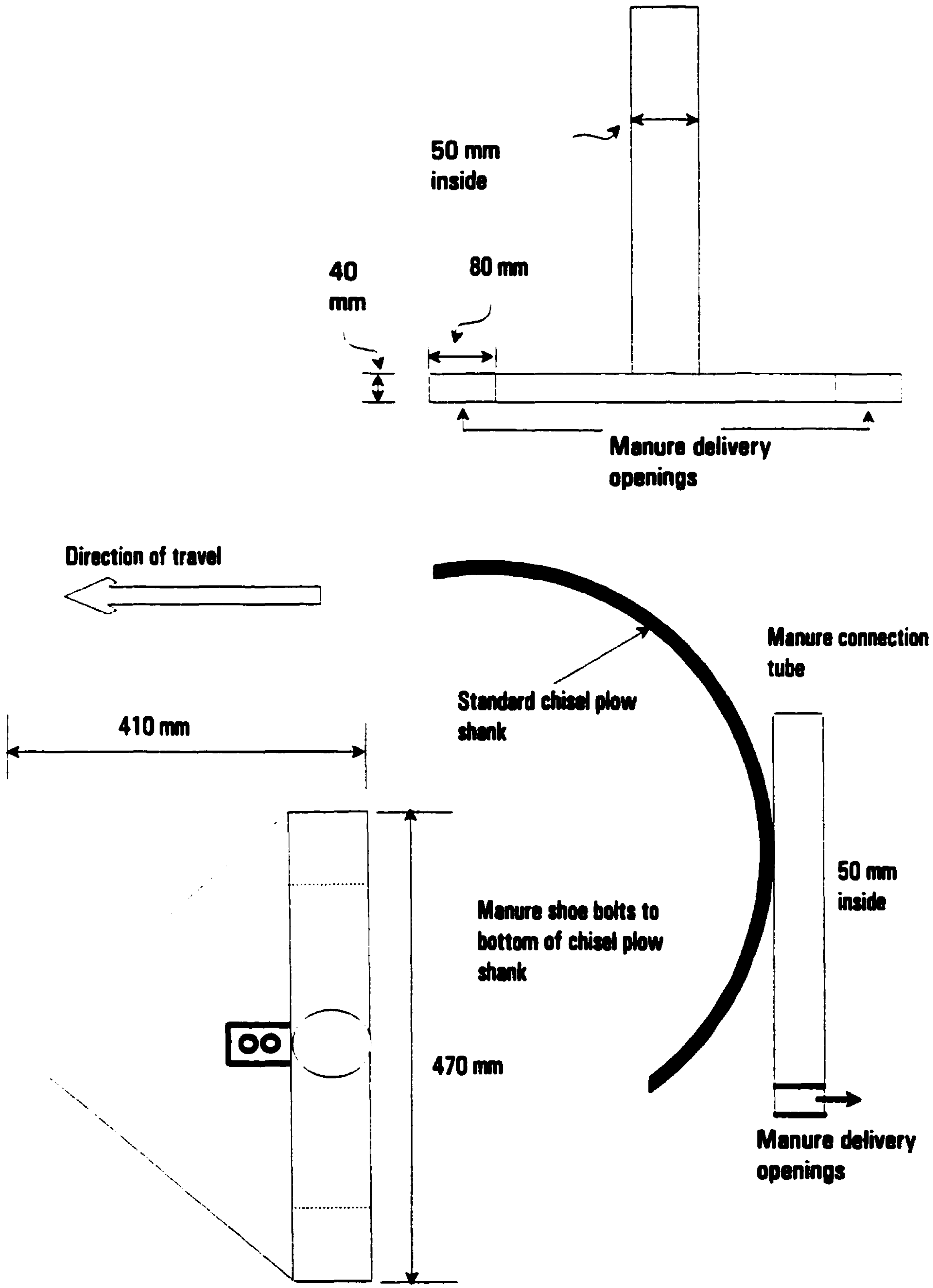

Figure 7.4 Split injector design to deliver manure in two bands at the end of the injector sweep.

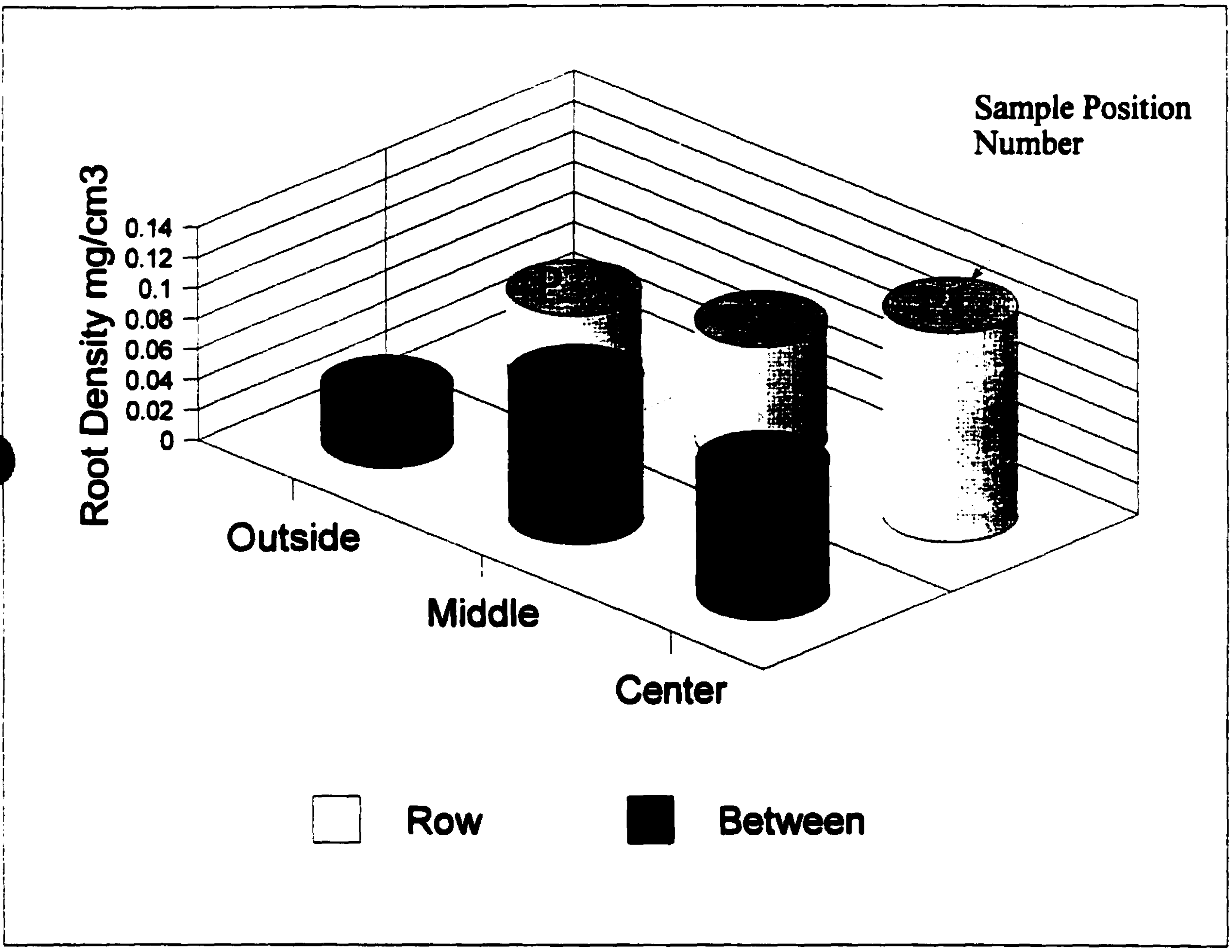

Figure 7.5 Root density data in mg/cm³ for the field core sample positions.

CHAPTER 8 GENERAL CONCLUSIONS

In general this research sets out to examine liquid hog manure as a nutrient source for the potato crop. The first step was a survey of hog farms on P.E.I. to determine the nutrient characteristics of local liquid hog manure. Results from this survey indicated that in general terms, manure on P.E.I. was similar to manure found elsewhere in the world. Important to note is that there were large differences between farms and thus it would not be possible to use local averages to determine accurate nutrient loading for individual farms. This work also outlined as sample collection procedure for on farm sample collection. Future work in this area might include a study of feed, seasonal effects, manure additives, feed additives and storage conditions on the nutrient characteristics of hog manures.

The second part of the research was to develop an infrastructure for manure storage, handling and application at the Harrington Research Farm, Crops and Livestock Research Centre, Charlottetown, P.E.I.. The storage facility consisted of two plastic tanks with a 3.5 kW motor and pump to transfer manure to and from the tanks. A 9000 l manure tanker with injectors was purchased from Nuhn Industries Ltd., Ontario. Calibration procedures were developed and a small field experiment was conducted which confirmed that the facilities and equipment functioned properly. Future work in this area will involve the purchase of a new tanker with a flow meter and on the go flow controller. The next step will be the integration of this with the global positioning to record and control field application patterns.

The two first parts of this research prepared the way for the major portion of this work consisting of two-three year field experiments. The first field experiment examined the placement of manure by injection prior to planting. Manure was placed under the row, 0.23 m beside the row and directly between the rows. Results indicated that manure placed under the row and beside the row gave slightly higher potato yields than manure placed between the rows. In general plots receiving manure had tuber yields equal to those which received extra Nitrogen fertilizer. Petiole nitrate-N levels measured during the growing season showed similar patterns to the yield results.

The second three year field experiment included the design and testing of liquid hog manure injectors in terms of the response of the potato crop to nutrient placement in the soil. Manure was injected between the potato rows using each configuration after the crop was planted. Potato tuber yield data over the three years indicated no differences among injector design nor between the injector treatments and the treatment which received the extra Nitrogen fertilizer.

Over both experiments, there was a decline in the severity of Rhizoctonia in one year for plots receiving manure compared to those which received only inorganic fertilizer. There were no differences in the incidence or severity of scab over the study.

As part of the research, a root sampling, separating and measurement technique was developed. This was used only in the second year of the injector field experiment and only on selected treatments. These limited data showed an increase in root mass for plots which received manure compared to those which received only inorganic fertilizer.

In general, one might have expected tuber yield differences among injector designs based on the first field experiment, root measurements and petiole nitrate-N levels. This was not the case, and was possibly due to the large quantities of manure injected and subsequent cultivation and hilling operations along with the lag time in nitrate availability from manure sources. Also potato experiments have a high degree of variability due to the limited number of plants in each row and thus, the large effects of missing plants or plants suffering from disease.

Future work on manure injection should look at timing of manure injection treatments, rates of manure injection and the other nutrients the manure might provide to the potato crop.

CHAPTER 9 CONTRIBUTION TO KNOWLEDGE

9.1 Manure Nutrient Characterization and Sampling

A sampling procedure was developed for sampling manure storage facilities. Manure nutrient characteristics for liquid swine manure on P.E.I. are defined and the variability established.

9.2 Infrastructure Development

The development, design, calibration and field testing of an infrastructure for conducting manure injection research was completed and evaluated and is available for others wishing to conduct research in this area.

9.3 Manure Nutrient Placement

Work conducted indicated that the closer manure can be placed to the sown potato row, the better the nutrient uptake and crop performance. Manure treatments were equal to treatments receiving extra Nitrogen fertilizer.

9.4 Liquid Manure Injector Designs

Various injector designs from simple to more complex were evaluated. All designs performed equally in terms of potato crop yields. Potato crop yields were equal to the treatment which received the extra Nitrogen fertilizer. Other parameters measured such as root mass and petiole nitrate-N indicated some differences in some years in manure injector performance.

9.5 Root Mass Determination

A field sampling, root separation and root measuring technique was developed and successfully used on a field experiment.

CHAPTER 10 REFERENCES

ASAE 1990. ASAE D384.1. Manure production and characteristics. 463-465 In *ASAE Standards 1990*. 37th Edition. ASAE, 2950 Niles Road, St. Joseph, Michigan, 49085-9659, USA.

Beauchamp E.G. 1983. Manure for crop production. Publication Number 83-039. Agdex Number 100/538. Ontario Ministry of Agriculture and Food, Toronto, Canada.

Beauchamp E.C. 1983. Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure. Canadian Journal of Soil Science 63:377-386.

Boone F.R., J. Bouma, L.A.H. de Smet. 1978. A case study on the effect of soil compaction on potato growth in a loamy sand soil. 1. Physical measurements and rooting patterns. Netherlands Journal of Agriculture Science. 26:405-420

Boone F.R., L.A.J. De Smet, C.D. Van Loon. 1985. The effect of a ploughpan in marine loam soils on potato growth. 1. Physical properties and rooting patterns. Potato Research. 28:295-314

Bran+Luebbe Analyzing Technology Inc., 1987. Elnsford, New York, USA. Technical Publication Number DSM-0005-00.4.

Campbell, A.J., S. Barrington. 1998. Liquid manure storages and application equipment development, calibration procedures and field verification in the potato crop. In press.

Campbell, A.J., S. Barrington, J.A. MacLeod. 1998a. Design and field testing of manure injectors for liquid hog manure into the growing potato crop. In press.

Campbell, A.J., S. Barrington, J.A. MacLeod. 1998b. Effect of manure placement relative to the sown row on nutrient utilization by the potato crop. In Press.

Campbell A.J, J.A. MacLeod, C. Stewart. 1997. Nutrient Characterization of Stored Liquid Hog Manure. Can. J. Agric. Engng. 39(1):043-048

Cao W., T.W. Tibbitts. 1992. Temperature cycling periods affect growth and tuberization in potatoes under continuous irrigation. HortScience 27(4):344-345

Choudhary M.A., C.J. Baker, L.D. Currie, and T.J. Lynch. 1988. Disposal of agricultural liquid waste by sub-soil injection. In Alternative Waste Treatment Systems. Edited by Rao Bhamidimarri. Elsivier, New York. PP 82-92.

Christie P. 1990. Accumulation of potentially toxic metals in grassland from long-term slurry application. In *Fertilizer and the Environment.* 24-130 Edited by Merckx R., Vereecken H., and Vlassak K. Leuven University Press, Karkenstraat 3, B 3000 Leuven/Louvain, Belgium.

Collins E.R. Jr., T.A. Dillaha, F.B. Givens and C.D. Eddleton. 1988. Farm manure management planning for Virginia. ASAE Paper 88-2048. St. Joseph, MI:ASAE.

Comfort S.D., P.P. Motavalli, K.A. Kelling, J.C. Converse. 1987. Soil profile N, P, and K changes from injected liquid dairy manure of broadcast fertilizer. Transactions of the ASAE 30(5)1364-1369.

De Roo H.C., P.E. Waggoner. 1961. Root development of Potatoes. Agronomy Journal. 53:15-17

Durrant M.J., B.J.G. Love, A.B. Messem, A.P. Draycott. 1973. Growth of crop roots in relation to soil moisture extraction. Annals of Applied Biology. 74:387-394

Fatemy F., K. Evans. 1986. Effects of globodera rostochiensis and water stress on shoot and root gowth and nutrient uptake of potatoes. Revue Nematology 9(2):181-184

Feldman M., and B.A. Compton. 1981. An equipment design for injecting liquid manure in sod fields. ASAE Paper Number 81-324. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Feldman M., and G.K.H. Thuns. 1976. An injector-tanker design to apply liquid manure between corn crop rows. CSAE Paper Number 76-214. CSAE, Box 381, RPO University of Saskatoon, SK, S7N-4J8.

Fraser H. 1985. Manure characteristics. Publication Number 85-109. Agdex Number 538. Ontario Ministry of Agriculture and Food.

Fulton J.M.; 1970. Relationship of root extension to the soil moisture level required for maximum yield of potatoes, tomatoes and corn. Canadian Journal of Soil Science. 50:92-94

Genstat V 1987. Reference Manual Clarendon Press, Walton Street, Oxford, England.

Godwin R.J., N.L., Warner, and M.J. Hann 1990. Comparison of umbilical hose and conventional tanker-mounted slurry injection systems. Agricultural Engineering 45(2)45-50.

Godwin R.J., N.L., Warner, and J.E. Hall 1985. Soil injection of liquid waste. In Proceedings of Fifth Annual Symposium on Agricultural Waste. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659. pp 63-72.

Gupta U.C. 1971. Boron and Molybdenum nutrition of wheat, barley, and oats grown in Prince Edward Island soils. *Canadian Journal of Soil Science* 51:415-422.

Hall J.E. 1986a. Machinery spreading: Soil injection as a barrier to odour dispersion. In Odour prevention and control of organic sludge and livestock farming. Edited by V.C. Nelsen, J.H. Voorburg, and P.L. L'Hermite. Elsevier Applied Science Publishers, London. pp 194-206.

Hall J.E. 1986b. Soil injection of organic manures. In Effects of land use on fresh waters. Editor J.F. de L.B.Salbe, Chichester, England. pp521-527.

Hann M.J., N.L. Warner and R.J. Godwin. 1987. Slurry injector design and operational practices for minimizing soil surface disturbance and crop damage. ASAE Paper Number 87-1610. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Ibrahim B.A., D.E. Miller. 1989. Effect of subsoiling on yield and quality of corn and potato at two irrigation frequencies. Soil Science Society of American Journal. 53:247-251

Kumar D., C.D. Eddleton, E.R. Collins, and T.A. Dillaha. 1990. Characterization of manure nutrient values in Virginia. ASAE Paper Number 90-2024. St.Joseph, MI:ASAE.

Lague C. 1986. Design of a semi-liquid dairy cattle manure spreader/injector. ASAE Paper Number 86-4056. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Lague C. 1991. Design of a semi-liquid dairy cattle manure spreader/injector. Applied Engineering in Agriculture 7(6)655-660.

Lamb J., J. VanRoestel. 1994. Effect of manure and fertilizer application methods on grain corn yield. Personal comm. 1994. Jack VanRoestal, Field Crop Specialist, Agricultural Center, Kentville, Nova Scotia, B4N-1J5, CANADA.

Lesczynski D.B., C.B. Tanner. 1976. Seasonal variation of root distribution of irrigated, field-grown russet burbank potato. American Potato Journal. 53:69-78

Linford K., R.E. McDole. 1977. Survey to investigate potato rooting in southern Idaho soils. Proceedings 28th Annual Fertilizer Conf. Pacific Northwest, Twin Falls, Idaho, July 12-14, 1977. pp109-114.

Marshall I. 1991. Going underground to solve a slurry worry. Power Farming July 26. pp24-26.

Maschhoff K.D. and A.J. Muehling. 1985. Using nurse tankers to transport liquid manure to the field from a 650-sow farrow-to-finish operation. 55-62 In *Agricultural Waste Utilization and Management* Dec 16-17, 1985 By ASAE, 2950 Niles Road, St. Joseph, Michigan, USA.

Motavalli P.P., K.A. Kelling, J.C. Converse. 1989. First-year nutrient availability from injected dairy manure. Journal of Environmental Quality. 18(2)180-185.

Nambu S., and T. Gemma. 1981. The effect of animal slurry injection on forage corn production. In Livestock Waste: A Renewable Resource Proceedings 4th International Symposium on Livestock Wastes. By ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659. pp 167-169.

Negi S., E. McKyes, R. Godwin, G. Eades and J.R. Ogilvie. 1976a. Engineering design of liquid manure injectors. CSAE Paper Number 76-211. CSAE, Box 381, RPO University of Saskatoon, SK, S7N-4J8.

Negi S.C., E. McKyes, R.J., Godwin, J.R. Ogilvie. 1976b. Development of mechanization for the efficient injection of liquid slurry wastes into agriculture soils. Report to Agriculture Canada Engineering Research Canada. DSS Contract RN:01843-5-0042, FC 1-1850-000-000-0414, Serial OSW5-0287.

Negi S.C., E. McKyes, R.J., Godwin, J.R. Ogilvie. 1978. Design and performance of a liquid manure injector. Transactions of the ASAE. 21(5)963-971.

Newman E.I.; 1966. A method of estimating the total length of root in a sample. Journal of Applied Ecology. 3:139-145

Overcash M.R., F.J. Humenik,and J.R. Miner. 1983a. *Livestock Waste Management. Volume I.* 180-248 CRC Press Inc, 2000 Corporate Blvk., N.W., Boca Raton, Florida, USA.

Overcash M.R., F.J. Humenik,and J.R. Miner, 1983b. *Livestock Waste Management. Volume II* 163-235 CRC Press Inc, 2000 Corporate Blvk., N.W., Boca Raton, Florida, USA.

Parker C.J., M.K.V. Carr, J.J. Jarvis, B.O. Puplampu, V.K. Lee. 1991. An evaluation of the minirhizotron technique for estimating root distribution in potatoes. Journal of Agricultural Science Cambridge. 116:341-350

Patni N.K., J.L.B. Culley. 1989. Corn silage yield, shallow groundwater quality and soil properties under different methods and times of manure application. Transactions of the ASAE 32(6)2123-2129

Petitte J.M., D.P. Ormrod, 1988. Effects of sulphur dioxide and nitrogen dioxide on shoot and root growth of Kennebec and Russet Burbank potato plants. American Potato Journal. 65:517-527

Pond W.G., and J.H. Maner. 1984. *Swine Production and Nutrition.* 546-547. AVI Publishing Company, Inc. Westport, Connecticut, United States.

Safley L.M. Jr., G.M. Lessman, J.D. Wolt, M.C. Smith. 1981. Comparison of corn yields between broadcast and injected applications of swine manure slurry. Proceedings of the 4th International Symposium on Livestock Waste, ASAE pp.178-180.

Safley L.M. Jr., J.C. Barker and P.W. Westerman. 1982. Modifications of a slurry manure injector for plot research. ASAE Paper Number 82-2504. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Safley Jr. L.M., P.W. Westerman, and J.C. Barker. 1986. Effect of manure injector type and spacing on corn yield. ASAE Paper 86-4545. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Safley Jr. L.M., P.W. Westerman and L.D. King. 1989. Effects of dairy manure application rate and timing, and injector spacing and type on corn silage production. Biological Wastes 28:203-216.

Saoud A.A., O. Van Cleemput, G. Hofman. 1992. Uptake and balance of labeled fertilizer nitrogen by potatoes. Fertilizer Research. 31:351-353

Sawyer J.E., R.G. Hoeft. 1990a. Effect of injected liquid beef manure on soil chemical properties and corn root distribution. Journal of Production Agriculture. 3:50-55

Sawyer J.E., R.G. Horft. 1990b. Greenhouse evaluation of simulated injected liquid beef manure. Agronomy Journal. 82:613-618.

Sawyer, J.E., M.A. Schmitt, R.G. Hoeft. 1990. Inorganic nitrogen distribution and soil chemical transformations associated with injected liquid beef manure. Agronomy Journal. 82:963-969.

Sawyer J.E., M.A. Schmitt, R.G. Hoeft, J.C. Siemens, D.H. Vanderholm. 1991. Corn production associated with liquid beef manure application methods. Journal of Production Agriculture. 4(3)335-344.

Schmitt M.A., J.E. Sawyer, R.G. Hoeft. 1992. Incubation of injected liquid beef manure: Effect of time and manure rate. Agronomy Journal. 84:224-228

Sen Tran T., M. Giroux. 1991. Effects of N rates and harvest dates on the efficiency of 15N-labeled fertilizer on early harvested potatoes (Solanum Tugerosum L.). Canadian Journal of Soil Science. 71:519-532

Singh G., R.A. Struchtemeyer. 1976. Snatomical response of potato stems and roots to soil moisture and rates of fertilizer. Agronomy Journal. 68:732-735

Sutton A.L., D.W. Nelson, J.D. Hoff, V.B. Mayrose. 1982. Effect of injection and surface application of liquid swine manure on corn yield and soil composition. Journal Environmental Quality. 11:468-472

Swaminathan K., B.C. Verma. 1977. Active root distribution profiles of Indian potato cultivars in relation to their capacity to extract phosphorus from the soil. Journal of Nuclear Agricultural Biology. 6:46-48

Swiezynski K.M., A. Sykala, J.K. Wroblewska. 1978. Differences in early growth of shoots and roots in potato clones. Potato Research. 21:241-248

Tossell R.W., G.J. Wall, W.T. Dickinson, R.P. Rudra, P.H. Groenevelt. 1990. The Guelph rainfall simulator II: Part 1-Simulated rainfall characteristics. Canadian Journal of Agricultural Engineering 32:205-213.

Tunney H. 1980. Fertilizer value of animal manures. *Farm and Food Research* 11(3)78-79.

Tunney H. 1981. An overview of the fertilizer value of livestock waste. In Livestock Waste: A Renewable Resource Proceedings 4th International Symposium on Livestock Wastes. By ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659. PP182-184.

Tunney H., S. Molloy. 1975. Variations between farms in N, P, K, Mg and dry matter composition of cattle, pig and poultry manures. *Irish Journal of Agricultural Research* 14:71-79.

Unger P.W., T.C. Kaspar. 1994. Soil compaction and root growth: A Review. Agronomy Journal. 86:759-766

Van Loon C.D., J. Bouma. 1978. A case study on the effect of soil compaction on potato growth in a loamy sand soil. 2. Potato plant responses. Netherlands Journal of Agricultural Science. 26:421-429

Vos J., J. Groenwold. 1986. Root growth of potato crops on a marine-clay soil. Plant and Soil 94(1):17-33.

Warner N.L., R.J. Godwin and J.E. Hall. 1987. Injection organic wastes into grasslands. Span 30,1,1987. pp9-11.

Warner N.L., R.J. Godwin. 1988. An experimental investigation into factors influencing the soil injection of sewage sludge. Journal of Agriculture Engineering Research. 39:287-300.

Warner N.L., R.J. Godwin and M.J. Hann. 1990. An economic analysis of slurry treatment and spreading systems for odour control. Agriculture Engineer Winter 1990. 45(1)100-105.

Warner N.L., R.J. Godwin and M.J. Hann. 1991. Modifications to slurry injector tines to reduce surface disturbance and improve slot closure under dry grassland conditions. Journal of Agricultural Engineering Research. 48(3):195-207.

Westerman P.W., L.M. Safley Jr., J.C. Barker. 1983. Potential harmful effects from land applying animal wastes. ASAE Paper No.83-2612. ASAE, 2950 Niles Rd., St. Joseph, Michigan, 49085-9659.

Widdowson F.V. A. Penny, and R.C. Flint. 1974. Results from experiments measuring the effects of large amounts of fertilizer and of farmyard manure on main-crop potatoes grown in sandy soil at Woburn, Bedfordshire. Journal of Agricultural Science Cambridge 82:117-127.

Wolt J.D., L.M. Safley Jr., G.M. Lessman, M.C. Smith. 1984. Influence of time of injection of liquid swine waste on silage yield and nutrient content of corn. Transactions of the ASAE 27(4)1135-1139.

Zublena J.P., J.C. Barker and J.W. Parker. 1990. Swine manure as a fertilizer source. *Soil facts.* Publication Number AG-439-4. The North Carolina Agricultural Extension Service.