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I am submitting herewith a thesis written by José A. Rangel entitled "Time and Methods of Liquid Dairy Manure Application for Nitrogen Utilization in Corn Silage Production." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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TIME AND METHODS OF LIQUID DAIRY MANURE APPLICATION FOR NITROGEN UTILIZATION IN CORN SILAGE PRODUCTION

A Thesis

Presented for the

Master of Science

Degree

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José A. Rangel

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ABSTRACT

Two field experiments were conducted at the Dairy Experiment Station, Lewisburg, TN, (i) to investigate inject versus broadcast application of liquid dairy manure both in the fall and spring as a source of nitrogen (N) for corn silage (Zea mays L.) production (Experiment 1), and (ii) to investigate the usefulness of a nitrification inhibitor [N-Serve, (nitrapyrin, 2-chloro-6-trichloromethyl pyridine)] in conserving manurial N applied through broadcasting and injecting in the fall (Experiment 2). Liquid dairy manure obtained from a pit receiving milking parlor wastes was applied in approximately equal amounts by weight to all manure treatments ($\sim$ 68 Mg $\cdot$ ha^{-1} in Experiment 1 and $\sim$ 90 Mg $\cdot$ ha^{-1} in Experiment 2); inorganic fertilizer treatments received 134 kg N $\cdot$ ha^{-1} as NH_4NO_3. Nitrapyrin treatments in Experiment 2 received N-Serve either as a tank mix calculated to give 4.7 L $\cdot$ ha^{-1} of the active ingredient (manure treatments) or as a broadcast application (inorganic N treatment). Each load of manure was sampled in the field prior to application. Grain and silage yields and tissue samples were collected from each plot, and soils were sampled in the fall of each year following corn harvest and prior to fall application of manure.

Times and methods of manure application had no influence on silage or grain yields, silage nutrient content, or soil test extractable nutrients in 1981-1982 (Experiment 1). This was probably because

of the high fertility status of the experimental area from prior manure application.

There was no effect of N-Serve on silage or grain yield, silage nutrient content or soil test extractable nutrients (Experiment 2), possibly because dry weather and soil temperature affected the response to N-Serve. In the second experiment, the inject application resulted in higher yields than broadcast application of manure, and conventional fertilization resulted in higher yields than did manure application. In this experiment manure application resulted in higher concentrations of phosphorus (P) and potassium (K) in silage than did conventional fertilization.

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CHAPTER I

INTRODUCTION

Animal manures are produced in large quantities each year in the U.S.A. Gilbertson et al. (1979) estimated the annual amount of animal manure production in the U.S.A. to equal 120 x 10^6 metric tons (dry weight). As a consequence of this large amount of annual manure production, an enormous problem arises regarding its disposal. Land application seems to be the most feasible answer to animal waste disposal since dairy manure can contain significant quantities of plant nutrients which can be beneficial in crop production. Today, due to the high cost of fossil fuel and commercial fertilizers, the value of dairy manure used as a substitute for commercial fertilizers has increased significantly.

Proper and timely application of dairy manure is important in order to maximize manurial nutrient utilization and minimize nutrient losses thus reducing the need for commercial fertilizers and the possibility for pollution. This thesis research was undertaken (i) to investigate inject versus broadcast application of liquid dairy manure both in fall and spring as a source of N for corn silage production and (ii) to investigate the usefulness of a nitrification inhibitor in conserving manurial N applied either broadcast or inject in the fall.

CHAPTER II

LITERATURE REVIEW

Animal manures are produced in large quantities each year in the United States. Gilbertson et al. (1979) estimated the annual amount of animal manure production in the U.S.A. to equal 120 x 10^6 metric tons (dry weight). Recently, a U.S.D.A. Task Force (Gilbertson et al., 1979) has estimated the total annual amount of manure production at 160 x 10^6 metric tons (dry weight).

Mantell (1975) noted that there are about 50 million cows in the United States which annually produce the equivalent amount of manure as produced by two billion people. As a consequence of this large amount of annual manure production an enormous disposal problem arises. Land application seems to be the most feasible answer to animal waste disposal since animal manures contain nutrients in quantities which can be beneficial in crop production.

Animal Manure Characteristics

Chemical Characteristics

Manures vary in nutrient concentration depending on factors such as the type and age of the animal, as well as different digestion processes, various feeds and feed additives, and the amount of decomposition, leaching, or mixing of manures with litter or soil.

Also, manures may change in chemical composition during storage and bedding (Meek et al., 1975; Brumm et al., 1978). Nitrogen content of dairy cattle manure varies from less than 1% to about 4% N (0.71 to 2.86 mol N · kg^{-1}) on a dry-weight basis. The phosphorus (P) content of dairy cattle manure ranges from 0.25% to 0.52% P (0.08 to 0.17 mol P · kg^{-1}) on a dry-weight basis, while the potassium (K) content of dairy cattle manure ranges from 0.34 to 3.0% K (0.09 to 0.77 mol P · kg^{-1}) on a dry-weight basis (Meek et al., 1975; Miner, 1971; Wallingford et al., 1975). Trace elements are also of consequence in fresh dairy cattle manure; manganese (Mn) and zinc (Zn) occur abundantly with lower levels of boron (B), copper (Cu), molybdenum (Mo), and cobalt (Co) (Meek et al., 1975; Meek et al., 1974; Atkinson et al., 1954).

Physical Properties

In addition to variation in nutrient content, manures vary widely in texture and structure. Manure collected from a natural earth floor reflects the texture of the soil from which the floor is constructed. Sometimes, as much as 50% of material collected as manure is soil, stones, gravel, and sand. Fresh cattle manures have a greater proportion of large fibrous particles than do poultry manures. Coarse particles greater than 2 mm comprise 11 to 18% of the dry matter of fresh cattle manures but 5% or less of chicken manures (Hafez et al., 1974). The average particle density of fresh poultry manure is 1.80 Mg · m^{-3} while that of dairy feces is 1.44 Mg · m^{-3} (Sobel, 1966).

Hafez et al. (1974) found that the particle density of various fresh manures ranged from 0.97 to 1.76 Mg $\cdot$ m^{-3}. Bulk densities of fresh dairy and chicken manures average about 0.99 and 1.06 Mg $\cdot$ m^{-3}, respectively (Meek et al., 1975; Hafez et al., 1974; Sobel, 1966; Azevedo et al., 1974).

Crop Yield Response to Manure Application

Crop yields, in an agronomic sense, are the most important considerations in animal manure application to the land. Studies of the effects of animal manure applications on forage and grain yields, in particular corn (Zea Mays L.) yields, have been completed recently or are currently underway in several states. Results of these investigations tend to differ, but many of the discrepancies are attributable to differences in soil types or chemical composition of the materials applied (Murphy et al., 1972).

The results of a nine-year study by Turk and Weidemann (1945) indicated that an annual increase in corn yields of 0.69 Mg $\cdot$ ha^{-1} resulted from applying 11.2 Mg $\cdot$ ha^{-1} $\cdot$ $year^{-1}$ of farmyard manure. It also was observed that higher rates of manure application (22.4 and 33.6 Mg $\cdot$ ha^{-1} $\cdot$ $year^{-1}$) resulted in higher crop yields, but lower rates of application gave higher returns per unit of applied manure.

Hensler et al. (1970) studied the effects of high application rates of solid dairy manure on Wisconsin soils and noted a depression of corn growth at the higher rates (204 and 613 Mg $\cdot$ ha^{-1}). Randall et al. (1975) noticed that at 770 Mg $\cdot$ ha^{-1} of manure applied over a three-year period, corn grain yields were noticeably depressed, due primarily to the high concentration of salt in the soil. In a two-year study conducted by Murphy et al. (1972), it was observed that corn silage yields were depressed when manure application rates exceeded 300 Mg $\cdot$ ha^{-1}; maximum yields occurred between 222 and 300 Mg $\cdot$ ha^{-1} of applied manure. The corn silage yields were depressed due to the high salt concentrations in the soil. Mathers and Stewart (1974) noticed that corn silage yields were reduced when manure was applied at 224 Mg $\cdot$ ha^{-1}. Their optimum corn silage yields occurred at the 22 Mg $\cdot$ ha^{-1} rate. Similarly, Manges et al. (1971) found yield depressions at high manure rates, with the maximum yields occurring at the rate of 231 Mg $\cdot$ ha^{-1}.

Studies over a period of 50 to 150 years which compared animal manures with mineral fertilizers have shown that equivalent yields can be sustained with either organic or inorganic sources of nutrients although yearly quantities of nutrients supplied were usually greater in manured plots (Bunting, 1965; McCalla et al., 1970). An experiment conducted in Pennsylvania from 1880 to 1938 compared annual manure application at the rate of 13 Mg $\cdot$ ha^{-1} to mineral fertilizer applied at recommended rates (Thompson et al., 1973). By 1900, manure-amended plots produced yields over twice that of non-fertilized control plots. The average corn yields for the plots which received manure were 1.25 Mg $\cdot$ ha^{-1} year^{-1} as compared to 1.10 Mg $\cdot$ ha^{-1} $\cdot$ year^{-1} for the mineral fertilizer plots over the term of the experiment. Prolonged manure application continued to show a beneficial effect on crop yields for several decades after manure was withheld from the plots (Azevedo et al., 1974).

Many experiments have demonstrated that in addition to corn, other crops respond positively to manure application to soil. Mathers et al. (1975) found that the maximum yields of grain sorghum were obtained at 22 Mg $\cdot$ ha^{-1} of applied manure. Grain sorghum yields were depressed, however, at much higher levels of manure application (268 or 536 Mg $\cdot$ ha^{-1}). A two-year study on the Texas High Plains by Mathers and Stewart (1971) with application rates up to 538 Mg $\cdot$ ha^{-1} $\cdot$ year^{-1} resulted in no significant increase in yields of grain sorghum (*Sorghum bicolor* L.). Rates of 269 and 538 Mg $\cdot$ ha^{-1} of annual manure application decreased yields of grain sorghum in both years. These researchers found that the heaviest application rate caused severe yield depression in the year of application but had much less effect the following year when the treatment was not repeated. Lund et al. (1975) found that rates of dairy cattle manure of 22.5 and 45 Mg $\cdot$ ha^{-1} incorporated into soil produced millet (*Pennisetem americanum* L.) and rye (*Secale cereale* L.) forage of good quality, however, yield decreased at rates of 90 Mg $\cdot$ ha^{-1}.

Problems Associated with Manure Application to Cropland

The application of high rates of manure to the soil has a substantial effect on soil N. Many researchers have found that manure applications which supply N in excess of crop needs result in nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) accumulation in the soil.

Soil Nitrate-Nitrogen

Mugwira (1979) found that the top 15 cm of soil receiving manure had higher NO_3-N content than the soil from no manure treatments at 90 to 270 Mg $\cdot$ ha^{-1} rates of manure application. He concluded that 45 Mg $\cdot$ ha^{-1} was the highest annual rate of dairy manure which could be applied without producing excessive NO_3-N accumulation in the soil. Mathers and Stewart (1974) found that with increasing application rates of cattle feedlot manure, soil NO_3-N increased. After applying cattle feedlot manure at the rate of 22 Mg $\cdot$ ha^{-1} $\cdot$ year for three years, NO_3-N in the top 180 cm of soil was maintained at 100 kg $\cdot$ ha^{-1}; however, at 45 Mg $\cdot$ ha^{-1} of applied manure, the soil NO_3-N increased slightly and at the 112 and 224 Mg $\cdot$ ha^{-1} rates, the levels of NO_3-N were increased in excess of 1000 kg $\cdot$ ha^{-1}. The highest concentrations of NO_3-N were found between 30 and 60 cm in the soil profile, although accumulations were found to 360 cm. Murphy et al. (1972) reported that large applications of feedlot manure resulted in soil NO_3-N accumulation to a depth of two meters. Meek et al. (1974) found that after applying 180 and 360 Mg $\cdot$ ha^{-1} of feedlot manure, NO_3-N was increased at 20 and 40-cm soil depths, but at 80 and 140 cm there were only small increases in NO_3-N resulting from manure application. The lack of movement of NO_3-N below the 80 cm depth at the higher rates of manure application was thought to be the result of denitrification. Mathers et al. (1975) observed high soil NO_3-N in the top 2 meters of soil, when $\geq$ 67 Mg $\cdot$ ha^{-1} of manure was applied. In some instances, NO_3-N from manure application was detected to a depth of 6 meters.

Long et al. (1975) incorporated 45 Mg · ha^{-1} · $year^{-1}$ (dry matter) of dairy cattle manure containing 1.3 mol total N · kg^{-1} into the upper 15 cm of topsoil for 3 years. They observed increased NO_3-N in topsoils cropped to pearlmillet and rye. In 1978, Magdoff observed an increase in soil N after 5 years of manure application at rates of 44 and 66 Mg · ha^{-1} · $year^{-1}$ (dry matter) to soils continuously cropped to corn.

Nitrate accumulation has also been noted when inorganic fertilizers are applied in large quantities. Olsen et al. (1970) compared inorganic N contents in soil profiles down to 2.4 meters below uncultivated and cultivated fields and barnyards. They found that NO_3-N was higher in cultivated soils than in barnyard soil, and both contained higher NO_3-N than uncultivated soils.

Schuman (1975), after applying inorganic fertilizer to a soil at 448 kg N · ha^{-1} for three years, found that NO_3-N increased to 720 kg · ha^{-1} below the corn root zone. During this period, the zone of maximum NO_3-N accumulation had shifted from 1 to 3.1 meters in the soil profile. He also observed leaching of NO_3-N into ground water. The rate of 168 kg N · ha^{-1}, which was the recommended rate of N for corn, resulted in no significant increases in NO_3-N below the corn root zone.

Potential Nitrate Pollution from Manure Application

A consequence of the build-up of NO_3-N in soils is the potential for its entrance into surface and ground waters through leaching. High NO_3-N concentrations are known to have caused illness and death to children because NO_3 is the precursor of nitrite (NO_2^-) implicated in the rare disease known as infantile methemoglobinemia or "bluebaby disease" (Webber et al., 1969). High NO_3-N concentration can also cause illness and possible death to livestock. Adriano et al. (1971) in the Chino-Corona dairy area of southern California reported that when dairy manure was applied to forage crops, providing 224 to 336 kg N $\cdot$ ha^{-1} $\cdot$ $year^{-1}$, the NO_3-N levels in the ground water supplies were $\leq$ 0.4 mmol $\cdot$ L^{-1} which was within water quality limits set by the U. S. Public Health Service. Koelliker et al. (1971) measured the NO_3-N level in a soil receiving swine manure and concluded that applications should be less than 672 kg N $\cdot$ ha^{-1} $\cdot$ $year^{-1}$. Annual manure applications of 112 Mg $\cdot$ ha^{-1} supplied more N than most crops could use; therefore, the NO_3-N concentration in the soil increased leading to potential ground water pollution when manure was applied in excess of crop needs (Mathers et al., 1974). Marriott et al. (1975) concluded that manure supplying total N at the rate of approximately two times the crop requirement might contribute NO_3-N to ground water.

Soil Ammonium-Nitrogen

Ammonium-nitrogen accumulations have also been noted at high application rates of cattle manure. Many researchers have found that ammonium-nitrogen (NH_4-N) is accumulated in the upper horizon of the soil.

After applying a total of 770 Mg · ha^{-1} over a three-year period, increased NH_4-N was found in the upper horizon (30 cm) of soil (Randall et al., 1975). Manges et al. (1971) also found that NH_4-N was accumulated in the upper layer of soil.

Salinity

Accumulations of salts may also occur when excessive amounts of manure are applied to the soil in areas of limited rainfall. Upon application of manure to the soil, monovalent and divalent cations such as NH_4^+, Na^+, K^+, Ca^{++}, and Mg^{++} can accumulate resulting in detrimental effects on soil physical and chemical properties (Murphy et al., 1972). In addition, the osmotic potential of the soil solution is directly affected by the amount of dissolved salts present. As the concentrations of these salts increase in the soil solution, water uptake by plants becomes increasingly difficult because the salts have a greater affinity for the water than do the plant roots; as a consequence, crops may be unable to satisfy their water requirement.

Rates of manure application exceeding 112 to 134.4 Mg · ha^{-1} frequently have led to salt problems, poor seed germination, and reduced yields in arid regions (Mathers et al., 1971; Cross et al., 1973; Reddell et al., 1971). Murphy et al. (1972) found that electrical conductivity in the soil increased linearly with manure application.

Crop yields were reduced with manure application of 314 Mg $\cdot$ ha^{-1} (dry basis) due to soluble salts contained in the manure (Cross et al., 1973). Murphy et al. (1972) also found large increases in exchangeable Na^+ and K^+ after application of 726 Mg $\cdot$ ha^{-1} of manure. This increase in exchangeable Na^+ and K^+ salts can have detrimental effects on the soil, through destruction of the soil structure and dispersion of the soil aggregates (Azevedo et al., 1974; McCalla, 1974). This breakdown of the soil structure is manifested by increased soil compaction and reduced infiltration, drainage, and soil aeration; as a consequence, crops can be damaged. Manges et al. (1971) observed salt injury in corn grown in soils that had received 276 and 943 Mg $\cdot$ ha^{-1} of manure.

Nitrate in Forage

Nitrate-nitrogen accumulation in plant tissue has also been noted in some plant species when grown in media containing more NO_3-N from manure application than needed to satisfy requirements for plant protein synthesis. Manges et al. (1971) found that applications of up to 98 Mg $\cdot$ ha^{-1} of cattle manure did not affect the NO_3-N levels in the subsequent corn crop. Mathers and Stewart (1971) reported the effects of large applications of solid beef feedlot wastes in Texas and found annual manure applications of 269 and 538 Mg $\cdot$ ha^{-1} increased NO_3-N concentration in the forage of grain sorghum. As a consequence of high concentrations of NO_3-N in plants grown on these areas, the authors concluded that inclusion of the silage in animal rations could cause health problems. Also, Pratt et al. (1972) found that the NO_3-N content of sudangrass (Sorghum bicolor L.) was increased when soils received 16 or 32 Mg · ha^{-1} of dry manure. Mathers et al. (1973) found high levels of NO_3-N in heavily manured sorghum forage during its early stages of growth, but the level dropped during maturation. Lund et al. (1975) found that when rates of dairy cattle manure exceeded 90 Mg · ha^{-1}, forage was high in NO_3-N and had K · $(Ca + Mg)^{-1}$ ratios that could be detrimental to animal health. Murphy et al. (1972) found that at high manure application rates (300 Mg · ha^{-1}), NO_3-N was as high as 0.05 mol · kg^{-1} in silage.

Nuisance Problems

Odors can be a troublesome problem in animal-waste handling. Animal wastes from confinement areas are very odorous because these wastes are stored anaerobically. The best way to control manure odors is to keep the manure in a dry and aerobic condition. When manure is applied to agricultural land, the best method to control odors is soil injection or incorporation of the manure into the soil after application (Meek et al., 1975).

Additional Effects of Manure upon Soil Properties

In addition to the traditional values placed on animal manures as fertilizers (supplying N, P, K, Ca, Mg and micronutrients), animal manures can also improve soil chemical and physical properties.

Chemical properties have been affected by addition or increasing of available nutrients (Salter et al., 1939). Organic matter in the soil has been increased due to manure applications (Mathers et al., 1975; Wallingford et al., 1975). Vitosh et al. (1973) found that the organic matter in the soil increased about 0.1% annually at 67.2 Mg $\cdot$ ha^{-1} of applied manure over a six-year period.

Much evidence suggests that animal manures can effect beneficial changes in soil physical properties by increasing the size of water-stable aggregates (Guttay et al., 1956; Elson, 1941), by increasing the water-holding capacity and decreasing evaporation rate (Unger et al., 1974), by increasing the infiltration rate of water (Mazurak et al., 1955; Mathers et al., 1977), and through increases in cation exchange capacity (Mathers et al., 1980). Improvements in soil aggregation, crop cover, and water penetration resulting from animal manure utilization contribute to reduced surface runoff and erosion. At manure application rates of 18 or 36 Mg $\cdot$ ha^{-1}, reduced runoff and erosion on both fallow and corn-cropped plots have been observed (Azevedo et al., 1974). Similarly, Minshall et al. (1970) were able to reduce summer rainfall runoff by one-half through incorporation of manure in soils. Zwerman et al. (1972) found that the application of 13 Mg $\cdot$ ha^{-1} of manure decreased runoff by 100%. Improved soil physical properties as a consequence of manure application can improve crop responses to a greater degree than would be expected from nutrient addition alone.

CHAPTER III

MATERIALS AND METHODS

Field Methods

Two field experiments were established at the Dairy Experiment Station, Lewisburg, TN, (i) to investigate inject versus broadcast application of liquid dairy manure both in the fall and spring as a source of N for corn silage production, and (ii) to investigate the usefulness of a nitrification inhibitor [N-Serve, (nitrapyrin-2 chloro-6-trichloromethyl pyridine)] in conserving manurial N applied through broadcasting and injecting in the fall.

The first experiment, initiated in the fall of 1980, consisted of six treatments in three replications (manure injected in fall, spring, and as a sidedress; manure broadcast in fall and spring; and conventional N fertilization). The experimental area was in a pasture and was approximately 1.2 hectares in size. The predominant soil type at this location is Lindside silt loam (fine silty, mixed, thermic Fluventic Haplodolls), with small intrusions of Huntington silt loam and Hermitage silt loam. These soils are well-drained and they are formed from recent alluvium.

Individual plots contained six rows of corn (Zea mays L., c.v. Pioneer 3147) planted on 0.91-meter row-spacing using minimum tillage techniques. Individual plots were 122 meters long by 5.5 meters wide (670 m^2).

Dairy manure was obtained from a liquid manure holding tank receiving wastes from the milking parlor floor (Sewell et al., 1975). An attempt was made to apply equal amounts of manure to all manure treatments by weight (approximately 68 Mg · ha^{-1}). Manure was applied with a Badger manure spreader equipped with three injectors on 91-cm centers. On injection treatments, injectors were inserted to an approximate depth of 20 cm below the ground surface, while on broadcast treatments, injectors remained approximately 30 cm above the ground surface. The manure spreader was weighed before and after application to determine the actual amount of manure applied to each plot. Each load of manure was sampled in the field prior to application. Subsamples were stored frozen until subsequently analyzed.

At the initiation of the experiment, soils tested high in P and K and had a favorable pH (≥ pH 6.0); therefore, lime and supplemental P and K were not applied to test plots for the duration of the experiment.

Inorganic fertilizer treatments received 134 kg N · ha^{-1} as NH_4-NO_3 broadcast by hand in the spring of each year. Corn was planted in late March of each year at an approximate planting rate of 45,000 plants per ha. In the first year, corn was sod-planted into orchardgrass (_Dactylis glomerata_ L.) sod which had previously been kiled by a broadcast application of paraquat [1,1'-dimethyl-4,4'-bipyridinium ion (as dichloride salt)]. Following corn harvest in 1981, the field was disked and sown to wheat (broadcast application); wheat was used for temporary pasture in winter months (2-3 days grazing). Wheat was killed by application of paraquat in spring 1982 and corn was minimum till-planted. Weeds were controlled by chemical means; Atrazine (2-chloro-4 ethylamino-6-isopropylamino-1,3,5-triazine) was applied at 3.74 L of the active ingredient per ha, and Dual [Metalachlor,2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] was applied at 2.34 L of the active ingredient per ha.

High moisture grain was hand-harvested from a 15.3-m length from the two center rows of each plot every year prior to silage harvest. Subsamples of grain were taken at harvest for moisture determination and elemental analysis by shelling grain from a representative sample of ears from each plot. All grain yields were adjusted to 15.5% moisture.

Silage was harvested mechanically with a self-propelled silage chopper. The four center rows of each six-row plot were harvested. Silage samples were collected from each plot, placed in cloth bags, and the wet weights obtained; dry weights were obtained after drying in a forced air oven at 60°C. All silage samples were then ground to pass 1-mm mesh screen and were stored in plastic bags prior to analysis. Silage yields were adjusted to 70% moisture.

Soils were sampled in fall of each year following corn harvest and prior to fall application of manure. Plots were sampled randomly to a 22.5 cm depth in three increments of 7.5 cm each, and were subsequently composited by treatment. Soil samples were air-dried and stored in cardboard boxes prior to analysis.

The second experiment, initiated in fall 1981, also consisted of six treatments in three replications (fall-applied manure either broadcast or inject, and spring-applied inorganic N, all treatments with and without nitrapyrin). Individual plots were 6 rows (5.5 meters) wide by 91.5 meters long (503 m^2), planted with corn (c. v. Pioneer 3147) on 0.91-meter row-spacing using minimum tillage techniques. The experiment was situated in an orchardgrass pasture where the soil type is Huntington silt loam (fine silty, mixed, thermic Fluventic Hapludolls) with small instrusions of Lindside silt loam and Heritage silt loam.

Dairy manure was obtained from the same holding tank used in the first experiment. All manure treatments received equal amounts by weight of manure (approximately 90 $Mg \cdot ha^{-1}$). Manure treatments with nitrapyrin received tank-mixed N-Serve calculated to give 4.7 $L \cdot ha^{-1}$ of the formulated material (320 ml of N-Serve per 4536 L tank).

Manure was applied with the same equipment and with the same procedures as used in the first experiment. The manure spreader was weighed before and after application to determine the actual amount of manure applied to each plot. Each load of manure was sampled in the field prior to application. Subsamples were stored frozen until analyzed.

Inorganic fertilizer treatments received 134 kg N $\cdot$ ha^{-1} as NH_4-N broadcast by hand in the spring of each year. The inorganic fertilizer treatments with nitrapyrin received 134 kg N $\cdot$ ha^{-1} plus 4.7 L $\cdot$ ha^{-1} of N-Serve as the formulated material applied broadcast prior to planting.

At the initiation of the experiment, soils tested high in P and K and had a favorable pH ($\geq$ pH 6.0); as a consequence, lime and supplemental P and K were not applied to test plots for the duration of the experiment.

The planting date, planting rate, cultivation procedures, weed control, grain and silage harvesting procedures, and grain, silage and soil sampling procedures were the same as used in the first experiment.

Laboratory Methods

Total N of silage was determined by digesting a 0.20 g sample of ground, oven-dry plant tissue in 10 ml concentrated H_2SO_4 and 15-20 ml of 35% hydrogen peroxide (H_2O_2). The digested samples were analyzed colorimetrically via autoanalyzer using the indophenol method (Thomas et al., 1967).

Phosphorus, K, Ca, Mg, and Na were determined by dry ashing in which 1.00 g of dry plant material was ashed for four hours at 450°C after which 10 ml of 1 M HNO_3 was added to each sample and samples were evaporated to dryness slowly on a hot plate. Each sample was washed with 10 ml of 1 M HCl, filtered through Whatman No. 42 filter paper, and brought to a constant volume (Johnson and Ulrich, 1959). Analysis for P was accomplished via autoanalyzer using phosphomolybdic acid blue colorimetry (Jackson, 1958); Na, K, Ca, and Mg were determined via atomic absorption/emission spectroscopy.

Manure samples were analyzed for total solids, total volatile solids, total phosphorus (TP), total Kjeldahl N (TKN), NH_4-N, and NO_3-N in the laboratories of the Agricultural Engineering Department using standard methods (A.P.H.A., 1975). Manure subsamples were also analyzed for concentrations of K, Ca, Mg, and Na using the same methods as for silage samples.

Soil samples were analyzed for pH (1:1 soil-water) and Mehlich I (0.05 M (1 HCl) and 0.025 M (1/2 H_2SO_4)) extractable P, K, Ca, and Mg at the University of Tennessee Soil Testing Laboratory, Nashville. Selected control samples were also run in the Department of Plant and Soil Science, Knoxville.

In the soil-test procedure employed, P, K, Ca, and Mg were extracted by shaking a 5-g soil sample in 20 ml of extracting solution for five minutes. Filtrates were analyzed for P using phosphomolybdic acid blue colorimetry, while K, Ca, and Mg were determined by atomic absorption/emission spectroscopy (Anonymous, 1974).

Soils sampled from the nitrapyrin experiment were extracted with 2 M KCl. Extracts were analyzed for NH_4-N using the colorimetric indophenol method (Technicon, 1973). Nitrate-N was determined by ultraviolet absorption at 330 nm using the method of standard additions.

CHAPTER IV

RESULTS AND DISCUSSION

Exp. 1: Time and Method of Manure Application

In general, various times and methods of manure application had no influence on silage or grain yields, silage nutrient content, or soil test extractable nutrients in two years of experimentation. This was attributed to (i) the high initial fertility of the experimental plot area as a consequence of prior manure application and (ii) poor plant stands and weed control problems (particularly in 1982) which increased variability across plots.

Manure Composition and Levels of Manure and Nutrient Loading

Manure applied to individual plots on a given date varied only slightly in contents of N, P, K, Ca, Mg, and Na (Appendix A). For the most part, coefficients of variation (CV) were less than 15% for treatments applied on a given date. Noticeable exceptions are apparent, however. For example, P from treatments applied in fall 1980 (Appendix A, Table 12) had CV > 50%. Such variations most likely represent inadequate agitation of manure in the pit prior to sampling as well as inherent variability in the analytical techniques employed.

Variation in manurial nutrient content among times of application was of the same relative magnitude as for among various methods of application or replications of a treatment on a given date (Table 1).

Total solids content of the liquid dairy manure demonstrated considerably greater variation than did nutrient content between dates of application. Thus, one would expect considerable variation in nutrient loadings if manure were applied at equal rates, even though nutrient content of this manure is relatively constant on a dry weight basis. Total volatile solids represented nearly 3/4 of the total solids content for all times and methods of application.

Average nutrient concentrations in the liquid dairy manure are in line with commonly reported values (Meek et al., 1975; Miner, 1971; Wallingford et al., 1975). Total Kjeldahl N (TKN = Organic - N plus NH_4-N) is a possible exception, in that values reported here are somewhat higher than those commonly reported. Ammonia-nitrogen comprised about half of the total N in this manure. The ratio of the mean amounts of N, P, and K applied as liquid dairy manure (1:0.2:0.7, on a percent dry weight basis) is quite similar to the balance of these nutrients in grasses (1:0.3:0.8; Mengel and Kirby, 1982). As such, this manure appears to represent an adequate source of primary macronutrients for corn silage production when applied in amounts sufficient to meet crop N requirements.

Total amounts of manure applied to individual replications of a treatment were relatively consistent on a given date of application, but the variation between individual methods and times of application

Table 1. Mean elemental concentration of liquid dairy manure applied in Exp. 1, Dairy Experiment Station, Lewisburg, TN.

Year-Treatment	Elemental Concentration†							Total‡ Solids	Total† Votile Solids
	TKN	NH_4-N	P	K	Ca	Mg	Na		
	mol · kg^{-1}							%	
Fall 1980									
Broadcast	2.83	1.05	0.11	--	--	--	--	9.56	74.73
Inject	2.94	1.10	0.24	--	--	--	--	9.31	73.84
Spring 1981									
Broadcast	2.25	1.07	0.33	0.48	0.32	0.21	0.16	12.87	71.27
Inject	3.13	1.06	0.33	0.43	0.26	0.20	0.17	12.86	70.85
Sidedress	2.95	1.35	0.32	--	--	--	--	11.12	--
Fall 1981									
Broadcast	3.07	1.27	0.30	0.83	0.30	0.25	0.17	8.37	72.52
Inject	3.28	1.17	0.31	0.86	0.33	0.28	0.18	7.91	73.22
Spring 1982									
Broadcast	3.10	1.31	0.30	0.66	0.23	0.22	0.11	9.62	68.01
Inject	3.34	1.33	0.31	0.64	0.23	0.22	0.11	8.50	67.35
Sidedress	2.45	1.00	0.40	0.85	0.11	0.32	0.06	10.50	75.91
Mean	2.93	1.17	0.30	0.68	0.25	0.24	0.14	10.06	71.97
± s	0.35	0.13	0.08	0.18	0.08	0.04	0.04	1.76	2.90

†Dry basis.

‡Wet basis.

% TVS = percent of total solids which are volatile.

was quite great (Appendix B; Table 2). Although a consistent rate of manure application was desired, this proved impractical with the equipment available. Manurial solids content and field conditions at the time of application interacted to cause non-uniform rates of manure application. Variation in solids content caused varied rates of manure delivery from injection ports; while field conditions (principally moisture content of the soil) caused variation in ground speed at the same gear setting on the tractor. It was not always possible to adjust rate of manure flow from injector ports and ground speed of the tractor so as to obtain consistent levels of manure application.

Total nutrient loadings varied primarily as a result of varied rates of manure application, and secondarily as a consequence of variation in manurial nutrient content. It was hoped that relatively uniform total N loadings could be achieved which would be sufficient to meet crop N demands. Total N loadings averaged 317 ± 50 kg $\cdot$ ha^{-1} across times and methods of application which is sufficient manurial N for corn silage production in the southeastern U.S. (Gilbertson et al., 1978). Total loadings of P, K, Ca, Mg, and Na varied to a greater degree than did N loadings. In all cases, nutrient loadings were sufficient to meet crop demands (Table 2).

Grain and Silage Yields

There were no differences in grain or silage yields in either 1981 or 1982 which could be attributed to time or method of manure application (Tables 3 and 4). This is probably because of high

Table 2. Mean amounts of liquid dairy manure applied and manure nutrient loading, Exp. 1, Dairy Experiment Station, Lewisburg, TN.

Year-Treatment	Manure Applied†	Nutrient Loading‡					
		N	P	K	Ca	Mg	Na
	- -Mg · ha^{-1}- -	- - - - - - - - - - - -		kg · ha^{-1}	- - - - - - - - - - - -		
Fall 1980							
Broadcast	73.7	279	24	--	--	--	--
Inject	74.8	286	51	--	--	--	--
Spring 1981							
Broadcast	70.4	285	94	171	115	45	34
Inject	72.3	407	96	157	98	45	35
Sidedress	73.9	339	80	--	--	--	--
Fall 1981							
Broadcast	93.3	335	73	250	90	48	29
Inject	72.8	264	56	194	76	39	24
Spring 1982							
Broadcast	66.4	277	59	165	59	34	16
Inject	98.0	390	81	207	78	44	21
Sidedress	85.9	310	113	300	39	71	13
Mean	78.2	317	73	206	79	47	25
± s	10.5	49.6	25.9	52.0	25.1	11.7	8.5

†Wet basis.

‡Dry basis.

Table 3. Corn silage and grain yields and silage nutrient content as influenced by time and method of liquid dairy waste application (Exp. 1), Dairy Experiment Station, Lewisburg, TN, 1981.

Treatment	Yield†		Silage Elemental Content					
	Silage‡	Grain§	N	P	K	Ca	Mg	Na
	- - $Mg \cdot ha^{-1}$ - -		- - - - - - - - - - - $mol \cdot kg^{-1}$ - - - - - - - - - - -					
1. Inject, fall	49.21	7.71	0.785	0.072	0.316	0.058	0.041	0.017
2. Broadcast, fall	48.01	7.18	0.788	0.079	0.316	0.055	0.042	0.017
3. Inject, spring	50.33	5.87	0.776	0.061	0.324	0.051	0.037	0.015
4. Broadcast, spring	46.29	5.70	0.723	0.068	0.309	0.056	0.043	0.017
5. Inject, 'sidedress'	49.06	7.08	0.833	0.068	0.317	0.050	0.041	0.015
6. Conventional Fertilization	49.80	6.57	0.788	0.059	0.270	0.053	0.039	0.014

†No significant differences in yield or nutrient content were identified by analysis of variance, 0.05 level.

‡30% DM.

§84.5% DM.

Table 4. Corn silage and grain yields and silage nutrient content as influenced by time and method of liquid dairy waste application (Exp. 1), Dairy Experiment Station, Lewisburg, TN, 1982.

Treatment	Yield† Silage‡	Yield Grain§	Silage Elemental Content N	P	K	Ca	Mg	Na
	- - Mg · ha^{-1} - -		- - - - - - - - - - -	-	mol · kg^{-1}	-	-	- - - - - - - - - - -
1. Inject, fall	34.80	5.40	0.964	0.088	0.336	0.058	0.048	0.002
2. Broadcast, fall	36.06	7.00	0.993	0.087	0.346	0.057	0.049	0.002
3. Inject, spring	36.59	5.21	0.874	0.076	0.340	0.063	0.054	0.002
4. Broadcast, spring	33.38	5.31	0.960	0.088	0.369	0.079	0.059	0.002
5. Inject, 'sidedress'	30.61	5.05	0.988	0.082	0.349	0.070	0.055	0.002
6. Conventional Fertilization	34.87	6.03	0.919	0.077	0.321	0.067	0.060	0.002

†No significant differences in yield or nutrient content were identified by analysis of variance, 0.05 level.

‡30% DM.

§84.5% DM.

fertility status of the experimental area from prior manure application. Yields were greatly different between 1981 and 1982, however. The 1981 growing season was highly favorable to corn production and this is reflected in the above-average grain and silage yields for this location. In 1982, cold weather, following the mid-March date of planting, resulted in a poor plant stand. An infestation of cutworms and problems with weed control (particularly johnsongrass (*Sorghum halepense* L. Pers)) further restricted crop response. As a consequence, grain and silage yields were considerably lower and more variable than in 1981.

Silage Nutrient Content

As with yield, there were no differences in the concentrations of nutrients in harvested silage that could be attributed to time or method of manure application in either year (Tables 3 and 4). For the most part, nutrient contents of silage were similar between years. Nitrogen and P concentrations in silage were somewhat lower in 1981 than 1982, probably as a consequence of greater plant growth resulting in a dilution effect on nutrients taken up by the crop. Sodium in silage was considerably higher in 1981 than in 1982. Silage Na concentrations were typical of corn silage (Wallingford et al., 1975) in 1981 but were atypically low in 1982; the reason for this difference is uncertain.

Total manurial N, P, and K loadings averaged 317, 73, and 206 $kg \cdot ha^{-1}$ across times and methods of application (Table 2), while the total N, P, and K removal by the crop averaged 161, 32, and 181 kg $\cdot$ ha^{-1} in 1981, and 137, 27, and 138 kg $\cdot$ ha^{-1} in 1982. Manure application was sufficient to meet crop nutrient demands in both years. Nitrogen removal in harvested silage averaged 51 and 43% of total N applied in 1981 and 1982, respectively. These values of N recovery are typical of estimated values of N recovery from dairy manure (Gilbertson et al., 1978).

<u>Soil Test Results</u>

Soil test parameters fluctuated considerably across time, probably as a consequence of sampling errors on these rather large plots. It was often difficult to distinguish strips which had received either broadcast or inject manure application and this complicated sampling efforts.

Soil pH was relatively constant among times of application and among various methods of application through the two years of experimentation. In general, the soil pH appeared unaffected by either manure treatment or conventional N fertilization (Table 5).

Soil test P levels tested extremely high when the experiment started (13 mg $\cdot$ kg^{-1} is considered high for soils of Tennessee) (Table 5). Extractable P appeared to decline slightly over time in the 0-8 cm sampling depth of manure treatments, but this is relatively unimportant since soil P remained at very high levels through time. In the conventional N fertilization treatment, the soil P values were extremely high at the start and remained very high throughout the experiment. Soil K levels tested very high (100 mg $\cdot$ kg^{-1} is considered high for soils

Table 5. Soil pH (1:1 soil-water) and soil test (dilute double-acid extractable) nutrients (Exp. 1), Dairy Experiment Station, Lewisburg, TN.

	Sampling Depth, cm								
	0-8			8-16			16-24		
Treatment	1980	1981	1982	1980	1981	1982	1980	1981	1982
					pH				
1. Inject-fall	5.9	5.7	6.4	6.0	5.6	6.5	6.0	5.8	6.4
2. Broadcast-fall	6.0	5.7	--	6.1	5.9	--	6.2	6.0	--
3. Inject-spring	5.8	5.8	6.4	5.9	5.7	6.4	5.8	5.8	6.5
4. Broadcast-spring	5.9	5.7	6.6	6.0	5.9	6.7	6.1	6.0	6.7
5. Inject-sidedress	6.0	5.9	6.5	6.0	5.8	6.5	6.1	6.0	6.6
6. Conventional fertilization	6.1	5.6	6.2	6.1	5.8	6.2	6.1	5.9	6.4
					P($mg \cdot kg^{-1}$)				
1. Inject-fall	80	60	30	60	60	50	60	50	50
2. Broadcast-fall	210	220	--	200	330	--	170	300	--
3. Inject-spring	150	180	120	120	110	100	90	120	70
4. Broadcast-spring	210	180	180	240	150	150	140	190	190
5. Inject-sidedress	220	120	150	200	170	300	100	250	300
6. Conventional fertilization	210	250	300	180	240	300	80	160	300

Table 5. (continued)

	Sampling Depth, cm								
	0-8			8-16			16-24		
Treatment	1980	1981	1982	1980	1981	1982	1980	1981	1982
					K($mg \cdot kg^{-1}$)				
1. Inject-fall	130	170	300	110	100	160	100	90	140
2. Broadcast-fall	270	360	--	100	100	--	90	160	--
3. Inject-spring	270	300	220	110	160	160	120	190	120
4. Broadcast-spring	250	360	200	120	200	160	110	130	80
5. Inject-sidedress	290	320	220	110	190	160	90	110	90
6. Conventional fertilization	240	260	200	150	100	130	103	60	90
					Ca($mg \cdot kg^{-1}$)				
1. Inject-fall	1780	1280	1550	1700	1280	1450	1760	1520	1500
2. Broadcast-fall	2380	2160	--	2300	2400	--	2400	2320	--
3. Inject-spring	2160	2080	2300	2110	1840	1850	1840	1760	1750
4. Broadcast-spring	2480	2000	2150	2570	2000	2200	2240	2080	2350
5. Inject-sidedress	2580	1760	2150	2500	2160	2600	1830	2400	2350
6. Conventional fertilization	2700	2230	1700	2130	2280	1750	1920	1910	1700

Table 5. (Continued)

Treatment	Sampling Depth, cm								
	0-8			8-16			16-24		
	1980	1981	1982	1980	1981	1982	1980	1981	1982
					Mg(mg · kg^{-1})				
1. Inject-fall	150	90	160	80	70	140	70	60	130
2. Broadcast-fall	140	180	--	90	100	--	80	110	--
3. Inject-spring	140	170	170	90	100	170	90	100	150
4. Broadcast-spring	160	160	180	110	90	160	110	90	130
5. Inject-sidedress	200	130	170	90	100	150	90	100	130
6. Conventional fertilization	160	120	140	100	100	130	100	90	120

of Tennessee) at the start and remained at high levels throughout the experiment in all the treatments. In 1981, soil K levels appeared to be increased in the 0-8 cm depth by manure application; by fall 1982 the values had decreased slightly but still remained high. With conventional N fertilization, soil test K values were very high but tended to remain slightly lower than those from manure treatments. Soil test Ca and Mg levels were extremely high at the start and demonstrated little variation of consequence with time.

Exp. 2: Use of a Nitrification Inhibitor for Fall Application of a Liquid Dairy Manure

N-Serve had no influence on silage or grain yield, silage nutrient content or soil test extractable nutrients in one year of experimentation. This was attributed to dry weather and warm soil temperatures at the time of application which affected the response to N-Serve. Differences in yield and silage nutrient content attributable to method of manure application were apparent, however.

Manure Composition and Levels of Manure and Nutrient Loading

As in Exp. 1, manure applied to individual plots on a given date did not vary greatly in contents of N, P, K, Ca, Mg, and Na (Appendix C). Nitrogen concentrations were quite consistent within treatments (CV $<$ 8% in all cases) but there was substantial variation in P, K, Ca, Mg, and Na, particularly in broadcast treatments. Limited manure availability in late fall meant broadcast treatments were applied at a different time than were inject treatments. This may partially explain why manure from broadcast treatments demonstrated more compositional variation than did the manure from inject treatments.

Mean manure composition when compared across treatments was very uniform (Table 6). Total solids content of the liquid dairy manure demonstrated little variation among treatments. Thus, one would not expect considerable variation in nutrient loadings when manure is applied at equal rates, because nutrient content of this manure is relatively constant on a dry weight basis. As in Exp. 1, average nutrient concentrations in the liquid dairy manure are in line with commonly reported values but again, total N values are slightly above average (Meek et al., 1975; Miner, 1971; Wallingford et al., 1975).

The method of manure application was modified somewhat in this experiment in order to obtain more consistent manure loadings on all plots. The results were levels of manure application which were 18% higher on the average than those achieved in Exp. 1 and greatly diminished variation in manure loadings (CV < 2.5%) (Appendix D, Table 7). Total N loadings averaged 379 ± 7 kg $\cdot$ ha^{-1} across methods of application. Total loadings of P, K, Ca, Mg, and Na varied to a greater degree than did N; but in all cases, nutrient loadings were sufficient to meet crop demands (Table 7).

Grain and Silage Yields

Analysis of variance indicated highly significant effects of treatments on both grain and silage yields (Table 8). Orthogonal

Table 6. Mean manure nutrient concentration applied in fall with and without a nitrification inhibitor (Exp. 2), Dairy Experiment Station, Lewisburg, TN, 1981.

	Nutrient Concentration[†]								
Treatment	TKN	NH_4-N	P	K	Ca	Mg	Na	Total[‡] Solids	Total[§] Votile Solids
	mol · kg^{-1}							%	
Broadcast	2.84	1.08	0.27	0.87	0.29	0.22	0.15	10.07	72.62
Broadcast+N-serve	2.98	1.28	0.25	0.56	0.31	0.21	0.13	9.59	69.50
Inject	3.11	1.10	0.33	0.68	0.25	0.21	0.14	9.32	63.73
Inject+N-serve	2.85	1.19	0.29	0.74	0.30	0.25	0.16	9.73	71.60
Mean	2.95	1.16	0.29	0.71	0.29	0.22	0.15	9.68	69.36
± s	0.13	0.09	0.03	0.13	0.03	0.02	0.01	0.31	3.97

[†] Dry basis.

[‡] Wet basis.

[§] TVS = Percent of total solids which are volatile.

Table 7. Mean manure applied and manure nutrient loading in fall with and without a nitrification inhibitor (Exp. 2), Dairy Experiment Station, Lewisburg, TN, 1981.

Year-Treatment	Manure Applied†	Nutrient Loading‡					
		N	P	K	Ca	Mg	Na
	- -Mg · ha^{-1}- -	- - - - - - - - - - - -	- -	kg · ha^{-1}	- - - - - - - - - - - -		
Fall 1981							
Broadcast	93.1	372	79	318	108	51	32
Broadcast+N-Serve	94.2	377	70	199	111	45	27
Inject	95.4	388	90	235	90	45	29
Inject+N-Serve	97.4	379	86	275	114	57	34
Mean	95.0	379	81	257	106	50	31
± s	1.8	6.7	8.8	51.3	10.8	5.7	3.1

†Wet basis.

‡Dry basis.

Table 8. Corn silage and grain yields and silage nutrient content as influenced by fall applied dairy manure with and without a nitrification inhibitor (Exp. 2), Dairy Experiment Station, Lewisburg, TN, 1982.

	Yield		Silage Elemental Content[§]					
Treatment	Silage[†]	Grain[‡]	N	P	K	Ca	Mg	Na
	- - - $Mg \cdot ha^{-1}$ - - -		- - - - - - - - - - - $mol \cdot kg^{-1}$ - - - - - - - - - - -					
1. Broadcast	39.57	5.44	0.638	0.102	0.300	0.105	0.074	0.002
2. Broadcast+N-Serve	43.31	5.58	0.688	0.096	0.289	0.089	0.075	0.002
3. Inject	49.21	7.60	0.705	0.094	0.297	0.088	0.071	0.002
4. Inject+N-Serve	49.73	7.87	0.736	0.095	0.294	0.083	0.069	0.002
5. Conventional fertilization	51.29	8.10	0.640	0.085	0.231	0.098	0.084	0.001
6. Conventional fertilization N-Serve	50.48	7.78	0.760	0.086	0.275	0.114	0.088	0.002
Significance of F-test[¶]	**	**	NS	*	*	NS	NS	NS

[†]30% DM.

[‡]84.5% DM.

[§]Dry basis.

[¶]Not significant (NS) or significant at the 1% (**) and 5% (*) levels, F-test.

comparisons were used to distinguish the effects of N-Serve vs. no N-Serve, broadcast vs. inject manure application, and manure vs. conventional N fertilization (Table 9). There was no effect of N-Serve on grain or silage yields. This could be attributed to dry weather and to fairly warm soil temperatures at the time of application which affected the response to N-Serve (Frye et al., 1980; Touchton et al., 1979). There were, however, differences in grain and silage yields between methods of manure application and between manure treatments and conventional N fertilization. Inject application of liquid dairy manure was more effective in producing high silage and grain yields than was broadcast application. This could be because with injection of manure the N losses by volatilization were minimal or at least less than with broadcast application (Brumm et al., 1978; Lauer et al., 1976). Conventional fertilization resulted in higher silage and grain yields than did manure application in general. This was largely a consequence of the lower yields obtained with broadcast application of manure. Inject application of manure, in fact, resulted in yields quite comparable to conventional fertilization.

Silage Nutrient Content

Of the silage elemental parameters evaluated, only P and K varied significantly by treatments (Table 8). These parameters were subjected to the same comparisons as were yield data (Table 9). There was no effect of N-Serve on the concentrations of P and K in harvested silage. Phosphorus and K concentrations in silage were somewhat higher

Table 9. Selected comparisons of corn silage and grain yields and silage P and K concentration as influenced by fall applied dairy manure with and without a nitrification inhibitor, (Exp. 2), Dairy Experiment Station, Lewisburg, TN, 1982.

	Yield				Silage Nutrient Content			
Comparison	Silage		Grain		P		K	
	- - - Mg · ha^{-1} - - -				- - - mol · kg^{-1} - - - -			
N-Serve vs. None	47.8 vs. 46.7	NS[†]	7.1 vs. 7.0	NS	0.092 vs. 0.094	NS	0.286 vs. 0.276	NS
Broadcast vs. Inject	41.4 vs. 49.5	**	5.5 vs. 7.7	**	0.099 vs. 0.095	NS	0.295 vs. 0.296	NS
Manure vs. Conv. Fert.	45.5 vs. 50.9	**	6.6 vs. 7.9	**	0.097 vs. 0.086	**	0.295 vs. 0.253	**

[†]Effects are not significant (NS) or are significant at the 1% (**) level.

with manure application than with conventional N fertilization. This could be attributed to the P and K contributed from manure (Meek et al., 1975; Miner, 1971; Wallingford et al., 1975), since conventional N fertilization treatments received no supplemental P or K as warranted by 1981 soil tests. Silage N, Ca, and Mg concentrations were typical of corn silage but silage Na concentrations were atypically low. A similar observation was made with respect to 1982 silage Na contents in Exp. 1 (Table 4, p. 26).

Total N, P, and K loadings averaged 379, 81, and 257 kg $\cdot$ ha^{-1} across methods of application; and the total N, P, and K removal by the crop averaged 131, 41, and 155 kg $\cdot$ ha^{-1}. Comparing the manurial nutrient loadings vs. the nutrient removal by silage, it is clear that the manure loadings provided sufficient manurial N, P, and K for corn silage production.

Soil Test Results

Soils were sampled for analysis following harvest in fall 1982 (Table 10). Soil pH was relatively constant among various treatments in the experiment. Soil P was uniformly high in all treatments, while soil test extractable K was appreciably lower for the conventional fertilizer treatments than it was for treatments receiving manure (Table 10). The NO_3-N was extremely high in all treatments. This could be attributed to nitrification of the high amounts of NH_4-N present (Table 6). Extractable NO_3-N tended to increase in the 8-16 cm sampling depth, indicating downward movement of manure broadcast

Table 10. Soil pH (1:1 soil-water), soil test (dilute double - acid extractable) nutrients, and KCl-extractable NO_3-N (Exp. 2), Dairy Experiment Station, Lewisburg, TN.

	Sampling Depth, cm											
	0-8	8-16	16-24	0-8	8-16	16-24	0-8	8-16	16-24	0-8	8-16	16-24
Treatment	pH			P			K			NO_3-N†		
				------------ mg · kg^{-1} ------------								
Fall 1981												
1. Broadcast	6.7	6.7	7.0	> 300	> 300	> 300	107	150	90	190	640	300
2. Broadcast+N-serve	6.7	6.7	6.5	> 300	> 300	> 300	100	120	150	130	150	300
3. Inject	6.8	6.7	7.1	> 300	> 300	> 300	140	140	90	150	420	240
4. Inject+N-serve	6.5	6.8	6.9	> 300	> 300	> 300	110	120	220	190	280	260
5. Spring fertilization	6.6	6.7	6.8	> 300	> 300	> 300	100	90	80	130	160	210
6. Spring fertilization+ N-serve	6.9	6.9	6.8	> 300	> 300	> 300	70	140	80	160	400	410

†2M KCl extractable NO_3-N, NH_4-N extracted in all cases was ≤ 10 mg · kg^{-1}.

the previous fall. Higher NO_3-N would be expected with depth of sampling of injected treatments due to the placement of manure in the soil. In all treatments, extractable NH_4-N was ≤ 10 mg · kg^{-1} indicating that N-Serve had not been effective in inhibition of manurial N conversion to NO_3-N.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two experiments were conducted at the Dairy Experiment Station, Lewisburg, TN, to (i) investigate inject versus broadcast application of liquid dairy manure both in the fall and spring as a source of N for corn silage production (Experiment 1) and (ii) to investigate the usefulness of a nitrification inhibitor in conserving manurial N applied either broadcast or inject in the fall (Experiment 2). Both experiments were designed to provide adequate N for corn silage production in order to evaluate the relative effectiveness of the various times and methods of application. All plots received approximately equal rates of manure application (68 $Mg \cdot ha^{-1}$ in Experiment 1 and 90 $Mg \cdot ha^{-1}$ in Experiment 2).

Whereas, there were no differences in corn grain or silage yields, silage nutrient content, or soil test extractable nutrients in Experiment 1, significant differences were obtained in Experiment 2. This was primarily due to the differences in soil fertility at the two experimental sites. Prior manure application at the site of Experiment 1 had caused high fertility status of the experimental area. Soil tests indicated medium to high soil fertility at the second experiment site, but these were not so high as to mask response to manure application.

In both experiments, there was little difference in manure composition between replications, methods, or times of application. At times, significant variation in one or more manure nutrient components were noted, but this was attributed to sampling and analytical errors more than to inherent variation in manure nutrient content. Total solids did vary appreciably with season of the year and this influenced total nutrient loadings in some instances.

In Experiment 2, analysis of variance indicated highly significant effects of selected treatments on both grain and silage yields. There was no effect of N-Serve on grain or silage yields. This could be attributed to dry weather and to warm soil temperatures at the time of application which affected the response to N-Serve. Inject application of liquid dairy manure was more effective in producing high silage and grain yields than was broadcast application. This could be because with injection of manure the N losses by volatilization were minimal. Conventional N fertilization resulted in higher silage and grain yields than did manure application. This was largely a consequence of the lower yields obtained with broadcast application of manure. Inject application of manure, in fact, resulted in yields quite comparable to conventional N fertilization.

There was no effect of N-Serve on the concentrations of P and K in harvested silage. Phosphorus and K concentrations in silage were somewhat higher with manure application than with conventional N fertilization in Experiment 2. This could be attributed to P and K contributed from manure. Silage N, Ca, and Mg concentrations were typical of corn silage but silage Na concentrations were atypically low.

Soil pH was relatively constant among various treatments in the second experiment. Soil P was uniformly high in all treatments, while soil test extractable K was appreciably lower for conventional N fertilization than it was for treatments receiving manure. The NO_3-N was extremely high in all treatments. This could be attributed to nitrification of the high amounts of NH_4-N present. In all treatments extractable NH_4-N was ≤ 10 mg $\cdot$ kg^{-1} indicating that N-Serve had not been effective in inhibition of manurial N conservation to NO_3-N.

The conclusions from these two field experiments were:

1. Times and methods of manure application had no influence on silage or grain yields, silage nutrient content, or soil test extractable nutrients in two years of experimentation where soils had received high amounts of broadcast manure application in the recent past (Exp. 1).
2. N-Serve had no influence on silage or grain yield, silage nutrient content, or soil test extractable nutrients in one year of experimentation (Exp. 2).
3. Inject resulted in higher yields than broadcast application of manure, and conventional N fertilization resulted in higher yields than did manure application in a pasture which had not received high levels of fertilization in the past (Exp. 2).
4. Manure resulted in higher concentrations of P and K in silage than did conventional N fertilization without supplemental P or K application (Exp. 2).

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APPENDICES

APPENDIX A

ELEMENTAL ANALYSIS OF LIQUID DAIRY MANURE

APPLIED IN EXPERIMENT 1

Table 11. Manure TKN (organic-N plus NH_4-N) concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	Replication 200	Replication 300	Average ± s	% CV
	- - - - - - - - mol · kg^{-1} - - - - - - - - -				
Fall 1980					
Broadcast	2.84	2.82	2.82	2.83 ± 0.01	0.4
Inject	2.88	3.04	2.90	2.94 ± 0.09	0.3
Spring 1981					
Broadcast	2.44	2.70	1.60	2.25 ± 0.58	25.8
Inject	3.21	3.46	2.70	3.12 ± 0.38	12.2
Sidedress	3.05	2.92	2.87	2.95 ± 0.09	3.1
Fall 1981					
Broadcast	2.93	3.19	3.12	3.08 ± 0.14	4.6
Inject	3.36	3.25	3.23	3.28 ± 0.08	2.0
Spring 1982					
Broadcast	3.03	3.12	3.16	3.10 ± 0.07	2.2
Inject	3.49	3.27	3.27	3.34 ± 0.13	3.4
Sidedress	2.53	2.38	2.45	2.45 ± 0.08	3.3

Table 12. Manure P concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	200	300	Average ± s	% CV
			$mol \cdot kg^{-1}$		
<u>Fall 1980</u>					
Broadcast	0.156	0.051	--	0.104 ± 0.074	71.2
Inject	--	0.143	0.336	0.240 ± 0.138	57.5
<u>Spring 1981</u>					
Broadcast	0.326	0.335	0.345	0.335 ± 0.010	3.0
Inject	0.333	0.332	0.332	0.332 ± 0.001	0.3
Sidedress	0.322	0.305	0.320	0.316 ± 0.010	3.2
<u>Fall 1981</u>					
Broadcast	0.274	0.332	0.305	0.305 ± 0.029	9.5
Inject	0.308	0.311	0.317	0.317 ± 0.004	1.3
<u>Spring 1982</u>					
Broadcast	0.288	0.299	0.306	0.298 ± 0.009	3.0
Inject	0.323	0.291	0.328	0.314 ± 0.020	6.4
Sidedress	0.309	0.446	0.453	0.403 ± 0.081	20.0

Table 13. Manure K concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -	mol · kg^{-1}	- - - - - - - -		
Fall 1980					
Broadcast	--	--	--	-- --	--
Inject	--	--	--	-- --	--
Spring 1981					
Broadcast	0.601	0.455	0.391	0.483 ± 0.107	22.2
Inject	0.504	0.450	0.343	0.432 ± 0.082	19.0
Sidedress	--	--	--	-- --	--
Fall 1981					
Broadcast	0.783	0.905	0.790	0.826 ± 0.069	8.4
Inject	0.982	0.783	0.818	0.861 ± 0.106	12.3
Spring 1982					
Broadcast	0.678	0.708	0.593	0.660 ± 0.060	9.1
Inject	0.698	0.647	0.568	0.638 ± 0.066	10.3
Sidedress	0.910	0.864	0.777	0.850 ± 0.068	8.0

Table 14. Manure Ca concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -	mol · kg^{-1}	- - - - - - - -		
Fall 1980					
Broadcast	--	--	--	-- --	--
Inject	--	--	--	-- --	--
Spring 1981					
Broadcast	0.300	0.325	0.325	0.317 ± 0.014	4.4
Inject	0.250	0.288	0.250	0.263 ± 0.022	8.4
Sidedress	--	--	--	-- --	--
Fall 1981					
Broadcast	0.320	0.300	0.265	0.295 ± 0.028	9.5
Inject	0.315	0.393	0.285	0.331 ± 0.055	16.6
Spring 1982					
Broadcast	0.238	0.208	0.250	0.232 ± 0.022	9.5
Inject	0.243	0.228	0.233	0.234 ± 0.008	3.4
Sidedress	0.115	0.112	0.098	0.108 ± 0.009	8.3

Table 15. Manure Mg concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -		mol · kg^{-1}	- - - - - - -	
Fall 1980					
Broadcast	--	--	--	-- --	--
Inject	--	--	--	-- --	--
Spring 1981					
Broadcast	0.210	0.206	0.202	0.206 ± 0.004	1.9
Inject	0.202	0.202	0.193	0.199 ± 0.005	2.5
Sidedress	--	--	--	-- --	--
Fall 1981					
Broadcast	0.239	0.276	0.247	0.254 ± 0.019	7.5
Inject	0.296	0.276	0.259	0.277 ± 0.019	6.9
Spring 1982					
Broadcast	0.234	0.210	0.206	0.217 ± 0.016	7.4
Inject	0.214	0.263	0.173	0.217 ± 0.045	20.7
Sidedress	0.355	0.338	0.279	0.324 ± 0.040	12.4

Table 16. Manure Na concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - - mol · kg^{-1} - - - - - - - -				
Fall 1980					
Broadcast	--	--	--	-- --	--
Inject	--	--	--	-- --	--
Spring 1981					
Broadcast	0.170	0.161	0.157	0.162 ± 0.007	4.3
Inject	0.157	0.170	0.170	0.165 ± 0.008	4.9
Sidedress	--	--	--	-- --	--
Fall 1981					
Broadcast	0.148	0.174	0.163	0.162 ± 0.013	8.0
Inject	0.200	0.161	0.174	0.178 ± 0.020	11.2
Spring 1982					
Broadcast	0.113	0.117	0.100	0.110 ± 0.009	8.1
Inject	0.122	0.117	0.087	0.109 ± 0.019	17.4
Sidedress	0.070	0.061	0.052	0.061 ± 0.009	14.8

APPENDIX B

TOTAL MANURE APPLICATION BY REPLICATION, EXPERIMENT 1

Table 17. Total manure application by replication, Experiment 1, wet basis.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - - mol · kg^{-1} - - - - - - - -				
Fall 1980					
Broadcast	70.0	71.7	79.3	73.7 ± 5.0	6.8
Inject	80.5	67.4	76.4	74.8 ± 6.7	9.0
Spring 1981					
Broadcast	70.8	71.8	68.7	70.4 ± 1.6	2.3
Inject	71.9	72.6	72.5	72.3 ± 0.4	0.6
Sidedress	68.2	77.9	75.5	73.9 ± 5.1	6.9
Fall 1981					
Broadcast	73.9	73.7	132.5	93.3 ±33.9	36.3
Inject	73.5	71.1	73.7	72.8 ± 1.4	1.9
Spring 1982					
Broadcast	63.0	67.8	68.4	66.4 ± 3.0	4.5
Inject	97.9	99.4	96.7	98.0 ± 1.4	1.4
Sidedress	93.4	84.1	80.1	85.9 ± 6.9	8.0

APPENDIX C

ELEMENTAL ANALYSIS OF LIQUID DAIRY MANURE

APPLIED IN EXPERIMENT 2

Table 18. Manure TKN (organic-N plus NH_4-N) concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - -	mol · kg^{-1}	- - - - - - - -		
Broadcast	2.61	2.86	3.04	2.84 ± 0.22	7.6
Broadcast+N-Serve	2.89	2.92	3.13	2.98 ± 0.13	4.4
Inject	3.11	3.05	3.19	3.12 ± 0.07	2.3
Inject+N-Serve	2.92	2.72	2.93	2.86 ± 0.12	4.2

Table 19. Manure P concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - -	mol · kg^{-1}	- - - - - - -		
Broadcast	0.29	0.26	0.28	0.28 ± 0.02	5.9
Broadcast+N-Serve	0.30	0.14	0.31	0.25 ± 0.10	37.6
Inject	0.30	0.33	0.32	0.32 ± 0.02	2.8
Inject+N-Serve	0.30	0.29	0.29	0.29 ± 0.01	3.1

Table 20. Manure K concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -	mol · kg^{-1}	- - - - - - - -		
Broadcast	1.13	0.80	0.68	0.87 ± 0.23	27.2
Broadcast+N-Serve	0.49	0.45	0.75	0.56 ± 0.16	29.3
Inject	0.71	0.68	0.65	0.68 ± 0.03	4.7
Inject+N-Serve	0.77	0.78	0.68	0.74 ± 0.06	7.8

Table 21. Manure Ca concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

Treatment	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -	mol · kg^{-1}	- - - - - - - -		
Broadcast	0.27	0.28	0.32	0.29 ± 0.03	8.7
Broadcast+N-Serve	0.24	0.36	0.32	0.31 ± 0.06	20.5
Inject	0.26	0.27	0.24	0.26 ± 0.02	7.5
Inject+N-Serve	0.29	0.29	0.32	0.30 ± 0.02	6.7

Table 22. Manure Mg concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

	Replication				
Treatment	100	200	300	Average ± s	% CV
	- - - - - - - - mol · kg^{-1} - - - - - - - -				
Broadcast	0.22	0.24	0.21	0.22 ± 0.02	7.7
Broadcast+N-Serve	0.21	0.14	0.26	0.20 ± 0.06	28.2
Inject	0.21	0.21	0.21	0.21 ± 0.01	2.4
Inject+N-Serve	0.25	0.24	0.26	0.25 ± 0.01	3.2

Table 23. Manure Na concentration, dry weight basis, Dairy Experiment Station, Lewisburg, TN, fall 1981.

	Replication				
Treatment	100	200	300	Average ± s	% CV
	- - - - - - - - mol · kg^{-1} - - - - - - - -				
Broadcast	0.14	0.17	0.14	0.15 ± 0.02	12.1
Broadcast+N-Serve	0.13	0.09	0.17	0.13 ± 0.04	33.8
Inject	0.15	0.15	0.13	0.14 ± 0.01	7.0
Inject+N-Serve	0.16	0.17	0.14	0.16 ± 0.01	3.6

APPENDIX D

TOTAL MANURE APPLICATION BY REPLICATION, EXPERIMENT 2

Table 24. Total manure application by replication, Experiment 2, wet basis.

Treatments	Replication 100	200	300	Average ± s	% CV
	- - - - - - - -	mol · kg^{-1}	- - - - - - - -		
<u>Fall 1981</u>					
Broadcast	93.9	91.9	93.5	93.1 ± 1.1	1.2
Broadcast+N-Serve	93.5	94.2	95.1	94.2 ± 0.8	0.9
Inject	94.8	94.7	96.6	95.4 ± 1.1	1.2
Inject+N-Serve	95.1	99.1	98.0	97.4 ± 2.1	2.2

APPENDIX E

SUMMARY AND CONCLUSIONS IN SPANISH

SUMARIO Y CONCLUSIONES

Dos experimentos fueron conducidos en la Estacion de Experimento Lechero en Lewisburg, TN, para (i) investigar la inyección contra el esparcimiento de la aplicacion del estiércol del ganado lechero aplicado los dos en el otoño y en la primavera como una fuente de N para la produccion del maiz ensilage (Experimento 1) y (ii) para investigar la utilidad de un inhibitor de nitrification para conservar N del estiércol aplicado como esparcido o inyectado en el otoño (Experimento 2). Los dos experimentos fuerón diseñados para proveer adecuado N para la producción del maiz ensilage con la finalidad de evaluar la relativa efectividad de varios tiempos y métodos de aplicación. Todas las replicaciones recibierón aproximadamente cantidades iguales de estiércol (68 Mg $\cdot$ ha^{-1} en Experimento 1 y 90 Mg $\cdot$ ha^{-1} en Experimento 2).

Por cuanto, no hubo diferencias en la producción del maiz en el grano o en el maiz ensilado, tampoco en el contenido nutriente del ensilage ni en los nutrientes extractables del suelo en el Experimento 1, diferencias significantes fuerón obtenidas en el Experimento 2. Esto fué principalmente debido a las diferencias de la fertilidad del suelo de los dos Experimentos. Previa aplicación de estiércol en el area del Experimento 1 ha causado alta condición de fertilidad del area experimental. Los análisis de los suelos indicaron medio con tendencia a alta fertilidad del suelo en el sitio del segundo experimento, pero esto no fue así tan alto como para cubrir la reacción de la aplicación del estiércol.

En ambos experimentos, habia una pequeña diferencia en la composición del estiércol entre las replicaciones, métodos, o tiempos de aplicación. En tiempos, una variación significante fué notada en uno o mas componentes de los nutrientes del estiércol, pero esto fue atribuido a los errores análiticos y a los errores durante la sacada de las muestras mas que la variación inherente del contenido nutriente en el estiércol. El total sólido si varió apreciablemente con la estación del año y esto afectó la carga total de nutrientes en algunas instancias.

En el Experimento 2, análisis de variación indicó altos efectos significantes de los tratamientos de la producción del grano y del ensilage. No hubo efecto de N-Serve sobre la producción del grano o en el ensilage. Esto podría ser atribuido al tiempo seco y a las temperaturas calientes del suelo en el tiempo de la aplicación la cual afectó la reacción de N-Serve. La aplicación inyectada del estiércol liquido fue más efectivo en producir mas ensilage y mas grano que el que produjo la aplicacion esparcida. Esto podría ser porque con inyección del estiércol la perdida del N por volatilizacion fue minima. La fertilizacion convencional del N resultó en mas alta producción de ensilage y granos que la aplicación del estiércol. Esto fué largamente una consequencia de la baja producción obtenida con la aplicación esparcida del estiércol. Aplicación inyectada del estiércol, en realidad, resultó en producción completamente comparable a la fertilización convencional del N.

No hubo efecto de N-Serve sobre las concentraciones de P y K en el ensilage cosechado. Fosforo y K concentraciones en el ensilage fuerón un poco mas alta con la aplicación del estiércol que con la fertilizacion convencional del N en el Experimento 2. Esto podria ser atribuido al P y al K aportado por el estiércol. Las concentraciones del N, Ca, y Mg en el ensilage fuerón típicas en el maiz eneilage pero con respecto a la concentración del Na en el ensilage fuerón muy bajas.

En el sequndo Experimento, el pH del suelo fue relativamente constante entre los varios tratamientos. El P del suelo fue uniformemente en todos los tratamientos, mientras en el K extractable del suelo fue apreciablemente mas bajo en la fertilización convencional del N que en los tratamientos que recibierón estiércol. El NO_3-N fue extremadamente alto en todos tratamientos. Esto podria ser atribuido a la nitrificacion de las altas cantidades de NH_4-N presente. En todos los tratamientos extractable NH_4-N fue $\leq$ 10 mg · ha^{-1} indicando que N-Serve no habis sido efectivo en la inhibicion del N estiércol en la conservacion de NO_3-N.

Las conclusiones de estos dos experimentos fueron:

1. Tiempo y método de la aplicación del estiércol no tuvo influencia sobre la producción de ensilage y granos, tampoco sobre el contenido nutriente del ensilage, o en nutrientes extractables del suelo en dos años de

experimentacion donde los suelos habia recibido altas cantidades de estiércol aplicado esparcidamente en el reciente pasado (Exp. 1).

2. N-Serve no tuvo influencia sobre la producción del ensilage o en el grano, tampoco sobre el contenido nutriente del ensilage, o sobre los nutrientes extractables del suelo en un año de experimentacion (Exp. 2).
3. El estiércol inyectado resultó en mas alta producción que la aplicación esparcida del estiércol, y la fertilización convencional del N resultó en mas alta producción que la aplicación del estiércol en el pasto la cual no habia recibido altos niveles de fertilización en el pasado (Exp. 2).
4. Estiércol resultó en mas altas concentraciones de P y K en el ensilage que en la fertilización convencional del N sin la aplicación adicional de P y K (Exp. 2).

APPENDIX F

CONVERSION TABLE OF SI UNITS

Table 25. Conversion table of SI units used in the thesis.

SI Unit	Equivalence
Molar concentration	
mol N kg^{-1}	1.4% N
mol P kg^{-1}	3.1% P
mol K kg^{-1}	3.9% K
mol Ca kg^{-1}	4.0% Ca
mol Mg kg^{-1}	2.4% Mg
mol Na kg^{-1}	2.3% Na
Amount of substance concentration	
1 M (1/2 H_2SO_4)	1 N H_2SO_4
1 M HNO_3	1 N HNO_3
1 M HCl	1 N HCl
2 M KCl	2 N KCl
Soil application rates	
$Mg \cdot ha^{-1}$	metric tons $\cdot$ ha^{-1}
$kg \cdot ha^{-1}$	$kg \cdot ha^{-1}$
Bulk density	
$Mg \cdot m^{-3}$	$g \cdot cm^{-3}$

VITA

José A. Rangel was born in San Cristóbal, Táchira State, Venezuela, on November 7, 1950. In 1974 he graduated from Simon Bolivar High School in San Cristóbal, Venezuela. In 1979 he received the Bachelor of Science degree in Plant and Soil Science from the Florida A&M University at Tallahassee. He received his Master of Science degree from The University of Tennessee, Knoxville, in June 1983 with a major in Plant and Soil Science. He is married to Ligia Montilva. They have one son, José Ramón Rangel.