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NUTRIENT CONTENT AND FERTILIZER VALUE OF LIVESTOCK MANURE WITH SPECIAL REFERENCE TO COW MANURE

Selostus: Karjanlannan, erityisesti naudanlannan ravinnepitoisuus ja lannoitusarvo

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Academic dissertation
To be presented, with the permission of the Faculty of
Agriculture and Forestry of the University of Helsinki,
for public criticism in the Small Festival Hall
on October 20th, 1989, at 12 o'cloc a.m.

PREFACE

The present study was carried out at the Department of Agricultural Chemistry and Physics, Agricultural Research Centre of Finland during 1982—1988. I want to express my sincere gratitude to Professor Paavo Elonen, Head of the Department of Agricultural Chemistry and Physics.

I wish to express my thanks to my teacher, Professor Antti Jaakkola, Head of the Department of Agricultural Chemistry, University of Helsinki, for the support and guidance he has given me over the years.

I would like to thank Professor Antti Jaakkola and Professor Paavo Elonen for checking my work and offering their valuable and constructive criticism.

My thanks are extended to the staff of the Department of Agricultural Chemistry and Physics for the technical assistance in my experiments at Jokioinen, to both the Head and staff of the Department of Soil Science for performing the soil analyses, to the Head and staff of the North Ostrobothnia Research Station for performing some of the grass experiments, and to the Association of Agricultural Advisory Centres for the collection of manure samples and farmers' responses to the inquiry.

The English manuscript has been linguistically revised by Mrs. Randi Kumpulainen and edited by Mrs. Paula Vogt, M.Sc., to whom I express my appreciation for their expert work.

The figures in this publication were drawn by Mrs. Rauha Kallio to whom I wish to express my gratitude.

Finally, I would like to thank the Agricultural Research Centre for accepting this study into its series of publications.

Sotkamo, May 1989

Erkki Kemppainen

CONTENTS

NUTRIENT CONTENT AND FERTILIZER VALUE OF LIVESTOCK MANURE WITH SPECIAL REFERENCE TO COW MANURE

Kemppainen, E. 1989. Nutrient content and fertilizer value of livestock manure with special reference to cow manure. Ann. Agric. Fenn. 28: 169—284. (Agric. Res. Centre, Kainuu Res. Sta., SF-88600 Sotkamo, Finland.)

The present study deals with the following topics: the nutrient content of manure, causes of its variation and utility of various easily measurable or assessable factors for its assessment; the use of cow slurry as a fertilizer for barley; cow slurry as a grassland fertilizer; and the effect of soil properties on ammonia volatilization from surface applied liquid cow manure.

A great deal of information on the average nutrient content of manure was obtained. Moreover, nutrient content was shown to be dependent on animal feeding and manure handling. These dependencies can be used in assessing nutrient content more precisely. The simultaneous use of dry matter and pH analyses for the determination of the nutrient content of manure was proved to be considerably better than the use of either of those variables separately. The rate of wash water can also be used in explaining the nutrient content of slurry and liquid manure.

The fertilizer value of cow slurry was examined in field experiments with barley and grass. The experiments with barley proved that, optimally, when slurry is spread in the spring, the efficiency of soluble nitrogen in slurry equals that of nitrogen in artificial fertilizer. As compared to the spring application, applications in the autumn and winter proved rather ineffective. Slurry application after the sowing of barley was also examined. Good results were obtained by slurry applied at about sprouting, but applications about 10 d after sprouting gave significantly poorer results.

Cow slurry was demonstrated to be significantly less effective as a grass fertilizer compared to its effect on barley. In general, slurry corresponded to less than 40—50 kg/ha of N in artificial fertilizer although the rate of total N applied in slurry averaged about 130 kg/ha and that of soluble N about 80 kg/ha.

Injected slurry generally proved superior to surface applied slurry for barley fertilization, but only a small benefit by injection was obtained in grass dry matter yields. However, injected slurry was found to be superior to surface applied slurry in raising the nitrogen uptake by grass.

Irrigation following slurry application had only slight effects on barley and grass yields. In some cases, negative effects by irrigation resulted.

Combined applications of slurry and mineral fertilizer generally proved superior compared to slurry alone. An especially beneficial effect by nitrogen supplementation was found on barley manured at or after sprouting.

Damage by the spreader and its injector tines was observed when slurry was spread on grass or on barley after sowing. In the case of grass, such damage was rather short-lived. As for barley, on the other hand, damage by slurry application after sowing was concluded to result partly from the slurry itself.

The effect of soil properties on ammonia volatilization from surface applied liquid cow manure was examined in the laboratory employing a dynamic incubation method. Clay content proved to be the most useful soil property for predicting the rate of ammonia volatilization.

Index words: slurry, liquid manure, solid manure, nutrient content, rapid methods, field tests, feeding, manure handling, injection, surface application, irrigation, nitrogen supplementation, trampling damage, barley, grassland, ammonia volatilization, clay, pH, liming, soil moisture, cation exchange capacity, texture, aggregates.

INTRODUCTION

The use of livestock manure as a fertilizer has been examined rather intensively in Finland from the beginning of the 20th century until the 1950's. One of the earliest papers on the profitable handling and use of manure was written by Lauri Kristian RELANDER (1907), the president of Finland from 1925 to 1931. Valuable research on livestock manure was further carried out by VALMARI (1921), SVINHUFVUD (1925), TUORILA (1929), TUORILA and TAINIO (1934), VIRTANEN (1935), HONKAVAARA (1936), VIRRI (1941), KAILA (1949, 1950 a, 1950 b), SALONEN and HONKAVAARA (1954), and YLÄNEN (1958). However, in the 1960's and 1970's only scanty research on manure has been carried out. Owing to the low price of artificial fertilizers, livestock manure was at that time usually regarded as a costly waste of only little benefit when used as a fertilizer.

The general attitude towards livestock manure changed drastically during the mid-1970's. As a result of the oil crisis, the cost of artificial fertilizers increased considerably. At the same time, inadequate handling and utilization of manure was recognized as a potential environmental threat. Thus, it became apparent that an effective use of livestock manure in plant production would both reduce fertilizer costs and also help protect the environment against pollution.

The use of livestock manure has been intensively studied in other European countries. Especially long-range research on this subject has been carried out in Denmark (IVERSEN 1924, 1927, 1934, 1938, 1943, 1944, 1957, F. HANSEN 1927, 1941, N.A. HANSEN 1928, JENSEN 1928, 1929, ANON. 1930, WESTED and IVERSEN 1938, IVERSEN and DORPH-PETERSEN 1949 a, 1949 b, 1952, KOFOED et al. 1969, 1985, KOFOED 1987).

Present-day research into livestock manure in Europe is very intensive. Several seminars and symposia have been held and the papers presented during those meetings have been published in books which are very valuable for scientists interested in the topic. In current European research, interest has been focused, for instance, on the effects of heavy applications of manure on the soil (BONCIARELLI 1977), nitrogen losses from manure (GASSER 1979, KOLENBRANDER 1981 a), nutrient content of manure (GERMON et al. 1980), preparation of manure by aeration or methanization (BESSON et al. 1985, BIDDLESTONE and GRAY 1985), rapid methods for estimating the fertilizer value of manure (TUNNEY 1986), negative effects by manure on plants (PRINS and SNIJDERS 1987), control of malodours from livestock farming (V.C. NIELSEN 1986, V.C. NIELSEN et al. 1988), and, in general, the efficient and environmentally safe use of manure (VETTER 1988).

The aim of this study was to examine the nutrient content and fertilizer value of manure in Finland. Of special interest was the variation in the nutrient content of manure and the utility of several factors in assessing its fertilizer value. Moreover, the effects of both time and method of manure application, irrigation following slurry application, damage to grass and the young barley crop by the spreader, the need for supplementary fertilization and the factors affecting ammonia loss from surface applied manure were studied. Cow slurry was used in field experiments because, on the one hand, cows are the most important animals on Finnish farms and, on the other hand, only a few studies on the use of slurry have been carried out in Finland thus far.

NUTRIENT CONTENT OF LIVESTOCK MANURE, CAUSES OF ITS VARIATION AND UTILITY OF VARIOUS FACTORS FOR ASSESSMENT

INTRODUCTION

The utilization of livestock manure is rather poor in many countries, as well as in Finland. The present situation results in economic losses and, at worst, environmental pollution. Several causes for the inadequate utilization of manure can be identified. Of these, an insufficient knowledge of the fertilizer value of manure probably is the most important. Farmers are often disappointed with the use of manure because they cannot predict its effect as precisely as that of artificial fertilizer. Such disadvantages by no means encourage farmers to make use of livestock manure as a fertilizer.

The objective of this study was to establish the nutrient content of manure in Finland. The effects of various factors on the properties of manure were examined in order to clarify whether recommendations for manure use can be specified on the basis of different feeding and manure handling methods. In addition, correlations and regressions were calculated in order to ascertain the utility of various easily measurable or assessable factors for assessing the nutrient content of manure. The study is based on manure samples collected from practical farms throughout Finland and an inquiry concerning animal feeding and manure handling on the same farms.

LITERATURE REVIEW

1. Nutrient content of manure

According to the literature, solid cow manure contains 18—25 % dry matter, 5.2—6.1 g/kg total N, 1.3—2.1 g/kg P and 3.5—6.0 g/kg K (KERÄNEN 1966, KJELLERUP 1981, ANON. 1982, BEAUCHAMP 1983 a). Cow slurry contains 7.3—10.0 % dry matter, 2.8—5.3 g/kg total N, 0.6—1.1 g/kg P and 2.1—4.9 g/kg K (KÄHÄRI 1974, ANON. 1978, 1982, GRACEY 1979, TUNNEY 1979, KJELLERUP 1981, AMBERGER 1982, VETTER 1982, BEAUCHAMP 1983 a, DESTAIN and RAIMOND 1983, MARAHRENS 1983, RIEDER 1983, WAGNER 1984). There are only a few results on the nutrient content of liquid cow manure in the literature. According to VIRTANEN (1935) and IVERSEN and DORPH-PETERSEN (1949 a), liquid cow manure contains 6—8 g/kg total N and 10—13 g/kg K, but practically no P.

Solid pig manure has been found to contain 18—25 % dry matter, 4.6—7.0 g/kg total N, 1.8—5.3 g/kg P and 2.9—3.7 g/kg K (SUTTON et al. 1979, KJELLERUP 1981, ANON. 1982, BEAUCHAMP 1983 a). Pig slurry contains 3.3—10.0 % dry matter, 3.7—7.0 g/kg total N, 0.9—2.0 g/kg P and 1.5—4.6 g/kg K (KÄHÄRI 1974, ANON. 1978, 1982, SUTTON et al. 1979, TUNNEY 1979, KJELLERUP 1981, AMBERGER 1982, VETTER 1982, BEAUCHAMP 1983 a, DESTAIN and RAIMOND 1983, MARAHRENS 1983, WAGNER 1984). According to VIRTANEN (1935) and STEINECK (1974), liquid pig manure contains 3.0—4.1 g/kg total N, 0.4 g/kg P and 5.0—6.9 g/kg K.

The nutrient content of poultry manure varies considerably depending on the rate of litter used. Manure produced by laying hens generally contains less dry matter and nutrients compared to that by broilers. However, some poultry manure is also handled and stored as slurry. Solid poultry manure contains 25—

70 % dry matter, 12.5—26.0 g/kg total N, 3.9—17.6 g/kg P and 3.8—17.2 g/kg K. Poultry slurry contains 7.5—16.0 % dry matter, 7.2—10.7 g/kg total N, 1.7—4.9 g/kg P and 2.8—8.3 g/kg K (ANON. 1978, 1980, 1982, LINDHARD and KJELLERUP 1979, KJELLERUP 1981, AMBERGER 1982, VETTER 1982, BEAUCHAMP 1983 a, DESTAIN and RAIMOND 1983, MARAHRENS 1983, WAGNER 1984).

In addition to N, P and K, livestock manure contains significant amounts of other elements essential to plant growth (SORTEBERG 1957, KÄHÄRI 1974, MAZUR et al. 1979, ANON. 1980, KJELLERUP 1981, KJELLERUP and MUNCH 1981, KLUGE and PODLESAK 1981, BEAUCHAMP 1983 a, KLAUSEN 1985, de la LANDE CREMER 1985). Owing to the supplementation of pig feeds with copper, the content of copper in pig manure is sometimes too high. Toxic effects on sheep and calves by grass fertilized with pig slurry have been demonstrated (ANON. 1978, 1982, POOLE et al. 1983).

2. Factors affecting the nutrient content of manure

a. Feeding

Feeding has an effect on both the rate and quality of faeces. It also affects the proportion of urine compared to solid excrement and the distribution of nutrients in these two constituents of manure.

The rate of faeces produced by a cow depends on the rate of dry matter in feeds (IVERSEN and DORPH-PETERSEN 1949 a). According to HAUGLAND (1942), 2 kg of solid faeces are produced per 1 kg of hay, but only 0.3 kg per 1 kg of silage. The proportion of urine in all faeces is the lowest (about 25 %) by hay feeding (HAUGLAND 1942). By silage feeding, the proportion of urine is about 30 % and, that by beet tops, about 40 %.

Feeding intensity considerably influences manure quality. Only a small proportion of the nutrients in feeds ends up in milk or meat. Moreover, the more intensive the feeding the higher the percentage of nutrients excreted in the faeces. According to IVERSEN and DORPH-PETERSEN (1949 a), cow faeces include about 75 % of the nitrogen and the phosphorus, and 90 % of the potassium supplied by feeds. Somewhat similar figures have been presented by BEAUCHAMP (1983 a) in Canada. Faeces of heifers and other young cattle contain as much as 90 % of the N and P, and 100 % of the K supplied from feeds (IVERSEN and DORPH-PETERSEN 1949 a).

On average, 50—55 % of the nitrogen and 70—75 % of the potassium in cow and pig faeces is included in urine (STEINECK 1974). Cow urine contains practically no phosphorus, but about 20 % of the phosphorus in pig faeces is found in urine. An intensified feeding regime especially increases the nitrogen content of urine and the proportion of nitrogen excreted in urine (HAUGLAND 1942, IVERSEN and DORPH-PETERSEN 1949 a, van VUUREN and MEIJS 1987). Feeding has only a minor effect on the nitrogen content of solid faeces. On the other hand, intensified feeding with P-rich feeds especially increases the phosphorus content of solid faeces (HAUGLAND 1942, IVERSEN and DORPH-PETERSEN 1949 a). An increase in the rate of potassium in feeds mainly raises the potassium content of urine, but intensified feeding does not necessarily mean an increase in the rate of K in feeds; often the reverse is true.

Earlier in this century, summer feeding and winter feeding substantially differed from each other. Since no silage was used and only small rates of concentrated feed were available, winter feeding was rather poor compared to the present. In the summer, feeds were considerably better. That difference was also reflected in the nutrient content of manure (F. HANSEN 1941, SCHÖLLHORN 1954). Manure produced in the summer contained significantly more nitrogen, phosphorus and calcium compared to that produced in winter. On the other hand, the plentiful use of hay and straw in the winter was seen as an increase in the dry matter and potassium contents of manure. With the increasing use of concentrated feed these differences vanished (IVERSEN 1924, N.A. HANSEN 1928, IVERSEN and DORPH-PETERSEN 1949 a).

In practical recommendations for manure use, the effect of feeding on the nutrient content of manure is only seldom taken into account (ANON. 1982, RIEDER 1983).

b. Effect of handling on the nutrient content of solid manure

The most commonly used litters: straw, sawdust and peat contain only slight amounts of plant nutrients (BENGTSSON et al. 1954). The use of litter generally increases the quantity of manure, but decreases the nutrient contents in manure dry matter. However, straw contains plenty of potassium.

Various litters differ from each other with respect to their capacity to bind urine and its nutrients. Acid peat has been shown to be the best litter. It can absorb urine as much as 12-fold compared to its dry weight and bind ammonia to about 2 % of its dry weight (TUORILA 1929, KEMPPAINEN 1987 a). As compared to acid peat, straw and sawdust appear to be rather poor litters. The superiority of acid peat has also been demonstrated in pot and field experiments with different kinds of manure (von FEILITZEN 1911, 1914, SVINHUFVUD 1925, KEMPPAINEN 1987 b).

The use of straw as a litter can result in nitrogen losses because straw loosens the manure and its decomposition raises the temperature of the manure heap (ANON. 1930). Ammonification of the nitrogen in urine proceeds so fast that plenty of ammonia is volatilized in spite of the easily decomposable straw in manure (KAILA 1950 a). Ammonia volatilization can be retarded by storing the manure in a large compressed heap; then the diffusion of ammonia becomes slower. Indeed, such storage has proved beneficial in the case of straw manure (SVINHUFVUD 1925, TUORILA 1941, VIRRI 1947, KOEPKE 1962, SCHMALFUSS and KOLBE 1963, RAUHE and KOEPKE 1967). The effect of compressing may, on the other hand, partly result from organic acids formed in anaerobic conditions (KAILA 1948).

Several chemicals have been examined for the prevention of nitrogen loss from manure (JENSEN 1928, EGNER 1932, IVERSEN 1934, KAILA 1948, 1950 a, IVERSEN and DORPH-PETERSEN 1952). However, the use of chemicals has generally proved too expensive. Harmful effects on plants have also been found.

Significant nutrient losses have been shown to be caused by leaching from an open solid manure storage (IVERSEN and DORPH-PETERSEN 1949 b). Both covering the storage and a plentiful use of litter prevent such losses (IVERSEN and DORPH-PETERSEN 1949 b).

c. Effect of handling on the nutrient content of slurry

The nutrient content in slurry dry matter can be affected mainly by nitrogen loss during storage. Even nitrogen loss is generally relatively small because pH is about neutral. In addition, the diffusion of ammonia in slurry is rather slow. In a usual storage, slurry does not warm up which would enhance ammonia volatilization.

Due to ammonia volatilization during storage, the surface layer of slurry usually contains significantly less ammonia than the deeper slurry layers (EGNER 1932, KOFOED et al. 1969). Such an ammonia-poor layer prevents further ammonia volatilization because diffusion is rather slow. The mixing of such a slurry should be avoided because mixing brings the ammonia-rich slurry to the surface. Aeration has also been shown to increase nitrogen loss from slurry significantly (STEVENS and CORNFORTH 1974 a, LOYNACHAN et al. 1976, SCHECHTNER 1978, KEMPPAINEN 1987 c).

The method of slurry transfer to the reservoir has also been found to affect the extent of nitrogen loss. Significantly higher losses occur when the reservoir is loaded from the top by a push ramp compared to loading from the bottom (MUCK et al. 1981, MUCK and STEENHUIS 1982).

d. *Effect of handling on the nutrient content of liquid manure*

Nitrogen in urine ammonifies very rapidly and can be volatilized already in the cowshed. In order to prevent nitrogen loss, the separation of urine from solid faeces must be carried out quickly (IVERSEN 1924).

The better the covering of the liquid manure cistern the smaller the nitrogen loss. Even a small crack in the covering may result in a significant nitrogen loss (IVERSEN 1924, EGNER 1932, VIRTANEN 1935).

Several chemicals have been examined in order to prevent nitrogen loss from liquid manure (JENSEN 1928, EGNER 1932, IVERSEN 1934, KAILA 1948, 1950 a, IVERSEN and DORPH-PETERSEN 1952). The effect of acidifying chemicals is weakened by the high buffer capacity of liquid manure. A thin oil layer above the liquid manure has been found to retard ammonia volatilization (SALONEN 1949). A water trap in the cistern can also have a nitrogen-preserving effect (IVERSEN 1924). Dilution of liquid manure by water has proved very effective in preventing ammonia loss (VIRRI 1941, SCHÖLLHORN 1954).

3. Assessing the nutrient content and fertilizer value of manure

The solubility (plant availability) of nitrogen in different manures varies considerably. It is affected e.g. by the proportion of urine in manure and nitrogen loss during storage. According to SLUIJSMANS and KOLENBRANDER (1977), the proportion of mineral N in total N is about 10 % in solid manure, about 50 % in slurry, and 94 % in liquid manure.

The content of mineral N is generally the higher the higher the content of total N (F. HANSEN 1941, ASMUS et al. 1971). Since nitrogen loss, however, generally increases as manure becomes more concentrated, the solubility of nitrogen then decreases.

The nitrogen effect of manure is further affected by the mineralization of organically bound nitrogen. Significant differences in the rate of nitrogen mineralization among various manures have been described. It can be concluded that the organically bound nitrogen in pig and poultry manure has a significantly higher fertilizer effect compared to that in cow manure (SLUIJSMANS and KOLENBRANDER 1977, MAAS and BELAU 1978).

The efficiency of manure nitrogen has varied considerably in different experiments. As compared to the nitrogen in artificial fertilizer, the efficiency of total N in solid cow and pig manure ranges from 25 to 50 % (SLUIJSMANS and KOLENBRANDER 1977, ANON. 1982), that in solid poultry manure from 60 to 85 % (ANON. 1980, 1982, BEAUCHAMP 1983 a), that in cow slurry from 30 to 70 % (LAINE 1967, SLUIJSMANS and KOLENBRANDER 1977, ANON. 1980, 1982, AMBERGER 1982), that in pig slurry from 65 to 75 % (SLUIJSMANS and KOLENBRANDER 1977, SUTTON et al. 1979, AMBERGER 1982, ANON. 1982, WAGNER 1984), that in poultry slurry from 65 to 70 % (ANON. 1980, 1982, AMBERGER 1982), and that in liquid manure from 75 to 80 % (SLUIJSMANS and KOLENBRANDER 1977). Differences found among various experiments apparently result from nitrogen losses during and after the spreading of manure.

The content of soluble nitrogen in manure can be determined in the laboratory by direct distillation of ammonia or by distillation of the ammonia extracted by a dilute acid. In Finland, the latter method has traditionally been used and soluble nitrogen has been shown to constitute about 20 % of the total N in solid manure, 57 % of that in cow slurry, and 73 % of that in pig slurry (KERÄNEN 1966, KÄHÄRI 1974).

According to laboratory determinations, 60—90 % of the phosphorus in manure is soluble (KAILA 1949, GERRITSE 1981, AMBERGER 1982, van FAASSEN and van DIJK 1987). In field experiments, however, the phosphorus in manure often has been observed to be as effective as that in artificial fertilizer (ASMUS et al. 1971, SHARMA et al. 1980, TUNNEY 1980, AMBERGER 1982, SMITH and van DIJK 1987). In the advisory literature, the phosphorus in manure is generally considered as effective as that in artificial fertilizer (VALMARI 1933, HAUGLAND 1942, ANON. 1978, 1980, RIEDER 1983).

The potassium in manure is generally regarded equally effective as that in artificial fertilizer (VALMARI 1933, HAUGLAND 1942, ASMUS et al. 1971, ANON. 1980, SHARMA et al. 1980, TUNNEY 1980, AMBERGER 1982, BEAUCHAMP 1983 a, RIEDER 1983).

Little is known about the fertilizer effect of trace elements in manure. It appears, however, that their fertilizer effect cannot be assessed on the basis of their contents in manure. KLUGE and PODLESAK (1981) found that, as compared to normal artificial fertilization, continuous manuring with slurry increased the content of boron and molybdenum in both plants and the soil extract. Slurry manuring also increased the contents of copper and zinc in soil extracts, but not those in plants. The content of manganese in plants and the soil extract decreased by continuous slurry manuring.

Various methods have been proposed for the simple determination of the nutrients in manure. Ammonium nitrogen can be determined colourimetrically or by methods based on ammonia oxidation (JENSEN 1929, T.A. STEWART 1968 a, KJELLERUP 1986, KLASSE and WERNER 1988).

The nutrient content of slurry and liquid manure can also be assessed on the basis of their dry matter content or specific gravity. Correlations between nutrients and these two easily measurable properties have been found to be relatively strong (PFENNINGER 1927, SCHÖLLHORN 1954, TUNNEY and MOLLOY 1975, HEDUIT et al. 1977, GRACEY 1979, MAZUR et al. 1979, TUNNEY 1979, DUTHION and GERMON 1980, DESTAIN and RAIMOND 1983, VILLAR et al. 1984).

MATERIAL AND METHODS

A total of 1 229 samples of cow, pig and poultry manure were collected from practical farms throughout Finland in 1982. The sample material consisted of 678 solid manures, 248 slurries and 303 liquid manures (Table 1). Samples were collected by local agricultural advisors who received written instructions for representative sampling in advance. The instructions stipulated that samples should be taken from stored and carefully mixed manure.

The farms for the sampling were chosen from the farm register of 1980. Cow, pig and poultry farms were selected separately. In order to obtain a reliable picture of Finland's total manure production, the farms with large numbers of livestock were weighed in the sampling.

All manure samples were analyzed for dry matter, pH, total N, soluble N, P, K, Ca and Mg.

Table 1. Number of manure samples analyzed.

Animal species	Type of manure			Total
	Solid manure	Slurry	Liquid manure	
Cow	555	140	276	971
Pig	73	108	27	208
Poultry	50	0		50
Total	678	248	303	1229

In addition, 1 022 samples were analyzed for Na, Fe, Cu, Zn and Mn, 108 samples for Cl, and 599 samples for B. In principle, manure analysis was carried out according to the procedure traditionally used in Finland (KERÄNEN 1966, KÄHÄRI 1974). The following methods were employed:

Dry matter: Samples were dried at 105 °C overnight.

Owing to a significant proportion of easily volatilizable compounds in manure such as ammonia, hydrogen sulphide and organic acids, it was concluded that the method did not yield accurate results. Dry matter content was underestimated whereas the nutrient contents measured from dried samples were overestimated. When comparing different manures, the error probably is the highest in liquid manures in which ammonia constitutes a significant portion of dry matter.

Total nitrogen: By the Kjeldahl method from 20 g of non-dried manure.

Soluble nitrogen: a) Solid manure: 25 ml of 2 M HCl + 25 ml of 2.5 M $CaCl_2$ + 150 ml of H_2O were added to 50 g of non-dried manure. The mixture was mechanically shaken for one hour after which it was centrifuged at 3 000 r.p.m. for 10 minutes and then filtered through Whatman 1 paper. 20 ml of the filtrate was distilled in the presence of a spoonful of solid MgO. 4 % boric acid was used as the receiver solution and 0.1 M HCl as the titrating acid.

b) Slurry and liquid manure: 50 ml of 2 M HCl + 50 ml of 2.5 M $CaCl_2$ were added to 100 g of non-dried manure. Thereafter the procedure was the same as for solid manure.

In order to clarify the differences between the results by the above-mentioned method and those by the direct distillation method used by many scientists (F. HANSEN 1927, YLÄNEN 1958, BREMNER and KEENEY 1965, VERMES 1981), a comparison was carried out. In the direct distillation, 10 g of non-dried manure and 150 ml of water were boiled in distillation tubes in the presence of a spoonful of solid MgO for 15 minutes, the period of time found sufficient for the volatilization of all ammonia. Altogether 47 solid manures, 25 slurries and 16 liquid manures were included in this methodological comparison.

The two analytical methods provided reasonably similar results. Correlation of the content of soluble nitrogen by the two methods was $r = 0.95$ ($P = 0.001$) for solid manures, $r = 0.95$ ($P = 0.001$) for slurries, and $r = 0.86$ ($P = 0.001$) for liquid manures. The method based on acid extraction always produced slightly higher contents compared to the direct distillation method. As a percentage of the content by the acid extraction method, the content by direct distillation averaged 98 % for solid manures, 92 % for slurries, and 90 % for liquid manures.

P, K, Na, Ca, Mg, Fe, Cu, Zn and Mn: a sample of 2.000 g of dried manure was used. Nutrients were determined according to KÄHÄRI and NISSINEN (1978).

Boron: Boron was determined in a 2.000 g sample of dried manure by an azomethine-H method developed by SHANINA et al. (1967) and using the procedure described for plant analysis by SAARELA (1985).

Chlorine: 10.00 g of non-dried manure was diluted 400-fold in two phases. At the same time, $Al(OH)_3$ and H_2O_2 were used in order to remove disturbing compounds. The diluted sample was adjusted slightly alkaline and chlorine determined by titrating with silver nitrate in the presence of potassium chromate (Mohr titration).

pH: Potentiometric determination from slurry and liquid manure without dilution, and from solid manure following dilution with deionized water (1:1).

When collecting manure samples from practical farms throughout Finland, agricultural advisors simultaneously distributed an inquiry of how the animals were fed and the manner of manure handling and storage. The results of the inquiry have been published by KEMPPAINEN

(1986). Some of the results were also used in this study. Different feeding and manure handling methods were used as bases of classification. In addition, the nutrient content of manure in different areas of Finland and in different herd size classes was calculated. Statistical analyses were carried out using a VAX 11/780 computer and SPSS^x program (ANON. 1983 a). Correlations and regressions were also calculated in order to clarify the utility of various easily measurable or assessable factors for assessing the nutrient content of manure.

RESULTS

1. Nutrient content of manure

The contents of dry matter, total N, soluble N, P and K; pH and the proportion of soluble N in total N are shown in Table 2. Poultry manure appeared to be the most concentrated and cow manure the least. As compared to the other manure types, liquid manures were relatively rich in soluble nitrogen and their pH was high. However, the variation of nutrient content appeared very strong (Appendix 1).

When different manures were compared with respect to their nutrient content per dry matter, liquid manures appeared to be especially concentrated (Table 3). Total N, P, K and Ca together constitute 45 % of the dry matter in liquid pig manure. As compared to liquid manures, solid manures and slurries are poorer in nitrogen and potassium because solid excrement contains only relatively small amounts of these nutrients. However, the contents of phosphorus, calcium and magnesium in manure dry matter are about the same for all manure types

Table 3. Average contents of total N, soluble N, P, K, Ca and Mg in manure dry matter. For the number of samples see Table 2.

Type of manure	Nutrients, g/kg of dry matter					
	tot. N	sol. N	P	K	Ca	Mg
COW						
Solid manure	25.5	7.0	9.0	23.2	13.0	5.0
Slurry	44.7	26.1	11.7	37.2	16.2	6.0
Liquid manure	139.8	127.3	5.7	232.4	9.3	6.6
PIG						
Solid manure	31.8	12.1	16.2	17.4	22.5	5.8
Slurry	76.3	55.2	21.4	30.0	30.3	7.6
Liquid manure	242.2	220.2	24.1	165.3	19.6	7.3
POULTRY						
Solid manure	46.3	25.4	20.8	20.6	63.6	5.4

Table 2. Average pH, proportion of soluble N in total N, and contents of dry matter, total N, soluble N, P and K in manure.

Type of manure	No. of samples	DM, %	pH	Nutrients, g/kg				sol. N/ tot. N, %
				tot. N	sol. N	P	K	
COW								
Solid manure	555	18.4	7.1	4.6	1.2	1.6	4.2	26
Slurry	140	8.1	7.0	3.3	1.8	1.0	2.8	56
Liquid manure	276	2.6	8.0	3.1	2.8	0.2	5.0	87
PIG								
Solid manure	73	23.0	7.1	7.2	2.8	3.7	4.0	37
Slurry	108	9.2	7.0	5.4	3.6	1.9	2.0	70
Liquid manure	27	1.8	7.6	2.6	2.2	0.5	1.4	86
POULTRY								
Solid manure	50	38.2	7.6	15.6	7.6	7.3	7.4	50

Table 4. Average contents of Na, Cl, Fe, Cu, Zn, Mn and B in manure dry matter.

Type of manure	No. of samples[1]	Nutrients per dry matter						
		Na	Cl	Fe	Cu	Zn	Mn	B
		g/kg		mg/kg				
COW								
Solid manure	457; 29; 281	2.9	10.8	1163	33	197	267	19
Slurry	105; 19; 75	4.9	24.1	978	47	275	277	27
Liquid manure	236; 32; 144	24.9	108.2	739	46	144	134	73
PIG								
Solid manure	63; 3; 33	4.0	10.2	1155	134	420	242	13
Slurry	91; 16; 35	11.7	18.0	1019	305	636	260	18
Liquid manure	22; 5; 10	42.4	56.2	914	176	449	184	48
POULTRY								
Solid manure	48; 4; 21	4.9	9.5	960	64	346	383	14

[1] The first figure stands for Na, Fe, Cu, Zn and Mn; the second for Cl; and the third for B.

because those nutrients mainly originate from solid excrement. Poultry manure appeared to be particularly rich in calcium.

The contents of sodium and chlorine in manure were considerable (Table 4). On a dry weight basis, liquid manures were found to be the most concentrated. When 40 m^3 of manure is spread per one hectar, the rate of sodium averages 36 kg/ha and that of chlorine 88 kg/ha.

The content of Fe per manure dry matter did not seem to depend on animal species. The contents of Cu and Zn were the highest in pig manures (Table 4). As compared to cow manures, the content of copper in pig manures was 4—6-fold. Poultry manure appeared especially rich in Mn whereas the content of B was the highest in cow manures.

2. Properties of manure in different areas of Finland

In 1980, Finland was divided into 18 agricultural advisory areas (Fig. 1). This division was employed for the examination of the nutrient content of manure in different areas of Finland. As affected by the particular agricultural advi-

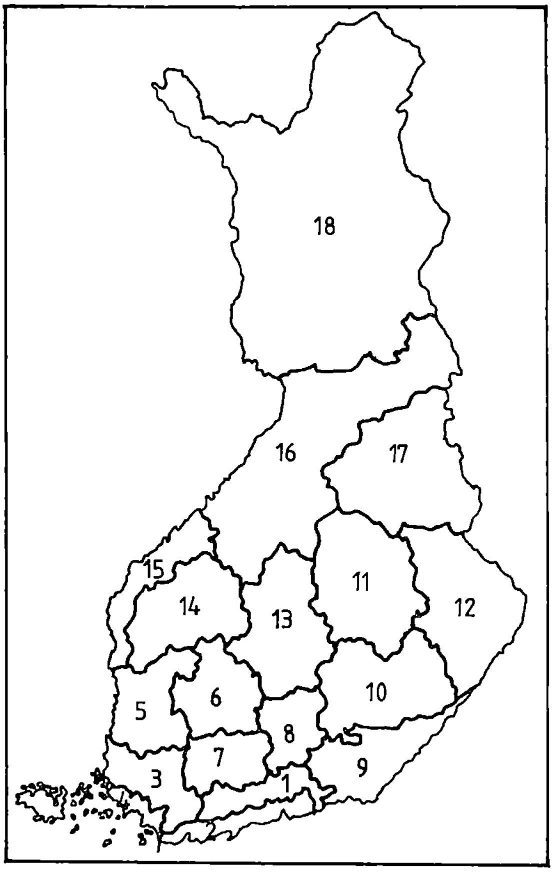

Fig. 1. Finland as divided into 18 agricultural advisory areas.

sory area, the following properties of manure were investigated: pH, dry matter, total N, soluble N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn and the proportion of soluble N in total N. Ca, Mg, Na, Fe, Cu, Mn and Zn were examined only on a dry weight basis whereas the other nutrients were studied both on a fresh weight and a dry weight basis.

Several significant differences among different areas were found. For pig and poultry manures, and for cow slurry and liquid cow manure, however, the number of samples from many agricultural advisory areas was very small. Differences among various areas were suspected of not being genuine, but to result unrepresentative sampling with respect to the area in question.

Only solid cow manure samples were regarded as somewhat representative. The properties of solid cow manure in different areas of Finland are shown in Tables 5 and 6. The most distinct differences are seen in the contents of P, Cu and Zn. Those contents were considerably higher in the three northernmost agricultural advisory areas compared to the other areas. Smaller differences were also seen for other nutrient contents.

3. Dependence of manure properties on herd size

The dependence of cow manure properties on the herd size was examined by classifying the farms into four classes: 1—10, 11—20, 21—30 and >30 cattle units per farm (1 CU = 1 dairy cow or 2 other cattle over 6 months old). Pig farms were classified into three groups: 1—100, 101—300 and >300 pig units per farm (1 PU = 1 fattening pig or 0.3 sow). The following properties of manure were examined: pH, dry matter, total N, soluble N, P, K and the proportion of soluble N in total N. The nutrients were examined both on a fresh weight and a dry weight basis.

Contents of dry matter, total N, soluble N and P in solid cow manure were higher the larger the herd size (Table 7). It is noteworthy that an increasing herd size also raised the nitrogen content in manure dry matter.

For cow slurry, significant differences were found only in the dry matter and nitrogen contents (Table 8). On a fresh weight basis the two nitrogen contents were higher the larger the herd size. The proportion of soluble N in total N and the contents of the two nitrogen fractions per dry matter were the highest in the smallest herd size class in which the slurry was the most diluted with respect to dry matter. This may indicate an especially favourable preservation of nitrogen in diluted conditions. However, the number of samples representing the smallest herd size class was very small compared to the other classes.

In liquid cow manure the contents of dry matter and potassium decreased by an increasing herd size. However, the contents of total N and soluble N per manure dry matter were lowest in the smallest herd size class (Table 9).

Only slight effects by herd size were found in the nutrient content of pig manure. However, the content of soluble nitrogen in pig slurry significantly increased by an increasing herd size. In the smallest herd size class (1—100 PU) the content of soluble nitrogen was 2.9 g/kg, in the second class (101—300 PU) 3.4 g/kg, and in the third class (>300 PU) 3.8 g/kg. The average content of soluble nitrogen in pig slurry was 3.6 g/kg. No other effects by herd size on the nutrient content of pig manure were significant at the 5 % level.

The rise in the nutrient content of manure by an increasing herd size was concluded to result mainly from differences in feeding. Responses by farms to the inquiry indicated that the use of silage as a base feed was more common the larger the herd size. Moreover, the use of concentrated feed was more plentiful the larger the herd size. The effects of those factors on manure quality are presented in the next chapter.

Table 5. Average pH, proportion of soluble N in total N, and contents of dry matter, total N, soluble N, P and K in solid cow manure in different areas of Finland. For a specification of different areas see Fig. 1.

Area	No. of samples	DM, %	pH	Nutrients, g/kg of fresh manure				sol. N/ tot. N, %
				tot. N	sol. N	P	K	
1	28	18.0	7.2	4.5	1.2	1.5	4.3	26
2	5	21.0	7.6	4.4	0.8	1.1	5.0	18
3	22	19.2	7.1	4.3	0.9	1.9	4.5	20
4	7	23.3	7.2	5.9	1.2	1.5	4.5	24
5	23	18.0	7.2	4.0	1.1	1.4	4.6	26
6	28	19.0	7.2	4.5	1.1	1.6	4.2	23
7	33	20.3	7.3	4.7	1.1	1.7	5.4	23
8	24	17.3	7.3	4.2	1.1	1.3	3.7	24
9	46	19.0	7.3	4.6	1.1	1.6	5.7	23
10	33	19.3	7.2	4.8	1.4	1.6	4.3	26
11	46	17.3	6.9	4.7	1.4	1.6	3.7	30
12	33	17.8	7.1	4.6	1.2	1.4	4.7	25
13	35	17.9	7.0	4.9	1.6	1.7	4.2	33
14	52	17.8	7.1	4.6	1.3	1.6	3.5	28
15	24	18.2	7.0	4.4	1.2	1.5	5.0	29
16	74	18.4	7.0	4.7	1.3	1.9	3.3	27
17	26	16.5	7.1	4.7	1.4	2.0	3.6	30
18	16	18.6	6.9	4.8	1.5	2.2	3.4	32
F-value		2.9***	3.1***	1.7*	2.1**	3.5***	3.9***	2.1**

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 6. Average contents of total N, soluble N, P, K, Ca, Mg, Na, Fe, Cu, Mn and Zn in solid cow manure in different areas of Finland. For a specification of different areas see Fig. 1.

Area	g/kg of dry matter							mg/kg of dry matter			
	tot. N	sol. N	P	K	Ca	Mg	Na	Fe	Cu	Mn	Zn
1	25.3	6.6	8.8	23.8	14.1	5.3	2.4	1092	28	235	176
2	21.6	4.1	5.7	24.0	9.2	4.3	2.0	1132	31	208	124
3	22.5	4.6	9.9	23.4	16.4	4.9	3.0	1090	37	230	193
4	25.1	6.1	7.0	22.2	11.3	4.1	3.1	2437	28	199	192
5	22.8	6.0	7.9	25.5	9.9	4.2	2.4	1055	27	313	171
6	23.7	5.6	8.5	22.4	12.9	4.6	2.9	1004	30	257	177
7	24.1	5.6	8.5	27.3	13.8	5.4	3.1	1588	31	246	187
8	24.7	6.0	7.2	21.8	10.7	4.3	3.3	478	17	206	151
9	25.3	6.0	8.4	30.5	12.8	4.8	2.5	1112	26	251	169
10	25.2	7.4	8.2	22.6	13.8	4.5	3.2	944	28	231	192
11	27.2	8.4	8.9	21.2	13.3	5.2	3.1	797	33	296	198
12	26.3	6.6	8.1	26.8	12.0	4.3	2.4	1075	40	268	166
13	27.6	9.4	9.3	24.1	14.1	5.1	3.5	747	32	249	210
14	25.8	7.5	8.7	19.9	11.3	4.7	2.6	932	30	260	202
15	24.1	6.8	7.9	29.1	8.3	4.2	2.7	713	21	297	162
16	25.8	7.0	10.4	17.7	13.6	5.5	3.4	888	40	293	242
17	28.6	8.8	11.8	21.8	17.2	6.2	3.3	844	40	326	214
18	26.0	8.5	12.3	18.1	16.9	6.5	3.5	967	46	312	330
F-value	2.5***	2.7***	5.2***	2.8***	2.7***	5.5***	1.5	2.2**	3.1***	2.3**	4.2***

** = significant at 1 % level, *** = at 0,1 % level

The number of samples for total N, soluble N, P, K, Ca and Mg is shown in Table 5. The number of samples for the other elements was slightly less totalling 414 for Na and Fe, and 457 for Cu, Mn and Zn.

Table 7. Properties of solid cow manure in various herd size clesses. Manure properties with significant differences are shown only.

Cow units per farm	No. of samples	DM, %	Per fresh manure			Per dry matter	
			tot. N	sol. N	P	tot. N	sol. N
			g/kg				
1—10	174	17.6	4.3	1.1	1.5	24.9	6.3
11—20	280	18.6	4.6	1.3	1.7	25.4	7.0
21—30	80	18.8	5.0	1.5	1.8	26.7	8.0
>30	21	20.3	5.4	1.5	1.8	27.4	8.1
F-value		5.5***	11.4***	6.9***	3.5*	2.8*	3.2*

* = significant at 5 % level, *** = at 0.1 % level

Table 8. Properties of cow slurry in various herd size classes. Manure properties with significant differences are shown only.

Cow units per farm	No. of samples	DM, %	Per fresh manure		Per dry matter		sol. N/ tot. N, %
			tot. N	sol. N	tot. N	sol. N	
			g/kg				
1—10	5	4.3	2.4	1.7	71.0	53.4	81
11—20	65	8.2	3.1	1.7	42.7	23.7	53
21—30	46	8.8	3.6	2.0	43.6	25.1	54
>30	24	7.5	3.4	2.1	47.0	28.7	60
F-value		2.9*	4.0**	4.1**	5.9***	7.8***	12.4***

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 9. Properties of liquid cow manure in various herd size classes. Manure properties with significant differences are shown only.

Cow units per farm	No. of samples	DM, %	Per fresh manure	Per dry matter	
			K	tot. N	sol. N
			g/kg		
1—10	54	3.7	5.9	118	105
11—20	157	2.3	4.9	144	132
21—30	55	2.7	4.8	147	134
>30	10	1.7	3.4	152	131
F-value		4.7**	2.8*	3.1*	2.7*

* = significant at 5 % level, ** = at 1 % level

4. Effect of feeding on the properties of manure

The effect of feeding on following properties of cow manure was examined: pH, dry matter, total N, soluble N, P, K, Ca, Mg, Fe, Cu, Mn and Zn. Ca, Mg, Fe, Cu, Mn and Zn were examined only on a dry weight basis whereas the other nutrients both on a fresh weight and a dry weight basis. The following classification was used: base feed 1) predominantly silage, 2) predominantly hay, 3) other (e.g. grain and straw). In another classification manures were grouped according to the rate of concentrated feed given to the animals: 1) under 5 kg/cow/d (<3 kg/young cattle/d), and 2) over 5 kg/cow/d (>3 kg/young cattle/d).

Base feed was found to have a significant effect on the properties of solid cow manure (Table 10). The contents of N, P, Mg, Cu, and Zn were higher by silage feeding compared to those by hay as a base feed. The number of samples representing the "other" base feed classification (no. 3) was so small that no definitive conclusions could be drawn.

The effect of base feed on the properties of cow slurry could not be examined because almost all slurry farms used silage as a base feed. However, base feed seemed to have a very clear effect on the nitrogen content in liquid cow manure dry matter (Table 11).

Table 11. Effect of base feed on the properties of liquid cow manure. Manure properties with significant differences are shown only.

Base feed	No. of samples	g/kg of dry matter	
		tot. N	sol. N
1 = Silage	141	155	143
2 = Hay	86	121	110
F-value		17.7***	15.1***

*** = significant at 0.1 % level

The rate of concentrated feed significantly affected the contents of P, Cu, Zn and Mn in solid cow manure (Table 12). An increasing rate of concentrated feed raised the contents of P, Cu and Zn, but lowered the content of Mn in manure dry matter.

The rate of concentrated feed did not at all affect the nutrient content of cow slurry. However, the content of soluble nitrogen in liquid cow manure was significantly greater by the higher rate of concentrated feed (137 g/kg of dry matter) than by the lower one (120 g/kg of dry matter).

5. Effect of manure handling on the properties of slurry

The effects of following factors on the properties of slurry were examined: water trap in slur-

Table 10. Effect of base feed on the properties of solid cow manure. Manure properties with significant differences are shown only.

Base feed[1]	No. of samples[2]	DM, %	Per fresh manure				Per dry matter			
			tot. N	sol. N	P	Mg	tot. N	P	Cu	Zn
			g/kg				g/kg		mg/kg	
1	259; 216	18.3	4.8	1.3	1.7	5.2	26.7	9.5	35	212
2	215; 175	18.1	4.2	1.1	1.5	4.6	23.9	8.1	29	176
3	6; 6	23.2	5.6	1.6	2.0	4.1	24.2	8.7	39	168
F-value		7.8***	24.6***	5.4**	12.0***	10.0***	16.1***	11.2***	4.9 **	6.8**

** = significant at 1 % level, *** = at 0.1 % level

[1] Base feed 1 = predominantly silage, 2 = predominantly hay, 3 = other base feed

[2] The first figure stands for tot. N, sol. N, P and Mg, and the latter for Cu and Zn.

Table 12. Effect of the rate of concentrated feed on the properties of solid cow manure. Manure properties with significant differences are shown only.

Rate of conc. feed[1]	No. of samples[2]	P in fresh manure	Per dry matter			
			P	Cu	Mn	Zn
		g/kg	g/kg	mg/kg		
1	272; 229	8.5	1.5	30	278	180
2	198; 164	9.6	1.8	35	249	215
F-value		14.6***	15.4***	5.4*	7.6**	13.0***

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

[1] 1 = under 5 kg/cow/d, 2 = over 5 kg/cow/d

[2] The first figure stands for P and the latter for Cu, Mn and Zn.

ry reservoir, the covering of the reservoir, and the access of wash water to the reservoir. The following properties of slurry were examined: pH, dry matter, total N, soluble N, P, K and the proportion of soluble N in total N. The nutrients were determined both on a fresh weight and a dry weight basis.

a. *Covering and the water trap*

The highest nutrient contents in cow slurry were found in samples taken from covered reservoirs (Table 13). A similar tendency was found for pig slurry samples too, but in this case the differences were not significant at the 5 % level. No significant effect on any property of cow or pig slurry by the water trap was observed.

b. *Access of wash water into the reservoir*

Wash water clearly decreased the contents of total N, soluble N and P in cow slurry (Table 14). On the other hand, wash water increased the phosphorus content in pig slurry dry matter.

Correlations were also calculated in which the dependence of slurry nutrient content on the rate of wash water (l/m^3 of slurry, farmers' assessment) was examined. Significant negative correlations were found for cow slurry but not for pig slurry (Table 15).

6. Effect of handling on properties of solid manure

The effects of the following factors on the properties of solid manure were examined:

Table 13. Properties of cow slurry stored in uncovered and covered reservoirs. Manure properties with significant differences are shown only.

Slurry basin	No. of samples	DM, %	Per fresh manure				Per dry matter		sol. N/ tot. N, %
			tot. N	sol. N	P	K	sol. N	P	
			g/kg						
Uncovered	51	7.3	2.9	1.5	0.7	2.4	22.7	10.2	53
Covered	82	8.7	3.6	2.1	1.1	3.1	27.5	12.7	58
F-value		4.7*	14.7***	21.8***	12.3***	9.6**	3.9*	6.8*	6.4*

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 14. Effect of wash water on the properties of cow and pig slurry. Manure properties with significant differences are shown only.

Access of wash water into reservoir	No. of samples[1]	Cow slurry				Pig slurry
		Per fresh manure			Per DM	Per DM
		tot. N	sol. N	P	P	P
		g/kg				
No	34; 20	3.8	2.2	1.2	13.3	18.2
Yes	101; 75	3.2	1.7	0.9	11.2	22.3
F-value		10.2**	14.8***	6.5*	4.1*	5.3*

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

[1] The first figure stands for cow slurry and the latter for pig slurry.

Table 15. Correlations of nutrients with the rate of wash water entering cow slurry reservoir. Significant correlations are shown only.

	Per fresh manure, g/kg			Per DM, g/kg
	tot. N	sol. N	K	K
Correlation (r) with the rate of wash water[1]	—0.20*	—0.32***	—0.26**	—0.19*

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level.

[1] l/m^3 of slurry, farmers' assessment

type and rate of litter, urine binding capacity; the bottom, walls and covering of the manure storage; technique of manure removal; and separation of the effluent from the solid manure storage. The following properties of solid manure were examined: pH, dry matter, total N, soluble N, P, K and the proportion of soluble N in total N. The nutrients were examined both on a fresh weight and a dry weight basis.

a. *Type and rate of litter, and urine binding capacity*

Litter type only slightly influenced manure properties. Apparently this was due to the uneven number of samples of different litter types. For example, only 11 manure samples with peat litter were included.

The dry matter content of solid cow manure was significantly lower than the average (18.3 %) when peat (17.3 %) or a combination of peat with straw (17.1 %) or with sawdust (17.5 %) was used as a litter. When the litter was straw, the dry matter content was 18.1 %, with sawdust 18.7 %, and with straw + sawdust 19.0 %. Since no differences were found in the rate of different litters used by the farms, this result truly represents the effect of litter type.

The rate of litter used (kg/cow/d, farmers' assessment) had a significant effect on several properties of solid cow manure (Table 16). An increasing rate of litter raised manure pH which reflects the effect of the alkaline urine being absorbed by solid manure more effectively. Other correlations were negative because the most commonly used litters contain only small

Table 16. Correlations of pH, soluble N, P and the proportion of soluble N in total N with the rate of litter added to solid cow manure. Significant correlations are shown only.

	pH	sol. N/ tot. N, %	Per dry matter, g/kg	
			sol. N	P
Correlation (r) with the rate of litter[1]	0.14**	—0.17***	—0.14**	—0.11*

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

[1] kg/cow/d, farmers' assessment

Table 17. Effect of the urine binding capacity of litter on the properties of solid cow manure. Manure properties with significant differences are shown only.

% of urine absorbed by the litter	No. of samples	pH	Per fresh manure g/kg				Per dry matter g/kg			sol. N/ tot. N, %
			tot. N	sol. N	P	K	tot. N	sol. N	P	
0— 25	283	7.1	4.7	1.3	1.7	4.0	26.2	7.5	9.5	28
25— 50	141	7.1	4.6	1.2	1.5	4.1	25.2	6.8	8.4	26
50— 75	69	7.2	4.4	1.1	1.7	4.5	24.4	6.6	9.2	25
75—100	56	7.3	4.4	1.0	1.5	4.9	24.0	5.2	8.0	21
F-value		5.3**	2.7*	5.2**	3.8*	3.2*	3.6*	4.6**	5.3**	4.6**

* = significant at 5 % level, ** = at 1 % level

amounts of nutrients. Litter undoubtedly binds urine into solid manure, but simultaneously soluble nitrogen is volatilized or biologically immobilized. On the other hand, an increasing rate of litter cannot help to preserve phosphorus because P is already present in solid excrement.

The effect of litter was also studied by classifying the samples according to the urine binding capacity of litter. Farmers were asked what percentage of urine was absorbed by the litter (assessment). Their responses were classified as follows: 0—25 %, 25—50 %, 50—75 %, and 75—100 %, respectively.

The urine binding capacity of litter significantly affected several properties of solid cow manure (Table 17). The greater the percentage of urine absorbed by the litter the higher the pH and K content, but the lower the nitrogen content. Also the proportion of soluble N in total N decreased by an increasing absorption of urine by the litter.

Litter type, rate or urine binding capacity had no significant effect on the properties of solid pig manure.

b. Structure of manure storage and manure removal

The nutrient content of solid cow manure was usually higher in storages equipped with concrete bottoms than in storages with bottoms of stone, wood or soil (Table 18).

According to farmers' responses to the inquiry, the low nutrient content of manure from storages with stone bottoms was partly ex-

Table 18. Effect of storage bottom material on the properties of solid cow manure. Manure properties with significant differences are shown only.

Storage bottom	No. of samples	Per fresh manure		Per dry matter		sol. N/ tot, N, %
		tot. N	sol. N	tot. N	P	
		g/kg				
Concrete	304	4.8	1.3	26.2	9.0	28
Stone	12	4.4	0.9	23.7	6.4	19
Wood	32	4.3	1.2	24.6	9.3	28
Soil	150	4.4	1.2	24.8	9.0	25
F-value		5.3**	3.4*	2.7*	2.7*	3.5*

* = significant at 5 % level, ** = at 1 % level

plained by the fact that these manures contained more litter than the other manures. The superiority of a concrete bottom, on the other hand, partly results from the fact that such storages are generally also covered (88 % covered). A water-tight bottom and a covered storage have a parallel effect on manure: both prevent nutrients from being leached. However, also the bottom material itself had an influence on the properties of manure as will be seen later.

The contents of some nutrients in poultry manure were significantly higher in storages equipped with concrete bottoms compared to storages with bottoms of soil (Table 19). Again, this effect partly results from the fact that storages with concrete bottoms generally also are covered whereas those with soil bottoms are not. The material used for the storage bottom had no significant influence on the properties of solid pig manure.

The effect of storage bottom material on properties of solid cow manure in both covered and uncovered storages was examined (Table 20). The results prove that greater advantage is obtained by a concrete bottom with open compared to covered storages.

Slight effects by the walls around the solid manure storage on nutrient contents were found (Table 21). Walls prevent the leaching of nutrients from manure and, on the other hand, prevent the access of water into the storage from the outside. However, it was observed that storages equipped with walls generally also were covered (78 % covered) whereas those without walls were not (7 % covered). Thus, covering itself may explain the result obtained. The existence of walls was not found to depend

Table 19. Effect of storage bottom material on the properties of solid poultry manure. Manure properties with significant differences are shown only.

Storage bottom	No. of samples	Per fresh manure	Per dry matter	
		sol. N	tot. N	K
		g/kg	g/kg	
Concrete	18	8.5	53.3	23.1
Soil	18	5.8	38.0	17.9
F-value		5.4*	4.4*	9.9**

* = significant at 5 % level, ** = at 1 % level

Table 20. Effect of storage bottom material on the properties of solid cow manure in covered and uncovered storages.

COVERING/ Bottom	No. of samples	Per fresh manure		Per dry matter		sol. N/ tot. N, %
		tot. N	sol. N	tot. N	P	
		g/kg				
UNCOVERED						
Concrete	90	5.0	1.5	26.4	9.2	29
Soil	83	4.4	1.3	25.1	9.3	27
F-value		9.1**	2.1	3.0	0.0	1.4
COVERED						
Concrete	135	4.7	1.3	26.2	9.0	27
Soil	19	4.6	1.3	27.5	9.8	28
F-value		0.2	0.0	0.7	0.8	0.1

** = significant at 1 % level

Table 21. Properties of solid cow and poultry manures in storages with and without walls. Manure properties with significant differences are shown only.

Manure storage	Solid cow manure		Solid poultry manure		
	No. of samples	tot. N per dry matter	No. of samples	tot. N per fresh manure	K per dry matter
		g/kg		g/kg	
Without walls	216	24.9	14	5.8	18.1
With walls	286	26.1	20	8.7	23.0
F-value		5.5*		5.9*	8.8**

* = significant at 5 % level, ** = at 1 % level

Table 22. Properties of solid cow and poultry manures in covered and uncovered storages. Manure properties with significant differences are shown only.

Manure storage	Solid cow manure			Solid poultry manure			
	No. of samples	K per fresh manure	K per dry matter	No. of samples	sol. N per fresh manure	K per fresh manure	K per dry matter
		g/kg			g/kg		
Uncovered	259	3.9	21.1	20	6.3	6.6	19.2
Covered	239	4.5	24.9	17	8.7	8.4	23.4
F-value		16.4***	22.6***		4.2*	4.1*	5.6*

* = significant at 5 % level, *** = at 0.1 % level

on the rate of litter used nor on the existence of a separate liquid manure cistern. No significant effect by the walls on the nutrient content of solid pig manure was demonstrated.

Cow and poultry manures from covered storages were significantly richer in K and soluble N compared to those from open storages (Table 22). Similar effects by covering on pig

Table 23. Potassium content of solid cow manure in covered and uncovered storages as affected by the urine binding capacity of litter.

% of urine absorbed by the litter	Covering of solid manure storage	No. of samples	K content in manure, g/kg	
			per fresh manure	per dry matter
0— 25	Uncovered	105	3.9	20.7
	Covered	84	4.5	25.0
	F-value		4.4*	11.8***
25— 50	Uncovered	48	3.7	21.0
	Covered	40	4.6	25.8
	F-value		10.4**	7.5**
50— 75	Uncovered	23	4.2	24.2
	Covered	28	5.1	27.8
	F-value		3.4	1.4
75—100	Uncovered	16	5.0	27.5
	Covered	25	5.1	28.4
	F-value		0.1	0.1

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

manure were also found, but they were not significant at the 5 % level. The existence of cover was not shown to be dependent on the rate or type of litter used nor on the existence of a separate liquid manure cistern.

Covering of the solid manure storage was found to be especially advantageous when only a minor proportion of urine was absorbed by the litter (Table 23). The advantage by covering seemed to diminish by an increasing absorption of urine, but then the content of potassium in solid manure was higher owing to an increasing rate of K in straw and urine.

The separation of effluent from the solid manure storage seemed to increase the content of total N in solid cow manure and that of soluble N in solid pig manure. However, separation of the effluent from the solid manure storage was found to be more common on farms using only small amounts of litter compared to those using plenty of litter. It was concluded that nitrogen content was influenced mainly by the rate of litter and only to a minor extent by effluent separation.

When solid manure samples were classified according to the technique used for manure removal from the cowshed, mechanically removed manure proved richer in nutrients compared to that removed manually (Tables 24 and 25).

There exist some theoretical grounds for why mechanically removed manure could be richer in nutrients compared to that removed manually. By mechanical removal, manure moves slowly and steadily which prevents ammonia volatilization. The modern removal technique in which solid manure is compressed and pushed through a subterranean tunnel from the cowshed to the storage seems very favourable with respect to nutrient preservation. In this technique, the manure heap in the storage is filled from underneath the storage. However, the result obtained in this study is apparently mainly due to other factors than the manure removal technique alone. It was found that the rate of litter used and its urine binding capacity were much smaller on farms employing mechanical removal compared to farms with manual manure removal. In addition, mechanical removal is more common on big farms where the manure is richer in nutrients due to better feeding and superior storages.

Table 24. Properties of solid cow manure by mechanical and manual removal. Manure properties with significant differences are shown only.

Manure removal	No. of samples	Per fresh manure			Per dry matter		sol. N/ tot. N, %
		tot. N	sol. N	P	tot. N	sol. N	
		g/kg					
Manually	386	4.4	1.2	1.6	24.8	6.5	25
Mechanically	152	5.1	1.5	1.7	27.5	8.2	29
F-value		40.3***	23.4***	1.9*	27.1***	17.0***	9.5**

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 25. Properties of solid poultry manure by mechanical and manual removal. Manure properties with significant differences are shown only.

Manure removal	No. of samples	DM, %	sol. N per fresh manure	Per dry matter				sol. N/ tot..N, %
				tot. N	sol. N	P	K	
			g/kg					
Manually	34	43.0	6.5	38.5	18.9	19.1	19.0	44
Mechanically	15	27.7	9.7	64.1	39.2	24.9	24.1	60
F-value		10.2**	9.5**	19.8***	14.6***	6.9*	9.5**	6.2*

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

7. Effect of handling on the properties of liquid manure

The effects of the following factors on the properties of liquid manure were examined: water-tightness, covering and construction material of the liquid manure cistern; access of rain and wash water to the cistern; water trap in the cistern; separation of the effluent from solid manure storage; and covering of the solid manure storage. The following properties of liquid manure were examined: pH, dry matter, total N, soluble N, P, K and the proportion of soluble N in total N. The nutrients were determined both on a fresh weight and a dry weight basis.

a. Construction material and water-tightness of the cistern

The construction material of the cistern was not found to have any effect on the nutrient content of liquid cow or pig manure. However, liquid cow manure from water-tight cisterns contained significantly more N and K, and its pH was higher compared to that from leaky cisterns (Table 26). Water-tightness of the cistern had no significant effect on the nutrient content of liquid pig manure.

The water-tightness of the liquid manure cistern hardly is a primary cause for the differences shown in Table 26. Soluble nutrients such as N and K should escape from leaky cisterns at an equal rate compared to water and no concentration of those nutrients should occur. On the contrary, differences between leaky and water-tight cisterns should be seen in the contents of dry matter and those nutrients which are bound in dry matter, e.g. phosphorus. It is apparent that the differences found in this study are caused by some other factors that correlate with the water-tightness of the cistern.

Table 26. Properties of liquid cow manure in leaky and water-tight cisterns. Manure properties with significant differences are shown only.

Liquid manure cistern	No. of samples	pH	Per fresh manure, g/kg		
			tot. N	sol. N	K
Leaky	51	7.8	2.5	2.3	3.9
Water-tight	209	8.2	3.3	3.0	5.4
F-value		11.8***	7.8**	5.9*	10.4**

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Feeding does not explain the difference. It was found, however, that the rate of wash water entering water-tight cisterns was considerably smaller compared to that entering leaky cisterns. Moreover, water-tight cisterns are better covered and thus better protected against the rain than are leaky cisterns.

b. *Access of the rain and wash water into cistern*

Access of the rainwater to the cistern clearly diminished the nutrient content of liquid cow manure (Table 27). This was concluded to be a dilution effect. Cisterns into which the rain can enter naturally are susceptible to ammonia volatilization, too. However, it was found that rainwater affected nitrogen content only as much as it affected dry matter content. Access of rainwater had no significant effect on the nutrient content of liquid pig manure.

The rate of wash water entering the cistern correlated negatively with pH and the content of K, but positively with the content of P in liquid cow manure (Table 28). On a dry weight basis, negative correlations with total N and soluble N were also found. An increase in the P content by an increasing rate of wash water

Table 27. Effect of the rain on the properties of liquid cow manure. Manure properties with significant differences are shown only.

Access of rain into cistern	No. of samples	DM, %	pH	Per fresh manure, g/kg			
				tot. N	sol. N	P	K
No	164	2.9	8.2	3.6	3.2	0.2	5.6
Yes	99	1.9	7.8	2.4	2.2	0.1	4.1
F-value		13.9***	13.1***	23.6***	17.8***	4.0*	15.4***

* = significant at 5 % level, *** = at 0.1 % level

Table 28. Correlations of pH and nutrients with the rate of wash water entering the liquid cow manure cistern. Significant correlations are shown only.

	pH	Per fresh manure, g/kg		Per dry matter, g/kg			
		P	K	tot. N	sol. N	P	K
Correlation (r) with the rate of wash water[1]	—0.24***	0.20**	—0.16*	—0.18**	—0.17**	0.15*	—0.22***

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

[1] l/m³ of manure, farmers' assessment

indicates the effect of phosphates in detergents. Only slight correlations between the rate of wash water and the nutrient content of liquid pig manure were found.

c. *Water trap, covering, and access of the effluent from solid manure storage into cistern*

No significant effects on the nutrient content of liquid manure by the water trap were found. However, the proportion of soluble N in total N in liquid cow manure was slightly higher in cisterns equipped with a trap (91 % soluble) compared to those without a water trap (87 % soluble).

Covering the cistern significantly affected only the content of total N in liquid cow manure dry matter. In open cisterns the content of total N was 115 g/kg of dry matter, in those with a concrete covering 151 g/kg, in those with a wooden covering 132 g/kg, and in those with stones and soil as a covering 124 g/kg. The result indicates volatilization of ammonia from poorly covered cisterns.

Access of the effluent from the solid manure storage into the liquid manure cistern significantly diminished the content of nitrogen in liquid cow manure (Table 29). The effect of the effluent from the solid manure storage was apparent only on farms with an open solid manure storage. On the farms having a covered solid manure storage no effect at all was demonstrated. The access of effluent from the solid manure storage had no significant effect on the nutrient content of liquid pig manure.

Table 29. Effect of the effluent from solid manure storage on the properties of liquid cow manure. Manure properties with significant differences are shown only.

Access of the effluent from solid manure storage into cistern	No. of samples	Per fresh manure		Per DM
		tot. N	sol. N	sol. N
		g/kg		
No	66	3.6	3.3	143.5
Yes	155	2.9	2.5	124.1
F-value		6.4*	6.6*	4.1*

* = significant at 5 % level

Table 30. Effect of the covering of solid manure storage on the properties of liquid cow manure. Manure properties with significant differences are shown only.

Covering of the solid manure storage	No. of samples	Per dry matter, g/kg	
		tot. N	sol. N
Uncovered	109	155.3	142.4
Covered	100	126.8	115.0
F-value		12.4***	9.8**

** = significant at 1 % level, *** = at 0.1 % level

Covering of the solid manure storage significantly diminished the content of nitrogen in liquid cow manure dry matter (Table 30). This result is explained by the fact that rainwater leaches soluble nutrients from solid manure into the liquid manure cistern. Since rainwater simultaneously dilutes the liquid manure further, those nutrients are seen only on a dry weight basis. It is not probable that other factors could have influenced the result. The covering of the solid manure storage had no significant effect on the nutrient content of liquid pig manure.

8. Assessment of nutrient content by easily measurable properties of manure

Mutual correlations between various manure properties were statistically examined in order to establish simple methods for assessing the nutrient content of manure. Only the most significant correlations are presented here.

a. *Correlations of various nutrients with dry matter*

The correlations of nutrients with dry matter varied considerably (Table 31). The correlation of total N with dry matter was the most promi-

Table 31. Correlations (r) of various manure properties with dry matter content.

	Cow manure			Pig manure			Poultry
	Solid	Slurry	Liquid	Solid	Slurry	Liquid	Solid
tot. N	0.37***	0.63***	0.52***	0.52***	0.80***	0.92***	0.41**
sol. N	—0.02	0.33**	0.30***	0.22	0.38***	0.86***	—0.34*
P	0.28***	0.58***	0.77***	0.57***	0.78***	0.66***	0.49***
K	0.19***	0.79***	0.34***	0.55***	0.39***	0.47*	0.69***
Ca	0.28***	0.79***	0.80***	0.34**	0.80***	0.93***	0.40**
Mg	0.41***	0.91***	0.81***	0.53***	0.83***	0.74***	0.74***
Na	0.14**	0.40***	0.26***	0.53***	0.46***	0.56**	0.63***
Fe	0.59***	0.80***	0.69***	0.46***	0.62***	0.92***	0.82***
Cu	0.41***	0.79***	0.79***	0.43***	0.28*	0.90***	0.21
Zn	0.31***	0.76***	0.88***	0.40**	0.72***	0.94***	0.47**
Mn	0.41***	0.82***	0.90***	0.42**	0.81***	0.96***	0.59***
pH	0.19***	0.07	—0.12	—0.01	—0.51***	—0.38	0.39*
sol. N/tot. N, %	—0.14**	—0.41***	—0.47***	0.02	—0.80***	—0.60**	—0.55***
No. of samples	457—555	105—140	236—276	63—73	91—108	22—27	48—50

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

nent in pig manures, especially in liquid pig manure. The correlation of soluble N with dry matter was considerable only in liquid pig manure; no significant correlation at all was found in solid cow or pig manure. In poultry manure the correlation of soluble N with dry matter was, surprisingly, negative. It was concluded that such a correlation can be found in manures with high dry matter contents. Immobilization and volatilization of ammonia may then be very intensive.

The correlation of P with dry matter was of about the same order as that of total N. The correlation of K with dry matter varied considerably; the most prominent correlation was found for cow slurry and the least prominent for solid cow manure. The correlation of Na with dry matter equalled that of potassium with dry matter.

The correlations of Ca and Mg with dry matter equalled those of trace metals (Fe, Cu, Mn, Zn) with dry matter. The correlations were much stronger for slurries and liquid manures than for solid manures. At best, the correlations of Mn and Zn with dry matter were about r = 0.95 (liquid pig manure). Such high correlations indicate that the content of those nutrients in dry matter is almost constant. The only significant exception was found for copper in pig slurry which correlated with dry matter only slightly.

The correlation of pH with dry matter varied considerably. The significant negative correlation in pig slurry may indicate that organic acids are formed from solid faeces during storage.

In general, dry matter correlated negatively with the proportion of soluble N in total N. Such a negative correlation results from the fact that solid excrement and litter contain only small amounts of soluble N, but especially solid excrement contains plenty of insoluble N. Litter can even immobilize soluble N from manure. In addition, ammonia volatilization is faster the more concentrated the manure.

Correlation diagrams representing the dependence of total N, soluble N, P and K on dry matter are shown in Appendices 2—8. It can be seen that, although many of the correlations were statistically significant, the use of dry matter analysis for assessing the nutrient content of manure may be of lesser benefit.

The correlations for liquid cow manure could be improved by omitting samples with a dry matter content over 4 %. Then the correlations with dry matter were as follows: r = 0.75*** for total N, r = 0.71*** for soluble N, r = 0.32*** for P, and r = 0.86*** for K. The omission of samples with a dry matter content over 4 % is justified because only a few such samples were included.

Most liquid pig manure samples were very diluted with respect to dry matter and the correlations were strongly influenced by just a few samples with high dry matter contents. If the samples with a dry matter content over 2 % are omitted, however, correlations with dry matter appear to be rather poor: r = 0.46* for total N, r = 0.39 for soluble N, r = 0.61** for P, and r = 0.81*** for K.

b. *Correlations of N, P and K with pH and total N*

In solid cow and pig manures the correlations of nutrients with pH were rather poor, being generally weaker than those of nutrients with dry matter (Table 32). In poultry manure, however, soluble N correlated more significantly with pH than with dry matter on a fresh weight basis.

In cow slurry and liquid cow manure the correlation of soluble N with pH was rather strong (Tables 33 and 34). In the corresponding pig manures, however, the correlation of soluble N with pH was not statistically significant although that of pH with the proportion of soluble N in total N was highly significant. It appears that some factors in pig manures prevent a rise in pH which would otherwise result from an increasing content of soluble N.

The correlations of nutrients with pH in liquid cow manure significantly improved when the samples with a dry matter content over 4 % were omitted. Then the correlations with pH were as follows: r = 0.72*** for total N, r = 0.74*** for soluble N, r = —0.21*** for P, and r = 0.54*** for K.

Correlation diagrams representing the dependence of soluble N on pH in cow slurry and liquid cow manure are shown in Appendix 9.

The correlation of soluble N with total N was the most prominent in liquid manures (r = 0.95—0.98). Significant correlations for other

Table 32. Correlations of total N, soluble N, P, K and the proportion of soluble N in total N with dry matter, pH and total N in various solid manures.

Animal species	Property of manure	On a fresh weight basis			On a dry weight basis		
		DM, %	pH	tot. N	DM, %	pH	tot. N
Cow	tot. N	0.37***	0.05		—0.37***	—0.08	
(n = 555)	sol. N	—0.02	0.10*	0.52***	—0.26***	—0.14**	0.66***
	P	0.28***	0.05	0.36***	—0.11*	—0.03	0.28***
	K	0.19***	0.36***	0.16***	—0.12*	0.29***	0.12*
	sol. N/tot. N, %	—0.14**	—0.15**	0.16***	—0.14**	—0.15**	0.34***
Pig	tot. N	0.52***	—0.04		—0.36**	—0.11	
(n = 73)	sol. N	0.22	—0.09	0.66***	—0.14	—0.15	0.65***
	P	0.57***	0.03	0.56***	0.02	0.01	0.21
	K	0.55***	0.21	0.35**	0.04	0.29*	0.09
	sol. N/tot. N, %	0.02	—0.12	0.22	0.02	—0.12	0.24
Poultry	tot. N	0.41**	0.29		—0.55***	0.09	
(n = 50)	sol. N	—0.34*	0.42**	0.27	—0.64***	0.13	0.82***
	P	0.49***	0.42**	0.58***	—0.53***	—0.02	0.50***
	K	0.69***	0.52***	0.43**	—0.47**	0.10	0.53***
	sol. N/tot. N, %	—0.55***	0.31*	—0.15	—0.55***	0.31*	0.44**

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 33. Correlations of total N, soluble N, P, K and the proportion of soluble N in total N with dry matter, pH and total N in cow and pig slurry.

Animal species	Property of manure	On a fresh weight basis			On a dry weight basis		
		DM, %	pH	tot. N	DM, %	pH	tot. N
Cow (n = 140)	tot. N	0.63***	0.33**		—0.59***	0.31**	
	sol. N	0.33**	0.48***	0.86***	—0.53***	0.37***	0.94***
	P	0.58***	0.05	0.51***	—0.04	0.02	0.12
	K	0.79***	0.37***	0.67***	—0.27*	0.46***	0.51***
	sol. N/tot. N, %	—0.41***	0.38***	—0.05	—0.41***	0.38***	0.60***
Pig (n = 108)	tot. N	0.80***	—0.32**		—0.64***	0.40***	
	sol. N	0.38***	0.17	0.77***	—0.66***	0.44***	0.99***
	P	0.78***	—0.24*	0.68***	—0.11	0.22*	0.14
	K	0.39***	—0.16	0.54***	—0.58***	0.34**	0.89***
	sol. N/tot. N, %	—0.80***	0.69***	—0.60***	—0.80***	0.69***	0.60***

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 34. Correlations of total N, soluble N, P, K and the proportion of soluble N in total N with dry matter, pH and total N in liquid cow and pig manure.

Animal species	Property of manure	On a fresh weight basis			On a dry weight basis		
		DM, %	pH	tot. N	DM, %	pH	tot. N
Cow (n = 276)	tot. N	0.52***	0.50***		—0.36***	0.72***	
	sol. N	0.30***	0.60***	0.95***	—0.35***	0.72***	0.98***
	P	0.77***	—0.19**	0.45***	0.24***	—0.40***	—0.34***
	K	0.34***	0.41***	0.72***	—0.54***	0.50***	0.49***
	sol. N/tot. N, %	—0.47***	0.56***	0.20**	—0.47***	0.56***	0.63***
Pig (n = 27)	tot. N	0.92***	—0.20		—0.61**	0.70***	
	sol. N	0.86***	—0.06	0.98***	—0.61**	0.72***	1.00***
	P	0.66***	—0.45*	0.62**	0.03	—0.36	—0.06
	K	0.47*	0.08	0.50*	—0.79***	0.58**	0.68***
	sol. N/tot. N, %	—0.55***	0.68***	—0.46*	—0.60**	0.68***	0.80***

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

manures were also found, with the exception of poultry manure (Tables 32—34).

Correlations of total N with P and K were rather strong, except for K in solid cow manure. This poor correlation may result from a varying amount of K-rich straw in the manure. The correlation of total N with the proportion of soluble N in total N was variable; for pig slurry and liquid pig manure significant negative correlations were obtained.

It proved interesting to examine the correlations of dry matter and pH with the nutrients in manure dry matter (Tables 32—34). In general, the correlations of nutrients with dry matter were negative. The materials that increase dry matter content, such as solid excrement and litter, contain only small amounts of nutrients. In addition, nitrogen loss by ammonia volatilization increases as the manure becomes more concentrated. The only exception found was for P which generally was only slightly affected by an increasing dry matter content. The behaviour of phosphorus is well understood because, contrary to N and K, P mainly originates from solid excrement. The significant negative correlation of P with dry matter in poultry manure indicates that then the elevated dry matter content mainly results from an increasing rate of litter but not from solid excrement.

In solid manures the correlations of pH with nutrients per manure dry matter were rather weak. In slurries and liquid manures, however, the correlations were rather strong: usually better compared to those of pH with nutrients on a fresh weight basis.

The method of calculating the correlations (dry weight vs. fresh weight basis) affected the correlations of total N with other nutrients in manure. The calculation on a dry weight basis clearly improved the correlation of total N with soluble N in poultry manure (Table 32) and that of total N with the proportion of soluble N in total N in liquid pig manure (Table 34).

c. *Effect of feeding and manure handling on the correlations*

It was attempted to improve the mutual correlations between different properties of manure by first classifying manure samples according to type of base feed, rate of concentrated feed and various factors in manure handling, such as the rate of litter, storage covering, and access of the rain and wash water into the reservoir.

The classification of manure samples into smaller groups significantly improved some correlations (r-values) but, owing to a simultaneous decrease in the number of samples considered, the statistical significance of correlations was often weakened. When considering the development of simple methods for assessing the nutrient content of manure, no essential improvements by the classifications were obtained.

9. Explaining nutrient content by several factors simultaneously

Dependence of total N, soluble N, P and K on other properties of manure and on some continuous variables in manure handling (the rate of litter or water in manure) was examined by a stepwise regression analysis. However, this kind of analysis yielded overly complicated regressions for practical purposes. In the final examination, forced regression analyses with easily measurable or assessable variables were calculated.

When examining the nutrient content of slurry, manure pH and dry matter content, and the rate of wash water (l/m^3 of slurry, farmers' assessment) were used as independent variables. Then the contents of total N, soluble N and P in cow slurry, and those of soluble N and P in pig slurry were explained far better compared to the use of dry matter or pH as an explaining factor alone (Table 35). Although the dry matter content had already been taken into account, also the rate of wash water appeared to have a statistically significant effect on the contents of soluble N and K in cow slurry and on the content of total N in pig slurry.

Manure pH and dry matter content, and the rate of wash water explained the nitrogen content of cow slurry from uncovered reservoirs much better than they explained that of cow slurry from covered reservoirs. For samples from uncovered reservoirs the coefficient of determination (R^2) was 0.69*** for total N, and 0.38*** for soluble N.

For explaining the nutrient content of solid cow and pig manure, manure pH and dry matter content, and the rate of litter (kg/cow/d) were used as independent variables. However, no improvement by this kind of regression analysis was demonstrated compared to the use of pH or dry matter as an explaining factor alone.

The content of soluble N in solid poultry manure was explained significantly better by pH and dry matter together than by either of those variables separately. The coefficient of determination (R^2) was 0.48*** and the corresponding equation $y = -14.1 - 0.13 \times DM\ \% + 3.50 \times pH$. Other properties of poultry

Table 35. Manure pH and dry matter, and the rate of wash water as explaining variables for the nutrient content of slurry and liquid manure.

Manure	Nutrient (y)	R^2	Equation
COW			
Slurry	tot. N, g/kg	0.52***	$y = -4.6 - 9.61 \times 10^{-4} \times x_1 + 0.19 \times x_2 + 0.92 \times x_3$
	sol. N »	0.35***	$y = -5.4 - 1.41 \times 10^{-3} \times x_1 + 0.06 \times x_2 + 0.98 \times x_3$
	P »	0.42***	$y = 0.4 - 2.74 \times 10^{-4} \times x_1 + 0.11 \times x_2 - 0.05 \times x_3$
	K »	0.60***	$y = -11.3 - 1.69 \times 10^{-3} \times x_1 + 0.24 \times x_2 + 1.77 \times x_3$
Liquid manure	tot. N »	0.62***	$y = -10.0 - 3.05 \times 10^{-4} \times x_1 + 0.49 \times x_2 + 1.48 \times x_3$
	sol. N »	0.53***	$y = -11.4 - 1.48 \times 10^{-4} \times x_1 + 0.31 \times x_2 + 1.66 \times x_3$
	P »	0.50***	$y = 0.4 + 5.58 \times 10^{-5} \times x_1 + 0.13 \times x_2 - 0.07 \times x_3$
	K »	0.35***	$y = -10.0 - 1.00 \times 10^{-3} \times x_1 + 0.53 \times x_2 + 1.71 \times x_3$
PIG			
Slurry	tot. N »	0.58***	$y = 0.7 - 5.45 \times 10^{-4} \times x_1 + 0.29 \times x_2 + 0.31 \times x_3$
	sol. N »	0.28***	$y = -5.0 - 4.52 \times 10^{-4} \times x_1 + 0.12 \times x_2 + 1.08 \times x_3$
	P »	0.67***	$y = -4.8 + 7.17 \times 10^{-4} \times x_1 + 0.23 \times x_2 + 0.66 \times x_3$
	K »	0.09	$y = 2.5 - 1{:}45 \times 10^{-3} \times x_1 + 0.06 \times x_2 - 0.13 \times x_3$
Liquid manure	tot. N »	0.81***	$y = -3.0 + 6.97 \times 10^{-4} \times x_1 + 0.76 \times x_2 + 0.56 \times x_3$
	sol. N »	0.70***	$y = -4.5 + 1.11 \times 10^{-3} \times x_1 + 0.55 \times x_2 + 0.74 \times x_3$
	P »	0.51*	$y = 2.4 - 3.93 \times 10^{-4} \times x_1 + 0.16 \times x_2 - 0.29 \times x_3$
	K »	0.38	$y = -0.9 + 1.74 \times 10^{-3} \times x_1 + 0.14 \times x_2 + 0.25 \times x_3$

* = significant at 5 % level, *** = at 0.1 % level

x_1 = the rate of wash water entering the reservoir, l/m³ of manure

x_2 = dry matter content, %, x_3 = pH

manure were not explained better by the simultaneous use of pH and dry matter than by those variables separately.

When examining the nutrient content of liquid manure, the manure pH and dry matter content, and the rate of wash water (l/m³ of manure, farmers' assessment) were used as independent variables. The contents of total N, soluble N and K in liquid cow manure, and those of P and K in liquid pig manure were explained much better by those variables together than by dry matter or pH separately (Table 35). However, the effect of wash water was statistically significant only in explaining the K content in liquid cow manure.

Manure pH and dry matter content, and the rate of wash water explain the nitrogen content of liquid cow manure best when the rain has entrance to the cistern: coefficient of determination (R^2) is then 0.76*** for total N, and 0.63*** for soluble N.

Manure pH and dry matter content, and the rate of wash water were used as explaining factors also for the liquid cow manure samples with less than 4 % dry matter. Then the coefficient of determination (R^2) was 0.78*** for total N, 0.74*** for soluble N, 0.26*** for P, and 0.77*** for K. It can be seen in the regression equations that small rates of wash water do not significantly affect the nutrient content of slurry or liquid manure. In most farms, the effect of wash water can be disregarded.

DISCUSSION

The present study design which includes various classifications of the material is rather difficult to interpret, and thus serious errors in interpreting the results may occur. Differences found in the nutrient content of manure may not truly result from the factor used for group-ing, but from another factor that correlates with the factor considered. This study has sought to avoid such errors.

In the present study, it appeared that the significance of differences was strongly influenced by the number of samples. Significant effects by several factors on the properties of cow manures were often found. Owing to the small number of samples, less information was obtained about the effects of various factors on the properties of pig manure. However, it was concluded that the effects of various factors on pig manures were parallel to those demonstrated for cow manures and can thus also be used for assessing the nutrient content of pig manures.

The importance of the number of samples was also seen when the material was classified into smaller groups, for instance when comparing the effect of storage walls in the cases of covered and uncovered storages. Such comparisons often proved fruitless because the number of samples for various alternatives was too small to obtain significant differences.

1. Nutrient content of manure

The nutrient content of manure elucidated in this study generally corresponded to that presented in the literature. Only a few significant differences compared to the literature were found.

The highest deviation from the literature was detected in the nutrient content of liquid cow manure. Nitrogen and potassium contents were only about 50 % of the contents in the literature but, contrary to the literature, liquid cow manure also contained some phosphorus (VIRTANEN 1935, IVERSEN and DORPH-PETERSEN 1949 a). The difference between the literature and this study is due to variation in manure sampling. The contents described in the literature represent fresh urine whereas those in this study represent stored liquid manure from practical farms. In practice, liquid manure is more diluted owing to the entrance of rain and wash water into the cistern and because ammonia is lost by volatilization. On the other hand, liquid cow manure also contains phosphorus as some solid manure is leached into the cistern. Indeed, the nutrient content of liquid cow manure found in this study corresponds well to that presented in the advisory literature (SIMAN 1981, ERIKSSON 1983).

In the present study the contents of N and K in solid cow manure were slightly lower compared to those in an earlier Finnish study (KERÄNEN 1966). The difference in the N content results only from variations in the dry matter content: on a dry weight basis the contents were the same. However, the content of P in manure dry matter has increased and that of K decreased compared to the results obtained by KERÄNEN (1966). These changes are typical in intensified feeding (F. HANSEN 1941, SCHÖLLHORN 1954). As compared to the earlier study in Finland, the content of Ca in manure dry matter averaged only about 70 %, but the contents of Mg and Na were almost equal (KERÄNEN 1966).

The nutrient content of cow slurry almost equalled that found in Finland in 1974 (KÄHÄRI 1974). On a dry weight basis the contents of total N, soluble N and P appear to have slightly increased whereas the content of K has slightly decreased. The content of Ca in slurry dry matter has remained unchanged, but the contents of Mg and Na have decreased by 20—25 %.

The contents of total N, soluble N, P and K in pig slurry dry matter differed significantly from those presented in Finland in 1974 (KÄHÄRI 1974). However, no significant differences were ascertained for Ca, Mg or Na. The difference between this study and that carried out in 1974 may be explained by different sampling. The study by KÄHÄRI (1974) was mainly based on samples from experimental stations and dairies in which feeding probably is more intensive compared to that on practical farms.

In addition, the number of samples in the earlier study was significantly smaller compared with this study. A significant difference was also found in the dry matter content of pig slurry which was presented to be 6.0 % by KÄHÄRI (1974), but 9.2 % in this study. Owing to this difference, the nutrient contents on a fresh weight basis were almost equal in these two studies.

The content of chlorine in manure corresponded to that in the literature (SORTEBERG 1957, KJELLERUP 1981, de la LANDE CREMER 1985). It can be calculated that even a moderate dose of manure per ha contains more chlorine than a normal dose of artificial fertilizer applied to fields in Finland (about 80 kg/ha of Cl). If harmful effects by chlorine are then to be avoided, for instance when cultivating potatoes or horticultural crops, also livestock manure should be used with caution. Indeed, the harmful effects by manure on the quality of potatoes found in several studies may result from excessive chlorine (VARIS 1970). Chlorine in manure probably is completely soluble and thus easily available to plants, but is also easily leached from the soil.

The contents of trace elements (Fe, Cu, Zn, Mn, B) in manure corresponded to those in the literature (SORTEBERG 1957, KLAUSEN 1985, de la LANDE CREMER 1985). The content of Cu in pig slurry corresponded to that presented in Western Europe (ANON. 1978, 1982, GERMON et al. 1980, PRIEM and MATON 1980, de la LANDE CREMER 1985). However, Cu in pig manure should not cause the same problems in Finland as in the Western European countries because in Finland the doses of manure applied to fields are generally moderate and practically no pig manure is spread on pastures.

2. Nutrient content of manure in different areas of Finland

The nutrient content of manure varied considerably among different areas of Finland. However, the causes and importance of such variation are not well understood. In fact, much of the variation may result from unrepresentative sampling with respect to the area studied.

The contents of P, Cu and Zn in solid cow manure proved to be higher in northern Finland compared to southern or central Finland. This may be due to the fact that, owing to the very limited possibilities for cereal cultivation, the use of concentrated fodder supplemented with mineral nutrients is much more common in northern Finland. Moreover, especially high contents of those nutrients are found in soils and plants in northern Finland (KÄHÄRI and NISSINEN 1978, SIPPOLA and TARES 1978).

No huge differences between manures from different areas of Finland were found in this study such as those found in Sweden during the 1930's and 1940's (MANELL 1948). At that time, animals in the southern areas were fed significantly better than those in the northern areas. The difference was clearly reflected in the nutrient content of manure (MANELL 1948).

3. Nutrient content of manure as affected by herd size

The nutrient content of cow manure generally proved to be higher the larger the herd size. This kind of dependence was concluded to be due mainly to differences in feeding intensity. Since herd size also affected the dry matter content of solid cow manure, which was only slightly affected by feeding as such, herd size was concluded to be a somewhat justifiable basis for assessing the nutrient content of manure. As a basis of classification, herd size apparently reflects parallel positive effects on manure by intensive feeding and profitable manure handling. An especially prominent effect by herd size on the nutrient content of solid cow manure was detected.

The fact that the nutrient content of cow manure depends on herd size might indicate that livestock manure in Finland is poorer in nutrients than that in Western Europe. The average herd size in Finland is rather small. When compared to Danish studies, indeed, such a difference for solid cow manure can be elucidated (KLAUSEN 1985).

4. Effect of feeding on the nutrient content of manure

The type of base feed (silage, hay or other) and the rate of concentrated fodder both influenced the nutrient content of cow manure. However, the number of samples by "other" base feed was so small that only the difference between silage and hay as a base feed is to be regarded as genuine. The nutrient content of cow manure by silage feeding clearly surpassed that by hay feeding. The rate of concentrated fodder mainly influenced the contents of P, Cu and Zn which increased by an increasing rate of concentrated fodder, while Mn, on the contrary, decreased.

Feeding is a useful basis for assessing the nutrient content of manure. It is clearly a primary factor affecting nutrient content.

5. Effect of handling on the properties of slurry

Both reservoir covering and access of wash water into the reservoir significantly affected the nutrient content of slurry. Covering the reservoir prevented the dilution of slurry by rainwater. Wash water affected cow and pig slurry in different ways: it mainly diluted cow slurry, but increased the nutrient content in pig slurry dry matter. The wash water from cowsheds chiefly consists of nutrient-poor water originating from the cleaning process of milk-gathering pipe systems, whereas that from pig houses brings along faeces and fodder wastes. The covering of the reservoir and access of wash water proved rather useful bases for assessing the nutrient content of cow slurry.

6. Effect of handling on the properties of solid manure

Nutrient content of solid manure was found to be affected by several factors in manure handling. However, only a few of those dependencies appeared useful for assessing the nutrient content of manure.

Litter material only slightly affected the properties of solid manure. However, the superiority of acid peat compared to straw, sawdust and cutter shavings has been established in earlier studies (von FEILITZEN 1911, 1914, SVINHUFVUD 1925, TUORILA 1929, KAILA 1950 a, KEMPPAINEN 1987 a, 1987 b). In this study the number of peat manure samples was so small that such differences were not detected.

An increasing rate of litter raised pH, but diminished the proportion of soluble N in total N in solid cow manure. Moreover, it lowered the contents of soluble N and P in cow manure dry matter. The effect on pH results from the more effective absorption of alkaline urine into manure. However, an increasing rate of litter further dilutes the manure with respect to the nutrients bound to solid excrement (phosphorus), and soluble N is either volatilized or immobilized during the decomposition of litter (ANON. 1930).

The urine binding capacity of litter significantly affected the properties of solid cow manure. The higher the absorption the lower the nitrogen content, but the higher the pH. The content of potassium increased by an improved absorption of urine which partly results from the K in straw and partly from that in urine. The urine binding capacity of litter was shown to be a useful basis for assessing the nutrient content of solid cow manure. It even proved to be a better basis of classification than the rate of litter used. This difference apparently is explained by the fact that different kinds of litter absorb urine at various rates.

The construction material of the storage bottom significantly affected some properties of solid cow and poultry manure. The manure from storages with concrete bottoms was richer in nutrients compared to that from other types of storages. This difference is naturally explained by the superiority of the concrete bottom in preventing nutrient losses through leaching. However, it was concluded that the storage bottom material can be used as a basis of classification only in uncovered storages and preferably between concrete and soil bottoms only.

Storage walls significantly affected some properties of solid cow and poultry manure. However, those differences may also be explained by some other factors that correlate with the existence of storage walls, e.g. storage covering. Since storage walls, on the other hand, affected manure properties only slightly, they were not regarded as a useful basis for assessing the nutrient content of manure.

The covering of the solid manure storage significantly affected the potassium content of cow manure, and the nitrogen and potassium contents of poultry manure. Covering appears to be a useful basis for assessing the contents of soluble nutrients in manure.

Separation of the effluent from solid manure storage seemed to increase the nitrogen content of solid manure. However, this effect was concluded to result mainly from the rate of litter used. Separation of the effluent seemed to be much more common on farms using only small rates of litter compared to those using plenty of litter. Separation of the effluent did not prove a reliable basis for assessing the nutrient content of manure.

The technique of manure removal seemed to have a significant effect on the nutrient content of manure. However, it was not concluded to be a primary factor affecting nutrient content, but to reflect the effects of several other factors, namely feeding intensity, rate of litter used, etc. The technique of manure removal is not regarded as a reliable basis for assessing the nutrient content of manure.

7. Effect of handling on the properties of liquid manure

The nutrient content of liquid manure was found to be affected by several factors. However, only a few of those dependencies proved useful for determining the nutrient content of liquid manure.

Liquid cow manure samples from water-tight cisterns contained significantly more nutrients than those from leaky cisterns. However, this effect was concluded to result mainly from factors other than water-tightness itself, namely the covering of the cistern and the dilution of liquid manure by the rain and wash water. Water-tightness did not appear to be a reliable basis for assessing the nutrient content of liquid manure.

Access of rainwater into the cistern clearly affected the nutrient content of liquid manure. It was thus regarded to be a useful basis for assessing the nutrient content of liquid manure.

Wash water significantly diluted liquid cow manure. However, the correlations found were too weak to be used in assessing the nutrient content of liquid manure. Wash water increased the content of P in liquid cow manure which indicates the effect of P-containing detergents.

Covering the cistern significantly affected only the content of total nitrogen in liquid cow manure dry matter. The highest contents were found for liquid manures stored in cisterns with concrete coverings and the lowest for those stored in uncovered cisterns. Since differences were only seen in the nitrogen content per manure dry matter, dilution by rain should not have significantly affected the result. The effect of covering was concluded to be caused by ammonia volatilization from poorly covered cisterns. Such an effect has been found by IVERSEN (1924) and VIRTANEN (1935), too. However, covering of the cistern did not prove to be a useful basis for assessing the nutrient content of liquid manure because no differences in the nutrient content on a fresh weight basis were found.

Separation of the effluent from solid manure storage into the cistern diminished the nitrogen content of liquid cow manure in the case of uncovered solid manure storages. Since this is clearly a dilution effect, separation of the effluent from solid manure storage can be used as a basis for assessing the nutrient content of liquid manure.

Covering the solid manure storage was found to decrease the nitrogen content of liquid cow manure dry matter. This result indicates that covering the solid manure storage prevents the leaching of nutrients into the cistern by the rain. However, covering the solid manure storage was not regarded to be a useful basis for assessing the nutrient content of liquid manure because no effects by covering on the nutrient contents on a fresh weight basis were found.

8. Assessing nutrient content by easily measurable properties of manure

Correlations of dry matter with nutrients do not, without qualification, justify the use of dry matter analysis in assessing the nutrient content of manure. In general, the correlations were poor for solid manures and especially poor for solid cow manure which is the most important manure in Finland. Significantly better correlations were found for slurries and liquid manures, but even then the correlations were clearly weaker than those found by TUNNEY and MOLLOY (1975), HEDUIT et al. (1977), GRACEY (1979), TUNNEY (1979), DUTHION and GERMON (1980), and DESTAIN and RAIMOND (1983). Special attention should be paid to the fact that dry matter correlated significantly worse with soluble nitrogen than with total nitrogen. However, the immediate fertilizer effect of manure depends mainly on soluble nitrogen. Dry matter analysis can best be used for assessing the nutrient content of pig slurry.

Correlations of dry matter with nutrients proved that Ca, Mg, Fe, Mn and Zn are mainly included in the solid phase of slurry and liquid manure. To a slightly lesser extent the same is true for total N, P and Cu, too. With regard to practical purposes this is an important finding. Slurry and liquid manure must be carefully mixed before being spread onto the field.

An interesting fact in the results is that the correlation of pH with dry matter in slurries and liquid manures was insignificant or even significantly negative. An increase in the dry matter content brings on acidification which covers the effect of an increasing content of ammonia on manure pH. Acid decomposition products are thought to be the cause.

The proportion of soluble N in total N generally decreased by an increasing dry matter content. This phenomenon was clearly seen in slurries, liquid manures and solid poultry manure. The decrease in nitrogen solubility by an increasing dry matter content may depend on several factors. The constituents that increase dry matter content (solid faeces, litter) contain only small amounts of soluble N, but solid faeces contain plenty of insoluble N. Litter straw, on the other hand, causes enhanced immobilization and volatilization of ammonia (ANON. 1930).

For poultry manure and all types of cow manure (solid, slurry, liquid) the content of soluble N was better explained by pH than by the dry matter content. However, also in those manures the correlations were rather poor. An interesting fact is that the increase in nutrient content usually is accompanied by an increasing pH in cow and poultry manures, but not in pig manures. The acidification following concentration appears to be more intensive in pig manures compared to cow and poultry manures.

Prediction of the content of soluble N on basis of total N is the most reliable for liquid manures ($r = 0.95$—0.98), then for slurries ($r = 0.77$—0.86) and the least reliable for solid manures ($r = 0.52$—0.66).

9. Explaining nutrient content by several factors simultaneously

In addition to separate correlations, it was attempted to explain the nutrient content of manure by the simultaneous use of various easily measurable or assessable factors. The simultaneous use of three variables significantly improved the coefficient of determination for several nutrients in slurry and liquid manure compared to the use of dry matter or pH separately. However, the effect of wash water proved significant only when water is added to manure in large amounts. The coefficients of determination could still be improved by first classifying the material according to various factors in manure handling. The use of several easily measurable or assessable factors simultaneously for assessing the nutrient content of slurry and liquid manure was found to be very useful.

However, the simultaneous use of several variables did not improve the coefficient of determination for the nutrients in solid manure compared to the use of dry matter or pH separately. The only exception found was for the content of soluble N in poultry manure which was explained far better by pH and dry matter together than by either of those variables alone.

COW SLURRY AS A FERTILIZER FOR BARLEY

INTRODUCTION

Owing to the oil crisis in the 1970's, there has been more interest in exploiting the full potential of livestock manure as a fertilizer. It has also been widely accepted that the effective utilization of manure in plant production at the same time helps prevent environmental pollution. Intensifying the utilization of manure mostly concerns nitrogen which, on the one hand, is very easily lost from manure and, on the other hand, can cause severe damage when leached to water resources or when volatilized into the atmosphere.

In principle, the fertilizer value of soluble nitrogen in manure should equal that of the nitrogen in artificial fertilizer. As a result of nitrogen losses from fields by leaching and volatilization, however, the fertilizer value of manure may decrease significantly. In addition to direct economic loss, nitrogen losses from manure are very harmful because they are difficult to quantify. In different experiments, nitrogen loss from manure spread onto the field has ranged from nil to almost 100 % (IVERSEN 1938, DAVIES 1970, ADRIANO et al. 1974, LAUER et al. 1976, BEAUCHAMP et al. 1978, VETTER and STEFFENS 1979, HOFF et al. 1981, STEENHUIS et al. 1981, UHLEN 1981, DÖHLER and WIECHMANN 1988, RANK et al. 1988).

The time of manure application and the incorporation of manure into the soil are considered the most important factors determining the efficiency of nitrogen in manure. Manure spread in autumn suffers from leaching whether incorporated into the soil or not. Surface applied manure always suffers from ammonia volatilization. In general, the efficiency of manure applied in spring clearly surpasses that of manure spread in autumn or in winter (TUORILA and TAINIO 1934, IVERSEN 1944, ASMUS et al. 1971, 1973, 1975, KOLENBRANDER 1981 a, KLAUSEN and NEMMING 1982, SMITH et al. 1985, BAADSGAARD 1987, VETTER 1988). An advantage by rapid incorporation is usually obtained in comparison to a delayed incorporation (VIRRI

1941, KLAUSNER and GUEST 1981, KOLENBRANDER 1981 b, SUTTON et al. 1982, LARSEN and KELLER 1985 a, TUNNEY and MOLLOY 1986, LARSEN 1987, SIMAN et al. 1987, DÖHLER and WIECHMANN 1988, RANK et al. 1988). For the immediate incorporation of liquid manure, an injection technique has been developed (IVERSEN 1934, WESTED and IVERSEN 1938).

On practical farms, however, difficulties are met in the spreading of manure before sowing in the spring. The period of time from the drying of the soil after winter to sowing is very short and labourious even without manure spreading. Farmers also avoid the spreading of manure before sowing in spring because, in their opinion, trampling damage to the soil would then be significant.

The spreading of manure after the sowing of spring cereals has been regarded as promising in many ways. Farmers would then have more time for manure spreading than before sowing. In addition, soils would have dried up and thus severe trampling damage would be avoided. However, little is known about the efficiency of manure spread after sowing and, if a poor effect of manure were to be found, would it be due to manuring too late or to trampling damage to the young crop by heavy spreader machines.

The aim of this study was to examine the efficiency of cow slurry spread onto the field at different times of the year. Different spreading times in the spring were of special interest. For slurry applications in the spring, the importance of trampling damage by the spreader was attempted to clarify. In addition, irrigation and nitrogen supplementation were examined as means for improving the efficiency of slurry spread after sowing. The importance of the rapid incorporation of slurry was examined by comparing the effects of surface applied and injected slurry.

MATERIAL AND METHODS

The use of cow slurry as a fertilizer for barley was examined in four different types of field experiments at Jokioinen (60° 49′ N, 23° 30′ E) in 1982—1987. One experiment lasted five years, another lasted four years, and two experiments lasted two years each.

In all experiments, a Finnish Teho-Lotina slurry spreader was used. The spreader weighs 2 250 kg, has a working width of 2.8—3.0 m, a capacity of 6.8 m^3, and is fitted with a bogie axle (ANON. 1983 b). The injector consists of six narrow tines about 47 cm apart. Injection depth was about 12 cm in all experiments. For surface application, an iron plate was adjusted beneath the tines in order to improve the evenness of slurry distribution. Driving speed was about 5 km/h in all experiments.

Experiment A1 tested the effects of the time and method of slurry application (Appendix 10). At different times of the year, 50 m^3/ha (fall 1982 — spring 1985) or 67 m^3/ha (fall 1985 — spring 1986) of cow slurry was applied to the experimental plots. Once in every autumn and twice in every spring, slurry was applied both by surface application and injection. In late fall, in winter, and in the beginning of May, slurry was spread only by surface application. In different years, the dates of slurry application were not exactly the same because of varying weather conditions (Table 36).

In addition to the slurry-manured plots, unfertilized plots, plots with 250 kg/ha of NPK (20-4-8), and plots with 500 kg/ha of NPK (20-4-8) were included. Artificial fertilizer was always applied by the placement technique in combination with sowing of barley in spring. The number of replicates in every experimental year was four.

Table 36. Dates of experimental treatments, ploughing, sowing, and harvesting for experiment A1.

Method of slurry application	Dates of slurry application			
	1982—1983	1983—1984	1984—1985	1985—1986
Surface	13.10.	15. 9.	7. 9.	12. 9.
Injection	»	»	»	»
Surface	25.10.	—	25.10.	7.10.
Surface	9.11.	25.11.	19.12.	5.12.
Surface	30. 3.	13. 4.	—	7. 4.
Surface	4. 5.	7. 5.	16. 5.	9. 5.
Surface	9. 5.	16. 5.	24. 5.	19. 5.
Injection	»	»	»	»
Surface	16. 5.	31. 5.	7. 6.	9. 6.
Injection	»	»	»	»
Ploughing in fall	25.10.	14.10.	25.10.	7.10.
Sowing in spring	10. 5.	19. 5.	27. 5.	24. 5.
Harvesting	21. 8.	26. 8.	3. 9.	26. 8.

In 1987 (residual effects) barley was sown 26.5. and harvested 14.9.

Experiment A1 was located on the same site from fall 1982 to summer 1987. The sites of differently manured plots were the same in different years, too. Barley fertilized with slurry was grown in the summers 1983—1986, but in 1987, the residual effects of slurry and NPK applied in the preceding years were examined. Then only 350 kg/ha of NPK (20-4-8) was applied over the whole experimental field. The experiment was located on a rather fertile sandy clay soil (Table 37).

Table 37. Information on experimental soils. Nutrients were determined according to Vuorinen and Mäkitie (1955), and pH from a mixture of soil/deionized water = 1/2.5.

Experiment no.	Soil type	pH	Nutrients, mg/l			
			P	K	Ca	Mg
A1	Sandy clay	6.20	30	310	2700	500
A2, A3, A4	Silty clay	6.80	32	230	2700	480

In every experimental year, cow slurry from the same farm was used to fertilize barley. The nutrient content of slurry was analyzed during each application and those separate nutrient analyses were used in calculating the apparent recovery and apparent efficiency of slurry soluble nitrogen. The average contents of nutrients in slurry are shown in Table 38.

Barley (*Hordeum vulgare* var. Pomo) was grown on the experimental plots. For harvesting, a Finnish Sampo-experimental harvester was used. The dates of sowing and harvesting are shown in Table 36. Grain yield was analyzed for dry matter content by weighing, and for nitrogen content by the Kjeldahl method.

Table 38. Average nutrient content of slurry used in experiment A1.

Analysis	Nutrients in slurry, g/l				
	1982—1983	1983—1984	1984—1985	1985—1986	$\bar{x}$
N total	2.20	2.70	1.71	2.46	2.27
N soluble	1.25	1.45	0.99	1.27	1.24
P	0.33	0.53	0.29	0.50	0.41
K	2.55	3.52	2.43	2.76	2.82
N sol./N tot., %	57	54	58	52	55

Experiment A2 had a split-split-plot design studying simultaneously the effects of irrigation following slurry application, time of slurry application in spring, and the method of slurry application (Appendix 11). The experiment lasted from 1983 to 1984 and it was located on a silty clay soil (Table 37).

Irrigation following the last slurry application in spring was the main experimental factor. During the night following the last slurry application, 30 mm of water was irrigated by sprinklers. The time lag between slurry application and the beginning of irrigation was 6—9 hours, and irrigation of 30 mm of water lasted about six hours.

Irrigation was not examined as a means for increasing grain yield as such, but as a means to improve the efficiency of surface applied slurry. In both experimental years, precipitation in May and June surpassed the long-term average; early summer 1984 can even be classified as very rainy. However, irrigation was carried out according to the field plan.

Each main plot included three subplots with different schedules for slurry application: 1—3 d before sowing, at sprouting (12—13 d after sowing), and about 10 d after sprouting (22—24 d after sowing). The rate of cow slurry was always 50 m^3/ha. In addition to the slurry-manured subplots, the following control treatments were included: unfertilized, 250 kg/ha of NPK (20-4-8), and 500 kg/ha of NPK (20-4-8). Artificial fertilizer was applied by the placement technique in combination with sowing. It can be seen from the field plan (Appendix 11) that unfertilized subplots were irrigated unevenly and thus cannot be compared to the other subplots with respect to irrigation. However, grain yields from unfertilized subplots and their nitrogen contents were used as a basis in calculating the apparent recovery and apparent efficiency of slurry soluble nitrogen.

Every subplot with slurry included two subsubplots. Slurry was spread either onto the soil surface or injected into the soil. Slurry was of the same origin as that used in experiment A1. The average nutrient contents in cow slurry are shown in Table 39. There were four replicates, except for unfertilized plots which had three replicates only.

The same barley was grown employing the same harvesting technique, and the same analyses for the grain yield were carried out as in experiment A1. Dates of experimental treatments, sowing, and harvesting are shown in Table 40.

Experiment A3 had a similar split-split-plot design as that of experiment A2, but instead of irrigation, nitrogen supplementation was the main experimental factor (Appendix 12). Prior to sowing, 120 kg/ha of artificial fertilizer containing 27,5 % of nitrogen but no P or K was applied in A_1-plots by the placement technique. The rate of cow slurry was always 60 m^3/ha. Other experimental factors were equal to those in experiment A2. The number of replicates was four.

Experiment A3 was carried out in 1985 and 1986 and it was located on a silty clay soil; the same site used for experiment A2 in the preced-

Table 39. Average nutrient content of slurry used in experiments A2 (1983—1984) and A3 (1985—1986).

Analysis	Nutrients in slurry, g/l				
	1983	1984	1985	1986	$\bar{x}$
N total	2.27	2.52	1.55	1.92	2.07
N soluble	1.20	1.43	1.04	1.26	1.23
P	0.61	0.54	0.23	0.32	0.43
K	4.24	3.51	2.83	2.96	3.39
N sol./N tot., %	53	57	67	66	61

ing years. Thus to a certain extent, the effects on barley growth by the time and method of slurry application in this experiment can be compared with those in experiment A2.

Barley variety, harvesting technique and analyses of barley grain yield were identical to those in experiments A1 and A2. Slurry of same origin was used, too. The average nutrient content of slurry is shown in Table 39 and the dates of experimental treatments, sowing and harvesting in Table 40.

Table 40. Dates of experimental treatments, sowing and harvesting for experiments A2 (1983—1984) and A3 (1985—1986).

	Date			
	1983	1984	1985	1986
Slurry application				
Before sowing	9.5.	16.5.	24.5.	19.5.
At sprouting	23.5.	31.5.	7.6.	9.6.
After sprouting	1.6.	12.6.	13.6.	19.6.
Irrigation	1.6.	12.6.	—	—
N supplementation	—	—	27.5.	23.5.
Sowing of barley	10.5.	19.5.	27.5.	28.5.
Harvesting	18.8.	24.8.	1.9.	27.8.

Experiment A4 lasted from 1983 to 1986 and it tested the trampling effect of the slurry spreader (Appendix 13). Experimental treatments were always carried out in combination with spreading of slurry in experiment A2 (1983—1984) or experiment A3 (1985—1986). Three trampling intervals were examined: 1—9 d before sowing, at sprouting (11—13 d after sowing), and about 10 d after sprouting (17—24 d after sowing). Every time, both surface application and injection were imitated. In addition, untrampled plots were included. There were four replicates.

No slurry was applied in experiment A4, but instead, 500 kg/ha of NPK (20-4-8) was applied over the whole experimental field by the placement technique in combination with sowing. The same barley was cultivated and same harvesting technique was used as in experiments A1—A3. Barley grain yield was analyzed for dry matter by weighing. The dates of experimental treatments, sowing and harvesting were identical to those of experiment A2 (1983—1984) or experiment A3 (1985—1986).

For experiments A1—A3, apparent recovery and apparent efficiency of soluble nitrogen in different fertilization treatments were calculated. The apparent recovery of soluble nitrogen was calculated as follows: (N uptake by the grain yield in treatment x — N uptake by the grain yield in unfertilized plots) × 100/the rate of soluble N applied to treatment x. The apparent efficiency of soluble nitrogen was calculated accordingly: (grain yield in treatment x — grain yield in unfertilized plots)/the rate of soluble N applied to treatment x. The nitrogen in artificial fertilizers used in the experiments was either nitrate or ammonium nitrogen, i.e. completely soluble.

For all experiments, visual examination during the growing seasons was carried out. The relative value of surface applied versus injected slurry was of special interest. In addition, it was attempted to clarify the effect of varying weather conditions on the efficiency of slurry. Information on weather conditions at Jokioinen is presented in Appendices 14—15.

The slurries used in experiments were analyzed for total nitrogen, soluble nitrogen, phosphorus, and potassium. Total nitrogen was analyzed by the Kjeldahl method, phosphorus by spectrometry and potassium by atomic absorption spectrometry. Soluble nitrogen was analyzed by extracting slurry samples with a $CaCl_2$-HCl-solution followed by distillation of ammonia from the extract. This method has been traditionally used in Finland and it gives results quite comparable to those obtained by direct distillation of manure ammonia (KÄHÄRI 1974).

Results were calculated using a VAX 11/780 computer and SAS statistical program (ANON. 1985). Tukey's test was used for examining the differences between treatments (STEEL and

TORRIE 1960). In the results, the 'Honestly Significant Difference' obtained by Tukey's test is expressed as HSD (P = 0.05). Significance of F-value is expressed by asterisks. One asterisk (*) indicates significance at the 5 % level (P = 0.05), two asterisks (**) at the 1 % level (P = 0.01), and three asterisks (***) at the 0,1 % level (P = 0.001).

RESULTS

Experiment A1: The results obtained in experimental years 1983—1986 are shown in Tables 41—44. Considering grain yield, nitrogen uptake, apparent recovery of soluble nitrogen and apparent efficiency of soluble nitrogen, slurry applications in spring clearly surpassed those in autumn or in winter. Moreover, injection was usually superior to surface application. However, the nitrogen content of grain was not as clearly affected by the time and method of slurry application. As compared to surface application, even a slight decrease in the nitrogen content by injection was often found.

When the apparent recovery of slurry soluble nitrogen was compared to that of nitrogen in artificial fertilizer applied in spring, the superiority of spring applications compared to autumn and winter applications was clearly seen (Table 45). The same is true with respect to the apparent efficiency of slurry soluble nitrogen. Table 45 also shows the interesting fact that when compared to the nitrogen in artificial fertilizer, slurry soluble nitrogen often was more effective in increasing grain yield (apparent efficiency) than in raising nitrogen uptake (apparent recovery).

In applications on 9.11.1982 and 13.4.1984, an undesirable effect by slurry was found. Grain yield and nitrogen uptake were then lower compared to the unfertilized plots. On basis of visual observations, those negative effects were due to severe trampling damage by the wheels of the spreader on a wet soil. Although the spreading on 13.4.1984 is classified as a spreading on a frozen soil, soil surface had already thawed to a depth of 5—7 cm. Once severely trampled while wet, the soil within the wheel tracks lost its structure and hardened during drying in spring. Deep wheel tracks were filled with dry surface soil during harrowing in spring, and plants growing within the tracks suffered from drought throughout the summer.

The advantage by injection compared to surface application averaged 450 kg/ha of grain for slurry applications in autumn, 220 kg/ha for slurry applications 1—5 days before sowing, and 360 kg/ha for slurry applications 6—16 days after sowing (Table 46). Significant advantages by injection did not logically fit especially for warm and rainless days following slurry application. However, for applications 1—5 days before sowing, the advantage by injection was greater the longer the interval between slurry spreading and incorporation of surface applied slurry.

When the residual effects of various manuring treatments in fall 1982 — spring 1986 were examined in 1987, no significant differences were found in the grain yield nor in its nitrogen content. Plots with 500 kg/ha of NPK (20-4-8) in the preceding years yielded 3 550 kg/ha of grain (85 % DM), unfertilized plots yielded 3 560 kg/ha, those with surface applied slurry 1—5 days before sowing 3 470 kg/ha, and those with injected slurry 1—5 days before sowing 3 500 kg/ha.

Experiment A2: As a separate experimental factor, irrigation of 30 mm of water during the night following the last slurry application had no significant effect on grain yield, moisture content of the grain at harvest, nitrogen content of grain, nor on nitrogen uptake by the

Table 41. Yield results of experiment A1 on sandy clay soil in 1983. Sowing 10.5.1983.

Date of slurry application	Method of slurry application	Soluble nitrogen, kg/ha	Grain yield (85 % DM), kg/ha	Nitrogen in grain, mg/g	Nitrogen uptake, kg/ha	Apparent recovery of soluble N[1]	Apparent efficiency of soluble N[2]
13.10.1982	Surface	65	2770	15.8	37	8	4
»	Injection	65	3380	14.8	43	17	13
25.10.1982	Surface	65	2800	15.3	37	8	4
9.11.1982	Surface	65	2060	15.4	27	<0	<0
30. 3.1983	Surface	59	3030	15.0	39	12	8
4. 5.1983	Surface	64	4350	14.4	53	33	28
9. 5.1983	Surface	64	4180	14.5	52	31	26
»	Injection	64	4050	13.6	47	23	24
16. 5.1983	Surface	56	4400	15.4	58	46	33
»	Injection	56	4760	14.8	60	50	40
Unfertilized			2540	15.0	32		
250 kg/ha NPK (20-4-8)		50	4410	14.6	55	46	37
500 kg/ha »		100	5630	15.8	76	44	31
HSD (P = 0.05)			1080	1.6	16		

[1] % of added soluble nitrogen found in grain yield
[2] kg of grain produced per kg of soluble nitrogen

Table 42. Yield results of experiment A1 on sandy clay soil in 1984. Sowing 19.5.1984.

Date of slurry application	Method of slurry application	Soluble nitrogen, kg/ha	Grain yield (85 % DM), kg/ha	Nitrogen in grain, mg/g	Nitrogen uptake, kg/ha	Apparent recovery of soluble N[1]	Apparent efficiency of soluble N[2]
15. 9.1983	Surface	69	2100	17.5	31	14	10
»	Injection	69	2710	17.3	40	28	19
25.11.1983	Surface	71	2430	17.6	37	23	15
13. 4.1984	Surface	82	1070	17.4	16	<0	<0
7. 5.1984	Surface	73	2380	14.4	29	11	14
16. 5.1984	Surface	70	2900	15.9	39	26	22
»	Injection	70	3090	15.2	40	27	24
31. 5.1984	Surface	70	2820	18.7	45	34	20
»	Injection	70	2960	18.0	45	34	22
Unfertilized			1390	17.9	21		
250 kg/ha NPK (20-4-8)		50	3030	16.6	43	44	33
500 kg/ha »		100	3670	18.5	58	37	23
HSD (P = 0.05)			950	2.5	16		

[1] % of added soluble nitrogen found in grain yield
[2] kg of grain produced per kg of soluble nitrogen

grain yield (Tables 47—48). Although the differences were not significant, irrigation decreased rather than increased yield, nitrogen content and nitrogen uptake.

The date of slurry application affected all of the yield parameters measured. In 1983, grain yield and nitrogen uptake were the highest by slurry application at sprouting (23.5.) whereas in 1984, the best results were obtained by slurry application before sowing (16.5.). On average, the moisture content of the grain at harvest and the nitrogen content of grain were higher the later the slurry application.

As compared to surface applied slurry, in-

Table 43. Yield results of experiment A1 on sandy clay soil in 1985. Sowing 27.5.1985.

Date of slurry application	Method of slurry application	Soluble nitrogen, kg/ha	Grain yield (85 % DM), kg/ha	Nitrogen in grain, mg/g	Nitrogen uptake, kg/ha	Apparent recovery of soluble N[1]	Apparent efficiency of soluble N[2]
7. 9.1984	Surface	59	1730	18.2	27	5	4
»	Injection	59	2130	18.6	34	17	11
25.10.1984	Surface	43	1900	18.1	29	12	9
19.12.1984	Surface	38	2210	17.8	33	24	19
16. 5.1985	Surface	57	3050	17.2	45	37	27
24. 5.1985	Surface	54	3060	18.2	47	43	29
»	Injection	54	3330	16.9	48	44	34
7. 6.1985	Surface	48	2670	21.5	49	52	24
»	Injection	48	2850	20.2	49	52	28
Unfertilized			1500	18.9	24		
250 kg/ha NPK (20-4-8)		50	3320	18.0	51	54	36
500 kg/ha »		100	4270	20.3	74	50	28
HSD (P = 0.05)			410	2.0	8		

[1] % of added soluble nitrogen found in grain yield
[2] kg of grain produced per kg of soluble nitrogen

Table 44. Yield results of experiment A1 on sandy clay soil in 1986. Sowing 24.5.1986.

Date of slurry application	Method of slurry application	Soluble nitrogen, kg/ha	Grain yield (85 % DM), kg/ha	Nitrogen in grain, mg/g	Nitrogen uptake, kg/ha	Apparent recovery of soluble N[1]	Apparent efficiency of soluble N[2]
12. 9.1985	Surface	66	1290	20.7	23	9	5
»	Injection	66	1480	21.7	27	15	8
7.10.1985	Surface	66	1820	20.7	32	23	13
5.12.1985	Surface	90	1440	20.4	25	9	5
7. 4.1986	Surface	107	1670	20.5	29	11	7
9. 5.1986	Surface	91	2260	23.5	45	31	14
19. 5.1986	Surface	88	1970	23.2	39	25	12
»	Injection	88	2520	23.0	49	36	18
9. 6.1986	Surface	85	1760	24.2	36	22	10
»	Injection	85	2500	23.5	50	39	18
Unfertilized			950	21.2	17		
250 kg/ha NPK (20-4-8)		50	2030	23.7	41	48	22
500 kg/ha »		100	2440	25.8	53	36	15
HSD (P = 0.05)			480	2.4	9		

[1] % of added soluble nitrogen found in grain yield
[2] kg of grain produced per kg of soluble nitrogen

jected slurry increased both grain yield and nitrogen uptake. In 1983, the advantage by injection was higher after than before sowing. In 1984, on the other hand, the advantage by injection was of about same magnitude before sowing and at sprouting, but significantly lower after sprouting. In both experimental years, the advantage by injection was higher on unirrigated plots as compared to irrigated plots.

In comparison with surface application, injection also increased the moisture content of the grain at harvest when carried out after sowing. Injection increased the nitrogen content of grain, too. In 1983, the increase in the nitro-

Table 45. Experiment A1. Efficiency of soluble nitrogen in slurry compared to that of nitrogen in artificial fertilizer applied in spring (average for 250 kg/ha and 500 kg/ha of NPK). The rate of soluble N in slurry averaged 67 kg/ha.

Slurry application schedule	Method of slurry · application	App. recovery of sol. N, Slurry/Artificial fert., %					App. efficiency of sol. N, Slurry/Artificial fert., %				
		1983	1984	1985	1986	$\bar{x}$	1983	1984	1985	1986	$\bar{x}$
Sept.—Oct., stubble field	Surface	18	35	10	21	21	12	36	13	27	22
»	Injection	38	69	33	36	44	38	68	34	43	46
Oct., just before ploughing	Surface	18		23	55		12		28	70	
Nov.—Dec., ploughed field	Surface	<0	57	46	21		<0	54	59	27	
March—April, frozen soil	Surface	27	<0		26		24	<0		38	
May, 11 d before sowing[1]	Surface	73	27	71	74	61	82	50	84	76	73
May, 3 d before sowing[2]	Surface	69	64	83	60	69	76	79	91	65	78
»	Injection	51	67	85	86	72	71	86	106	97	90
May—June, 11 d after sowing[3]	Surface	102	84	100	52	85	97	71	75	54	74
»	Injection	111	84	100	93	97	118	79	88	97	96

[1] range 6—15 days, [2] range 1—5 days, [3] range 6—16 days

Table 46. Experiment A1. Yield increase by injection compared to surface application, mean air temperature and total precipitation during five days following slurry application, and date of incorporation of surface applied slurry.

Date of slurry application	Yield increase by injection, kg/ha (85 % DM)	Mean temperature and total precipitation,		Incorporation of surface applied slurry, date
		°C	mm	
Applications in fall				
13.10.1982	+610	2.7	8.0	25.10.
15. 9.1983	+610	12.9	24.7	14.10.
7. 9.1984	+400	11.4	17.4	25.10.
12. 9.1985	+190	9.5	6.7	7.10.
Applications 1—5 d before sowing				
9. 5.1983	—130	9.9	12.2	9. 5.
16. 5.1984	+190	17.3	0.1	19. 5.
24. 5.1985	+270	12.9	1.3	27. 5.
19. 5.1986	+550	10.8	13.6	23. 5.
Applications 6—16 d after sowing				
16. 5.1983	+360	13.2	25.4	—
31. 5.1984	+140	17.7	23.4	—
7. 6.1985	+180	10.2	2.7	—
9. 6.1986	+740	15.9	0.1	—

gen content by injection was higher the later the slurry application whereas in 1984, the highest increase was found by injection at sprouting (31.5.).

Irrigation seemed to decrease the apparent recovery and apparent efficiency of slurry soluble nitrogen more than those of the nitrogen in artificial fertilizer (Tables 49—50). On average, the apparent efficiency of soluble nitrogen was the highest when slurry was applied before sowing. However, the apparent recovery of soluble nitrogen was the highest when slurry was applied at sprouting (12—13 days after sowing). The effects of the time and method of slurry application are further discussed in connection with the results of experiment A3.

Table 47. Experiment A2 on silty clay soil in 1983. Effect of various experimental factors on barley grain yield (85 % DM), moisture content of the grain at harvest, nitrogen content in grain, and nitrogen uptake by the grain yield. Sowing 10.5.1983. The rate of soluble N in slurry averaged 60 kg/ha.

Date of slurry application	Method of slurry application	Irrigation 1.6.1983							
		No	30 mm	No	30 mm	No	30 mm	No	30 mm
		Yield, kg/ha		% moisture		Nitrogen, mg/g		N uptake, kg/ha	
9.5.1983	Surface	4230	3280	20	20	15.7	14.6	56	40
»	Injection	4850	3570	20	20	15.7	14.8	65	45
23.5.1983	Surface	4300	2970	23	23	15.7	16.0	57	40
»	Injection	5230	3660	28	28	17.2	15.6	77	49
1.6.1983	Surface	3720	2890	27	27	15.1	15.2	48	37
»	Injection	4560	3350	31	30	17.4	17.1	68	48
F-values:	Date of slurry appl.	5.8*		335.8***		7.3**		3.9*	
	Method of slurry appl.	93.7***		89.4***		17.6***		62.1***	
	Irrigation × Method	5.7*						6.8*	
	Date × Method			22.5***		6.5**			
Unfertilized		2460	2150	26	26	17.0	16.4	36	30
250 kg/ha NPK (20-4-8)		4490	4230	19	19	15.0	15.3	57	55
500	»	6070	5470	18	19	17.4	16.2	90	75
F-values (unfertilized plots excluded):									
	Rate of NPK	149.6***						40.6***	

Significance of F-values: * = at 5 % level, ** = at 1 % level, *** = at 0.1 % level.
F-values with significance better than 5 % are shown only.

Table 48. Experiment A2 on silty clay soil in 1984. Effect of various experimental factors on barley grain yield (85 % DM), moisture content of the grain at harvest, nitrogen content in grain, and nitrogen uptake by the grain yield. Sowing 19.5.1984. The rate of soluble N in slurry averaged 72 kg/ha.

Date of slurry application	Method of slurry application	Irrigation 12.6.1984							
		No	30 mm	No	30 mm	No	30 mm	No	30 mm
		Yield, kg/ha		% moisture		Nitrogen, mg/g		N uptake, kg/ha	
16.5.1984	Surface	1970	1560	17	19	16.5	14.9	28	20
»	Injection	2750	2050	19	17	17.4	15.6	41	28
31.5.1984	Surface	1790	1050	21	20	17.3	17.0	27	15
»	Injection	2570	1500	33	34	18.1	18.2	40	23
12.6.1984	Surface	1470	1090	26	28	18.6	18.9	23	17
»	Injection	1980	1180	34	33	19.1	19.0	32	19
F-values:	Date of slurry appl.	10.5**		144.0***		17.1***			
	Method of slurry appl.	86.1***		204.6***		9.4**		79.7***	
	Irrigation × Method	9.7**						9.4**	
	Date × Method	3.9*		70.3***					
	Irrig. × Date × Method			3.9*					
Unfertilized		570	650	23	24	20.1	20.4	10	11
250 kg/ha NPK (20-4-8)		2070	1870	18	18	16.1	16.6	28	27
500	»	3080	3080	17	18	19.0	17.9	50	47
F-values (unfertilized plots excluded):									
	Rate of NPK	402.3***				11.5*		123.4***	

Significance of F-values: * = at 5 % level, ** = at 1 % level, *** = at 0.1 % level.
F-values with significance better than 5 % are shown only.

Table 49. Experiment A2 on silty clay soil in 1983—1984. Apparent recovery of soluble nitrogen in barley grain yield.

Slurry application schedule	Method of slurry application	Apparent recovery of soluble N in grain yield, %					
		1983		1984		$\bar{x}$	
		Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.
Before sowing[1]	Surface	33	17	25	13	29	15
»	Injection	48	25	43	24	46	25
At sprouting[2]	Surface	35	17	24	6	30	12
»	Injection	68	32	42	17	55	25
After sprouting[3]	Surface	20	12	18	8	19	10
»	Injection	53	30	31	11	42	21
250 kg/ha NPK (20-4-8)		42	50	36	32	39	41
500 »		54	45	40	36	47	41

[1] 1—3 d before sowing, [2] 12—13 d after sowing, [3] 22—24 d after sowing

Table 50. Experiment A2 on silty clay soil in 1983—1984. Apparent efficiency of soluble nitrogen in increasing barley grain yield (kg of grain/kg of soluble N).

Slurry application schedule	Method of slurry application	Apparent efficiency of soluble N					
		1983		1984		$\bar{x}$	
		Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.
Before sowing[1]	Surface	30	19	19	13	25	16
»	Injection	40	24	30	19	35	22
At sprouting[2]	Surface	31	14	17	6	24	10
»	Injection	46	25	28	12	37	19
After sprouting[3]	Surface	21	12	13	6	17	9
»	Injection	35	20	20	7	28	14
250 kg/ha NPK (20-4-8)		41	42	30	24	36	33
500 »		36	33	25	24	31	29

[1] 1—3. d before sowing, [2] 12—13 d after sowing, [3] 22—24 d after sowing

Visual observations from experiments A2 and A3 proved that very severe damage to the young barley crop was caused by slurry applied after sowing, especially by the application after sprouting. In the plots with surface applied slurry, barley seedlings within the wheel tracks were killed owing to the formation of a hard crust as the soil dried up. In plots treated with injected slurry, a high number of barley seeds was lifted onto the soil surface and exposed to drying. It was astonishing to see how well the young crop recovered during the summer, especially on plots with injected slurry.

Visual observations from experiment A2 also indicated that there may exist a negative interaction between surface applied slurry and irrigation thereafter. Irrigation following surface application seemed to enhance sludging and crust formation in the silty clay soil used in this experiment.

Experiment A3: On the whole, nitrogen supplementation increased grain yield, its nitrogen content and nitrogen uptake (Tables 51—52). On the other hand, nitrogen supplementation decreased the moisture content of the grain at harvest.

Table 51. Experiment A3 on silty clay soil in 1985. Effect of various experimental factors on barley grain yield (85 % DM), moisture content of the grain at harvest, nitrogen content in grain, and nitrogen uptake by the grain yield. Sowing 27.5.1985. The rate of soluble N in slurry averaged 62 kg/ha.

Date of slurry application	Method of slurry application	Nitrogen supplementation, kg/ha							
		No	33	No	33	No	33	No	33
		Yield, kg/ha		% moisture		Nitrogen, mg/g		N uptake, kg/ha	
24.5.1985	Surface	2700	3350	32	30	19.5	20.0	45	57
»	Injection	3350	3850	29	27	18.1	19.7	52	64
7.6.1985	Surface	2450	3160	35	32	19.9	21.2	42	57
»	Injection	2390	2800	41	36	21.3	23.0	43	55
13.6.1985	Surface	2310	3030	38	33	20.0	20.2	39	52
»	Injection	1920	2480	44	36	21.6	21.7	35	46
F-values:	N supplementation	57.1**		121.8**		18.5*		75.9**	
	Date of slurry appl.	42.1***		90.1***		21.6***		16.3***	
	Method of slurry appl.			44.6***		15.4***			
	N suppl. × Date			6.3*					
	N suppl. × Method			5.3*					
	Date × Method	33.5***		53.2***		16.9***		9.6**	
Unfertilized		900	1840	39	31	19.4	17.5	15	27
250 kg/ha NPK (20-4-8)		2970	3540	30	28	17.3	18.9	44	57
500 »		3980	4190	28	28	19.5	22.1	66	79
HSD (P = 0.05) for controls:									
N supplementation means		220		1		0.8		4	
Rate of NPK in same N suppl.		230		2		1.6		4	

Significance of F-values: * = at 5 % level, ** = at 1 % level, *** = at 0.1 % level.
F-values with significance better than 5 % are shown only.

Table 52. Experiment A3 on silty clay soil in 1986. Effect of various experimental factors on barley grain yield (85 % DM), moisture content of the grain at harvest, nitrogen content in grain, and nitrogen uptake by the grain yield. Sowing 28.5.1986. The rate of soluble N in slurry averaged 76 kg/ha.

Date of slurry application	Method of slurry application	Nitrogen supplementation, kg/ha							
		No	33	No	33	No	33	No	33
		Yield, kg/ha		% moisture		Nitrogen, mg/g		N uptake, kg/ha	
19.5.1986	Surface	2690	2930	38	40	20.3	23.2	46	58
»	Injection	3080	3370	35	37	20.4	24.3	53	70
9.6.1986	Surface	2180	2690	43	42	21.1	23.5	39	54
»	Injection	3300	3650	46	43	21.4	23.8	60	74
19.6.1986	Surface	1890	2440	44	41	24.1	23.9	39	49
»	Injection	2620	2830	46	43	21.9	23.0	49	55
F-values:	N supplementation	125.7**				28.5*		100.1**	
	Date of slurry appl.	18.4***		43.9***		4.8*		9.0**	
	Method of slurry appl.	156.6***						93.9***	
	N suppl. × Date			6.9*		7.8**			
	Date × Method	12.4***		6.2**		5.4*		9.5**	
Unfertilized		1410	2330	41	40	17.3	19.6	21	39
250 kg/ha NPK (20-4-8)		2830	3170	37	38	19.5	24.0	47	65
500 »		3290	3490	37	40	23.3	26.9	65	80
HSD (P = 0.05) for controls:									
N supplementation means		280		4		1.0		5	
Rate of NPK in same N suppl.		500		5		1.4		10	

Significance of F-values: * = at 5 % level, ** = at 1 % level, *** = at 0.1 % level.
F-values with significance better than 5 % are shown only.

On average, the highest grain yield and nitrogen uptake were obtained on plots with a slurry treatment before sowing, and the lowest on plots with the latest slurry application. The moisture content of the grain at harvest increased by delayed slurry applications but, to a certain extent, this negative effect could be avoided by nitrogen supplementation. The nitrogen content of grain was the lowest on plots with a slurry application before sowing, however, nitrogen content could succesfully be increased through nitrogen supplementation.

In 1986, injected slurry always produced a higher yield and N uptake compared to surface applied slurry, but in 1985 injection was advantageous only before sowing. When carried out after sowing, injection also increased the moisture content of the grain at harvest. However, this harmful effect could be lessened by nitrogen supplementation. In 1985, injection before sowing decreased the nitrogen content of grain, but in later slurry applications injection increased the nitrogen content. In 1986, the method of slurry application affected the nitrogen content of grain only slightly.

On the whole, nitrogen supplementation decreased the apparent recovery of soluble nitrogen only slightly (Table 53). However, the apparent efficiency of soluble nitrogen clearly diminished by nitrogen supplementation (Ta-

Table 53. Experiment A3 on silty clay soil in 1985—1986. Apparent recovery of soluble nitrogen in barley grain yield.

Slurry application schedule	Method of slurry application	Apparent recovery of soluble N in grain yield, %					
		1985		1986		$\bar{x}$	
		No N	N suppl.	No N	N suppl.	No N	N suppl.
Before sowing[1]	Surface	48	48	33	25	41	37
»	Injection	60	60	42	41	51	51
At sprouting[2]	Surface	44	48	24	20	34	34
»	Injection	45	45	51	46	48	46
After sprouting[3]	Surface	39	40	24	13	32	27
»	Injection	32	31	37	21	35	26
250 kg/ha NPK (20-4-8)		58	60	52	52	55	56
500 »		51	52	44	41	48	47

[1] 3—9 d before sowing, [2] 11—12 d after sowing, [3] 17—22 d after sowing

Table 54. Experiment A3 on silty clay soil in 1985—1986. Apparent efficiency of soluble nitrogen in increasing barley grain yield (kg of grain/kg of soluble N).

Slurry application schedule	Method of slurry application	Apparent efficiency of soluble N					
		1985		1986		$\bar{x}$	
		No N	N suppl.	No N	N suppl.	No N	N suppl.
Before sowing[1]	Surface	29	24	17	8	23	16
»	Injection	40	32	22	14	31	23
At sprouting[2]	Surface	25	21	10	5	18	13
»	Injection	24	15	25	17	25	16
After sprouting[3]	Surface	23	19	6	1	15	10
»	Injection	16	10	16	7	16	9
250 kg/ha NPK (20-4-8)		41	34	28	17	35	26
500 »		31	24	19	12	25	18

[1] 3—9 d before sowing, [2] 11—12 d after sowing, [3] 17—22 d after sowing

ble 54). The highest recoveries and efficiencies of soluble nitrogen were found for slurry treatments before sowing, and injection usually was superior to surface application.

The efficiency of slurry soluble nitrogen in experiments A2 and A3 was compared to that of the nitrogen in artificial fertilizer (Table 55). Surface applied slurries and that injected before sowing were as effective in increasing barley grain yield as in raising nitrogen uptake. For injections after sowing, however, the apparent recovery clearly surpassed the apparent efficiency of slurry soluble nitrogen. When measured by the apparent efficiency of soluble nitrogen, injection before sowing proved to be the best treatment.

In experiments A2 and A3, yield increase by injection compared to surface application varied between different dates of slurry application and different years (Table 56). No defini-

Table 55. Experiments A2 and A3 on silty clay soil in 1983—1986. Efficiency of soluble nitrogen in slurry compared to that of nitrogen in artificial fertilizer (average for 250 kg/ha and 500 kg/ha of NPK). Results from unirrigated plots in 1983—1984, and from plots without nitrogen supplementation in 1985—1986, only. The rate of soluble N in slurry averaged 68 kg/ha.

Slurry application schedule	Method of slurry application	Apparent recovery of sol. N, Slurry/Artificial fert., %			App. efficiency of sol. N, Slurry/Artificial fert., %		
		1983—1984	1985—1986	$\bar{x}$	1983—1984	1985—1986	$\bar{x}$
Before sowing[1]	Surface	67	80	74	75	77	76
»	Injection	107	99	103	104	103	104
At sprouting[2]	Surface	70	66	68	72	60	66
»	Injection	128	93	111	110	83	97
After sprouting[3]	Surface	44	62	53	51	50	51
»	Injection	98	68	83	84	53	69

[1] 1—9 d before sowing, [2] 11—13 d after sowing, [3] 17—24 d after sowing

Table 56. Experiments A2 and A3 on silty clay soil. Yield increase by injection compared to surface application, mean air temperature and total precipitation during five days following slurry application, and date of incorporation of surface applied slurry. Yield increase for unirrigated plots and for those without N supplementation, only.

Date of slurry application	Yield increase by injection, kg/ha (85 % DM)	Mean temperature and total precipitation,		Incorporation of surface applied slurry, date
		°C	mm	
	Applications 1—9 d before sowing			
9.5.1983	+ 620	9.9	12.2	9.5.
16.5.1984	+ 780	17.3	0.1	18.5
24.5.1985	+ 650	12.9	1.3	27.5.
19.5.1986	+ 390	10.8	13.6	23.5.
	Applications 11—13 d after sowing			
23.5.1983	+ 930	14.1	1.6	—
31.5.1984	+ 780	17.7	23.4	—
7.6.1985	— 60	10.2	2.7	—
9.6.1986	+1120	15.9	0.1	—
	Applications 17—24 d after sowing			
1.6.1983	+ 840	11.0	24.7	—
12.6.1984	+ 510	11.6	11.7	—
13.6.1985	— 390	11.8	17.0	—
19.6.1986	+ 730	15.2	2.0	—

tive conclusions can be drawn regarding the effect of weather conditions on the advantage obtained by injection. Nor did the advantage by injection seem to be related to the time lag between slurry spreading and the incorporation of surface applied slurry.

Experiment A4: Trampling experiments showed that no harmful effect whatsoever was caused by treatments before sowing (Table 57). The highest yield decrease was found when injection was imitated after sprouting (17—24 days after sowing), but even then yield decrease averaged only 9 % compared to the untreated plots.

Trampling treatments before sowing had no effect on the moisture content of the grain at harvest (Table 58). Imitation of injection after sowing, however, clearly delayed the ripening of the barley grain yield.

Experiment A4 demonstrated that only slight damage to the young barley crop would be caused by the spreader. However, visual observations during the growing seasons proved that the effect of wheel tracks was much more harmful in the actual slurry experiments compared to the trampling experiments. In the experiments with slurry, the moistening of the

Table 57. Experiment A4. Effect of various trampling treatments on barley grain yield on silty clay soil in 1983—1986. No slurry was applied, but 500 kg/ha of NPK (20-4-8) was applied over the whole experimental field.

Trampling schedule	Method of trampling	Grain yield, kg/ha (85 % DM)				
		1983	1984	1985	1986	x̄
Before sowing[1]	Surface	5880	3180	3410	3080	3890
»	Injection	5890	2960	3430	3350	3910
At sprouting[2]	Surface	6070	2930	3160	2970	3780
»	Injection	5920	2930	2920	3030	3700
After sprouting[3]	Surface	5690	2960	3100	3150	3730
»	Injection	5430	3040	2690	2640	3450
Untreated		5820	3010	3270	3110	3800
HSD (P = 0.05)		370	160	260	300	

[1] 1—9 d before sowing, [2] 11—13 d after sowing, [3] 17—24 d after sowing

Table 58. Experiment A4. Effect of various trampling treatments on the moisture content of barley grain at harvest on silty clay soil in 1983—1986. No slurry was applied, but 500 kg/ha of NPK (20-4-8) was applied over the whole experimental field.

Trampling schedule	Method of trampling	Moisture content of the grain at harvest, %				
		1983	1984	1985	1986	x̄
Before sowing[1]	Surface	20	17	29	45	28
»	Injection	20	19	31	44	29
At sprouting[2]	Surface	21	19	32	46	30
»	Injection	26	24	36	47	33
After sprouting[3]	Surface	21	20	31	44	29
»	Injection	24	23	34	46	32
Untreated		20	17	30	44	28
HSD (P = 0.05)		2	4	2	3	

[1] 1—9 d before sowing, [2] 11—13 d after sowing, [3] 17—24 d after sowing

soil within the wheel tracks by slurry finally hardened this silty clay soil almost impermeable thus killing plenty of barley seedlings within the wheel tracks. This did not occur in the trampling experiments using only artificial fertilizer, nor in the actual slurry experiments with injected slurry. In plots with slurry injected after sowing, on the other hand, damage to barley seedlings seemed to be caused by a high concentration of slurry in the injection stripes.

DISCUSSION

In accordance with the literature, slurry applied in spring was found to be much more effective compared to that applied in autumn or in winter (TUORILA and TAINIO 1934, IVERSEN 1944, KLAUSEN and NEMMING 1982, VETTER 1988). The efficiency of slurry applied onto the soil surface in September—October averaged only 20 to 25 % of that by the best slurry treatment in spring which roughly equalled that of artificial fertilizer applied in spring.

The high recoveries of the soluble nitrogen in spring applied slurry do not necessarily indicate that all of the soluble N originally present in slurry would have been as effective as that in artificial fertilizer. Significantly higher nitrogen losses through denitrification are often found when using slurry compared to artificial fertilizer (S. CHRISTENSEN 1983, 1985 a). Moreover, a part of the soluble N may have been immobilized during the initial stages of slurry decomposition in the soil (RAUHE et al. 1973, FLOWERS and ARNOLD 1983). However, if such soluble nitrogen losses have occurred they have been compensated by partial mobilization of originally organic N during the decomposition of slurry in the soil. On the whole, soluble nitrogen seems to explain the nitrogen efficiency of slurry on barley rather well.

In experiment A1 with different dates of slurry application throughout the year, the highest negative effects by slurry were found with the treatment of a wet soil in autumn or late winter. Farmers, who avoid spreading of slurry in spring in order to avoid trampling damage, may thus cause much greater damage when spreading manure at other times of the year. Trampling causes long-term damage to the soil. In autumn, the soil usually is rather wet. Spreading on a completely frozen soil, on the other hand, is seldom possible due to restrictions on winter application.

When examining different dates of slurry application in the spring (experiments A2 and A3), spreading before sowing proved the most worthwhile. In the best treatments, the apparent efficiency of slurry soluble nitrogen equalled that of the nitrogen in artificial fertilizer. Spreading at sprouting was rather profitable too, especially when measured by the apparent recovery of slurry soluble nitrogen. As compared to those, spreading about 10 d after sprouting appeared to be rather disadvantageous.

There are reports in the literature indicating that spring cereals would be especially susceptible to damage by the injector tines just at and shortly after sprouting, but less susceptible later on (BJELKE-HOLTERMANN 1966). However, in experiments at Jokioinen, not represented in this study, the injection of slurry into barley from four to five weeks after sowing produced still greater damage to the young barley crop.

The grain yield by slurry spread onto the soil surface about 10 d after sprouting averaged 80 % of that by the slurry spread onto the soil surface before sowing (experiments A2 and A3, unirrigated plots and those without nitrogen supplementation). By injection, the corresponding figure was 75 %. These figures are significantly lower than what would be expected on basis of the trampling experiments (96 % when imitating surface application, and 88 % when imitating injection). Might this difference between the actual slurry experiments and the trampling experiments then result from a delayed fertilizer effect of slurry spread after sowing? Apparently not. No significant interaction was found between the time of slurry application and nitrogen supplementation in experiment A3, i.e. a yield decrease by a delayed slurry application was the same whether artificial fertilizer was applied prior to sowing or not.

The difference between the actual slurry experiments and the trampling experiments results from a negative interaction between trampling and slurry. On basis of visual observations, the damage to young crop by slurry application after sowing was higher (actual slurry experiments) compared to that by imitation (trampling experiments). In plots with surface applied slurry, this was due to the moistening by slurry of the soil within the wheel tracks resulting in sludging and crust formation. In plots with injected slurry, the disadvantageous effect of slurry application 10 d after sprouting apparently resulted from an excessively high slurry concentration in the injection stripes. It was concluded that trampling experiments cannot be used in assessing the damage by slurry application after sowing.

Irrigation following a slurry application 10 d after sprouting had no significant effect on yields. It could have improved the efficiency of slurry spread on the soil surface earlier on the same day, but no such effect was found. In both experimental years 1983—1984, the early summers were rainy; as were the days following slurry application 10 d after sprouting.

Irrigation even seemed to decrease the apparent recovery and apparent efficiency of slurry soluble nitrogen. Since no such effect by irrigation was observed on plots with artificial fertilizer, a negative interaction between slurry and irrigation is suspected. In that case, anaerobic decomposition of slurry in the soil resulting in the production of phytotoxic compounds and enhanced denitrification would be the cause (MEEK et al. 1974, STEVENS and CORNFORTH 1974 b, BURFORD 1975, MCALLISTER 1977 a, RYDEN and LUND 1980, S. CHRISTENSEN 1983, 1985 a, 1985 b, 1985 c). Moreover, it was found through visual examinations during growing seasons that especially after surface application, irrigation seemed to enhance sludging and crust formation in the silty clay soil used for the experiment.

In both experimental years 1983—1984, irrigation seemed to reduce the advantage obtained by injection. However, this may not result from an advantageous effect by irrigation on plots with surface applied slurry, but rather from a disadvantageous effect by irrigation on plots with injected slurry. Again, the anaerobic decomposition of slurry in the soil is assumed to be the cause. The injection of slurry into soil has been demonstrated to create conditions especially advantageous for denitrification (JARVIS et al. 1987, THOMPSON et al. 1987, COMFORT et al. 1988).

Nitrogen supplementation proved to be advantageous in many ways. Although it could not prevent the yield decrease caused by delayed slurry applications (in plots with N supplementation), nitrogen supplementation always increased the barley grain yield compared to plots without nitrogen supplementation. In addition, nitrogen supplementation prevented or lessened the delay in the ripening of the barley grain yield caused by slurry applications after sowing and that caused by injection. Nitrogen supplementation also increased the nitrogen content of grain. These positive effects are so important that nitrogen supplementation is therefore highly recommended, especially if slurry is to be spread after sowing. In addition, artificial nitrogen applied in combination with manure may have a significant residual effect because mineral nitrogen is immobilized during the decomposition of manure (RAUHE et al.

1973, FLOWERS and ARNOLD 1983).

Injected slurry was usually superior to surface applied slurry in raising grain yield and nitrogen uptake. In a few cases, however, a negative effect by injection was found, especially when carried out after sowing. Injection after sowing also raised the moisture content of the grain at harvest, i.e. delayed ripening of the grain yield. A similar effect by injection on the nitrogen content of grain was found as well. These effects of slurry injection after sowing agree well with those caused by injection of anhydrous ammonia to barley after sowing (FOGH 1974, 1978).

Theoretically, the advantage by injection compared to surface application should depend on weather conditions. The greatest advantage should thus be obtained when the slurry application is followed by warm and rainless days (ERNST and MASSEY 1960, ADRIANO et al. 1974, FENN and KISSEL 1974, HOFF et al. 1981, BEAUCHAMP et al. 1982, RANK et al. 1988). In this study, however, no such logical dependence was found. The difference between the above theory and the practical findings may result from varying damage to the soil and the young barley crop by the spreader.

In experiment A1, slurry often was more effective in raising grain yield than in raising nitrogen uptake. This finding could indicate that the fertilizer effect of slurry did not solely depend on the soluble nitrogen in slurry. Positive effects by slurry on soil structure and water relations may then be important. In experiments A2 and A3, however, surface applied slurries and injection before sowing were as effective in increasing grain yield as in raising nitrogen uptake. By injections after sowing in experiments A2 and A3, the apparent recovery clearly surpassed the apparent efficiency of slurry soluble nitrogen. In this case the damage by injector tines to the young barley crop reduced the grain yield more severely than it decreased nitrogen uptake.

No residual effect by slurry applied to the same plots in four successive years was found. Although some residual effect was expected on the basis of the calculations by SLUIJSMANS and KOLENBRANDER (1977), the result is in agreement with several findings (DESTAIN et al. 1985, KIRCHMANN 1985, SMITH et al. 1985). Only slight or no residual effects were found when using only moderate rates of manure.

Finally, this series of experiments encourages the use of cow slurry as a fertilizer for barley. The best results are obtained by application before sowing in the spring. Slurry treatment at sprouting proved rather profitable, too. In general, injection offers greater advantage compared to surface application. An advantage of injection, not examined in this study, is the avoidance of run-off problems (KOFOED 1981, VOORBURG 1981). Malodours are usually diminished by injection as well (THYSELIUS 1988). Irrigation with water after slurry application did not prove worthwhile whereas the addition of artificial nitrogen fertilizer to slurry plots before sowing was found to be advantageous in many ways.

COW SLURRY AS A GRASSLAND FERTILIZER

INTRODUCTION

Owing to specialization in agriculture, the use of cow slurry as a grassland fertilizer is of great importance in Finland. Cows are fed predominantly grass silage produced by the farms. Relatively few studies, however, have been carried out on the effect of livestock manure and on the problems associated with its use on grassland. The studies performed indicate that slurry is a valuable fertilizer (RINNE 1977, HAKKOLA 1980 a, 1980 b, TAKALA 1984). The comparison of surface application and injection, however, has presented contradictory results (HAKKOLA 1980 b, TAKALA 1984). Damage to the sward caused by injection tines has been reported to be a significant problem (TAKALA 1984).

The value of slurry as a grassland fertilizer has been studied considerably in countries with a longer tradition of slurry use. Moreover, in those experiments the fertilizer value of slurry has been well established (CASTLE and DRYSDALE 1962, DRYSDALE 1963, 1965, MCALLISTER 1966 a, 1966 b, T.A. STEWART 1968 b, SLUIJSMANS and KOLENBRANDER 1977, LECOMTE 1980, SCHECHTNER et al. 1980, FURRER et al. 1982, GRACEY 1982). The problems reported concern nitrogen losses through denitrification and ammonia volatilization, growth disturbances due to high application rates, increasing contents of nitrate and potassium in grass forage, decrease in soil hydraulic conductivity through blockage of soil pores, and worsening of the palatability and hygienic quality of the fodder (ADRIANO et al. 1973, CORNFORTH 1973, HINRICHS et al. 1974, MEEK et al. 1974, STEVENS and CORNFORTH 1974 b, BURFORD 1975, 1976, MCALLISTER 1977 a, COLLINS 1980, PAIN and SANDERS 1980, SCHECHTNER et al. 1980, TUNNEY et al. 1980, LEA et al. 1982, LUTEN et al. 1982, BISCHOFF 1984, KUMAR et al. 1984, 1985, REID et al. 1984, SCHECHTNER 1986).

Ammonia volatilization, a serious problem in surface application, has been shown to diminish if the manure is spread during calm, cool and humid weather (EGNER 1932, ADRIANO et al. 1974, LAUER et al. 1976, BEAUCHAMP et al. 1978, 1982, HOFF et al. 1981, SHERLOCK and GOH 1984). Rain following slurry application very effectively saves ammonia. To avoid the escape of ammonia in unfavourable weather conditions, the injection method has been developed. Promising results by injection were obtained as early as the 1930's (IVERSEN 1934, WESTED and IVERSEN 1938). Slurry injection on grassland, on the other hand, has resulted in problems concerning damage to grass roots by injection tines, uneven distribution of slurry nutrients and soil oxygen depletion through the rapid decomposition of slurry (RÖNNINGEN and WESETH 1974, KOLENBRANDER 1981 b, LARSEN and KELLER 1985 b, HALL 1986, TUNNEY and MOLLOY 1986, PRINS and SNIJDERS 1987).

The objective of the present study was to examine the value of cow slurry as a grassland fertilizer. The comparison of surface applied and injected slurry was of special interest. Irrigation following slurry application was examined as a means to reduce ammonia volatilization. In addition, the use of artificial fertilizer in combination with slurry, and the harmful effects to grass caused by the wheels and injection tines of the spreader were investigated.

MATERIAL AND METHODS

A total of thirteen field experiments were carried out in 1982—1988. Four experiments lasted three years each, four experiments two years each and five experiments one year each. Eight experiments were carried out at Jokioinen (60° 49′ N, 23° 30′ E) and five at Ruukki (64° 40′ N, 25° 00′ E).

In all experiments a Finnish Teho-Lotina slurry spreader was used. The spreader weighs 2 250 kg, has a working width of 2.8—3.0 m, a capacity of 6.8 m^3 and is fitted with a bogie axle (ANON. 1983 b). The injector consists of six narrow tines spaced about 47 cm apart. Injection depth was about 12 cm in all experiments. For surface application, an iron plate was adjusted beneath the tines in order to improve the evenness of slurry distribution. The driving speed was about 5 km/h in all experiments.

Experiments B1 and B2 tested the effect of irrigation following slurry or NPK application, the difference between surface applied and injected slurry, and whether slurry can be applied on the same field in successive years without damaging the sward. The experiments had a split-split-plot design (Appendix 16) and both lasted three years. Experiment B1 was located on a sandy clay soil at Jokioinen and experiment B2 on a sandy loam soil at Ruukki (Table 59).

Irrigation following slurry or NPK application was the main experimental factor. In general, 30 mm of water was irrigated during the night following fertilization, but in the last experimental year at Jokioinen, 20 mm of water was irrigated only. The time lag between fertilization and the beginning of irrigation was 6—9 hours. Sprinkler irrigation was used, and irrigation of 30 mm of water lasted about six hours.

Each main plot included three subplots with different years of slurry application. Slurry was applied either in the first year only, in the first and the second year, or in all three experimental years. Slurry was always applied only once a year, within nine days after the first cut. Thus, every year the second grass yield represents the immediate effect of slurry whereas the first and the third grass yields represent residual effects. The rate of slurry ranged from 40 to 67 m^3/ha.

For the first grass yield every year, 400 kg/ha NPK (20-4-8) was applied over the whole experimental field at Jokioinen, and 300 kg/ha at Ruukki. For the third grass yield at Jokioinen, 300 kg/ha NPK (20-4-8) was applied over the

Table 59. Properties of the experimental soils. Nutrients were determined according to VUORINEN and MÄKITIE (1955), and pH from a mixture of soil : deionized water = 1 : 2.5.

Experiment no.	Soil Type	pH	mg/l of soil			
			Ca	K	Mg	P
B1	Sandy clay	6.7	2500	260	460	30
B2	Sandy loam	6.0	850	30	85	16
B3, B7, B8, B9	Clay	6.3	3300	430	570	17
B4a	Carex peat	5.6	1750	75	340	7
B4b	Carex peat	5.1	1970	50	320	7
B4c	Sand	6.3	1830	60	140	16
B5, B6	Sandy clay	6.3	2200	270	680	3
B10	Clay	6.1	2400	260	430	9
B11	Sandy loam	5.5	700	55	65	16
B12	Sandy loam	6.0	750	30	75	16
B13	Carex peat	5.4	1800	70	370	7

B4a = experiment B4 in 1985, B4b = experiment B4 in 1986 and B4c = experiment B4 in 1987 whole field in 1984 and 1985, but in 1983 none was applied. To the subplots with slurry in the first year or in the first and the second years only, 400 kg/ha NPK (20-4-8) was applied after the first cut in the second and the third years, or in the third experimental year, respectively. In addition to the slurry-manured subplots, the following control treatments were included: unfertilized, 200 kg/ha and 400 kg/ha NPK (20-4-8). It can be seen from the field plan in Appendix 16, that the unfertilized subplots were irrigated unevenly and thus cannot be compared to the other subplots with respect to irrigation. However, grass yields from unfertilized subplots and their nitrogen contents were used as a basis for calculating the apparent recovery of nitrogen.

Each subplot with slurry included two sub-subplots. Slurry was applied either onto the grass surface or injected into the soil.

At Jokioinen, the experiment lasted from 1983 to 1986, and that at Ruukki from 1982 to 1985. The dates for cuts and experimental treatments are shown in Table 60, and the amounts of nutrients applied in slurry in Table 61. A Haldrup—1 500 experimental mower was used for cutting the grass. At Ruukki, the grass sward was established in 1981, and the seed mixture contained 70 % *Phleum pratense* var. Tammisto and 30 % *Festuca pratensis* var. Boris. At Jokioinen, the grass sward was established in 1982, and the seed mixture contained 60 % *Phleum pratense* var. Tarmo and 40 % *Festuca pratensis* var. Kalevi. The number of replicates

Table 60. Dates of experimental treatments and cuts in different experiments.

Experiment no.	Year	Treatment after the first cut	Cut no.		
			1	2	3
		Slurry or NPK application			
B1	1983	13.6.	8.6.	19.7	29. 9.
	1984	12.6.	6.6.	25.7.	5.10.
	1985	20.6.	17.6.	7.8.	18. 9.
	1986	—	10.6.	—	—
B2	1982	8.7.	30.6.	10.9.	—
	1983	8.7.	30.6.	18.8.	—
	1984	6.7.	27.6.	10.9.	—
	1985	—	3.7.	—	—
B3	1984	15.6.	11.6.	25.7.	11.10.
	1985	20.6.	18.6.	7.8.	18. 9.
	1986	23.6.	12.6.	14.8.	—
	1987	—	22.6.	—	—
B4	1985	10.7.	26.6.	28.8.	—
	1986	2.7.	17.6.	14.8.	—
	1987	1.7.	30.6.	20.8.	—
	1988	—	21.6.	—	—
		Trampling with the spreader			
B5	1983	13.6.	10.6.	19.7	—
B6	1984	15.6.	11.6.	25.7.	5.10.
B7	1984	15.6.	11.6.	25.7.	11.10.
	1985	—	17.6.	7.8.	—
B8	1985	20.6.	17.6.	7.8.	18. 9.
	1986	—	12.6.	14.8.	—
B9	1986	23.6.	12.6.	14.8.	—
B10	1985	24.6.	17.6.	5.8.	18. 9.
B11	1983	7.7.	29.6.	31.8.	—
	1984	—	13.6.	—	—
B12	1984	20.6.	15.6.	30.7.	—
	1985	—	28.6.	—	—
B13	1985	5.7.	1.7.	26.8.	—

Table 61. Amounts of nutrients applied in slurry in different experiments.

Experiment no.	Year	Amount of slurry, m^3/ha	kg/ha			
			Total N	Soluble N	P	K
B1	1983	50	126	61	25	135
	1984	50	126	73	28	171
	1985	67	96	64	13	158
B2	1982	40	120	71	29	70
	1983	40	120	71	26	83
	1984	40	120	68	27	105
B3	1984	60	151	88	34	207
	1985	60	85	58	12	140
	1986	60	121	76	22	196
B4	1985	60	199	118	34	155
	1986	60	146	94	29	154
	1987	60	177	106	41	142

was four, except for unfertilized plots with three replicates only.

Results for slurry plots in experiments B1 and B2 were first calculated with respect to irrigation and the method of slurry application in every experimental year separately (Tables 62—67 and 70—75). By this method of calculation, the number of replicates was twelve in the first experimental year, eight in the second year and four in the third year. In addition, results for yields representing residual effects at the end of experiments were calculated with respect to all the experimental factors: irrigation, the year and the method of slurry application (Tables 68—69 and 76—77). In this calculation the number of replicates was four.

Experiments B3 and B4 tested the effect of artificial fertilizer in combination with slurry. Experiment B3 was located on a heavy clay soil at Jokioinen and it lasted from 1984 to 1987 (Table 59). It included main plots with no slurry, 60 m^3/ha of cow slurry by surface application and 60 m^3/ha of cow slurry by injection (Appendix 17). Subplots included following treatments: no NPK, 167 kg/ha, 333 kg/ha and 500 kg/ha NPK (20-4-8).

Experimental treatments were carried out only once a year, within two weeks after the first cut. Thus the immediate effect of slurry and NPK is seen in the second grass yield, while the residual effects are seen in the first and the third grass yields. For the first and the third grass yields each year at Jokioinen, 400 kg/ha and 300 kg/ha NPK (20-4-8) were applied, respectively. The dates for the cuts and experimental treatments are shown in Table 60, and the amounts of nutrients applied in slurry in Table 61. Grass was cut with a Haldrup—1 500 experimental mower. The grass sward was established in 1983 and consisted of *Phleum pratense* var. Tarmo only. The number of replicates was four.

Experiment B4 was carried out at Ruukki in 1985—1988, and was similar to experiment B3 at Jokioinen. However at Ruukki, the experiment was carried out on different soils in different years (Table 59). Only two grass yields per year were cut. For the first yield, 500 kg/ha of NPK (18-3-12) was applied in 1986 and in 1988, but in 1987, 650 kg/ha of NPK (18-3-12) was applied. The grass contained 70 % *Phleum pratense* var. Tammisto and 30 % *Festuca pratensis* var. Boris.

Weather information for experiments B1—B4 is presented in Appendices 18—19.

Experiments B5—B13 tested the damage to grass caused by the wheels and injection tines of the spreader. All experiments included the following treatments by the spreader: surface application (wheels only), injection (wheels and injection tines), injection and rolling thereafter (wheels, injection tines and the roll), and no treatment with the spreader (Appendix 20). Treatments were carried out only once a year, within eleven days after the first cut. No slurry was applied, but instead, experiments were fertilized with 400—500 kg/ha NPK (20-4-8). Experiments B5—B10 were located on clay soils at Jokioinen, and experiments B11—B13 on peat and loam soils at Ruukki (Table 59). Grasses were one to three years old when used for the experiments and they had been established with seed mixtures consisting mainly of *Phleum pratense* and *Festuca pratensis*.

The roll used in experiments at Jokioinen was a Finnish Ranko-roll with a working width of 2.0 m, a diameter of 55 cm and a total weight of 740 kg. The roll used at Ruukki weighed 750 kg and had a working width of 2.75 m and a diameter of 35 cm. The number of replicates was four in all the experiments. The dates for cuts and experimental treatments are shown in Table 60. For cuts, a Haldrup-1 500 experimental mower was used. Grass was always cut so that the effect of one wheel track could be seen in the yield results.

All experiments were examined visually during the growing seasons. The relative value of surface applied versus injected slurry was of special interest.

Grass samples from experiments B1—B4 were analyzed for dry matter, total nitrogen, phosphorus and potassium. Nitrogen was analyzed by the Kjeldahl method using a Tecator apparatus. Phosphorus was measured spectrometrically using a vanadate method, and the cations by atomic absorption spectrometry (KÄHÄRI and NISSINEN 1978). From the yields and their nitrogen contents, nitrogen uptake and its apparent recovery were calculated.

Some cuts in experiments B1—B4 were also analyzed for nitrate. Since no significant differences between treatments were found, those results are not presented. Variation between replicates was very high. Nitrate in grass could be increased by slurry and NPK in some replicates but irregularly. Nitrate was analyzed by an ionselective electrode using the method developed by AURA (1985).

Slurries used in the experiments were analyzed for dry matter, total nitrogen, soluble nitrogen, phosphorus and potassium. Soluble nitrogen was analyzed by extracting the samples with a $CaCl_2$-HCl-solution followed by ammonia distillation. This method is traditionally used in Finland and it gives results quite comparable to those obtained by direct distillation of manure ammonia (KÄHÄRI 1974).

Results were computed using a VAX 11/780 computer and SAS statistical program (ANON. 1985). Tukey's test was employed to examine the differences between treatments (STEEL and TORRIE 1960). In the results the 'Honestly Significant Difference', obtained by Tukey's test is expressed as HSD (P = 0.05).

The significance of F-values is expressed by asterisks. One asterisk (*) indicates significance at the 5 % level (P = 0.05), two asterisks (**) at the 1 % level (P = 0.01), and three asterisks (***) at the 0.1 % level (P = 0.001).

Statistical significance could not be calculated for N uptake, N content, P content and K content in the second cut in 1987 in experiment B4 because samples for chemical analysis were combined to represent treatments.

RESULTS

Experiment B1: Irrigation following fertilization had only a slight influence on grass yields and their chemical properties on the sandy clay soil at Jokioinen (Tables 62—66). It increased the second yield by NPK fertilizer in 1985, but decreased the nitrogen content in the second grass yield in 1983. No other effects by irrigation were significant at the 5 % level.

Table 62. Grass dry matter yields in experiment B1 on sandy clay soil at Jokioinen (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Grass dry matter yield, kg/ha in cut/year								
		2/1983	3/1983	1/1984	2/1984	3/1984	1/1985	2/1985	3/1985	1/1986
No irrigation	Surface	1110	1240	3040	1770	1540	3380	2050	1680	3400
»	Injection	1120	1380	3400	1870	1510	3170	2480	1760	3440
Irrigation	Surface	1160	1160	3070	1860	1510	3130	2240	1770	3350
»	Injection	1110	1280	3340	1690	1460	3100	2690	1750	3450
F-value:	Irrigation	0.2	0.1	0.0	0.5	0.4	1.0	1.1	0.9	0.0
	Method of appl.	0.1	15.9***	5.5*	0.2	0.6	3.4	20.0**	1.2	2.8
	Interaction	0.3	0.1	0.1	3.3	0.1	1.7	0.0	2.9	0.6
No irrigation	Unfertilized	640	650	2600	470	1530	3180	930	1480	3160
»	1/2 NPK	1530	1370	2910	2400	1410	3040	2320	1690	3330
»	1 NPK	2130	2140	2700	2960	1500	3130	3140	1820	3320
Irrigation	Unfertilized	650	630	3060	460	1430	3040	940	1520	3180
»	1/2 NPK	1310	1260	2760	2140	1390	3190	2360	1720	3200
»	1 NPK	2170	1770	3230	2980	1430	2880	3970	1770	3440
F-value (unfertilized plots excluded):										
	Irrigation	0.5	0.5	0.7	0.4	5.8	0.2	16.9*	0.1	0.0
	Rate of NPK	20.3**	107.3***	0.1	31.1**	0.6	2.3	55.1***	2.6	1.5
	Interaction	0.7	4.7	0.7	1.2	0.1	7.7*	5.9	0.4	1.8

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 63. Nitrogen uptake by grass in experiment B1 on sandy clay soil at Jokioinen (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Nitrogen uptake, kg/ha in cut/year								
		2/1983	3/1983	1/1984	2/1984	3/1984	1/1985	2/1985	3/1985	1/1986
No irrigation	Surface	22	19	71	29	32	89	35	50	91
»	Injection	27	21	78	37	32	83	51	54	93
Irrigation	Surface	23	17	69	29	30	83	36	51	90
»	Injection	26	20	74	34	30	83	50	51	91
F-value:	Irrigation	0.0	0.1	0.2	0.4	1.1	0.6	0.0	0.4	0.2
	Method of appl.	10.9**	28.5***	3.3	26.4***	0.0	3.2	154.9***	1.6	0.4
	Interaction	1.2	0.3	0.1	1.7	0.1	2.5	0.6	2.5	0.0
No irrigation	Unfertilized	10	10	57	7	30	82	15	44	82
»	1/2 NPK	30	20	64	37	28	82	41	49	86
»	1 NPK	52	30	62	59	31	85	68	55	88
Irrigation	Unfertilized	10	10	68	7	29	80	16	44	80
»	1/2 NPK	25	18	59	32	27	83	38	49	83
»	1 NPK	50	26	71	57	30	77	83	52	92
F-value (unfertilized plots excluded):										
	Irrigation	3.0	0.2	0.1	1.1	2.7	0.3	4.9	1.9	0.1
	Rate of NPK	58.3***	60.4***	0.3	272.6***	3.1	0.8	124.0***	9.2*	3.1
	Interaction	0.2	0.7	0.6	0.7	0.0	8.9*	7.6*	0.9	1.0

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 64. Nitrogen content in grass dry matter in experiment B1 on sandy clay soil at Jokioinen (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Nitrogen content in grass dry matter, g/kg in cut/year								
		2/1983	3/1983	1/1984	2/1984	3/1984	1/1985	2/1985	3/1985	1/1986
No irrigation	Surface	19.9	14.8	23.6	16.2	20.6	26.5	17.0	30.1	26.9
»	Injection	24.3	15.4	23.2	19.8	21.2	26.1	20.8	30.7	27.0
Irrigation	Surface	20.0	14.6	22.9	15.8	20.1	26.5	16.1	28.8	26.9
»	Injection	22.9	15.2	22.1	20.4	20.6	26.7	18.9	28.9	26.5
F-value: Irrigation		13.5*	0.1	7.8	0.0	4.0	1.9	3.8	5.8	0.3
Method.of appl.		85.6***	10.5**	4.0	85.5***	3.7	0.2	41.7***	0.4	0.0
Interaction		3.5	0.0	0.3	1.2	0.0	0.7	1.0	0.3	0.2
No irrigation	Unfertilized	15.9	14.7	22.1	14.5	19.7	25.7	16.1	29.8	25.9
»	1/2 NPK	19.4	14.7	22.6	15.3	20.0	27.0	17.7	28.9	25.7
»	1 NPK	24.4	14.1	23.4	20.0	20.6	27.2	21.8	30.2	26.5
Irrigation	Unfertilized	15.0	15.8	22.3	14.7	20.4	26.1	16.9	29.1	25.3
»	1/2 NPK	18.7	14.2	21.8	15.2	19.2	26.1	16.1	28.6	26.0
»	1 NPK	22.8	14.6	21.9	19.3	20.8	26.9	21.0	29.5	26.8
F-value (unfertilized plots excluded):										
Irrigation		30.9*	0.0	3.7	1.5	0.7	0.5	3.4	0.6	0.7
Rate of NPK		41.0***	0.2	0.6	100.1***	7.1*	0.9	120.8***	6.1*	2.4
Interaction		0.6	4.6	0.3	0.5	1.7	0.2	1.0	0.1	0.0

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 65. Phosphorus content in grass dry matter in experiment B1 on sandy clay soil at Jokioinen (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate efects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Phosphorus content in grass dry matter, g/kg in cut/year								
		2/1983	3/1983	1/1984	2/1984	3/1984	1/1985	2/1985	3/1985	1/1986
No irrigation	Surface	3.6	2.2	3.8	3.4	3.3	3.9	2.7	4.7	4.3
»	Injection	3.6	2.3	3.7	3.8	3.3	3.9	2.8	4.7	3.2
Irrigation	Surface	3.4	2.1	3.7	3.4	3.3	3.9	2.6	4.6	4.3
»	Injection	3.6	2.2	3.7	3.8	3.3	3.8	2.8	4.9	4.2
F-value: Irrigation		1.0	2.3	0.7	0.0	0.0	0.1	0.3	0.1	0.0
Method of appl.		1.2	10.9**	3.7	48.1***	0.8	2.1	18.3**	0.9	0.2
Interaction		0.9	0.0	1.2	0.7	0.0	0.7	0.2	1.7	0.4
No irrigation	Unfertilized	2.9	2.2	3.6	2.9	3.1	3.8	2.5	4.4	4.3
»	1/2 NPK	3.3	2.1	3.6	3.2	3.1	3.9	2.7	4.6	4.3
»	1 NPK	3.8	2.1	3.8	4.0	3.3	3.9	3.1	4.7	4.2
Irrigation	Unfertilized	2.8	2.3	3.7	2.9	3.2	3.9	2.6	4.4	4.3
»	1/2 NPK	3.1	2.0	3.6	3.1	3.1	3.9	2.5	4.3	4.2
»	1 NPK	3.8	2.1	3.6	3.9	3.4	4.0	3.1	4.9	4.2
F-value (unfertilized plots excluded):										
Irrigation		0.9	0.0	1.9	0.2	0.1	0.1	0.1	0.0	0.8
Rate of NPK		93.1***	4.1	1.6	35.7***	4.5	4.2	65.1***	8.2*	0.2
Interaction		0.2	2.5	1.1	0.0	0.3	1.0	4.1	3.8	1.2

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 66. Potassium content in grass dry matter in experiment B1 on sandy clay soil at Jokioinen (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Potassium content in grass dry matter, g/kg in cut/year								
		2/1983	3/1983	1/1984	2/1984	3/1984	1/1985	2/1985	3/1985	1/1986
No irrigation	Surface	36.1	16.8	37.6	28.4	29.9	38.2	25.1	40.5	40.2
»	Injection	38.4	17.7	38.2	32.1	29.4	38.1	29.0	40.7	40.9
Irrigation	Surface	35.7	16.3	38.1	27.7	28.7	38.3	25.3	39.0	41.1
»	Injection	37.3	16.9	38.0	32.2	28.6	37.9	29.2	40.5	39.7
F-value: Irrigation		1.6	0.3	0.1	0.0	1.1	0.0	0.0	1.4	0.2
Method of appl.		13.8***	8.0**	0.6	49.9***	1.0	0.6	34.7**	1.3	0.2
Interaction		0.5	0.2	1.5	0.4	0.4	0.2	0.0	0.9	2.2
No irrigation	Unfertilized	27.6	15.5	35.7	20.5	27.5	37.2	20.2	38.9	39.8
»	1/2 NPK	37.0	16.2	36.9	27.3	27.4	37.4	25.4	37.7	39.0
»	1 NPK	43.3	17.2	38.3	36.8	28.0	37.2	31.1	38.4	37.8
Irrigation	Unfertilized	28.2	17.2	37.1	21.9	27.4	38.0	21.8	40.7	39.4
»	1/2 NPK	36.3	16.0	36.7	26.4	26.5	36.8	24.4	38.3	38.3
»	1 NPK	42.5	17.6	37.1	35.3	27.9	38.7	32.7	38.9	37.7
F-value (unfertilized plots excluded):										
Irrigation		0.4	0.0	0.4	4.6	0.2	0.3	0.3	0.8	0.3
Rate of NPK		14.9**	11.4*	1.1	75.9***	2.4	4.2	171.4***	5.7	4.7
Interaction		0.0	0.5	0.3	0.1	0.5	5.4	6.3*	0.1	0.6

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

The method of slurry application had a more significant effect on grass yields and their chemical properties than irrigation had. Injected slurry often produced higher yields with higher nitrogen uptakes and nutrient contents compared to surface applied slurry. Yields by injected slurry averaged 4.8 % higher than those by surface applied slurry on unirrigated plots, and 3.2 % higher on irrigated plots. The corresponding increase by injection in N uptake averaged 8.6 % on unirrigated plots and 7.1 % on irrigated plots. In the first experimental year, injected slurry also seemed to have a higher residual effect compared to surface applied slurry. Method of application had no significant interaction with irrigation.

The effects of irrigation and method of slurry application on the succeeding grass yield varied considerably in different years. Variation can be explained by the weather conditions after slurry application (Appendix 18). In 1983 and 1984, when no effect or a negative effect by irrigation and injection was found, slurry application was followed by rainy days, in 1984 by rather cool days as well. In 1985, when a slightly positive effect by irrigation and a clearly positive effect by injection was found, the days following slurry application were warm and rainless. The early summers of 1983 and 1984 were also exceptionally rainy but, in 1985, normal (Appendix 19). Although not determined, soil moisture content at the time of slurry application must have been accordingly higher in 1983 and 1984 compared to that in 1985.

According to visual examinations, surface applied slurry always had a faster effect on grass growth compared with injected slurry. Grass by surface application turned green at an equal rate compared to that by artificial fertilizer whereas by injection the grass responded to slurry significantly slower. By injection, a lag period of about two weeks was observed during which time the fertilizer effect of slurry slowly migrated from the injection stripes to the middle of the injection rows. These observations were verified by determining the nitro-

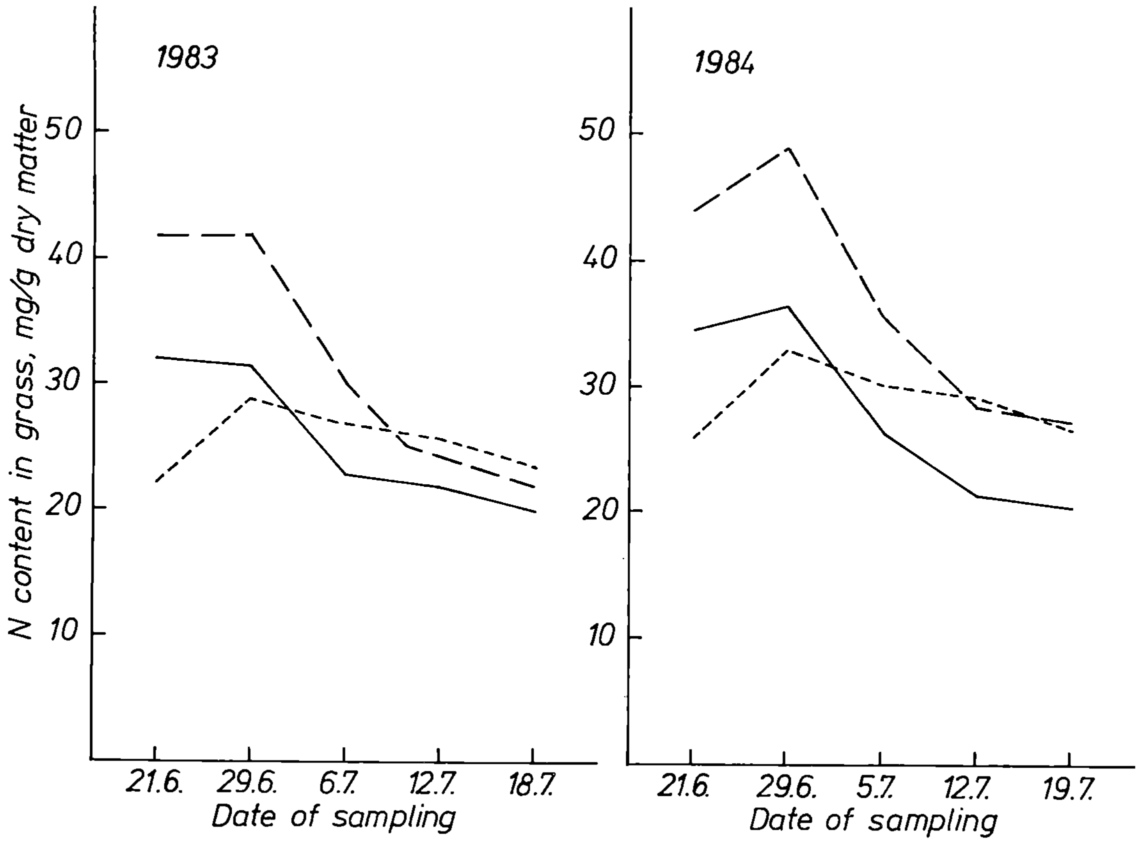

Fig. 2. Nitrogen content in grass samples collected from experiment B1 in 1983 and 1984. On plots with injected slurry the samples were taken from the middle of injection row spaces (——— = surface applied slurry, - - - - - - = injected slurry, — — — = NPK). Manuring 13.6.1983 and 12.6.1984.

gen content in grass samples (Fig. 2). On plots with injected slurry, grass samples were taken from the middle of injection row spaces, i.e. 23—25 cm apart from slurry stripes. Grass by surface applied slurry and that by NPK behaved in a parallel manner whereas that by injected slurry had a significantly lower nitrogen content for about two weeks after fertilization. Nitrogen content in grass by injected slurry, however, surpassed that by surface applied slurry in the second cut. Similar visual observations were also obtained in experiments B2, B3 and B4.

As compared to NPK fertilizer, cow slurry proved to be rather ineffective. Although the rate of total nitrogen applied in slurry ranged from 96 to 126 kg/ha and that of soluble nitrogen from 61 to 73 kg/ha in different years, yields by slurry hardly corresponded to those by 40 kg/ha nitrogen in NPK fertilizer. In many cases, however, the residual effect of slurry seemed to surpass that of NPK.

The apparent recovery of nitrogen varied considerably in different years (Table 67). However, the apparent recovery of nitrogen in injected slurry clearly surpassed that in surface applied slurry. Irrigation seemed to decrease the apparent recovery of nitrogen in slurry and that of nitrogen in 200 kg NPK/ha, but not that of nitrogen in 400 kg NPK/ha. When the apparent recoveries of slurry soluble nitrogen were compared to those of nitrogen in 400 kg

Table 67. Apparent recovery of nitrogen in experiment B1 at Jokioinen. No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Cut/Year												$\bar{x}$ for sums
		2/83	3/83	1/84	ε	2/84	3/84	1/85	ε	2/85	3/85	1/86	ε	
		Apparent recovery of slurry soluble nitrogen, %												
No irrigation	Surface	20	15	23	58	30	3	10	43	31	9	14	54	52
»	Injection	28	18	34	80	41	3	1	45	56	16	17	89	71
Irrigation	Surface	21	11	2	34	30	1	4	35	31	11	16	58	42
»	Injection	26	16	11	53	37	1	4	42	53	11	17	81	59
		Apparent recovery of slurry total nitrogen, %												
No irrigation	Surface	10	7	11	28	17	2	6	25	22	6	10	38	30
»	Injection	13	9	17	39	24	2	1	26	39	11	12	61	42
Irrigation	Surface	10	6	1	17	17	1	2	21	22	8	11	40	26
»	Injection	13	8	6	26	21	1	2	25	37	8	12	56	36
		Apparent recovery of nitrogen in artificial fertilizer, %												
No irrigation	1/2 NPK	50	25	18	93	75	<0	0	70	52	10	8	70	78
»	1 NPK	53	25	6	84	65	1	4	70	55	11	6	72	75
Irrigation	1/2 NPK	38	20	<0	35	63	<0	8	65	44	10	6	60	53
»	1 NPK	50	20	4	74	63	1	<0	60	69	8	12	90	75

NPK/ha, the efficiencies were 69 %, 95 %, 56 % and 79 % for surface applied slurry without irrigation, injected slurry without irrigation, surface applied slurry with irrigation and injected slurry with irrigation, respectively. It can also be seen in the apparent recovery of nitrogen that the effect of slurry was distributed throughout the three succeeding cuts more evenly than that of NPK.

When the grass dry matter yields of the third cut in 1985 and the first cut in 1986 were calculated with respect to all experimental factors: irrigation, year of slurry application and the method of slurry application, no significant differences between treatments were found (Table 68). However, the year of slurry appli-

Table 68. Grass dry matter yields in the 3rd cut in 1985 and in the 1st cut in 1986 in experiment B1 at Jokioinen (residual effects).

Year of slurry application	Irrigation	Method of slurry application	Grass dry matter yield, kg/ha	
			3/1985	1/1986
1983	No irrigation	Surface	1800	3390
»	»	Injection	1830	3390
»	Irrigation	Surface	1860	3350
»	»	Injection	1750	3380
1983 + 1984	No irrigation	Surface	1780	3480
»	»	Injection	1850	3460
»	Irrigation	Surface	1750	3440
»	»	Injection	1700	3360
1983 + 1984 + 1985	No irrigation	Surface	1680	3400
»	»	Injection	1760	3440
»	Irrigation	Surface	1770	3350
»	»	Injection	1750	3450
Unfertilized	No irrigation		1480	3160
»	Irrigation		1520	3180

No significant differences among slurry treatments were found at 5 % level.

Table 69. Residual effect of the year of slurry application on nutrient contents in grass in the third cut in 1985 and in the first cut in 1986 in experiment B1 at Jokioinen.

Year of slurry application	3rd cut in 1985 g/kg dry matter			1st cut in 1986 g/kg dry matter
	N	P	K	K
1983	29.8	4.9	40.4	39.0
1983 + 1984	30.7	4.9	41.1	38.7
1983 + 1984 + 1985	29.6	4.7	40.2	40.5
HSD (P = 0.05)	0.8	0.1	0.8	0.9

Irrigation or the method of application had no significant effects at 5 % level

cation slightly influenced the N, P and K content of the third grass yield in 1985 and the K content of the first grass yield in 1986 (Table 69). In the third cut in 1985, their contents were the highest in grass manured with slurry in 1983 and 1984, but in the first cut in 1986 the K content was the highest in grass manured with slurry during all the experimental years.

Experiment B2: Irrigation following fertilization seemed to have a considerable effect on grass yields and their chemical properties on the sandy loam soil at Ruukki. Owing to a high variation between replicates, however, only a few differences were statistically significant (Tables 70—74). In two cases, irrigation significantly decreased the nitrogen content and in three cases the phosphorus content of grass.

Injected slurry produced higher yields with higher nitrogen uptakes and nutrient contents compared to surface applied slurry, especially in the first and the second experimental years. Yields by injected slurry averaged 6.3 % higher than those by surface applied slurry on unirrigated plots, and 4.1 % higher on irrigated plots. The corresponding increase in N uptake by injection averaged 12.4 % on unirrigated plots, and 6.1 % on irrigated plots. The method of slurry application had no significant residual effect. Nor was interaction found between irrigation and the method of application.

The days following slurry application were rainless and rather warm each year (Appendix 18). July 1984, however, was exceptionally rainy which seems to coincide with the poor

Table 70. Grass dry matter yields in experiment B2 on sandy loam soil at Ruukki (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Grass dry matter yield, kg/ha in cut/year					
		2/1982	1/1983	2/1983	1/1984	2/1984	1/1985
No irrigation	Surface	1490	6610	1650	5620	1940	2980
»	Injection	1710	6480	2500	5510	2890	2470
Irrigation	Surface	2240	6610	2290	5520	3430	3160
»	Injection	2750	6850	2710	5690	3390	2820
F-value: Irrigation		1.3	0.3	2.0	0.0	4.6	0.3
Method of appl.		4.7*	0.2	12.3**	0.0	0.8	1.1
Interaction		0.8	1.9	1.4	0.3	1.0	0.1
No irrigation	Unfertilized	650	5870	960	4950	1710	2230
»	1/2 NPK	3030	6630	1750	4590	3900	3020
»	1 NPK	2130	6620	2860	4670	4540	2540
Irrigation	Unfertilized	700	6290	710	4270	2130	1600
»	1/2 NPK	2930	6430	2070	4310	3940	2390
»	1 NPK	2760	6680	3020	4960	4920	2580
F-value (unfertilized plots excluded):							
Irrigation		0.2	0.0	0.4	0.0	0.8	1.3
Rate of NPK		2.4	0.1	22.0**	0.3	48.1***	0.1
Interaction		1.1	0.1	0.1	0.2	2.2	0.4

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 71. Nitrogen uptake by grass in experiment B2 on sandy loam soil at Ruukki (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Nitrogen uptake, kg/ha in cut/year					
		2/1982	1/1983	2/1983	1/1984	2/1984	1/1985
No irrigation	Surface	26	89	30	79	31	56
»	Injection	31	88	57	78	49	46
Irrigation	Surface	33	84	44	88	59	58
»	Injection	45	86	59	78	67	53
F-value: Irrigation		0.8	0.9	1.7	0.1	2.7	0.3
Method of appl.		7.9**	0.0	17.9***	1.2	1.5	0.9
Interaction		1.0	0.2	1.5	1.0	0.2	0.1
No irrigation	Unfertilized	10	72	16	71	27	39
»	1/2 NPK	50	74	31	57	73	56
»	1 NPK	39	90	64	66	115	58
Irrigation	Unfertilized	9	78	13	62	38	35
»	1/2 NPK	41	84	34	57	67	48
»	1 NPK	41	81	60	67	113	56
F-value (unfertilized plots excluded):							
Irrigation		0.6	0.0	0.0	0.0	0.3	0.6
Rate of NPK		0.8	0.3	25.7**	1.0	169.7***	0.1
Interaction		0.6	0.8	0.3	0.0	0.5	0.1

** = significant at 1 % level, *** = at 0.1 % level

Table 72. Nitrogen content in grass dry matter in experiment B2 on sandy loam soil at Ruukki (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Nitrogen content in grass dry matter, g/kg in cut/year					
		2/1982	1/1983	2/1983	1/1984	2/1984	1/1985
No irrigation	Surface	17.2	13.5	17.8	13.9	16.6	18.7
»	Injection	18.8	13.6	23.2	14.0	16.6	19.2
Irrigation	Surface	14.3	12.7	19.0	15.5	16.4	18.0
»	Injection	16.3	12.5	21.3	13.6	19.3	19.4
F-value: Irrigation		11.3*	7.6	0.2	0.2	0.4	0.0
Method of appl.		19.4***	0.0	27.9***	2.4	1.9	1.6
Interaction		0.1	0.2	4.2	3.2	1.9	0.4
No irrigation	Unfertilized	14.8	12.3	16.8	14.2	15.9	17.5
»	1/2 NPK	17.4	11.0	17.1	12.4	18.6	18.4
»	1 NPK	18.3	13.7	22.2	14.2	25.4	22.1
Irrigation	Unfertilized	12.7	12.2	17.5	14.5	16.8	20.9
»	1/2 NPK	14.0	13.1	16.1	13.1	17.0	20.1
»	1 NPK	15.2	11.9	19.6	13.6	23.0	21.8
F-value (unfertilized plots excluded):							
Irrigation		4.1	0.1	24.9*	0.0	7.8	1.3
Rate of NPK		0.5	0.8	22.1**	3.5	70.0***	7.8*
Interaction		0.0	5.8	0.8	1.3	0.2	1.0

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

Table 73. Phosphorus content in grass dry matter in experiment B2 on sandy loam soil at Ruukki (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Phosphorus content in grass dry matter, g/kg in cut/year					
		2/1982	1/1983	2/1983	1/1984	2/1984	1/1985
No irrigation	Surface	3.0	2.6	3.8	2.6	3.5	2.9
»	Injection	3.3	2.6	3.8	2.6	3.4	2.8
Irrigation	Surface	2.8	2.5	3.9	2.6	3.4	2.9
»	Injection	3.1	2.5	3.8	2.5	3.5	2.9
F-value: Irrigation		9.4	17.0*	0.6	4.3	0.1	0.4
Method of appl.		13.1***	0.2	0.2	1.0	0.0	1.5
Interaction		0.1	0.9	0.8	0.0	0.6	0.7
No irrigation	Unfertilized	2.7	2.5	3.8	2.6	3.5	2.6
»	1/2 NPK	2.9	2.4	3.4	2.6	3.2	2.9
»	1 NPK	3.1	2.6	4.0	2.6	3.2	2.8
Irrigation	Unfertilized	2.3	2.3	3.6	2.7	3.2	2.7
»	1/2 NPK	2.5	2.5	3.4	2.4	3.0	2.9
»	1 NPK	2.6	2.3	3.6	2.6	2.9	2.8
F-value (unfertilized plots excluded):							
Irrigation		15.3*	0.9	13.9*	0.4	4.6	0.0
Rate of NPK		0.5	0.0	9.2*	1.0	0.0	1.1
Interaction		0.1	1.5	2.1	2.3	0.1	0.0

* = significant at 5 % level, *** = at 0.1 % level

Table 74. Potassium content in grass dry matter in experiment B2 on sandy loam soil at Ruukki (1/2 NPK = 200 kg/ha NPK 20-4-8, 1 NPK = 400 kg/ha). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Potassium content in grass dry matter, g/kg in cut/year					
		2/1982	1/1983	2/1983	1/1984	2/1984	1/1985
No irrigation	Surface	25.7	19.4	28.6	17.9	29.6	26.8
»	Injection	28.8	19.8	33.4	16.7	24.5	24.1
Irrigation	Surface	24.5	18.3	30.4	18.6	25.8	26.3
»	Injection	27.2	19.4	30.6	17.2	25.0	23.5
F-value: Irrigation		1.1	3.5	0.1	0.1	0.4	0.1
Method of appl.		18.3***	1.4	3.1	2.0	5.7	4.6
Interaction		0.1	0.3	2.8	0.0	3.1	0.0
No irrigation	Unfertilized	17.6	16.0	17.4	15.0	16.9	21.0
»	1/2 NPK	25.1	18.6	23.6	17.4	24.7	24.4
»	1 NPK	24.2	16.6	25.6	14.1	26.0	24.6
Irrigation	Unfertilized	18.4	17.9	19.9	14.5	14.5	23.5
»	1/2 NPK	22.5	18.2	24.1	13.6	21.6	24.9
»	1 NPK	22.3	17.6	24.8	15.5	25.1	27.5
F-value (unfertilized plots excluded):							
Irrigation		1.5	0.1	0.0	0.8	0.6	0.9
Rate of NPK		0.1	0.9	0.8	0.2	2.6	2.3
Interaction		0.0	0.2	0.2	2.1	0.5	1.7

*** = significant at 0.1 % level

effect of injected slurry on irrigated plots of that year (Appendix 19).

In terms of grass dry matter yields, the relative efficiency of cow slurry compared to NPK fertilizer varied considerably in different years and different treatments. In the second experimental year, the efficiency of slurry was generally rather high, but in the first and the third years quite low. For the first experimental year, however, comparison is difficult due to the poor effect by the higher rate of NPK. The residual effect of slurry was especially high in the second experimental year.

The apparent recovery of nitrogen varied considerably in different years. However, injected slurry was clearly more effective than surface applied slurry, and irrigation following slurry application was advantageous (Table 75). In combination with NPK fertilizer, however, irrigation seemed to have a slightly negative effect. In some cases, the apparent recovery of nitrogen in NPK was well over 100 % but averaged 80—90 %. When the apparent recoveries of the soluble nitrogen in slurry were compared to that of nitrogen in 400 kg NPK/ha, the efficiencies were 44 %, 66 %, 81 % and 95 % for surface applied slurry without irrigation, injected slurry without irrigation, surface applied slurry with irrigation and injected slurry with irrigation, respectively. The effect of slurry seemed to be distributed in the two grass yields per year more evenly than that of NPK fertilizer.

When the grass dry matter yields of the first cut in 1985 were calculated with respect to all the experimental factors: irrigation, year of slurry application and the method of slurry application, no significant differences between treatments were found although slightly higher grass yields were obtained from plots manured with slurry during all the experimental years compared to the other plots (Table 76). However, the year of slurry application significantly influenced the nitrogen and potassium content in grass (Table 77). Contents were the highest in grass manured with slurry in 1982 and 1983. The low N and K contents in grass manured with slurry during all the experimental years apparently result from a dilution effect.

Experiment B3: Experimental treatments after the first cut did not significantly affect the

Table 75. Apparent recovery of nitrogen in experiment B2 at Ruukki. No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Irrigation after fertilization	Method of application/ Rate of NPK	Cut/Year									$\bar{x}$ for sums
		2/82	1/83	ε	2/83	1/84	ε	2/84	1/85	ε	
		Apparent recovery of slurry soluble nitrogen, %									
No irrigation	Surface	23	24	46	20	11	31	6	25	31	36
»	Injection	30	23	52	58	10	68	32	10	43	54
Irrigation	Surface	34	8	42	44	37	80	31	34	65	62
»	Injection	51	11	62	65	23	87	43	26	69	73
		Apparent recovery of slurry total nitrogen, %									
No irrigation	Surface	13	14	28	12	7	18	3	14	18	21
»	Injection	18	13	31	34	6	40	18	6	24	32
Irrigation	Surface	20	5	25	26	22	48	18	19	37	37
»	Injection	30	7	37	38	13	52	24	15	39	43
		Apparent recovery of nitrogen in artificial fertilizer, %									
No irrigation	1/2 NPK	100	5	105	38	<0	3	115	43	158	89
»	1 NPK	36	23	59	60	<0	54	110	24	134	82
Irrigation	1/2 NPK	83	15	98	53	<0	40	73	33	105	81
»	1 NPK	41	4	45	59	6	65	94	26	120	77

Table 76. Grass dry matter yields in the 1st cut in 1985 in experiment B2 at Ruukki (residual effects).

Year of slurry application	Irrigation	Method of slurry application	Grass dry matter yield, kg/ha
			1/1985
1982	No irrigation	Surface	2300
»	»	Injection	2150
»	Irrigation	Surface	2720
»	»	Injection	2750
1982 + 1983	No irrigation	Surface	2450
»	»	Injection	2690
»	Irrigation	Surface	2600
»	»	Injection	1930
1982 + 1983 + 1984	No irrigation	Surface	2980
»	»	Injection	2470
»	Irrigation	Surface	3160
»	»	Injection	2820
Unfertilized	No irrigation		2230
»	Irrigation		1600

No significant differences among slurry treatments were found at 5 % level.

Table 77. Residual effect of the year of slurry application on nutrient contents in grass in the 1st cut in 1985 in experiment B2 at Ruukki.

Year of slurry application	N g/kg dry matter	K g/kg dry matter
1982	21.5	26.5
1982 + 1983	22.1	28.0
1982 + 1983 + 1984	18.8	25.2
HSD (P = 0.05)	1.8	2.3

Irrigation or the method of application had no significant effects at 5 % level.

second or the third grass yield in the first year (Table 78). Variation between replicates was high and relatively high yields were obtained without any fertilization. However, the residual effect of slurry application in 1984 was seen in a slightly but significantly lower yield in the first cut in 1985 compared to plots without slurry.

In the second cut in 1985, slurry treatments had no significant effect on grass yields although the yields by slurry averaged 280 to 300 kg/ha higher compared to those without slurry. However, the effect of NPK was often significant and a significant interaction between slurry and NPK was also found. Yield response to NPK was much more prominent on plots without slurry than on the plots with slurry. The effect of slurry exclusively seemed to equal that of the lowest rate of NPK alone. However, the single highest yield was obtained without slurry. No significant differences were found in the third cut in 1985 nor in the first cut in 1986 although slurry and NPK both seemed to have a slight residual effect.

In the second cut in 1986, both slurry treatments increased yields significantly compared to the plots without slurry. Effect of NPK was significant especially on plots without slurry. The effect of slurry exclusively seemed to equal that of the lowest rate of NPK alone. However, the single highest yield was obtained without slurry. Injected slurry had a significant residual effect in the first cut in 1987 compared to plots without slurry. No other residual effects were significant.

Despite significantly variable weather conditions after slurry application in different years, yields by injected slurry and surface applied slurry were almost equal in all the experimental years (Appendix 18). As compared to the

Table 78. Grass dry matter yields in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Grass dry matter yield, kg/ha in cut/year							
		2/1984	3/1984	1/1985	2/1985	3/1985	1/1986	2/1986	1/1987
No slurry	0	4050	2180	3220	860	1640	3900	1000	1620
»	167	4200	2100	3350	1860	1680	3860	1690	1600
»	333	4310	1940	3390	2620	1660	3700	2150	1930
»	500	4020	2100	3220	3130	1620	3840	2560	1940
	x̄	4140	2080	3290	2120	1650	3830	1850	1770
Surface appl.	0	3620	2170	3060	1840	1670	3670	1610	2060
»	167	3590	2020	2980	2340	1730	3960	2080	2340
»	333	4030	2140	2930	2640	1680	3990	2180	2310
»	500	4020	2420	2880	2780	1780	4000	2370	2660
	x̄	3810	2190	2960	2400	1710	3910	2060	2350
Injection	0	3520	2050	3200	1740	1790	3890	1800	2500
»	167	3920	2350	2830	2190	1700	3890	2120	2500
»	333	3740	2190	2970	2940	1830	3830	2230	2490
»	500	3850	1990	2920	2800	1890	3920	2270	2430
	x̄	3760	2150	2980	2420	1800	3880	2100	2480
HSD (P = 0.05) for									
Slurry treatment means		940	610	170	520	210	280	120	650
NPK in same slurry treatment		980	680	630	450	280	430	440	670
F-value: Interaction		0.5	1.0	0.5	7.4***	0.7	1.1	4.7**	0.9

** = significant at 1 % level, *** = at 0.1 % level

Table 79. Nitrogen uptake by grass in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8) No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Nitrogen uptake, kg/ha in cut/year							
		2/1984	3/1984	1/1985	2/1985	3/1985	1/1986	2/1986	1/1987
No slurry	0	71	45	83	13	46	87	18	44
»	167	81	45	86	31	46	87	34	44
»	333	81	40	90	49	47	86	50	51
»	500	87	43	83	68	49	91	67	50
	x̄	80	43	86	40	47	88	42	47
Surface appl.	0	74	45	80	31	50	84	37	53
»	167	77	46	80	48	52	95	57	65
»	333	101	49	81	60	56	92	68	63
»	500	101	57	80	74	55	98	79	71
	x̄	88	49	80	53	53	92	60	63
Injection	0	83	43	85	37	55	91	51	68
»	167	99	53	78	50	56	94	66	71
»	333	95	52	80	77	63	96	72	72
»	500	103	51	79	76	68	98	79	73
	x̄	95	50	81	60	60	95	67	71
HSD (P = 0.05) for									
Slurry treatment means		22	16	8	12	5	9	6	17
NPK in same slurry treatment		26	18	16	15	11	13	14	21
F-value: Interaction		0.9	0.9	0.4	2.0	1.1	0.6	2.2	0.4

plots without slurry, yield increase by surface applied slurry averaged 3.2 % and that by injected slurry 4.2 %.

The results for nitrogen uptake were parallel to those for grass dry matter yield, but often the differences were more significant (Table 79). For instance, nitrogen uptake by the third yield in 1985 from injected slurry surpassed that from surface applied slurry which, in turn, surpassed that from the plots without slurry. As compared to the plots without slurry, the increase in N uptake by surface applied slurry averaged 13.9 %, and that by injected slurry 22.5 %.

Differences were also found in the nitrogen, phosphorus and potassium contents of grass (Tables 80—82). In general, their contents were raised by an increasing rate of NPK and were the highest by injected slurry and the lowest without slurry. Differences between injection and surface application were especially prominent when comparing the plots without and those with only a small rate of NPK.

In the first experimental year, the apparent recovery of nitrogen was rather poor, in some cases even negative (Table 83). In 1985, significantly higher recoveries were obtained. The figures for 1986, in turn, roughly equal those of 1985. On the whole, an increasing rate of NPK did not worsen the apparent recovery of slurry nitrogen. Apparent recovery of nitrogen was generally higher for injected slurry than for surface applied slurry. When the apparent recoveries of the soluble nitrogen in slurry were compared to those of nitrogen in artificial fertilizer, the efficiency averaged 67 % for surface applied slurry and 105 % for injected slurry.

Experiment B4: Effect on grass yield of the slurry treatment (no slurry — surface application — injection) was statistically significant only in the second cut in 1987 (Table 84). Then grass yields by injected slurry clearly surpassed

Table 80. Nitrogen content in grass dry matter in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Nitrogen content in grass dry matter, g/kg in cut/year							
		2/1984	3/1984	1/1985	2/1985	3/1985	1/1986	2/1986	1/1987
No slurry	0	17.4	20.6	26.1	14.7	28.2	22.3	17.7	26.9
»	167	19.4	21.1	25.6	16.9	27.4	22.7	20.0	27.2
»	333	18.8	20.5	26.6	18.7	28.3	23.2	23.5	26.2
»	500	21.5	20.4	26.0	21.9	30.3	23.6	26.7	26.1
	$\overline{x}$	19.3	20.6	26.1	18.0	28.6	23.0	22.0	26.6
Surface appl.	0	19.9	20.4	26.3	16.8	29.9	22.9	23.0	25.3
»	167	21.2	22.5	26.8	20.5	29.9	24.0	27.6	27.2
»	333	25.0	22.9	28.0	22.6	33.7	23.0	31.1	27.4
»	500	25.2	24.2	28.0	26.7	31.3	24.4	33.4	26.9
	$\overline{x}$	22.8	22.5	27.3	21.6	31.2	23.6	28.8	26.7
Injection	0	23.5	20.8	26.8	21.3	30.4	23.4	28.8	27.2
»	167	25.0	22.7	27.6	22.7	33.1	24.4	31.0	28.4
»	333	25.6	23.9	27.2	26.2	34.3	24.9	32.5	28.8
»	500	26.6	25.8	27.3	27.1	36.3	25.1	35.1	29.8
	$\overline{x}$	25.2	23.3	27.2	24.3	33.5	24.5	31.8	28.6
HSD (P = 0.05) for									
Slurry treatment means		1.9	1.5	2.1	1.3	2.6	0.9	1.6	2.3
NPK in same slurry treatment		4.0	4.0	4.0	3.6	4.4	2.5	4.4	3.8
F-value: Interaction		1.1	1.3	0.3	1.1	1.6	0.4	0.9	0.8

Table 81. Phosphorus content in grass dry matter in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Phosphorus content in grass dry matter, g/kg in cut/year							
		2/1984	3/1984	1/1985	2/1985	3/1985	1/1986	2/1986	1/1987
No slurry	0	3.2	2.9	3.2	1.9	3.9	3.6	2.4	3.6
»	167	3.4	2.9	3.2	2.1	4.1	3.6	2.6	3.8
»	333	3.3	2.7	3.3	2.4	4.2	3.5	2.7	3.6
»	500	3.5	2.9	3.2	2.6	4.4	3.5	2.9	3.6
	$\bar{x}$	3.4	2.8	3.3	2.2	4.2	3.5	2.7	3.6
Surface appl.	0	3.5	2.8	3.3	2.2	4.1	3.4	2.9	3.5
»	167	3.8	3.1	3.4	2.4	4.2	3.6	3.0	3.8
»	333	4.1	3.3	3.4	2.5	4.4	3.5	3.0	3.8
»	500	4.1	3.5	3.3	2.6	4.5	3.5	3.1	3.9
	$\bar{x}$	3.9	3.2	3.4	2.4	4.3	3.5	3.0	3.7
Injection	0	3.9	3.0	3.2	2.2	4.3	3.5	2.9	3.7
»	167	3.9	3.1	3.3	2.3	4.3	3.5	3.0	3.7
»	333	4.0	3.3	3.2	2.4	4.5	3.4	3.0	3.7
»	500	4.0	3.6	3.3	2.4	4.5	3.4	3.2	3.9
	$\bar{x}$	3.9	3.3	3.3	2.3	4.4	3.4	3.0	3.8
HSD (P = 0.05) for									
Slurry treatment means		0.3	0.4	0.1	0.2	0.2	0.1	0.2	0.2
NPK in same slurry treatment		0.5	0.4	0.3	0.2	0.4	0.2	0.3	0.4
F-value: Interaction		1.0	2.7*	0.4	4.7**	0.3	0.9	0.6	1.3

* = significant at 5 % level, ** = at 1 % level

Table 82. Potassium content in grass dry matter in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Potassium content in grass dry matter, g/kg in cut/year							
		2/1984	3/1984	1/1985	2/1985	3/1985	1/1986	2/1986	1/1987
No slurry	0	31.3	26.1	34.6	17.9	35.2	34.0	17.0	33.9
»	167	34.1	25.9	35.1	20.4	36.0	34.5	23.8	34.1
»	333	34.5	24.3	35.4	23.9	36.3	33.2	28.0	33.4
»	500	36.3	25.3	35.4	28.4	37.6	33.2	31.4	34.2
	$\bar{x}$	34.0	25.4	35.1	22.6	36.3	33.7	25.1	33.9
Surface appl.	0	35.4	25.7	35.6	21.6	35.8	33.8	26.0	33.5
»	167	38.7	27.3	36.5	25.0	36.1	34.2	30.2	35.2
»	333	40.4	28.2	35.6	27.2	38.3	35.0	32.5	36.2
»	500	41.5	29.7	35.9	29.3	40.1	34.9	32.7	37.1
	$\bar{x}$	39.0	27.7	35.9	25.8	37.6	34.5	30.3	35.5
Injection	0	39.1	26.0	36.0	23.4	39.0	34.1	29.9	35.2
»	167	40.1	27.6	35.7	25.5	38.4	33.6	32.2	36.9
»	333	40.9	28.7	35.3	27.7	41.1	33.4	32.5	35.7
»	500	40.2	30.7	36.1	29.9	40.5	34.0	35.5	37.1
	$\bar{x}$	40.1	28.2	35.8	26.6	39.8	33.8	32.5	36.2
HSD (P = 0.05) for									
Slurry treatment means		3.6	3.6	0.4	2.1	4.4	1.6	2.6	1.8
NPK in same slurry treatment		5.3	3.4	1.9	2.6	3.8	2.2	4.1	3.3
F-value: Interaction		0.7	2.5*	0.7	2.3	0.7	1.3	4.4**	1.0

* = significant at 5 % level, ** = at 1 % level

Table 83. Apparent recovery of nitrogen in experiment B3 on clay soil at Jokioinen (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 and 3 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Cut/Year											$\bar{x}$ for sums
		2/84	3/84	1/85	ε	2/85	3/85	1/86	ε	2/86	1/87	ε	
Apparent recovery of slurry soluble nitrogen, %													
Surface appl.	0	3	0	<0	0	31	7	<0	33	25	12	37	21
»	167	<0	1	<0	<0	29	10	14	53	30	28	58	30
»	333	23	10	<0	23	19	16	10	45	24	16	40	34
»	500	16	16	<0	28	10	10	12	33	16	28	44	35
Injection	0	14	<0	2	14	41	16	7	64	43	32	74	48
»	167	20	9	<0	20	33	17	12	62	42	36	78	51
»	333	16	14	<0	18	48	28	17	93	29	28	57	51
»	500	18	9	<0	20	14	33	12	59	16	30	46	39
Apparent recovery of slurry total nitrogen, %													
Surface appl.	0	2	0	<0	0	21	5	<0	22	16	7	23	13
»	167	<0	1	<0	<0	20	7	9	36	19	17	36	18
»	333	13	6	<0	13	13	11	7	31	15	10	25	21
»	500	9	9	<0	17	7	7	8	22	10	17	27	22
Injection	0	8	<0	1	8	28	11	5	44	27	20	47	30
»	167	12	5	<0	12	22	12	8	42	26	22	48	32
»	333	9	8	<0	11	33	19	12	64	18	17	35	32
»	500	11	5	<0	12	9	22	8	40	10	19	29	24
Apparent recovery of nitrogen in artificial fertilizer, %													
No slurry	167	30	0	9	39	55	0	0	55	48	0	48	47
»	333	15	<0	10	18	54	1	<0	54	48	10	58	44
»	500	16	<0	0	14	55	3	4	62	49	6	55	44

Table 84. Grass dry matter yields in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Grass dry matter yield, kg/ha in cut/year					
		2/1985	1/1986	2/1986	1/1987	2/1987	1/1988
No slurry	0	2790	2910	2910	3830	770	3780
»	167	4040	3240	4310	3780	1650	3350
»	333	4420	3180	4680	3730	2010	3580
»	500	4510	3410	5150	4040	2230	3540
	$\bar{x}$	3940	3190	4260	3840	1670	3560
Surface appl.	0	4030	3390	3500	4170	920	3670
»	167	4140	3540	4040	4140	1270	3870
»	333	4390	3630	4340	4210	1680	3880
»	500	4370	3450	5280	4300	1690	3960
	$\bar{x}$	4230	3480	4290	4200	1390	3850
Injection	0	3830	3310	4010	3730	1710	3850
»	167	4510	3770	4290	3990	2160	4250
»	333	4310	3360	4380	3910	2320	4150
»	500	4590	3480	4670	3980	2780	3820
	$\bar{x}$	4310	3500	4340	3900	2240	4010
HSD (P = 0.05) for							
Slurry treatment means		400	560	520	490	500	630
NPK in same slurry treatment		460	280	860	450	880	420
F-value: Interaction		8.7***	3.9**	3.1*	0.6	0.6	3.6**

* = significant at 5 % level, ** = at 1 % level, *** = at 0.1 % level

those from the other plots. However, the yields by surface applied slurry averaged 4.6 % higher compared to those from plots without slurry. The corresponding yield increase by injected slurry was 9.1 %.

An increasing rate of NPK often raised grass yields significantly. The highest yield increases by NPK were obtained on plots without slurry.

The highest yield increase by injected slurry compared to surface applied slurry (in the second cut in 1987) seemed to coincide with relatively low precipitation following slurry application (Appendix 18).

Nitrogen uptake by grass shows differences between various slurry treatments more clearly compared with grass dry matter yields (Table 85). As compared to the plots without slurry, N uptake from plots with surface applied slurry averaged 7.1 % higher. The average increase in N uptake by injected slurry was correspondingly 21.1 %.

Experimental treatments also affected the contents of nitrogen, phosphorus and potassium in grass dry matter (Tables 86—88). Contents were generally the highest with injected slurry and the lowest without slurry, and they increased by an increasing rate of NPK. In many cases, however, the residual effects of slurry and NPK were negative.

The apparent recovery of nitrogen in injected slurry clearly surpassed that of nitrogen in surface applied slurry (Table 89). The greatest difference between surface application and injection was seen in the last experimental year on a sand soil. An increasing rate of NPK did not weaken the efficiency of slurry nitrogen significantly. When the apparent recoveries of the soluble nitrogen in slurry were compared to those of nitrogen in artificial fertilizer, the efficiency averaged 20 % for surface applied slurry and 55 % for injected slurry. Thus the efficiency of slurry nitrogen in this experiment was

Table 85. Nitrogen uptake by grass in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Nitrogen uptake, kg/ha in cut/year					
		2/1985	1/1986	2/1986	1/1987	2/1987	1/1988
No slurry	0	34	68	58	91	11	96
»	167	50	74	87	91	26	89
»	333	62	82	100	86	35	92
»	500	68	75	112	88	43	90
	$\bar{x}$	54	75	89	89	29	92
Surface appl.	0	53	71	67	95	15	91
»	167	61	84	91	98	22	100
»	333	67	83	95	93	31	101
»	500	70	85	130	99	30	100
	$\bar{x}$	63	81	96	96	24	98
Injection	0	63	75	97	87	35	95
»	167	77	81	105	94	48	118
»	333	80	76	112	96	50	103
»	500	86	85	128	95	61	106
	$\bar{x}$	77	80	110	93	49	105
HSD (P = 0.05) for							
Slurry treatment means		12	18	9	11	—	18
NPK in same slurry treatment		15	18	21	12	—	16
F-value: Interaction		1.2	0.7	2.3	1.1	—	2.4

Statistical significance for nitrogen uptake in cut 2/1987 could not be calculated

Table 86. Nitrogen content in grass dry matter in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Nitrogen content in grass dry matter, g/kg in cut/year					
		2/1985	1/1986	2/1986	1/1987	2/1987	1/1988
No slurry	0	12.2	23.1	19.6	23.8	13.8	25.4
»	167	12.3	22.5	20.1	23.8	15.8	26.6
»	333	14.2	25.6	21.4	22.9	17.5	25.9
»	500	15.1	22.0	21.9	21.8	19.3	25.5
	x̄	13.4	23.3	20.8	23.1	16.6	25.9
Surface appl.	0	13.2	21.1	19.2	22.9	16.1	24.8
»	167	14.7	23.5	22.4	23.6	17.0	26.0
»	333	15.2	23.0	22.1	22.0	18.5	25.9
»	500	16.0	24.6	24.4	23.1	18.0	25.1
	x̄	14.8	23.0	22.0	22.9	17.4	25.5
Injection	0	16.5	22.7	24.2	23.4	20.7	24.9
»	167	17.0	21.6	24.6	23.6	22.4	27.9
»	333	18.6	22.7	25.8	24.8	21.8	24.9
»	500	18.7	24.5	27.5	24.0	22.1	27.8
	x̄	17.7	22.9	25.5	23.9	21.7	26.4
HSD (P = 0.05) for							
Slurry treatment means		2.3	3.8	2.1	3.6	—	2.4
NPK in same slurry treatment		2.6	5.0	3.2	3.2	—	2.6
F-value: Interaction		0.4	1.3	0.9	1.0	—	1.9

Statistical significance for nitrogen content in cut 2/1987 could not be calculated

Table 87. Phosphorus content in grass dry matter in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Phosphorus content in grass dry matter, g/kg in cut/year					
		2/1985	1/1986	2/1986	1/1987	2/1987	1/1988
No slurry	0	2.3	3.3	2.9	3.9	2.5	3.7
»	167	2.5	3.3	2.9	3.8	2.8	3.6
»	333	2.7	3.2	2.9	3.5	3.1	3.6
»	500	2.7	3.1	2.8	3.4	3.4	3.4
	x̄	2.6	3.2	2.9	3.6	3.0	3.6
Surface appl.	0	2.7	3.2	3.0	3.8	3.1	3.5
»	167	2.9	3.1	3.1	3.6	3.1	3.6
»	333	2.9	3.0	3.0	3.5	3.3	3.5
»	500	3.0	3.1	3.1	3.6	3.6	3.6
	x̄	2.9	3.1	3.1	3.6	3.3	3.6
Injection	0	2.9	3.2	3.1	3.6	2.8	3.6
»	167	2.9	3.0	2.9	3.6	3.6	4.0
»	333	2.9	3.0	3.0	3.6	3.3	3.5
»	500	2.9	3.3	3.1	3.6	3.4	3.8
	x̄	2.9	3.1	3.0	3.6	3.3	3.7
HSD (P = 0.05) for							
Slurry treatment means		0.2	0.2	0.3	0.3	—	0.5
NPK in same slurry treatment		0.2	0.3	0.4	0.4	—	0.3
F-value: Interaction		3.6 **	1.6	0.5	1.3	—	2.7*

* = significant at 5 % level, ** = at 1 % level
Statistical significance for phosphorus content in cut 2/1987 could not be calculated

Table 88. Potassium content in grass dry matter in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Potassium content in grass dry matter, g/kg in cut/year					
		2/1985	1/1986	2/1986	1/1987	2/1987	1/1988
No slurry	0	20.3	32.9	27.4	26.0	17.2	29.6
»	167	22.9	33.9	26.8	25.6	18.9	29.8
»	333	25.2	34.1	27.2	26.6	18.6	29.8
»	500	26.8	31.8	27.2	24.7	21.7	29.5
	$\bar{x}$	23.8	33.4	27.1	25.7	19.1	29.7
Surface appl.	0	27.0	32.5	28.0	30.4	23.3	30.6
»	167	29.3	31.7	29.7	29.2	23.0	31.7
»	333	28.7	31.1	28.1	29.1	23.2	31.5
»	500	29.7	33.3	29.1	29.4	25.6	30.9
	$\bar{x}$	28.7	32.2	28.7	29.5	23.8	31.2
Injection	0	29.9	32.4	32.7	30.6	23.0	31.1
»	167	29.8	30.5	31.3	31.6	29.8	33.1
»	333	31.9	33.2	32.6	32.0	25.9	30.2
»	500	31.8	34.2	32.3	31.3	25.3	33.2
	$\bar{x}$	30.8	32.6	32.2	31.4	26.0	31.9
HSD ($P = 0.05$) for							
Slurry treatment means		3.1	3.8	3.5	4.7	—	2.5
NPK in same slurry treatment		3.2	5.2	4.6	4.6	—	3.2
F-value: Interaction		2.1	1.2	0.4	0.4	—	1.2

Statistical significance for potassium content in cut 2/1987 could not be calculated

Table 89. Apparent recovery of nitrogen in experiment B4 at Ruukki (NPK-fertilizer = 20-4-8). No. 2 cuts represent immediate effects while no. 1 cuts represent residual effects.

Slurry treatment	NPK kg/ha	Cut/Year									$\bar{x}$ for sums
		2/85	1/86	ε	2/86	1/87	ε	2/87	1/88	ε	
		Apparent recovery of slurry soluble nitrogen, %									
Surface appl.	0	16	3	19	10	4	14	4	<0	<0	11
»	167	9	8	18	4	7	12	<0	10	7	12
»	333	4	1	5	<0	7	2	<0	8	5	4
»	500	2	8	10	19	12	31	<0	9	<0	12
Injection	0	25	6	31	41	<0	37	23	<0	22	30
»	167	23	6	29	19	3	22	21	27	48	33
»	333	15	<0	10	13	11	23	14	10	25	19
»	500	15	8	24	17	7	24	17	15	32	27
		Apparent recovery of slurry total nitrogen, %									
Surface appl.	0	10	2	11	6	3	9	2	<0	<0	7
»	167	6	5	11	3	5	8	<0	6	4	7
»	333	3	1	3	<0	5	1	<0	5	3	2
»	500	1	5	6	12	8	20	<0	6	<0	7
Injection	0	15	4	18	27	<0	24	14	<0	13	18
»	167	14	4	17	12	2	14	12	16	29	20
»	333	9	<0	6	8	7	15	8	6	15	11
»	500	9	5	14	11	5	16	10	9	19	16
		Apparent recovery of nitrogen in artificial fertilizer, %									
No slurry	167	48	18	67	88	0	88	45	<0	24	59
»	333	42	21	63	63	<0	55	36	<0	30	50
»	500	34	7	41	54	<0	51	32	<0	26	39

Table 90. Effect of trampling treatments with the spreader and roll on the second grass yield in experiments B5—B10 at Jokioinen and experiments B11—B13 at Ruukki. Treatments were carried-out after the first cut. No slurry was applied, but the experiments were fertilized with artificial fertilizer.

Treatment	Grass dry matter yield, kg/ha in experiment no.									
	B5 Sandy clay	B6 Sandy clay	B7 Clay	B8 Clay	B9 Clay	B10 Clay	B11 Sandy loam	B12 Sandy loam	B13 Carex peat	$\bar{x}$
Untreated	2870	6330	4260	2990	2410	3730	3020	4960	4810	3930
As by surface appl.	2860	6070	4010	3090	2200	3450	3270	4870	4630	3830
As by injection	2760	5880	3680	2710	2020	3100	2480	4470	4180	3480
» + rolling	2290	5010	3510	2400	1900	3110	2320	4130	4000	3190
HSD (P = 0.05)	300	440	990	690	650	340	1130	1300	550	

Table 91. Residual effects of trampling treatments in experiments B5—B13. Relative dry matter yields (untreated = 100).

Treatment	Jokioinen			Ruukki
	3rd cut in the same year	1st cut in the following year	2nd cut in the following year	1st cut in the following year
As by surface appl.	103	100	97	101
As by injection	106	87	101	98
» + rolling	103	92	99	92
No. of experiments	4	2	2	2

clearly poorer compared to experiments B1—B3.

Experiments B5—B13: No significant yield reduction was caused by the wheels of the spreader when surface application was simulated (Table 90). Injection tines, however, caused a clear reduction on the succeeding grass yield (11 %). A still higher yield reduction averaging 19 % resulted from the treatment with injection tines and rolling thereafter.

At Jokioinen where three grass yields per year were cut, the treatments had no negative effect on the third grass yield (Table 91). However, a reduction was found again in the first yield of the following year. The negative residual effect of treatments was also obtained at Ruukki.

DISCUSSION

In terms of dry matter production, cow slurry seemed to be rather ineffective compared to artificial fertilizer. In general, slurry corresponded to less than 40—50 kg/ha nitrogen in artificial fertilizer although the rate of total nitrogen in slurry averaged about 130 kg/ha and that of soluble N about 80 kg/ha. These results correspond reasonably well with the literature. As compared to the nitrogen in artificial fertilizer, most experiments indicate a 60—90 % efficiency of cow slurry soluble nitrogen and a 30—80 % efficiency of its total nitrogen (HERRIOTT and WELLS 1962, HERRIOTT et al. 1963, 1964, 1965, MCALLISTER 1966 a, 1966 b, T.A. STEWART 1968 b, NAESS and MYHR 1976, SLUIJSMANS and KOLENBRANDER 1977, KIELY 1980, LECOMTE

1980, SCHECHTNER et al. 1980, KOLENBRANDER 1981 b, TUNNEY 1981, GRACEY 1982, SMITH et al. 1985, TUNNEY and MOLLOY 1986). In this study, the advantage by injection compared to surface application was quite slight averaging 110 kg dry matter/ha/cut.

As to the apparent recovery of soluble nitrogen, the effectiveness of surface applied slurry averaged 53 % and that of injected slurry 82 % compared to artificial fertilizer (64 % and 91 %, respectively, if experiment B4 with exceptionally low N recoveries is omitted). Thus the efficiency of surface applied slurry in terms of apparent recovery of nitrogen roughly equalled that in terms of dry matter production. The effectiveness of injected slurry, however, was significantly higher when measured by the apparent recovery of nitrogen as compared to its dry matter productivity. The difference between the two application methods stems from the fact that injection raised the nitrogen content in plants more effectively than surface application did. This corresponds to the results of TUNNEY and MOLLOY (1986), and van der MEER et al. (1987). Significantly higher nitrogen percentages and uptakes have often been recorded by the injection method. When assessing the value of injection compared to surface application, not only dry matter yields should be considered but also the efficiency by which nitrogen, and other nutrients as well, are transferred into plants. As compared to dry matter yields, nitrogen uptake has been found to be a more reliable measure for the efficiency of slurry on grassland (LUTEN et al. 1982).

The ability of injected slurry to produce higher nitrogen percentages and uptakes but not equally higher yields compared to those by surface application may have several causes. For example, the injection tines damage grass roots thus retarding growth. Other causes may involve the high concentration of slurry in injection stripes resulting in direct chemical damage to the roots, or the consumption of soil oxygen through rapid decomposition (MCALLISTER 1977 b, PRINS and SNIJDERS 1987). In addition, the slow diffusion of slurry nutrients from the injection stripes may be a growth-retarding factor. Whatever the actual cause, injected slurry seemed to have a significantly slower effect on grass growth compared to surface applied slurry, as verified also by visual examination. It took a much longer time for the grass to turn green after injection than following surface application. This finding agrees with those by RÖNNINGEN and WESETH (1974), and van der MEER et al. (1987).

The effect of injection was thus to retard grass growth for a period of time after which the grass grew as if it were younger and less mature compared to growth by surface application. The above mentioned effect, in combination with the avoidance of ammonia volatilization, resulted in higher nitrogen percentages and uptakes by plants. The superiority of injection in comparison with surface application in raising nitrogen percentage and uptake was also often seen as a residual effect in later cuts. TUNNEY and MOLLOY (1986) noted that most of the benefit of injection compared to surface application is in fact due to the residual effect in later cuts. A similar conclusion was drawn by van der MEER et al. (1987). The poor effect on the first grass yield following injection has been proposed to result from anaerobic decomposition of slurry which produces toxic compounds in the soil (TUNNEY and MOLLOY 1986).

Very often, slurry also increased the P and K content in grass compared to unfertilized plots. In some cases their contents by slurry surpassed those by a normal rate of artificial fertilizer (1NPK), especially the K content. In some cuts the 4— % safety limit for potassium was exceeded, in particular when slurry was applied in combination with NPK. However, the limit could be exceeded also by NPK alone. Injection seemed to raise the P content slightly but the K content significantly more effectively than did surface application. The difference between the two application methods was generally highest in the first yield following slurry application and diminished in the later cuts. An increase in plant P and K content through slurry is a very common phenomenon (MCALLISTER 1966 b, NAESS and MYHR 1976, TUNNEY et al. 1980, ASMUS et al. 1982, HÅLAND 1984 a). Often the contents in the soil increase as well (CASTLE and DRYSDALE 1962, MCALLISTER 1977 a, TUNNEY et al. 1980, HÅLAND 1984 b, LAVES and THUM 1984, SPALLACCI and BOSCHI 1985). The superiority of injection compared to surface application in raising the K content in grass was also found by TUNNEY and MOLLOY (1986).

The effect of slurry phosphorus is of special interest. In several studies the phosphorus in livestock manure has been shown to be as effective or even more effective than that in artificial fertilizer (ASMUS et al. 1971, SHARMA et al. 1980, GERRITSE 1981). Organic manuring has also been demonstrated to improve the efficiency of artificial phosphorus fertilizer (KAILA 1950 a, K.F. NIELSEN et al. 1953, MAYR and KAINDL 1959, JACQUIN et al. 1983, KHANNA et al. 1983). Several interpretations have been proposed: organic decomposition products and carbon dioxide dissolving calcium phosphates, decrease in soil pH and redox potential, priming effect on soil organic phosphorus, restricted adsorption of organic phosphorus compounds on soil particles, etc. Enhanced phosphorus uptake through increasing ammonium nutrition may also have an effect (RILEY and BARBER 1971, STEELE and SAUNDERS 1980). In this study, the relative efficiency of slurry phosphorus compared to that of P in artificial fertilizer was not determined. However, slurry P seemed to have a significant fertilizing effect, and nothing indicates that a shortage of phosphorus could have restricted grass growth in slurry plots.

An effect by slurry on grass nitrate content was not established reliably in this study. Injection could increase grass nitrate content more than surface application because slurry is injected in narrow concentrated stripes (TUNNEY and MOLLOY 1986, van der MEER et al. 1987). However, the rates of slurry used in these experiments were rather small compared to those producing nitrate problems (LUTEN et al. 1982).

The optimal advantage by injection compared to surface application seemed to coincide with warm and rainless days following slurry application. When application was followed by rainy days, no benefit or a slight yield decrease by injection was recorded. Thus in accordance with the literature, rain and cool weather following surface application saves ammonia in the same way injection does (EGNER 1932). However, the only slight difference in yields by injection and surface application in rainy summers may also indicate a disadvantageous interaction between slurry injection and a high soil moisture content. In this case, soil oxygen depletion and the production of phytotoxic compounds through the anaerobic decomposition of slurry might be the cause. In experiments B1 and B2 disadvantageous effects by injection compared to surface application were observed only on plots irrigated after slurry application. The highest yield increase by injection was obtained at Jokioinen during the relatively dry summer of 1985, but significantly lower increases were usual in the preceding wet years. In general, the recovery of fertilizer nitrogen on grassland has been found to be higher in normal and dry years than in wet years (van der MEER 1982). This phenomenon was also demonstrated in experiment B1 at Jokioinen.

When considering the first grass yield after slurry application, injection seemed to be more advantageous on the loam soil and on the sand soil at Ruukki in comparison with the clay soils at Jokioinen. Although the difference can be explained by different weather conditions after slurry application, soil type may also have an effect. In a coarse soil the disadvantageous effects of injected slurry mentioned above might be of lesser importance compared to those in a dense clay soil. Experiments by LARSEN and KELLER (1985 b) indicate slighter damage to grass by injection on sandy soils than on clay soils. A similar result was obtained by FOGH (1978) when examining the damage to a young barley crop by ammonia injection on different types of soils. HALL (1986), on the other hand, observed a more even fertilizing effect of slurry between injection rows on sand soils compared to clay soils. Still another explanation for the difference is that ammonia volatilization may be higher from coarse soils due to their smaller active surface area. However, the residual effect of injected slurry often surpassed that of surface applied slurry at Jokioinen, but vice versa at Ruukki. This indicates a faster effect of injected slurry in coarse soil, but a slower effect in clay soil.

Irrigation was not examined as a means of increasing yields as such, but as one to prevent ammonia volatilization, in the way that slurry dilution has been found to do (SCHÖLLHORN 1954, T.A. STEWART 1968 b, SCHECHTNER et al. 1980, SCHECHTNER 1986). Another positive effect by irrigation could be the rinsing of grass after surface application (SIMON et al. 1982). However, only a few effects by irrigation were statistically significant. At Ruukki, irrigation had a negative effect on the nitrogen and phosphorus content in grass in some cuts, but apparently this was due to the distribution of these nutrients into an increasing grass yield by irrigation: in other words, a dilution effect. At Jokioinen in 1983, however, the significant decrease in grass nitrogen content by irrigation was not associated with an increasing yield. Excessive soil moisture content causing nitrogen losses through denitrification is assumed to be the cause (MEEK et al. 1974, STEVENS and CORNFORTH 1974 b, BURFORD 1975, 1976, PAIN and SANDERS 1980, RYDEN and LUND 1980, TUNNEY and MOLLOY 1986, JARVIS et al. 1987, COMFORT et al. 1988). According to S. CHRISTENSEN (1981, 1983) denitrification losses are clearly higher following slurry application than with artificial fertilization.

Although the effect of irrigation on grass yields was not statistically significant, far higher yield increases by irrigation were obtained on the loam soil at Ruukki than on the clay soil at Jokioinen. Moreover, the advantage by irrigation was generally higher in combination with surface applied slurry than in combination with injected slurry. These observations agree with those describing the effects of weather and soil type mentioned above.

Experiments with artificial fertilizer in combination with slurry proved that, in general, yields comparable to those by a normal dose of NPK can be obtained by slurry + a smaller rate of NPK. Although the immediate effect of slurry + NPK may be slightly lower compared to that by a normal rate of NPK alone, the higher residual effect of slurry + NPK compensates the difference. Also in the Woburn long-term experiments in England a similar beneficial effect by livestock manure + NPK has been found. Apparent recoveries of nutrients in manure did not decrease through NPK use (WIDDOWSON and PENNY 1971). HERRIOTT et al. (1964) encourage the supplementation of slurry with at least artificial nitrogen in order to exploit the full potential of the potassium in slurry.

In experiment B3 in 1985, however, the residual effect of slurry + NPK applied in the preceding summer was negative compared to plots without slurry. The young grass established in late summer 1983 did not respond well to any fertilization treatments in 1984 but suffered from the high amounts of nutrients in slurry + NPK. Again, this was seen as a significantly negative residual effect in 1985. Such odd behaviour may result from the fact that the grass was established in August 1983 after fallowing the field since the preceding autumn. Plant nutrients may have been liberated abundantly in the soil during fallowing thus reducing the need for fertilization. The disadvantageous effect of slurry on the first yield in 1985 may then be caused by winter damage associated with excessive fertilization.

When the effect of slurry application technique on grass yields was examined without slurry, yield decreases by the injection tines and by the roll were recorded. The often recommended procedure of rolling the field after slurry injection appeared to be especially harmful to the sward. Rolling after injection is recommended in order to level the soil and thus avoid the contamination of grass fodder by soil material in the cuts. According to these results, rolling after slurry injection should not be carried out as a rule but only in conditions with a high likelihood of grass fodder contamination. The negative effect of injector tines on the sward corresponds to the results by RÖNNINGEN and WESETH (1974), KOLENBRANDER (1981 b) and PRINS and SNIJDERS (1987). LEYSHON (1982) found that the negative effect on an alfalfa sward of a single placement fertilization with NPK persisted for over two years. In general, the deeper the penetration by injection tines into the soil the greater the damage (KOLENBRANDER 1981 b, LEYSHON 1982). An increasing driving speed and a decreasing soil moisture content during injection have also been shown to increase the damage by injection (FOGH 1978, HALL 1986).

Although the negative effect on grass yields by injection tines was well established in experiments B5—B13 without slurry application, no significant differences were found in experiments B1 and B2 after one to three years' manuring with injected or surface applied slurry. Yields in the fourth year were almost equal in all plots irrespective of different treatments in the preceding years. Thus slurry can be injected into grassland in successive years at least once a year without causing detrimental effects to the sward.

Finally, this series of experiments encourages the use of cow slurry as a grassland fertilizer. Slurry injection seems to be favourable in many ways although it causes some damage to the sward. An advantage by injection not examined in the present study is the production of grass fodder of better hygienic quality compared to that by surface application (SCHECHTNER 1986). Moreover, run-off and malodour problems are avoided by injection (KOFOED 1981, VOORBURG 1981, THYSELIUS 1988). Irrigation following surface application may be a useful means for the improvement of slurry efficiency, especially when a rainless period is expected. The use of artificial nitrogen fertilizer in combination with slurry is recommended.

EFFECT OF SOIL PROPERTIES ON AMMONIA VOLATILIZATION FROM LIQUID COW MANURE

INTRODUCTION

Ammonia volatilization from manure during and after being spread on the field has several negative consequences. Firstly, a significant proportion of the fertilizer value of manure is easily lost which results in immediate economic loss. Secondly, owing to huge variation in the extent of ammonia volatilization, the true fertilizer value of exposed manure cannot be precisely assessed which, in turn, causes great difficulties in modern systematic agriculture. Finally, ammonia emissions from manure may contribute to environmental pollution.

Ammonia volatilization from manure has been intensively studied since the beginning of the 20th century (LIECHTI and RITTER 1910, 1913, VALMARI 1921, JENSEN 1928, TUORILA 1929, EGNER 1932, VIRRI 1941). The focus of interest has been determining the extent of ammonia volatilization and the factors affecting it. From 0 to almost 100 % of manure ammonia has been lost in different experiments and this variation has commonly been ascribed to varying weather conditions during and after manure application (IVERSEN 1927, ERNST and MASSEY 1960, B.A. STEWART 1970, WATKINS et al. 1972, ADRIANO et al. 1974, LAUER et al. 1976, BEAUCHAMP et al. 1978, 1982, HOFF et al. 1981, SHERLOCK and GOH 1984, DÖHLER and WIECHMANN 1988, RANK et al. 1988).

The importance of weather conditions in interpreting results is easy to understand as experiments have generally been carried out with one soil or a few soils only. In some studies, attention has also been paid to the soil properties which affect ammonia volatilization from manure: mainly soil pH and moisture content (ERNST and MASSEY 1960, B.A. STEWART 1970, WATKINS et al. 1972, ADRIANO et al. 1974, AVNIMELECH and LAHER 1977, BOUWMEESTER and VLEK 1981). GASSER (1964), FAURIE et al. (1975), and RYAN and KEENEY (1975) have emphasized the importance of soil cation exchange capacity and texture in ammonia volatilization. However, considering their practical implications, the effect of soil properties on ammonia volatilization has been overlooked, indeed.

The prevention of ammonia volatilization from manure during and after spreading has been attempted by several methods. Chemicals and adsorbing materials have been examined which diminish the partial pressure of ammonia when added to manure: acids, superphosphate, neutral salts, clay minerals and peat (LIECHTI and RITTER 1910, 1913, von FEILITZEN 1911, 1914, GERLACH 1919, STUTZER 1919, VALMARI 1921, JENSEN 1928, TUORILA 1929, EGNER 1932, IVERSEN 1934, HONKAVAARA 1936, VIRRI 1941, KAILA 1950 a, MOLLOY and TUNNEY 1983, JÄGGI and WALTHER 1987, BANGAR et al. 1988, WITTER and LOPEZ-REAL 1988). Dilution of manure with water has also been regarded as a promising means to retard ammonia volatilization (VIRRI 1941, SCHÖLLHORN 1954, T.A. STEWART 1968 b, 1970, SCHECHTNER et al. 1980). In addition, techniques for manure spreading have been developed which attempt a minimal exposure of manure to the air; the injection method being an extreme case (IVERSEN 1934, WESTED and IVERSEN 1938, KLAUSNER and GUEST 1981, LARSEN and KELLER 1985 a, LARSEN 1987, RODHE et al. 1988). None of these ammonia-saving methods has been widely accepted due to difficulties met in practical conditions and because, in general, their profitability is rather poor. When applied to conditions with the highest likelihood of ammonia volatilization, however, some of these methods might prove worthwhile.

Several different methods have been employed for the determination of ammonia volatilization from manure. In earlier experiments, indirect methods were mostly used including the determination of yield response to surface applied versus incorporated manure, or periodical sampling after exposing the manure in the laboratory or outdoors (IVERSEN 1927, 1934). One direct method for the determination of ammonia volatilization has also been in use for at least 70 years, namely the incubation method which includes the placement of manure into closed vessels and absorption of ammonia in acid traps (LIECHTI and RITTER 1910, 1913, JENSEN 1928, VIRRI 1941). Recently, a variety of canopy and micro-meteorological techniques for measuring ammonia volatilization *in situ* have been developed and employed successfully (MCGARITY and RAJARATNAM 1973, DENMEAD et al. 1974, 1982, KISSEL et al. 1977, BEAUCHAMP et al. 1978, HUTCHINSON et al. 1982, VALLIS et al. 1982, RYDEN and LOCKYER 1985, B.T. CHRISTENSEN 1986, STEVENS and LOGAN 1987, THOMPSON et al. 1987).

The objective of this study was to elucidate the relationship between various soil properties and ammonia volatilization from surface applied liquid cow manure; a manure with one of the highest nitrogen losses when applied onto the soil surface. A special task was to develop an easy method for predicting the likelihood of ammonia volatilization from different soil types by which the need for various ammonia-saving measures could be assessed. In addition, some modifications of the dynamic incubation method for measuring ammonia volatilization were examined.

MATERIAL AND METHODS

Measurement of ammonia volatilization in general

Ammonia volatilization from liquid cow manure applied onto the soil surface was measured using the dynamic incubation method described in Fig. 3. The principle of the procedure was the same as that in JENSEN'S (1928) and VIRRI'S (1941) experiments. Experimental soils were placed into plastic pots having internal dimensions of 13 cm, 6.3 cm and 15 cm (height), 1.0 liter of soil per each. The pots were equipped with three air-intake pipes and two air-outlet pipes, 4 mm in diameter. The experimental apparatus was built for the simultaneous analysis of ammonia volatilization from eight soil samples. Eight soil samples, comprised of different soils, were employed in each analytical phase instead of replicates of one soil at the same time.

Twenty-five ml of liquid cow manure was pipetted onto the soil surface of the plastic pots. Liquid manure was spread very evenly over the soil surface, but pipetting close to pot walls was avoided. Liquid manure was obtained from a practical farm and because it was rather diluted compared to fresh cow urine (2.5 mg NH_3-N/ml), it was fortified with analytic-grade urea to a final concentration of 4.6 mg of NH_3-N/ml. Thus the amount of NH_3-N applied to each soil sample was 115 mg which corresponds to about 135 kg of NH_3-N/ha. The pH of the liquid manure was 8.96. Ammonification of all added urea was verified prior to using the liquid manure in the experiments.

Ammonia volatilized from a pot was absorbed in three successive vessels each of which contained 30 ml of 4 % boric acid and 120 ml of deionized water. The boric acid vessels were replaced by new ones three times during each 23-hour analytical phase: after one hour, three hours and six hours from the beginning of the measurement. The content of NH_3-N in those vessels and in the vessel replaced after 23 hours was then determined by titration with 0.1 N HCl.

Laboratory air with a rather constant relative humidity of 30 % was sucked through the air space above soil samples and through the acid traps. Suction into the apparatus was by a vacuum pump. Before entering the pump, the rubber pipes from the eight simultaneous measurements were combined into one. In order to ensure the even passage of air during the

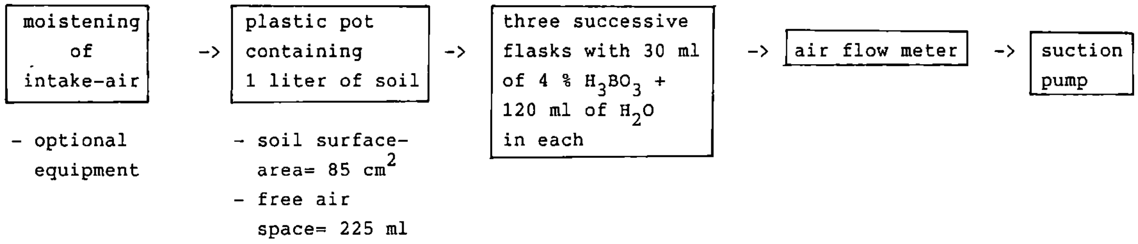

Fig. 3. A scheme representing the procedure used in measuring ammonia volatilization from surface applied liquid cow manure. Eight measurements were carried out simultaneously.

eight simultaneous measurements, rubber pipes of exactly same diameter and length were used. The evenness of air passage was also verified by preliminary experiments in which ammonia volatilization from NH_4OH-solutions applied onto the soil surface was examined. In addition, in the actual experiments replicates of one soil were never put into the same places as they were analyzed on successive days.

The evenness of air passage throughout the whole experimental period of several months was measured by an air flow meter connected to the air-intake of the vacuum pump. Air passage through the whole experimental apparatus was a constant 45 l/min. Per one minute, the amount of air passing through each plastic pot was 25-fold compared to the free air space in a pot. The average speed of air in the pot air space was 2.6 cm/s.

Preliminary studies

In preliminary studies, the proper functioning of the ammonia volatilization apparatus was tested with a NH_4OH-solution containing 385 mg of nitrogen/25 ml. In experiments with air-dry sandy soils, as much as 98 % of added nitrogen was found to volatilize in just 10 hours. Air bubbling in the receiver vessels was found to be even during the eight simultaneous measurements and likewise for the amount of ammonia volatilized.

In addition, for a fine sand soil with a pH ($CaCl_2$) of 6.24, ammonia volatilization from 25 ml sample of surface applied liquid cow manure was tested in a 50-hour measuring period. The number of replicates was four. As percentage of the ammonia added in liquid manure, 4.54, 8.54, 13.00, 24.87, 27.37, 30.62 and 31.22 % had volatilized in 1, 3, 6, 23, 30, 47 and 50 hours, respectively. Volatilization seemed to fit well into a logarithmic equation:

$$\text{N volatilization (\% of added N)} = 3.33 + 16.05 \times \log_{10} \text{time (hours)}$$

The coefficient of determination (r^2) for the equation was 0.99 ($P = 0.001$). However, ammonia volatilization had not entirely ceased even in 50 hours, being very difficult to predict thereafter. As visually assessed from a curve drawn on basis of the original observations, ammonia volatilization in a 50-hour period was concluded to represent about 95 % of that during a considerably longer period of time, for instance one week. On the basis of this conclusion, ammonia volatilization in 23 hours — the period of time used in the actual experiments — represents about 77 % of the total volatilization.

Effect of soil properties on ammonia volatilization

Altogether 63 soil samples were collected from southern Finland and used in ammonia volatilization experiments by the method described above. According to the soil texture classification used in Finland (Fig. 4), mineral soils (46 samples) fell into following classes:

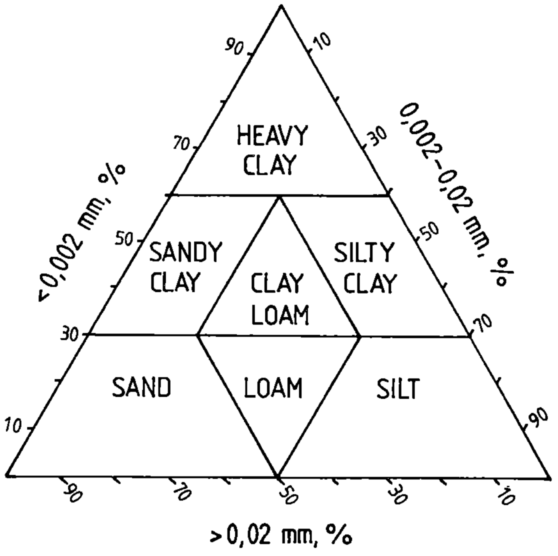

Fig. 4. Soil texture classification according to JUUSELA and WÄRE (1956). Sand soils are further divided into fine sand and sand depending on the ratio of fine sand (0.02—0.2 mm) to sand (0.2—2.0 mm).

Heavy clay soils	8	samples
Sandy clay soils	3	»
Clay loam soils	10	»
Silty clay soils	3	»
Silt soils	2	»
Loam soils	7	»
Fine sand soils	9	»
Sand soils	4	»

In addition, 17 organogenic soils ($C > 11.6$ %) were included. The organogenic soils were further divided into two classes according to their content of organic carbon: those with less and those with more than 23.2 % of carbon. The latter ones represent true peat soils. The number of replicates for the measurement of ammonia volatilization was four for all soils. Soil samples were air-dry when used in the experiment.

With the exception of a few soils, soil samples were analyzed for pH($CaCl_2$), pH(H_2O), cation exchange capacity at pH 7 (CEC), proportion of alkali and earth alkali metals in cation exchange capacity (base saturation), amount of acidic ions (total acidity), and carbon. The rate of urine absorption into soils was assessed visually. In addition, mineral soils were analyzed for clay, silt and sand fractions, and for aggregate-size distribution by dry-sieving.

Soil pH, CEC, base saturation and total acidity were determined according to the methods of soil testing in use in Finland (ANON. 1986). The determination of CEC, base saturation and total acidity includes the extraction of a soil sample with an ammonium acetate solution (pH 7.0). From this solution, Ca, K, Na, and Mg are then determined by atomic absorption spectrometry and exchangeable hydrogen by titration. Carbon content in soils was determined by a dry-combustion method using a LECO CR-12 analyzer (SIPPOLA 1982). The rate of urine absorption into the soil was assessed on a scale from zero to three, zero representing very slow absorption and three very rapid absorption.

Soil texture analysis (clay, silt, fine sand and sand fractions) was carried out using the method developed by ELONEN (1971). Aggregate-size analysis by dry-sieving was performed by shaking vigorously by hand a sample of 300 g of mineral soil for 20 seconds on two superimposed sieves: a 6-mm sieve and a 2-mm sieve. Beneath the sieves there was a plate collecting material finer than 2 mm. Actually, the material passed through the 2-mm sieve did not consist of true aggregates but chiefly of coarse primary particles (sand). However, also this fraction is termed"aggregates" as distinguished from "particles" measured by soil texture analysis.

Experiments with moistening of intake-air

Twenty-five soils altogether were used in a comparison in which the effect of moistening the intake-air was examined. The experiment had four replicates. The soil samples consisted of one heavy clay, one sandy clay, three clay loams, one silty clay, one silt, five loams, five fine sands, one sand and seven organogenic soils. Due to the small and uneven number of different soils, they were regrouped into the following soil types: 1. clay soils, 2. silt and loam soils, 3. fine sand and sand soils, and 4. organogenic soils. Air-dry soils were used in this experiment.

Intake-air was moistened by sucking laboratory air through a 2-liter plastic pot containing 500 ml of deionized water. Dry air was piped into the bottom of the pot via two glass pipes, and the moistened air was taken from the upper part of the pot via three rubber pipes. Humidity was measured by hygrometers placed in additional glass pots between the water pots and those including the soil and liquid manure. Relative humidity of the moistened air was 80 %, and that of dry laboratory air 30 %. Otherwise, the procedure used in this comparison was the same as described above.

Comparison between dry and moistened soil

Altogether 32 soil samples were used in an experiment in which the effect of soil moisture on ammonia volatilization from liquid cow manure was studied. The number of replicates in those measurements was four. Soil samples consisted of six heavy clays, two sandy clays, three clay loams, one silty clay, two silts, five loams, three fine sands, one sand and nine organogenic soils. Due to the small and uneven number of different soils, they were regrouped into the following soil types: 1. heavy clay soils, 2. other clay soils, 3. silt and loam soils, 4. fine sand and sand soils, and 5. organogenic soils.

The soil samples were moistened by filling the plastic pots with thin layers of soil which were then moistened with deionized water separately. Excessive moistening was avoided, however. After moistening, the pots were covered with plastic lids and allowed to stand until the next day. Moisture content was determined by weighing the soil before and after drying for one day at 105 °C. The average moisture contents of different soils were as follows (%):

	air-dry	moistened
heavy clay soils	6	33
other clay soils	3	31
silt and loam soils	7	36
fine sand and sand soils	2	29
organogenic soils	25	62

It can be concluded that the moistened silt, loam, fine sand and sand soils contained more free water, i.e. were actually wetter compared to the clay soils.

Effect of liming an acid soil

A fine sand soil with an initial pH($CaCl_2$) of 4.97 was limed with 2.5 g, 5.0 g, 7.5 g, 12.5 g or 17.5 g of $Ca(OH)_2$/5 l of air-dry soil. After liming, each treatment was watered to field capacity and mixed thoroughly. Soils were then incubated for 14 days after which they were dried and used for measurement of ammonia volatilization from surface applied liquid cow manure. pH($CaCl_2$) increased from the initial value to 5.40, 5.80, 6.13, 6.59 and 6.91 by 2.5, 5.0, 7.5, 12.5 and 17.5 g of $Ca(OH)_2$/5 l of soil, respectively. The ammonia volatilization measurements had four replicates.

Statistical methods

A VAX 11/780 computer and SAS statistical program were used for calculating the results (ANON. 1985). Analyses of variance, analyses of correlation and analyses of regression were carried out according to STEEL and TORRIE (1960).

In the results, statistical significance is usually expressed with asterisks. One asterisk (*) indicates significance at the 5 % level (P = 0.05), two asterisks (**) at the 1 % level (P = 0.01), and three asterisks (***) significance at the 0.1 % level (P = 0.001). Tukey's Honestly Significant Difference at the 5 % level was also used and it is expressed as HSD (P = 0.05).

RESULTS

Ammonia volatilization from the 63 soils examined

Statistical information on the chemical and physical properties of the soils studied and on ammonia volatilization from surface applied liquid cow manure is presented in Table 92. On average, ammonia volatilization from mineral soils clearly surpassed that from organogenic soils. Compared with organogenic soils, min-

Table 92. Statistical information on the soils used in laboratory experiments.

Soil property	No. of soils	$\bar{x}$	s	Min.	Max.
	Mineral soils				
pH ($CaCl_2$)	46	5.01	0.56	2.92	6.06
pH (H_2O)	46	6.08	0.57	3.30	6.95
CEC, meq/100 g	45	22.9	8.6	9.6	44.6
Base saturation, %	45	58.9	17.1	19.0	86.1
Total acidity, meq/100 g	45	8.9	4.9	3.4	30.1
Carbon, %	46	2.7	1.1	0.8	6.1
Clay (<0.002 mm), %	45	36.4	22.1	4.0	78.0
Silt (0.002—0.02 mm), %	45	23.8	13.8	4.0	62.0
Fine sand (0.02—0.2 mm), %	45	27.2	17.4	4.0	72.0
Sand (0.2—2.0 mm), %	45	12.5	15.0	0.0	59.0
Aggregates >6 mm, %	46	33.2	18.1	0.0	66.0
Aggregates 2—6 mm, %	46	26.5	9.8	1.0	43.0
Aggregates <2 mm, %	46	40.3	23.5	14.0	99.0
Rate of urine absorption	46	2.82	0.38	1.00	3.00
Ammonia volatilized in 23 h, %	46	6.73	7.55	0.14	31.39
	Organogenic soils				
pH ($CaCl_2$)	17	4.49	0.84	3.20	6.23
pH (H_2O)	17	5.34	0.70	4.35	6.90
CEC, meq/100 g	16	58.7	15.4	38.2	90.3
Base saturation, %	16	42.0	22.6	12.5	90.9
Total acidity, meq/100 g	16	34.6	18.2	4.0	75.9
Carbon, %	17	26.8	13.7	11.7	52.5
Rate of urine absorption	17	1.80	0.89	0.75	3.00
Ammonia volatilized in 23 h, %	17	2.58	1.99	0.51	7.36

eral soils had a higher pH-value, a lower CEC-value, lower total acidity, and absorption of urine into mineral soils was clearly faster.

When the experimental soils were classified according to the classification system used in Finland by their texture and content of organic carbon, the various soil types showed considerable differences with respect to ammonia volatilization from surface applied liquid cow manure (Table 93). Ammonia volatilization was

Table 93. Ammonia volatilization in 23 hours from different soil types.

Soil type	No. of soils	Ammonia volatilization, %				% clay
		$\bar{x}$	s	Min.	Max.	
Heavy clay	8	0.71	0.40	0.14	1.46	71
Other clays						
Sandy clay	3	2.39	1.40	1.28	3.97	37
Clay loam	10	2.90	1.72	0.56	6.33	43
Silty clay	3	0.55	0.33	0.21	0.86	55
Silt	2	9.70	0.07	9.65	9.75	27
Loam	7	7.55	2.68	4.75	12.96	25
Fine sand	9	13.30	9.73	2.80	31.39	14
Sand	4	18.54	7.29	12.16	27.42	9
Organogenic soils						
C<23.2 %	11	2.23	1.99	0.51	7.36	—
C>23.2 %	6	3.23	2.01	0.94	6.32	—

very low from clay soils, but considerably higher from the coarser mineral soils. Moreover, ammonia volatilization was slightly higher from the true peat soils compared to the organogenic soils with a smaller percentage of carbon. However, the number of soils was so small in many classes that these figures should be regarded only as indicative.

Ammonia volatilization from mineral soils

Ammonia volatilization correlated significantly with CEC, base saturation, total acidity, carbon content, clay content, fine sand content, sand content and all aggregate-size classes (Table 94). The correlations of ammonia volatilization with the fine sand and sand contents and the content of aggregates <2 mm were positive whereas all other significant correlations were negative. The best linear relationship was found for % aggregates <2 mm ($r = 0.89$, $P = 0.001$). However, % aggregates <2 mm is an undefined fraction consisting of small aggregates and coarse primary particles.

Diagrams representing the relationship between ammonia volatilization from surface applied liquid cow manure and CEC, clay content, % aggregates >6 mm, % aggregates 2—6 mm and % aggregates <2 mm are shown in Figs. 5—9. Some of the relationships were distinctly linear (% aggregates <2 mm) whereas others were clearly curved (CEC, % clay). CEC and clay content proved the most promising for predicting ammonia volatilization.

The correlation of ammonia volatilization with CEC, % clay, % aggregates >6 mm, and % aggregates 2—6 mm could be improved by calculating a logarithmic relationship (ammonia volatilization in 23 hours = $\log_{10}x$). The coefficients of correlation were then as follows:

$\log_{10}$ (CEC)	$r = —0.79$, $P = 0.001$
$\log_{10}$ (% clay)	$r = —0.89$, $P = 0.001$
$\log_{10}$ (% ag. >6 mm)	$r = —0.84$, $P = 0.001$
$\log_{10}$ (% ag.2—6 mm)	$r = —0.84$, $P = 0.001$

The regression equation representing the dependence of ammonia volatilization on clay content was found to be:

N volatilization (% of added N) = 35.00 — 19.450 × $\log_{10}$ (% clay)

It was attempted to improve the correlation of ammonia volatilization with CEC by excluding the two most deviating observations (Fig. 5), but even then that correlation remained

Table 94. Correlation coefficients (r), probability of correlation (P), and number of observations (n) showing the dependence on soil properties of ammonia volatilization in 23 hours.

Soil property	Mineral soils			Organogenic soils		
	r	P	n	r	P	n
pH ($CaCl_2$)	0.09	n.s.	46	0.02	n.s.	17
pH (H_2O)	0.15	n.s.	46	0.08	n.s.	17
CEC, meq/100 g	—0.70	***	45	—0.05	n.s.	16
Base saturation, %	—0.34	*	45	0.19	n.s.	16
Total acidity, meq/100 g	—0.31	*	45	—0.11	n.s.	16
Carbon, %	—0.46	**	46	0.36	n.s.	17
Rate of urine absorption	—0.08	n.s.	46	—0.48	*	17
Clay (<0.002 mm), %	—0.77	***	45			
Silt (0.002—0.02 mm), %	—0.26	n.s.	45			
Fine sand (0.02—0.2 mm), %	0.66	***	45			
Sand (0.2—2.0 mm), %	0.63	***	45			
Aggregates >6 mm, %	—0.74	***	46			
Aggregates 2—6 mm, %	—0.76	***	46			
Aggregates <2 mm, %	0.89	***	46			

n.s. = not significant, * = significant at 5 % level, ** = significant at 1 % level, *** = significant at 0.1 % level

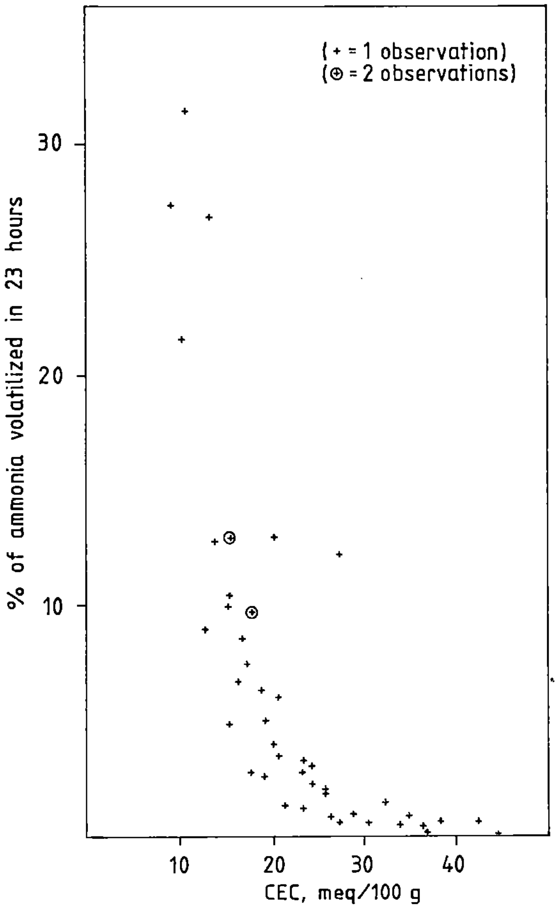

Fig. 5. Correlation of ammonia volatilization (y) with cation exchange capacity (x) (45 mineral soils). y = 20.93 — 0.62x (r = —0.70, P = 0.001).

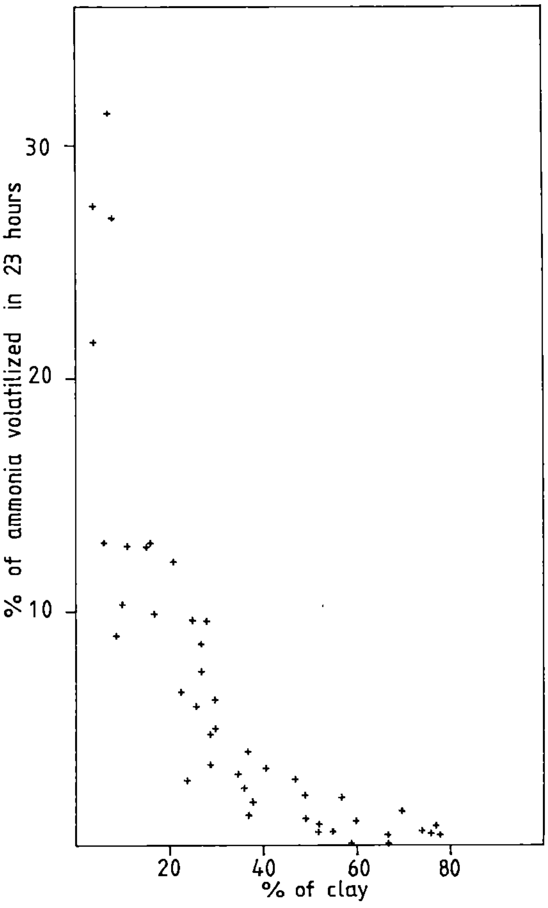

Fig. 6. Correlation of ammonia volatilization (y) with clay content (x) (45 mineral soils). y = 16.50 — 0.27x (r = —0.77, P = 0.001).

clearly weaker (r = —0.82) compared to that of ammonia volatilization with clay content.

When examining the dependence of ammonia volatilization on several soil properties simultaneously, stepwise as well as forced regression analyses were calculated. The best of those equations yielded coefficients of determination (R^2) as high as 0.93. For instance, when CEC, % aggregates <2 mm, and % aggregates >6 mm were used for explaining ammonia volatilization, R^2 was 0.88. With $\log_{10}$ (% clay) and $\log_{10}$ (% aggregates 2—6 mm) in the equation, the coefficient of determination (R^2) was 0.88, as well. Aggregate-size distribution was always the first factor entered into the equation after % clay or CEC in a forward stepwise regression analysis. However, CEC and aggregate-size distribution are seldom measured and are thus rather useless for predicting ammonia volatilization in practice.

In order to examine the true dependence of ammonia volatilization on different soil properties, mutual correlations between all soil properties were calculated. Clay content cor-

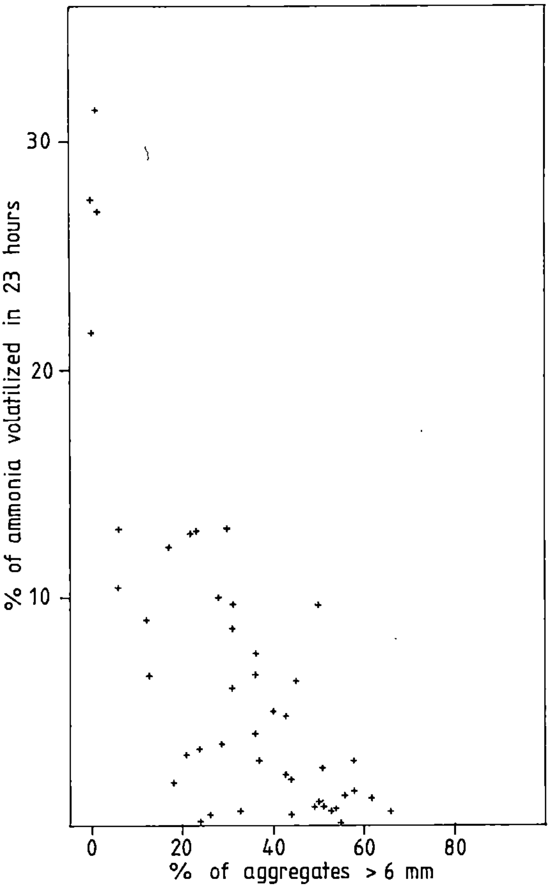

Fig. 7. Correlation of ammonia volatilization (y) with % of aggregates >6 mm (x) (46 mineral soils). y = 17.61 — 0.32x (r = —0.74, P = 0.001).

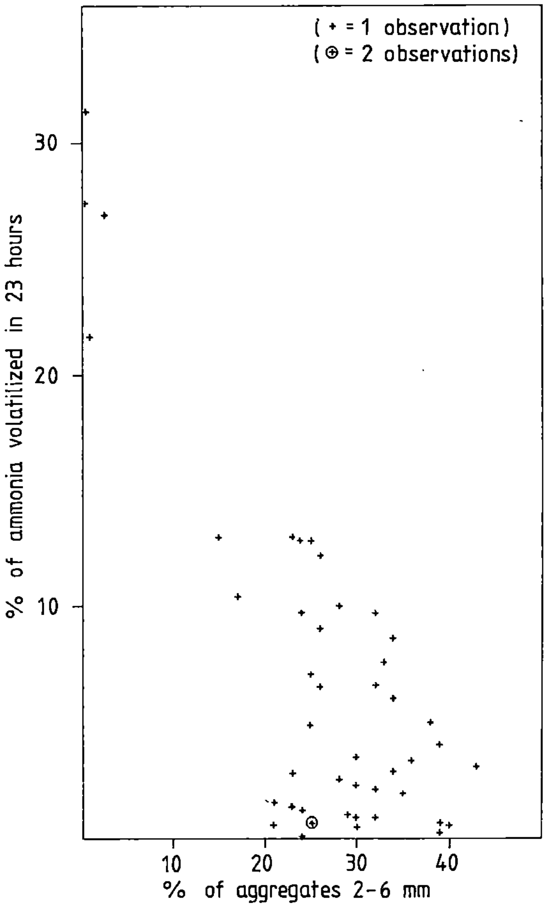

Fig. 8. Correlation of ammonia volatilization (y) with % of aggregates 2—6 mm (x) (46 mineral soils). y = 22.47 — 0.59x. (r = —0.76, P = 0.001).

related by far the best with CEC (r = 0.92, P = 0.001); even the correlations of clay content with various sand contents and different aggregate-size classes were considerably worse. Correspondingly, there was no soil property correlating better with CEC than clay content.

Ammonia volatilization from organogenic soils

Ammonia volatilization correlated significantly only with the rate of urine absorption into soil (Table 94). This correlation was negative. However, when the correlation diagram was examined, the dependence of ammonia volatilization on the rate of urine absorption was found to be very unsatisfactory for predicting ammonia volatilization in practice. That can be concluded from the low coefficient of correlation, too.

Experiments with moistening of intake-air

No significant effect by the moistening of intake-air on ammonia volatilization in 23 hours

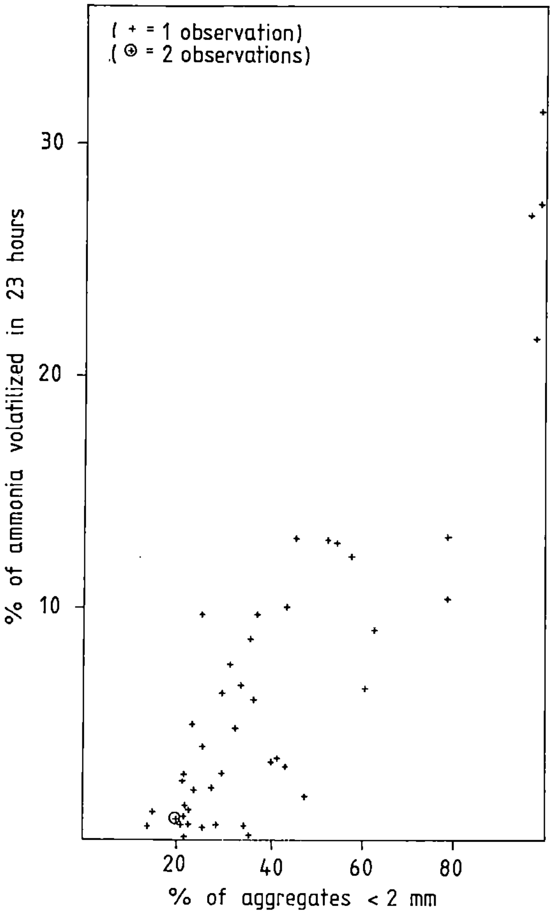

Fig. 9. Correlation of ammonia volatilization (y) with % of aggregates <2 mm (x) (46 mineral soils). y = —4.98 + 0.29x (r = 0.89, P = 0.001).

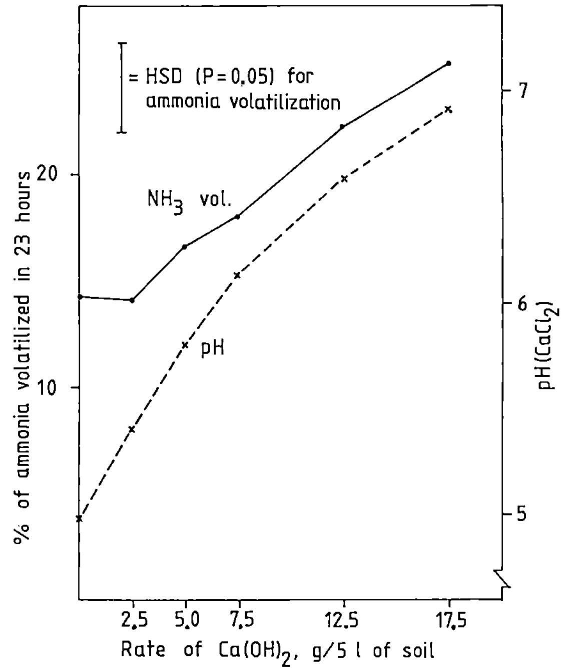

Fig. 10. Effect of liming on soil pH and ammonia volatilization from liquid cow manure.

was found (Table 95). Although moistening of the intake-air seemed to increase ammonia volatilization slightly from some soils and decrease it from the other soils, no significant interaction between the moistening of intake-air and soil type was established.

Table 95. Effect of moistening intake-air on ammonia volatilization from surface applied liquid cow manure in 23 hours.

Soil type	No. of soils	Ammonia volatilization, %	
		Dry intake-air	Moistened intake-air
Mineral soils			
Clay	6	1.40	2.49
Silt + loam	6	8.18	8.97
Fine sand + sand	6	12.30	11.98
Organogenic soils	7	5.53	4.40
x̄		6.80	6.86
F-value: moistening of intake-air		0.0	
soil type		35.3***	
interaction		0.5	

*** = significant at 0.1 % level

Table 96. Effect of moistening soil on ammonia volatilization in 23 hours from surface applied liquid cow manure and rate of urine absorption in different soil types.

Soil type	No. of soils	Ammonia volatilization, %		Rate of urine absorption	
		Air-dry soils	Moistened soils	Air-dry soils	Moistened soils
Mineral soils					
Heavy clay	6	0.78	1.45	2.88	1.96
Other clays	6	2.72	9.27	2.96	1.17
Silt + loam	7	8.31	22.71	2.57	0.36
Fine sand + sand	4	20.42	36.11	2.75	0.50
Organogenic soils	9	2.77	3.04	1.67	1.86
$\bar{x}$		5.80	12.35	2.47	1.25
F-value: moistening of soil		38.6***		223.9***	
soil type		71.7***		16.5***	
interaction		9.4***		37.3***	

*** = significant at 0.1 %.level

Comparison between dry and moistened soil

A significantly higher percentage of manure ammonia volatilized from moistened soils compared to that from air-dry soils (Table 96). Moistening the soil influenced ammonia volatilization from heavy clay and organogenic soils only slightly, but drastically that from the other soil types. An increase in ammonia volatilization by moistening the soil seemed to coincide with a simultaneous worsening of urine absorption into the soil.

Effect of liming an acid soil on ammonia volatilization

The liming of an acid soil increased ammonia volatilization from surface applied liquid cow manure (Fig. 10). However, ammonia volatilization did not increase by the smallest rate of $Ca(OH)_2$, but a somewhat linear increase by an increasing rate of lime began only after soil $pH(CaCl_2)$ had reached about 5.5. On the other hand, soil pH increased steadily by an increasing rate of lime.

DISCUSSION

The volatilization of ammonia from surface applied manure is a very complex phenomenon that is affected by manure characteristics, weather conditions during and after spreading, and soil properties. This study shows the effect of various properties of typical Finnish soils with constant weather conditions and using one type of manure only. On the basis of this study, no definitive conclusions on the significance of soil properties compared to that of other factors affecting ammonia volatilization can be drawn. It appears, however, that also soil properties should be regarded as important factors affecting ammonia volatilization from manure.

A great deal of research has been carried out in order to examine the influence of weather conditions on ammonia volatilization. The effect of soil properties on ammonia volatilization has often been overlooked, although soil pH, soil CEC, soil carbon content, soil texture, and soil moisture content have been referred to as factors of importance (Ernst and Massey 1960, Ivanov 1963, Du Plessis and Kroontje

1964, GASSER 1964, WATKINS et al. 1972, ADRIANO et al. 1974, FAURIE et al. 1975, RYAN and KEENEY 1975, AVNIMELECH and LAHER 1977, BEAUCHAMP 1983 b, FRENEY et al. 1983).

In this study, ammonia volatilization was found to correlate best with soil clay content. Volatilization was smaller the higher the clay content, i.e. the greater the surface area of soil particles. The fact that ammonia volatilization correlated better with clay content than with CEC may result from the fact that clay content to some extent takes into account also an other important factor, namely aggregate-size distribution. Soils with a high content of clay-size primary particles mostly consist of true aggregates. Once absorbed into those aggregates, ammonia is thought to be preserved not only by purely chemical bonds determined by CEC, but also by remaining in a rather diluted state as evaporation of water from such aggregates is slow. Moreover, owing to the good surface structure of clay soils, liquid manure can penetrate those soils faster compared to the soils with no secondary structure.

This study presents clay content to be the most useful criterion for predicting the rate of ammonia volatilization from surface applied liquid manure in Finnish mineral soils. No correspondingly simple basis for predicting ammonia volatilization from organogenic soils was found. It is very likely that the proportion of finer mineral particles determines ammonia volatilization also in organogenic soils, but this could not be verified because those soils were not analyzed for clay, silt and sand fractions.

The present study showed that soil pH cannot be used as a basis for assessing ammonia volatilization from manure in different types of Finnish soils. There are several soil properties more important than pH in soils. In this respect, results obtained from calcareous soils cannot be adapted to our conditions. However, when a single soil is considered, an increasing pH by liming undoubtedly promotes ammonia volatilization from manure. A significant increase in ammonia volatilization by liming was found although the pH of limed soil was below 7.

The moisture content of the air circulated over exposed manure is known to have an influence on ammonia volatilization (VIRRI 1941). Although it does not directly affect the partial pressure of ammonia in the air, an increasing moisture content retards the evaporation of water from manure. That, in turn, prevents ammonia from being concentrated in manure. In the present study, the moistening of intake-air did not significantly affect ammonia volatilization from manure. This finding agrees with that of JENSEN (1928).

Soil moisture content has been found to affect the rate of ammonia volatilization from surface applied liquid manure. According to JENSEN (1928) and VIRRI (1941), ammonia volatilization from a properly moistened soil is considerably slower compared to that from a dry soil or a wet soil. The water originally present in the soil dilutes manure thus retarding ammonia volatilization. The penetration of liquid manure into a properly moistened soil is usually faster compared to that in a dry soil. On the other hand, excessive moisture in a soil can retard the penetration of liquid manure if soil pores are completely saturated with water. In this study, the moistening of the soil before manure application clearly increased ammonia volatilization from sandy clay, silty clay, clay loam, silt, loam, fine sand and sand soils, but only slightly that from heavy clay and organogenic soils. On the other hand, moistened clay soils were concluded to be actually drier compared to the other moistened mineral soils. An increase in ammonia volatilization seemed to coincide with a poorer absorption of urine into the soil. An increase in ammonia volatilization from manure by an increasing soil moisture content was also found by ADRIANO et al. (1974).

The present study sought to clarify which soil types are especially prone to ammonia volatilization from surface applied manure. The practical implications of this study may be considerable. If no ammonia-saving measures are employed on a farm, the spreading of manure can be directed to fields with the lowest risk of ammonia volatilization from manure. On farms where ammonia-saving measures such as injection, addition to manure of certain chemicals or dilution of manure with water are available, those measures can be directed to fields with the highest likelihood of ammonia volatilization from surface applied manure.

CONCLUSIONS

Nutrient content of manure

The results of the present study generally correspond to those reported in the literature. However, this study shows that the differences in feeding and manure handling can be used to assess the nutrient content of manure on practical farms. This is helpful in the specification of recommendations for manure use.

The rapid methods most commonly employed for estimating the fertilizer value of manure include the determination of dry matter or specific gravity, or the change in pressure when ammonia is oxidized to nitrogen gas (TUNNEY 1988). The results of this study prove that direct methods instead of indirect methods should be applied. The correlations of dry matter with nutrients appeared to be rather weak; especially that of dry matter with soluble nitrogen. The correlation of dry matter with soluble nitrogen has often been completely disregarded in the literature.

In several types of manure the correlations of nutrients with pH proved stronger compared to those of nutrients with dry matter; especially with respect to soluble nitrogen. Moreover, the simultaneous use of dry matter and pH analyses proved very useful for estimating the nutrient content of manure. This methodology should be further developed. According to TUNNEY (1988), the dry matter content correlates very strongly with the specific gravity of slurry and liquid manure, the simultaneous determination of specific gravity and pH therefore appears to be very promising. The rate of wash water added to manure should also be taken into consideration if water is added to manure in large amounts.

Cow slurry as a fertilizer for barley

The effects by time and method of slurry application found in this study generally corresponded to those presented in the literature. Optimally, when slurry was spread in spring, the soluble nitrogen in slurry proved as efficient as that in artificial fertilizer. However, the advantage by injection compared to surface application was not found to depend on weather conditions as strongly as has been assumed.

The harmful effect on the young barley crop by the spreader and its injection tines was attempted to clarify in separate trampling experiments without slurry. However, such experiments proved rather fruitless because then the negative interaction between trampling and the slurry itself was not taken into account.

Irrigation following slurry application might affect the efficiency of slurry positively, the same way as by the dilution of manure with water before spreading (VIRRI 1941, SCHÖLLHORN 1954, T.A. STEWART 1968 b, SCHECHTNER 1986, PRINS and SNIJDERS 1987). In this study, however, irrigation following slurry application was found to be detrimental. The negative effect by irrigation was concluded to result from anaerobic decomposition of slurry in the soil. The experimental soils were rather compacted and the experimental years quite rainy.

Nitrogen supplementation was demonstrated to be advantageous in many ways. However, no residual effect by slurry spread on same plots in four successive years was found. The above findings are very important with regard to the use of slurry in practical farms.

Cow slurry as a grassland fertilizer

The results obtained on the effect of cow slurry as a grassland fertilizer are analogous to those obtained by RÖNNINGEN and WESETH (1974), TUNNEY and MOLLOY (1986) and van der MEER et al. (1987). As compared to surface application, injection was a superior method especially in raising the apparent recovery of nitrogen. However, a lag phase of several weeks was observed in the effect of injected slurry which probably resulted from damage to the grass by the injector tines, the high concentration of slurry in the injection stripes, and the slow diffusion of slurry nutrients in the soil (PRINS and SNIJDERS 1987). Owing to the delayed effect of injected slurry, considerable residual effects in later cuts were found.

The present study revealed that the highest advantage obtained by injection compared to surface application seemed to coincide with slurry application followed by warm and rainless days. Moreover, the advantage by injection appeared to be greater on the sand soil at Ruukki than on the clay soil at Jokioinen. An identical difference in the effect of injection on different types of soils was also found by FOGH (1978), LARSEN and KELLER (1985 b), and HALL (1986). Several interpretations for this difference have been proposed, including a less harmful effect on grass roots by the injector tines and a faster distribution of slurry nutrients in a coarse soil. However, such a difference may also result from the low ammonia binding capacity of sand soils, as shown in the fourth part of this study.

The effect of irrigation following slurry application was statistically significant in only a few cases and then negative effects were observed. Such negative effects were concluded to be the result of anaerobic decomposition of slurry in the soil which produces toxic compounds and enhances denitrification.

Experiments with artificial fertilizer in combination with slurry proved that the effects of slurry and fertilizer nitrogen were additional up to an optimal level of nitrogen supply. The result corresponds with those obtained by WIDDOWSON and PENNY (1971) and van der MEER et al. (1987).

In accordance with the literature, negative effects on grass by the injector tines were found in the trampling experiments without slurry (RÖNNINGEN and WESETH 1974, KOLENBRANDER 1981 b, LEYSHON 1982). However, such negative effects appeared rather short-lived in the actual slurry experiments. No detrimental residual effects on the sward were observed after one to three years of manuring with injected slurry.

Effect of soil properties on ammonia volatilization

Soil properties were shown to have a significant effect on ammonia volatilization from surface applied liquid cow manure. Ammonia volatilization correlated best with soil textural classes, aggregate-size classes and cation exchange capacity. As opposed to that presented by numerous studies, however, soil pH did not appear to be a useful basis for predicting the extent of ammonia volatilization. It was concluded that ammonia volatilization from different soil types can best be predicted by the clay content of soil.

On basis of the present study, slurry and liquid manure should be spread on fields with the lowest risk of ammonia volatilization, i.e. clay soils. On the other hand, ammonia-saving measures should be directed mainly to coarse mineral soils.

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SELOSTUS

Karjanlannan, erityisesti naudanlannan ravinnepitoisuus ja lannoitusarvo

ERKKI KEMPPAINEN

Maatalouden tutkimuskeskus

Tässä neliosaisessa tutkimuksessa selvitettiin karjanlannan ravinnepitoisuutta, sen vaihtelua ja arviointia, naudan lietelannan käyttöä ohran ja nurmen lannoitteena sekä maan ominaisuuksien vaikutusta pintaan levitetyn naudan virtsan ammoniakin haihtumiseen.

Karjanlannan ravinnepitoisuudesta ja siihen vaikuttavista tekijöistä saatiin paljon uutta tietoa. Eläinten ruokinnan voimaperäisyys ja lannan käsittelytapa osoittautuivat käyttökelpoisiksi perusteiksi lannan ravinnepitoisuutta arvioitaessa. Lannan kuiva-ainepitoisuus ja pH selittivät yhdessä lannan ravinnepitoisuutta huomattavasti paremmin kuin kumpikaan näistä tekijöistä yksin. Myös lantaan joutuvan pesuveden määrää voidaan käyttää virtsan ja lietelannan ravinnepitoisuuden selittäjänä lannan kuiva-ainepitoisuuden ja pH:n ohella.

Kenttäkokeissa ilmeni, että ohran lannoitteeksi keväällä levitetyn naudan lietelannan liukoinen typpi on parhaimmillaan väkilannoitetypen veroista. Syys- ja talvilevitykset osoittautuivat kevätlevitykseen verrattuna varsin tehottomiksi. Hyviä tuloksia saatiin myös levitettäessä naudan lietelantaa ohran orastumisvaiheessa, mutta noin 10 päivää orastumisen jälkeen tehdyt levitykset osoittautuivat jo melko huonotehoisiksi.

Naudan lietelannan teho nurmen lannoitteena osoittautui selvästi heikommaksi kuin sen teho ohralla. Yleensä lietelanta vastasi teholtaan korkeintaan 40—50 kiloa väkilannoitetyppeä hehtaaria kohden, vaikka nurmelle annettu lietemäärä sisälsi kokonaistyppeä keskimäärin 130 kg/ha ja liukoista typpeä 80 kg/ha.

Lietelannan sijoitus osoittautui huomattavasti pintalevitystä tehokkaammaksi ohraa viljeltäessä, mutta lietelannan levitystavan vaikutus nurmen kuiva-ainesatoihin oli vähäinen. Sijoitus kohotti kuitenkin selvästi nurmen typenottoa pintalevitykseen verrattuna.

Lietelannan levityksen jälkeisellä sadetuksella oli vain vähäisiä vaikutuksia ohran ja nurmen satoihin. Joissakin tapauksissa sadetus osoittautui haitalliseksi.

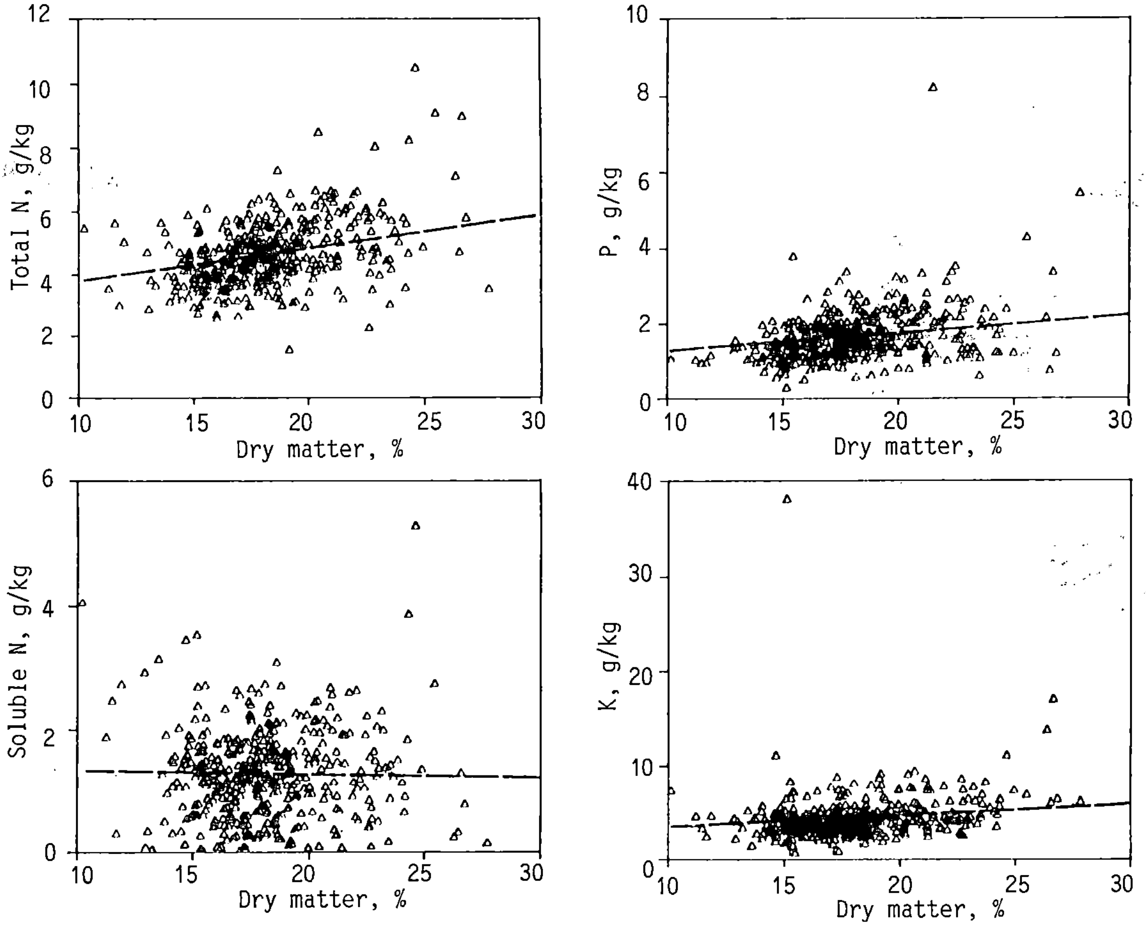
Lietelannan vaikutuksen täydentäminen väkilannoitteella osoittautui hyödylliseksi. Erityisen edullinen vaikutus väkilannoitetypellä oli orastumisvaiheessa tai orastumisen jälkeen lietelannoitetun ohran kasvuun.

Lietevaunu ja sen sijoitusvantaat vaurioittivat nurmea ja ohran orasta. Nurmelle aiheutunut vaurio osoittautui melko lyhytikäiseksi. Ohran oraalle lietelannoituksesta aiheutunut vaurio taas näytti johtuvan osittain lietelannasta itsestään.

Maan ominaisuuksien vaikutusta naudan virtsan ammoniakin haihtumiseen tutkittiin laboratoriokokein. Maan lajitekoostumus osoittautui tärkeimmäksi ammoniakin haihtumiseen vaikuttavaksi tekijäksi ja savespitoisuus käyttökelpoisimmaksi perusteeksi haihtumista arvioitaessa.

Appendix 1. Variation of nutrient content in different manures (see Table 2).

Type of manure	Coefficient of variation, %						
	DM, %	pH	tot. N	sol. N	P	K	sol. N/ tot. N, %
COW							
Solid manure	20	6	24	58	44	55	49
Slurry	44	4	30	39	60	43	20
Liquid manure	96	10	65	68	250	60	18
PIG							
Solid manure	24	6	31	61	49	58	48
Slurry	55	6	35	31	68	50	17
Liquid manure	128	7	69	64	140	36	14
POULTRY							
Solid manure	43	9	46	45	36	38	45



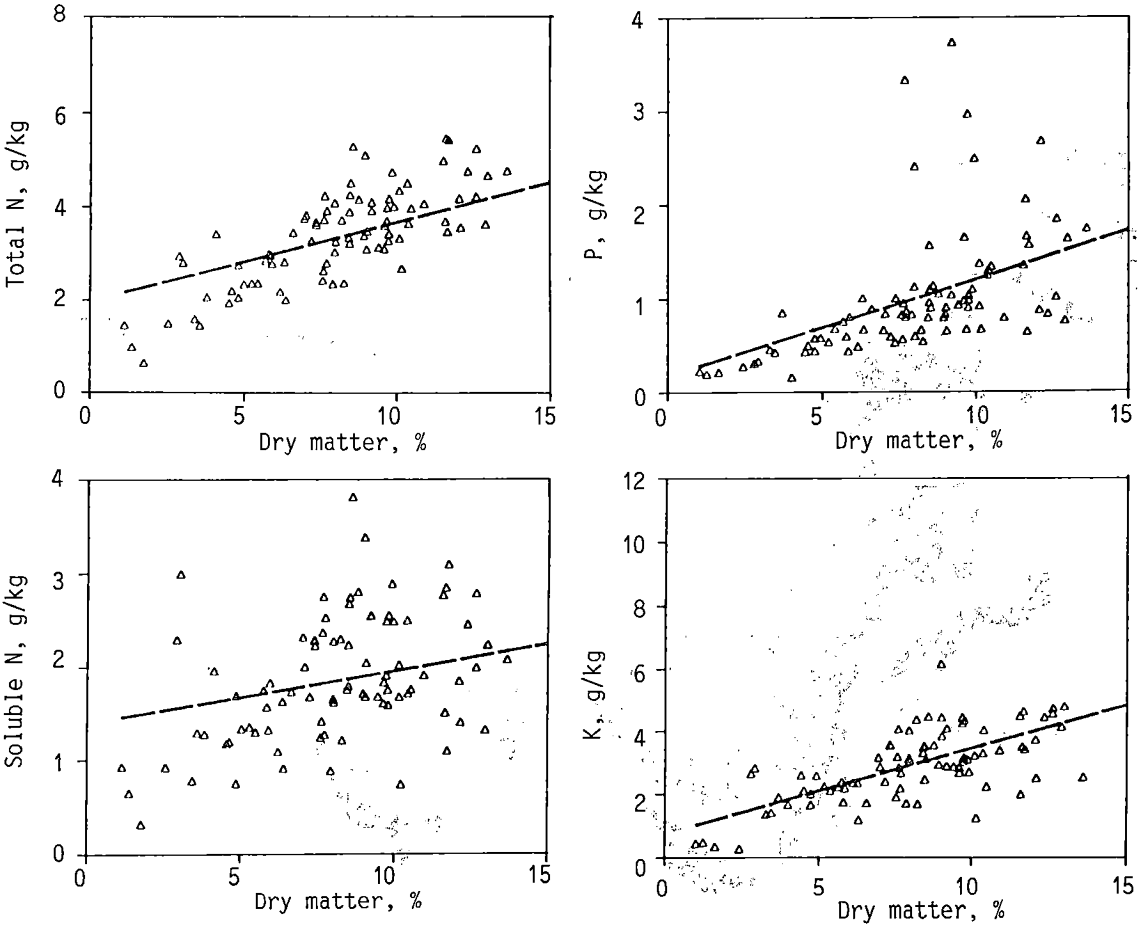
Appendix 2. Solid cow manure.

Correlation of dry matter (x) with total nitrogen (y).
$y = 2.72 + 0.11x$ ($r = 0.37$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 1.37 — 0.004x$ ($r = —0.02$).

Correlation of dry matter (x) with phosphorus (y).
$y = 0.78 + 0.05x$ ($r = 0.28$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = 2.17 + 0.12x$ ($r = 0.19$, $P = 0.001$).



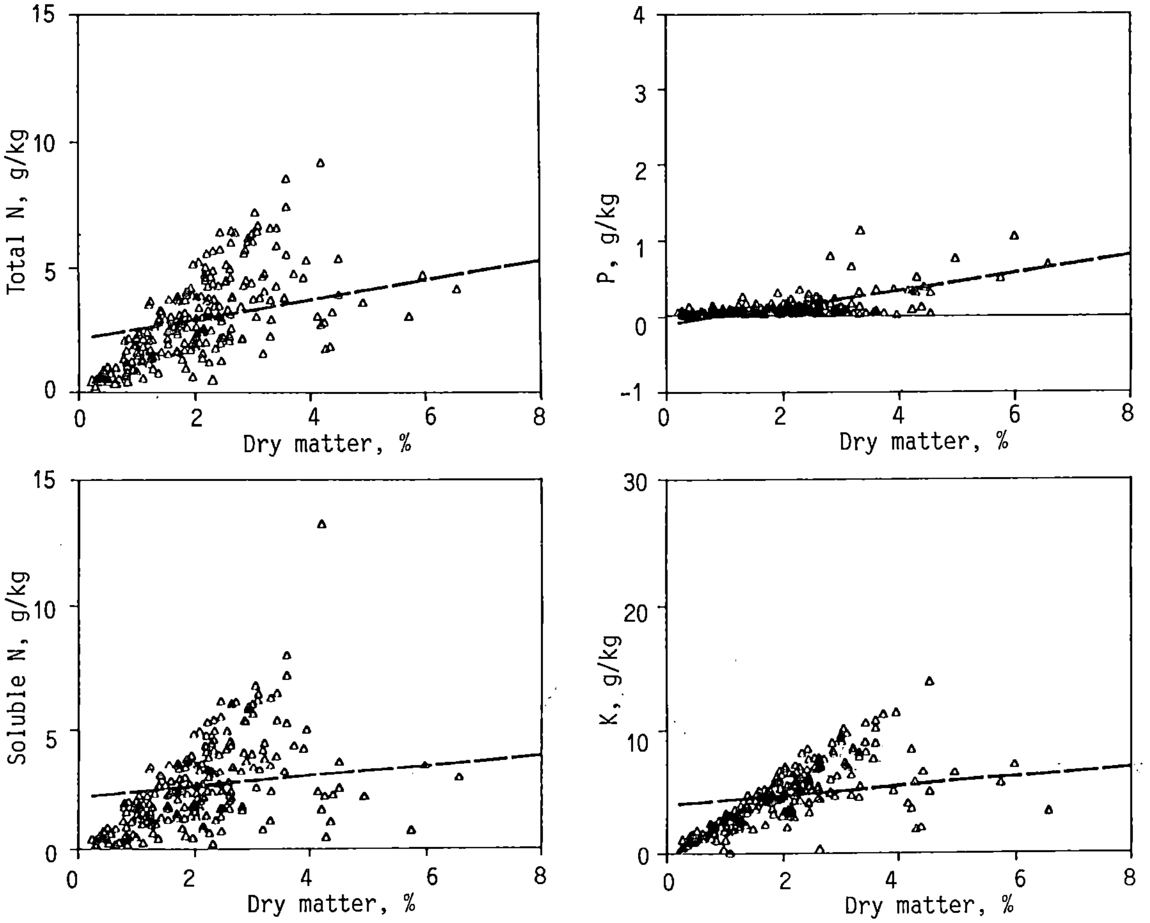
Appendix 3. Cow slurry.

Correlation of dry matter (x) with total nitrogen (y).
$y = 2.00 + 0.17x$ ($r = 0.63$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 1.41 + 0.06x$ ($r = 0.33$, $P = 0.01$).

Correlation of dry matter (x) with phosphorus (y).
$y = 0.15 + 0.10x$ ($r = 0.58$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = 0.69 + 0.28x$ ($r = 0.79$, $P = 0.001$).



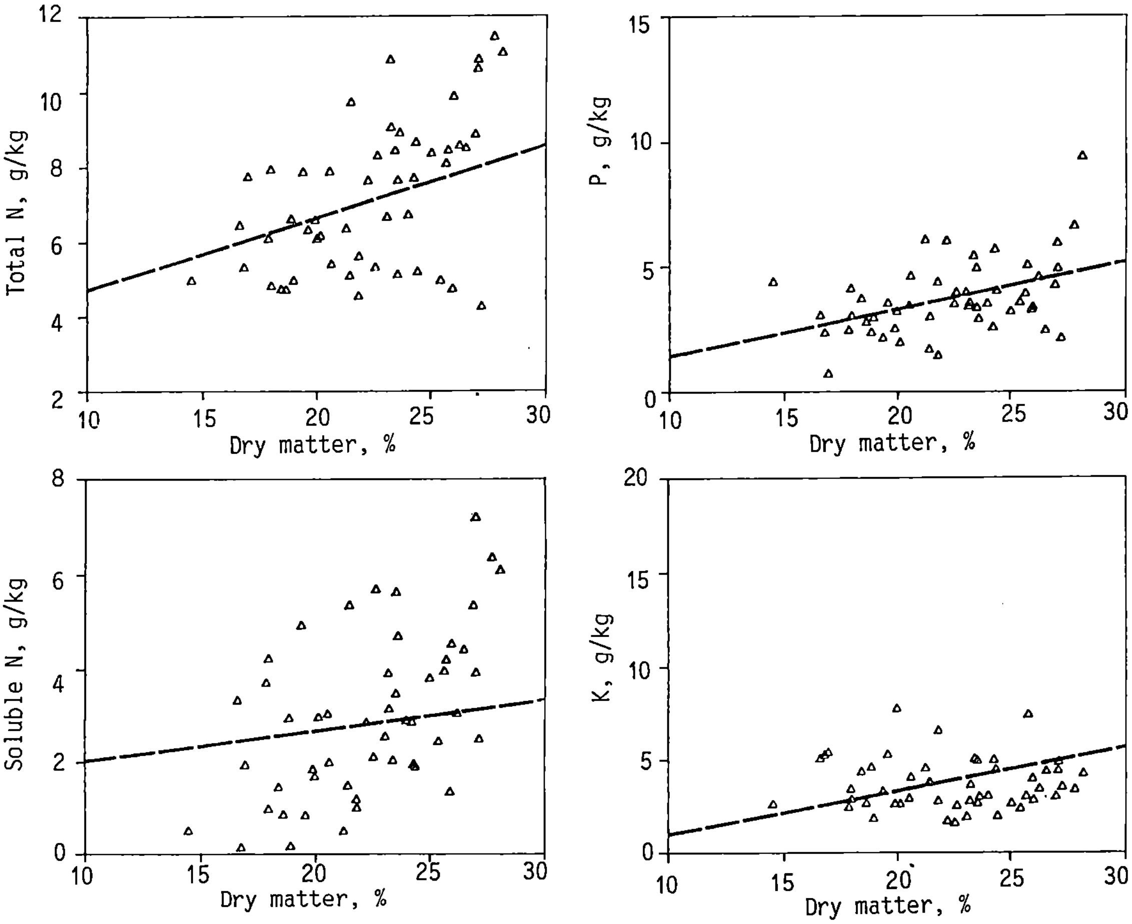
Appendix 4. Liquid cow manure.

Correlation of dry matter (x) with total nitrogen (y).
$y = 2.05 + 0.40x$ ($r = 0.52$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 2.16 + 0.22x$ ($r = 0.30$, $P = 0.001$).

Correlation of dry matter (x) with phosphorus (y).
$y = -0.12 + 0.12x$ ($r = 0.77$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = 3.93 + 0.38x$ ($r = 0.34$, $P = 0.001$).



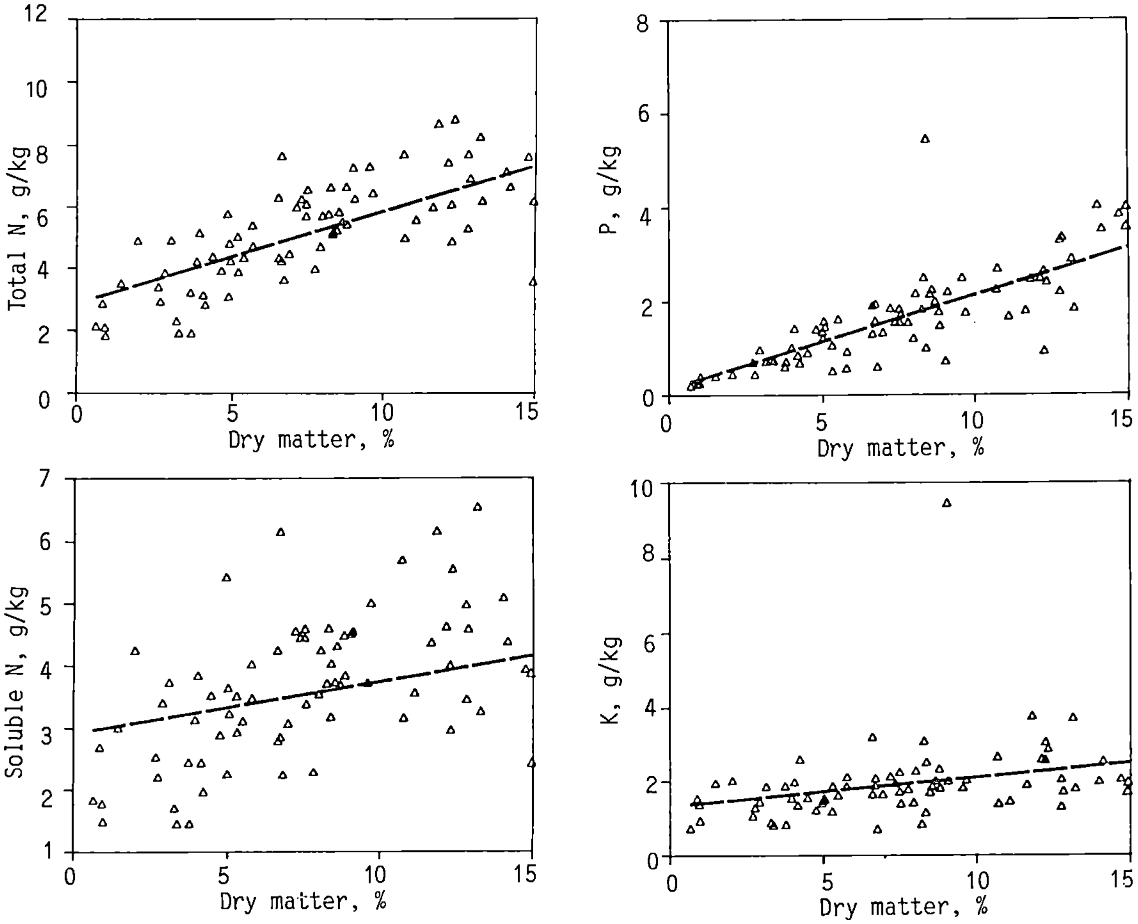
Appendix 5. Solid pig manure.

Correlation of dry matter (x) with total nitrogen (y).
$y = 2.81 + 0.19x$ ($r = 0.52$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 1.36 + 0.07x$ ($r = 0.22$).

Correlation of dry matter (x) with phosphorus (y).
$y = -0.44 + 0.19x$ ($r = 0.57$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = -1.37 + 0.24x$ ($r = 0.55$, $P = 0.001$).



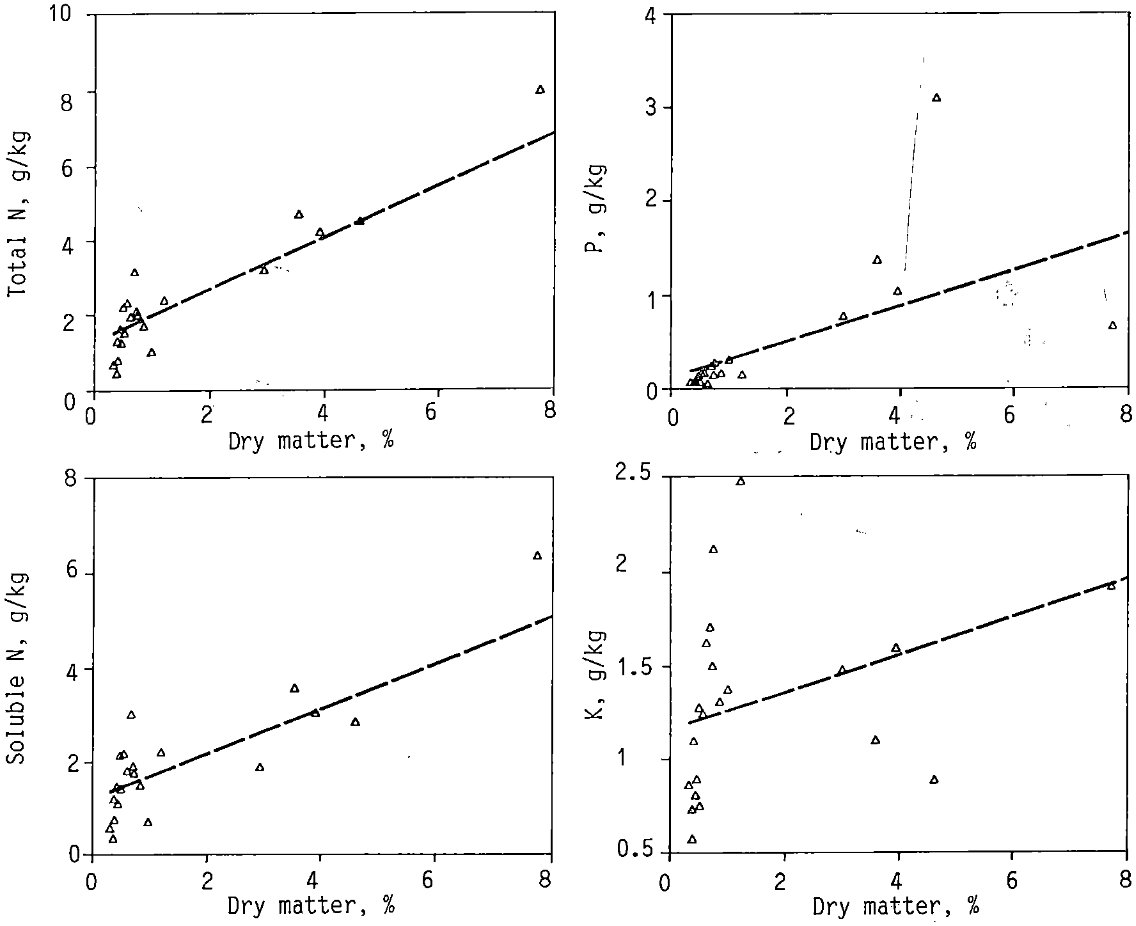
Appendix 6. Pig slurry.

Correlation of dry matter (x) with total nitrogen (y).
$y = 2.84 + 0.30x$ ($r = 0.80$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 2.92 + 0.08x$ ($r = 0.38$, $P = 0.001$).

Correlation of dry matter (x) with phosphorus (y).
$y = 0.10 + 0.20x$ ($r = 0.78$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = 1.31 + 0.08x$ ($r = 0.39$, $P = 0.001$).



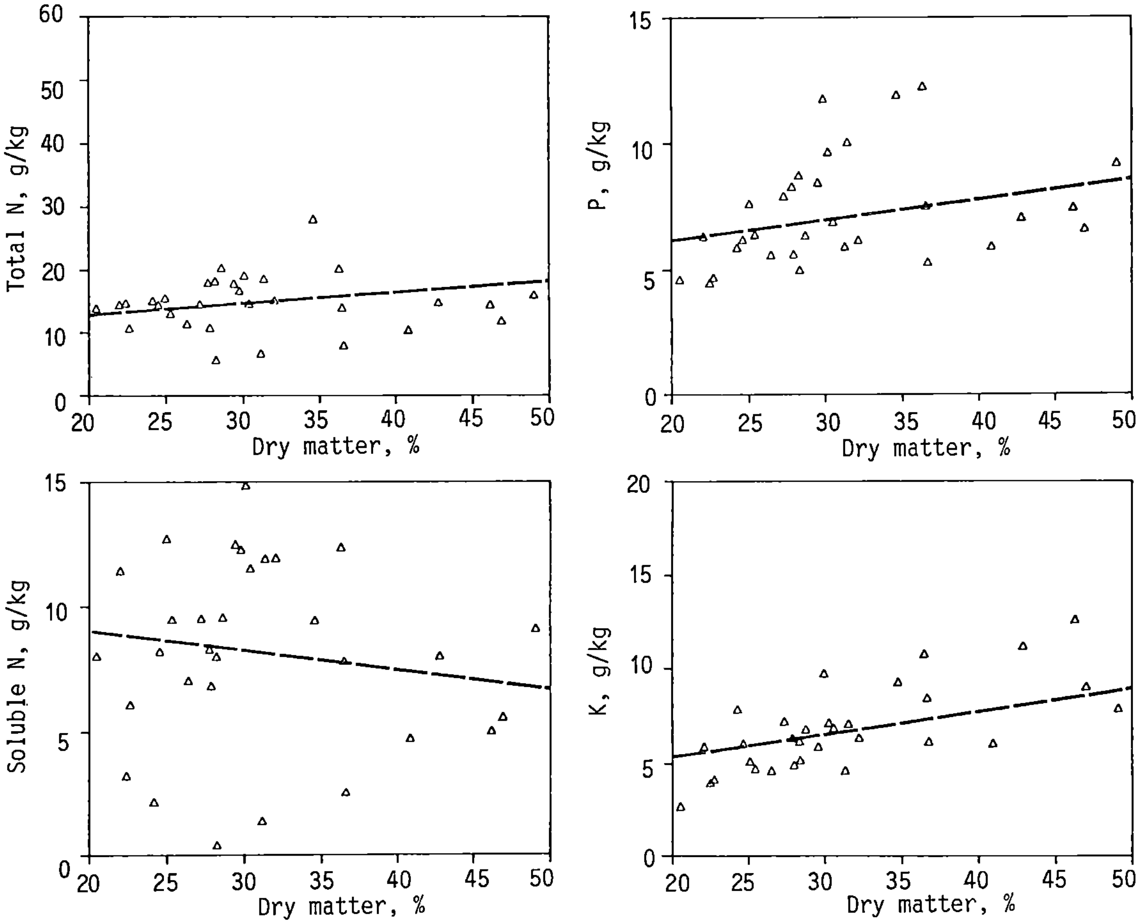
Appendix 7. Liquid pig manure.

Correlation of dry matter (x) with total nitrogen (y).
$y = 1.25 + 0.71x$ ($r = 0.92$, $P = 0.001$).

Correlation of dry matter (x) with soluble nitrogen (y).
$y = 1.20 + 0.49x$ ($r = 0.86$, $P = 0.001$).

Correlation of dry matter (x) with phosphorus (y).
$y = 0.12 + 0.19x$ ($r = 0.66$, $P = 0.001$).

Correlation of dry matter (x) with potassium (y).
$y = 1.17 + 0.10x$ ($r = 0.47$, $P = 0.05$).



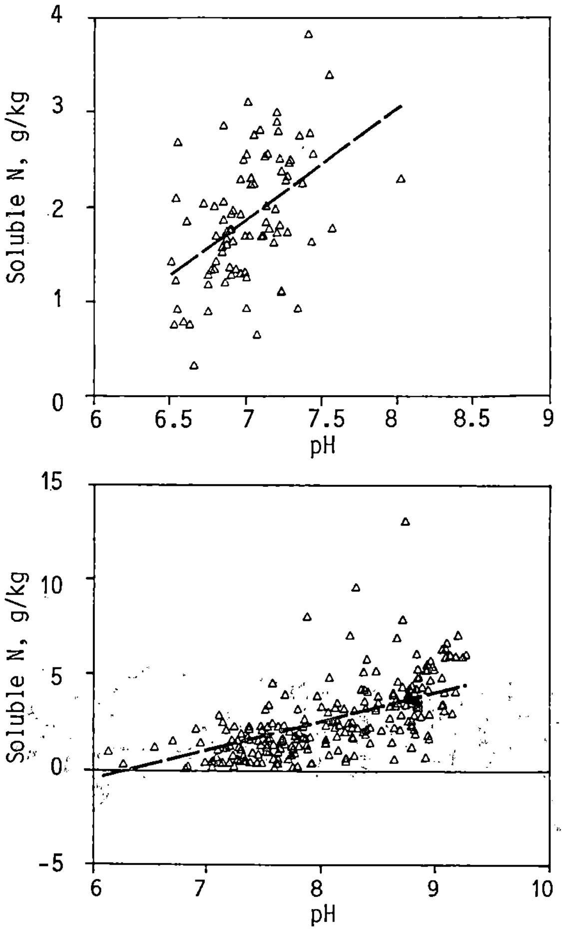
Appendix 8. Solid poultry manure.

Correlation of dry matter (x) with total nitrogen (y).
y = 8.75 + 0.19x (r = 0.41, P = 0.01).

Correlation of dry matter (x) with soluble nitrogen (y).
y = 10.50 — 0.08x (r = —0.34, P = 0.05).

Correlation of dry matter (x) with phosphorus (y).
y = 4.56 + 0.08x (r = 0.49, P = 0.001).

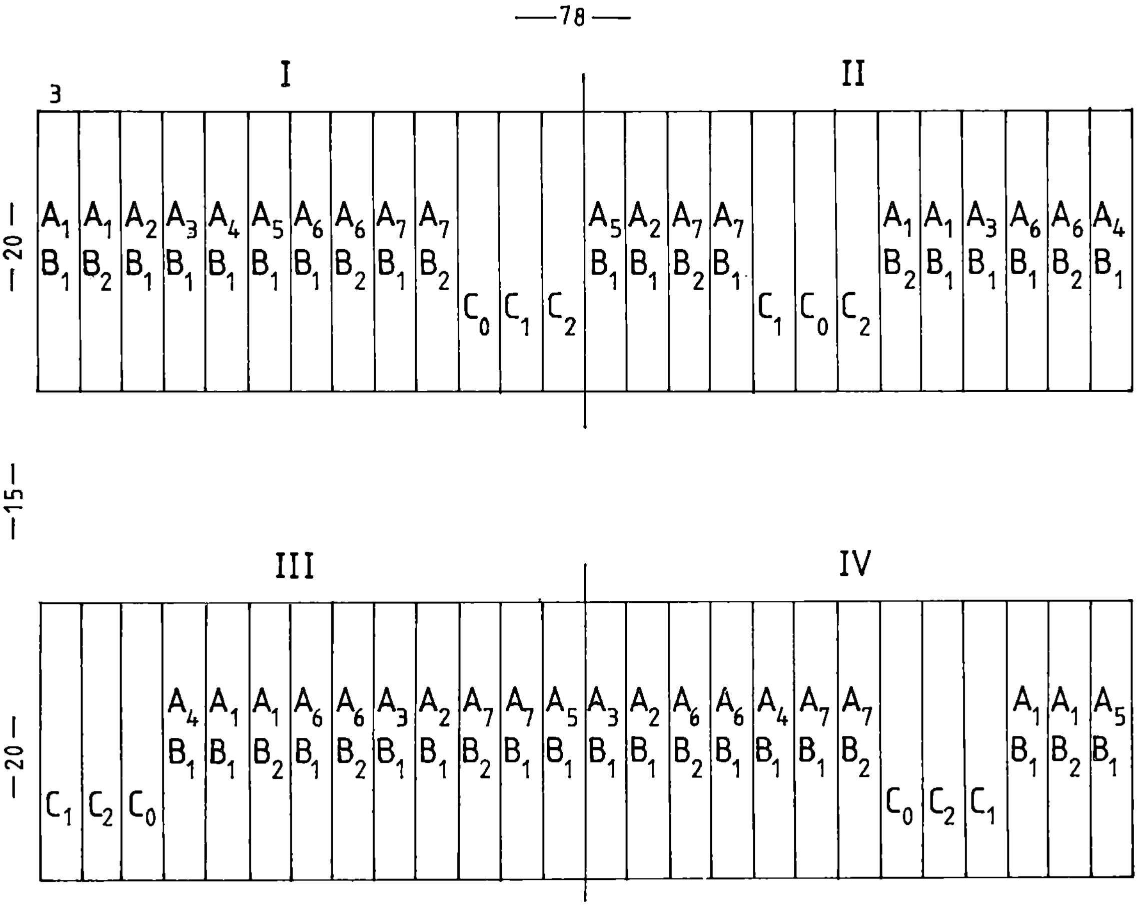
Correlation of dry matter (x) with potassium (y).
y = 2.99 + 0.12x (r = 0.69, P = 0.001).



Appendix 9. Cow slurry and liquid manure.

Correlation of pH (x) with soluble nitrogen (y) in cow slurry (upper).
y = —6.29 + 1.17x (r = 0.48, P = 0.001).

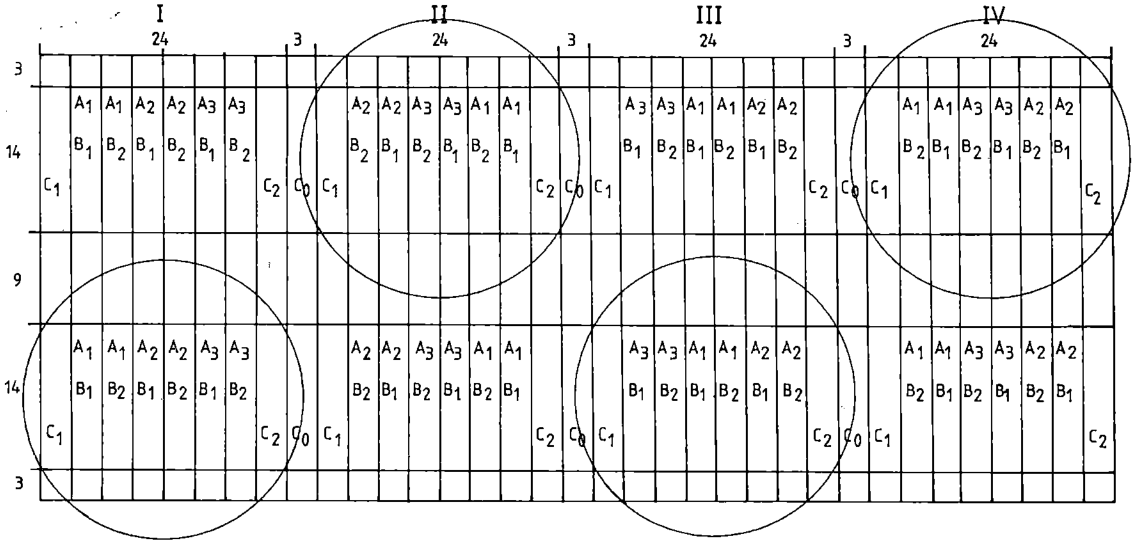
Correlation of pH (x) with soluble nitrogen (y) in liquid cow manure (lower).
y = —9.49 + 1.52x (r = 0.60, P = 0.001).



Appendix 10. Field plan for experiment A1.

A	Slurry application schedule
A_1	Sept.—Oct., on stubble field
A_2	Oct., just before ploughing
A_3	Nov.—Dec., on ploughed field
A_4	March—April, on frozen soil
A_5	May, 1—2 weeks before sowing
A_6	May, 1—5 days before sowing
A_7	May—June, at sprouting

B	Method of slurry application
B_1	On soil surface
B_2	Injected
C	Control treatments
C_0	Unfertilized
C_1	250 kg/ha of NPK (20-4-8)
C_2	500 kg/ha of NPK (20-4-8)



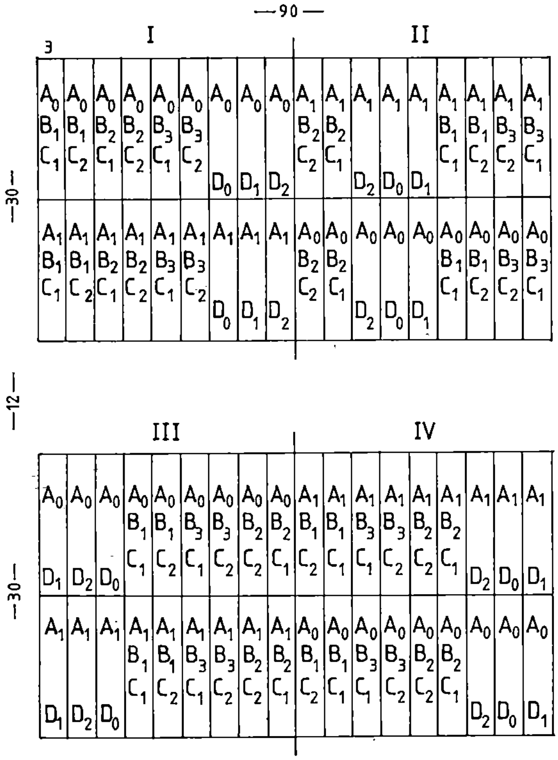
Appendix 11. Field plan for experiment A2.

A **Slurry application schedule**
A_1 Before sowing
A_2 At sprouting
A_3 10 d after sprouting

B **Method of slurry application**
B_1 On soil surface
B_2 Injected

C **Control treatments**
C_0 Unfertilized
C_1 250 kg/ha of NPK (20-4-8)
C_2 500 kg/ha of NPK (20-4-8)

D **Irrigation**
D_0 Unirrigated ☐
D_1 Irrigated ◎



$A_0 B_1 C_1$	$A_0 B_1 C_2$	$A_0 B_2 C_1$	$A_0 B_2 C_2$	$A_0 B_3 C_1$	$A_0 B_3 C_2$	$A_0 D_0$	$A_0 D_1$	$A_0 D_2$	$A_1 B_2 C_2$	$A_1 B_2 C_1$	$A_1 D_2$	$A_1 D_0$	$A_1 D_1$	$A_1 B_1 C_1$	$A_1 B_1 C_2$	$A_1 B_3 C_2$	$A_1 B_3 C_1$
$A_1 B_1 C_1$	$A_1 B_1 C_2$	$A_1 B_2 C_1$	$A_1 B_2 C_2$	$A_1 B_3 C_1$	$A_1 B_3 C_2$	$A_1 D_0$	$A_1 D_1$	$A_1 D_2$	$A_0 B_2 C_2$	$A_0 B_2 C_1$	$A_0 D_2$	$A_0 D_0$	$A_0 D_1$	$A_0 B_1 C_1$	$A_0 B_1 C_2$	$A_0 B_3 C_2$	$A_0 B_3 C_1$

$A_0 D_1$	$A_0 D_2$	$A_0 D_0$	$A_0 B_1 C_1$	$A_0 B_1 C_2$	$A_0 B_3 C_1$	$A_0 B_3 C_2$	$A_0 B_2 C_2$	$A_0 B_2 C_1$	$A_1 B_1 C_2$	$A_1 B_1 C_1$	$A_1 B_3 C_1$	$A_1 B_3 C_2$	$A_1 B_2 C_2$	$A_1 B_2 C_1$	$A_1 D_2$	$A_1 D_0$	$A_1 D_1$
$A_1 D_1$	$A_1 D_2$	$A_1 D_0$	$A_1 B_1 C_1$	$A_1 B_1 C_2$	$A_1 B_3 C_1$	$A_1 B_3 C_2$	$A_1 B_2 C_2$	$A_1 B_2 C_1$	$A_0 B_1 C_2$	$A_0 B_1 C_1$	$A_0 B_3 C_1$	$A_0 B_3 C_2$	$A_0 B_2 C_2$	$A_0 B_2 C_1$	$A_0 D_2$	$A_0 D_0$	$A_0 D_1$

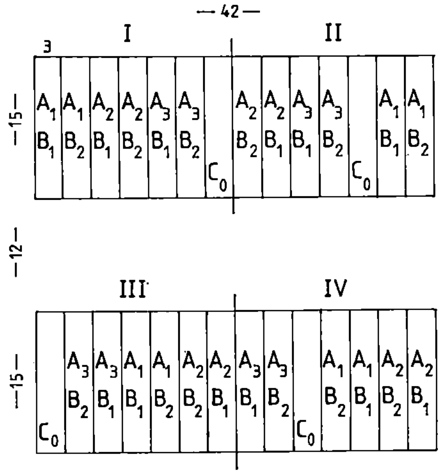
Appendix 12. Field plan for experiment A3.

A N supplementation
A_0 No N supplementation
A_1 33 kg/ha of N

B Slurry application schedule
B_1 Before sowing
B_2 At sprouting
B_3 10 d after sprouting

C Method of slurry application
C_1 On soil surface
C_2 Injected

D Control treatments
D_0 Unfertilized
D_1 250 kg/ha of NPK (20-4-8)
D_2 500 kg/ha of NPK (20-4-8)



$A_1 B_1$	$A_1 B_2$	$A_2 B_1$	$A_2 B_2$	$A_3 B_1$	$A_3 B_2$	C_0	$A_2 B_2$	$A_2 B_1$	$A_3 B_1$	$A_3 B_2$	C_0	$A_1 B_1$	$A_1 B_2$

C_0	$A_3 B_2$	$A_3 B_1$	$A_1 B_1$	$A_1 B_2$	$A_2 B_2$	$A_2 B_1$	$A_3 B_1$	$A_3 B_2$	C_0	$A_1 B_2$	$A_1 B_1$	$A_2 B_2$	$A_2 B_1$

Appendix 13. Field plan for experiment A4.

A Trampling schedule
A_1 Before sowing
A_2 At sprouting
A_3 10 d after sprouting

B Method of trampling
B_1 Surface application imitated
B_2 Injection imitated

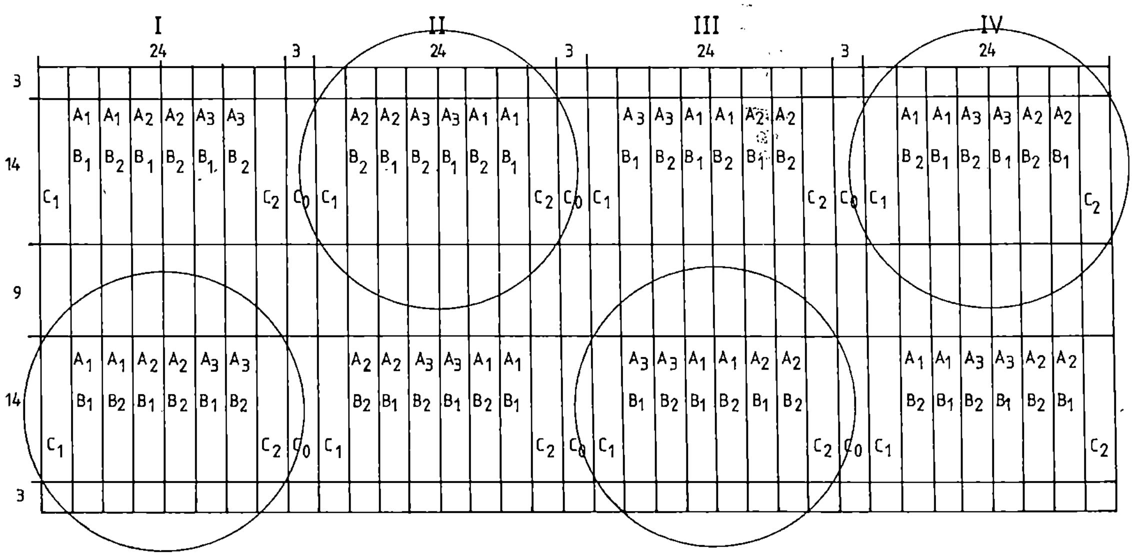
C Control treatment
C_0 Without trampling

Appendix 14. Monthly mean temperatures and total monthly precipitation at Jokioinen.

	1982—1983		1983—1984		1984—1985		1985—1986		1931—1960	
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
September	9.7	67	11.0	86	9.2	77	8.9	51	9.7	61
October	4.1	30	5.4	63	6.6	99	6.4	36	4.3	61
November	3.1	101	—2.4	37	0.8	57	—2.0	55	—0.1	51
December	—1.0	64	—3.6	76	—2.3	40	—7.0	52	—3.5	41
January	—2.0	59	—5.4	75	—16.5	31	—8.8	45	—7.2	35
February	—8.9	6	—5.4	33	—16.2	28	—12.6	7	—7.8	27
March	—3.6	31	—5.4	38	—2.6	30	—1.0	28	—4.6	25
April	4.8	22	4.2	18	0.5	32	2.1	36	2.2	33
May	11.0	44	12.6	66	8.6	43	10.5	52	8.8	39
June	13.3	84	13.1	113	13.2	41	16.3	11	13.7	42
July	16.6	41	14.8	91	15.3	55	16.2	65	16.2	70
August	15.0	58	13.8	69	15.5	119	12.9	110	14.7	74

Appendix 15. Daily mean temperatures and precipitation on days following slurry application in the autumn and spring. Dates of slurry application are indicated by an asterisk.

1982—1983			1983—1984			1984—1985			1985—1986		
Date	°C	mm	Date	°C	mm	Date	°C	mm	Date	°C	mm
13.10.*	3.2	2.5	15.9.*	11.7	1.9	7.9.*	10.0	—	12.9.*	7.5	—
14.	5.7	5.4	16.	11.7	2.9	8.	13.1	0.0	13.	7.1	—
15.	3.1	0.0	17.	15.5	13.1	9.	10.8	1.7	14.	10.7	0.1
16.	1.8	0.1	18.	13.2	—	10.	11.2	12.6	15.	11.8	6.5
17.	— 0.3	0.0	19.	12.6	6.8	11.	11.8	3.1	16.	10.4	0.1
9. 5.*	8.9	0.0	16.5.*	17.5	—	24.5.*	7.5	—	19.5.*	7.5	0.5
10.	11.4	4.1	17.	19.1	—	25.	8.9	1.3	20.	10.8	12.0
11.	9.4	4.4	18.	18.5	—	26.	13.1	—	21.	13.5	—
12.	11.1	0.0	19.	15.1	0.1	27.	16.7	—	22.	11.7	1.1
13.	8.5	3.7	20.	16.1	—	28.	18.2	—	23.	10.6	—
16. 5.*	12.9	1.1	31.5.*	17.5	0.0	7.6.*	7.8	—	9.6.*	10.8	—
17.	15.2	12.5	1.6.	17.6	—	8.	10.1	0.3	10.	13.9	—
18.	13.5	—	2.	18.6	—	9.	10.7	1.7	11.	16.7	—
19.	14.3	—	3.	18.2	—	10.	10.7	—	12.	20.3	0.1
20.	10.3	11.8	4.	16.6	23.4	11.	11.5	0.7	13.	17.7	0.0
23. 5.*	14.7	—	12.6.*	9.1	0.1	13.6.*	12.0	—	19.6.*	21.3	—
24.	13.3	—	13.	12.2	4.5	14.	12.8	7.2	20.	15.7	1.9
25.	13.7	—	14.	10.6	6.5	15.	10.7	9.0	21.	14.8	—
26.	15.1	—	15.	12.6	0.6	16.	10.2	0.4	22.	11.3	0.1
27.	13.7	1.6	16.	13.6	0.0	17.	13.4	0.4	23.	12.9	—
1. 6.*	12.8	3.3									
2.	11.3	5.9									
3.	13.2	14.2									
4.	10.7	—									
5.	6.8	1.3									



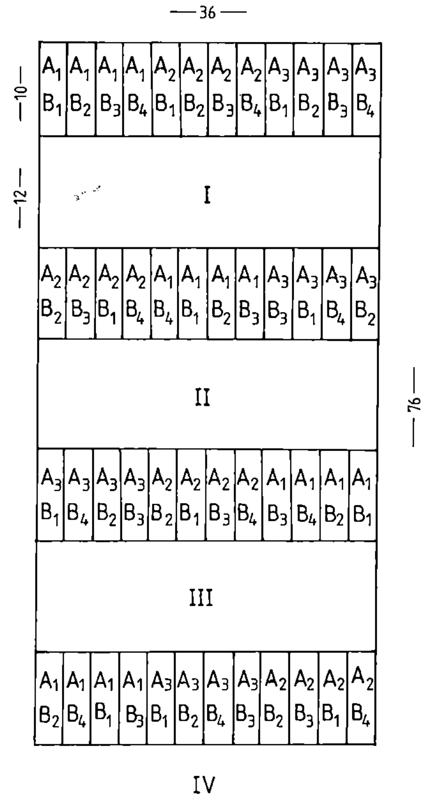
Appendix 16. Field plan for experiments B1 and B2.

A Year of slurry application
A_1 In the 1st year only
A_2 In the 1st and the 2nd year
A_3 In all three years

B Method of slurry application
B_1 Surface application
B_2 Injection

C Controls
C_0 Unfertilized
C_1 ½ NPK = 200 kg (20-4-8)/ha
C_2 1 NPK = 400 kg (20-4-8)/ha

D Irrigation
D_0 Unirrigated □
D_1 Irrigated ◎



Appendix 17. Field plan for experiments B3 and B4.

A Slurry application
A$_1$ No slurry
A$_2$ Surface application, 60 m^3/ha
A$_3$ Injection, 60 m^3/ha

B Rate of NPK
B$_1$ No NPK
B$_2$ 167 kg (20-4-8)/ha
B$_3$ 333 kg (20-4-8)/ha
B$_4$ 500 kg (20-4-8)/ha

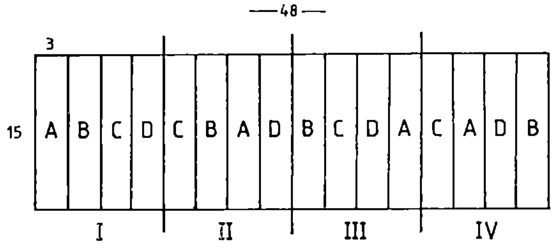
Appendix 18. Daily mean temperature and precipitation for dates following slurry application. Dates of slurry application are indicated by an asterisk.

Jokioinen			Ruukki		
Date	°C	mm	Date	°C	mm
13.6.1983*	17.5	—	8.7.1982*	14.6	—
14.6.1983	18.1	—	9.7.1982	16.9	—
15.6.1983	18.0	0.0	10.7.1982	15.0	—
16.6.1983	16.4	27.1	11.7.1982	18.7	—
17.6.1983	15.4	5.8	12.7.1982	18.0	—
12.6.1984*	9.1	0.1	8.7.1983*	19.8	—
13.6.1984	12.2	4.5	9.7.1983	21.4	—
14.6.1984	10.6	6.5	10.7.1983	21.2	—
15.6.1984*	12.6	0.6	11.7.1983	17.5	—
16.6.1984	13.6	0.0	12.7.1983	17.6	—
17.6.1984	13.5	3.0			
18.6.1984	14.9	0.0	6.7.1984*	11.8	—
19.6.1984	14.0	7.4	7.7.1984	14.3	0.0
			8.7.1984	14.8	—
20.6.1985*	17.3	—	9.7.1984	17.1	—
21.6.1985	19.0	—	10.7.1984	18.1	—
22.6.1985	18.7	—			
23.6.1985	19.5	—	10.7.1985*	16.5	—
24.6.1985	20.5	—	11.7.1985	17.3	—
			12.7.1985	18.4	—
			13.7.1985	18.6	2.0
23.6.1986*	12.9	—	14.7.1985	16.7	0.1
24.6.1986	12.6	—			
25.6.1986	17.0	—	2.7.1986*	13.6	0.7
26.6.1986	21.6	—	3.7.1986	12.3	—
27.6.1986	21.8	2.5	4.7.1986	12.4	2.8
			5.7.1986	15.2	0.8
			6.7.1986	15.8	4.2
			1.7.1987*	12.7	3.8
			2.7.1987	13.1	1.0
			3.7.1987	10.9	—
			4.7.1987	12.6	—
			5.7.1987	15.5	—

Appendix 19. Weather information for field experiments B1—B4.

	Monthly mean temperature, °C							
	1982	1983	1984	1985	1986	1987	1988	1931—1960
Jokioinen								
May		11.0	12.6	8.6	10.5	7.6		8.8
June		13.3	13.1	13.2	16.3	12.1		13.7
July		16.6	14.8	15.3	16.2	14.8		16.2
August		15.0	13.8	15.5	12.9	11.7		14.7
Ruukki								
May	7.1	9.8	11.6	5.6	8.8	6.7	8.6	7.3
June	9.4	12.4	13.0	13.0	15.5	12.3	14.9	12.8
July	15.5	16.0	14.7	15.2	15.8	13.7	18.4	16.2
August	13.2	12.4	12.5	14.3	10.9	10.5	12.8	14.0

	Monthly total precipitation, mm							
	1982	1983	1984	1985	1986	1987	1988	1931—1960
Jokioinen								
May		44	66	43	52	38		39
June		84	113	41	11	81		42
July		41	91	55	65	68		70
August		58	69	119	110	83		74
Ruukki								
May	73	96	26	31	59	28	19	32
June	22	60	65	31	31	85	38	57
July	25	55	114	65	40	87	79	71
August	94	30	34	112	147	104	100	71



Appendix 20. Field plan for experiments B5—B13.

A = Untreated
B = As by surface application
C = As by injection
D = As by injection + rolling thereafter

SISÄLLYS — CONTENTS

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