THE USE OF FERTILIZERS ON GRASSLAND WITH PARTICULAR REFERENCE TO ORGANIC MANURE

by

ALEXANDER DOUGLAS DRYSDALE

THESIS SUMMARY

Constituents of the urine of livestock which could have an effect on pasture include nitrogen, phosphorus, potassium, water, indole-acetic acid, hormones and other substances, yet despite its high potential value as a fertilizer, virtually all the urine produced by stock in winter runs to waste. This waste of urine constitutes an important loss of plant nutrients but in addition it causes a pollution problem in water courses. The logical solution is the use of the urine as a liquid manure on the land but much more detailed and conclusive knowledge is required of its effect on plant growth, and in this thesis three experiments are reported in which different agronomic aspects of the use of the liquid manure on grassland have been studied.

In the first experiment a preliminary comparison was made of the value of applications of liquid manure, conventional dry fertilizers ("Nitro-Chalk", muriate of potash and superphosphate) and water. In the second experiment detailed information was collected on the interaction of five application rates of liquid manure supplying from 0 to 400 lb nitrogen/acre and three application rates of fertilizer nitrogen ("Nitro-Chalk") supplying from 0 to 200 lb nitrogen/acre, with and without phosphate and potash fertilizers, when applied to a perennial ryegrass and white clover sward. The third experiment compared dressings of liquid manure and of dry fertilizer applied at the same time, both treatments supplying 69 lb nitrogen and 114 lb potassium/acre and applied in different months during the winter on six types of sward.

These experiments explained many of the contradictory results obtained from earlier trials in which the effect of urine on pasture was studied.

In the first two experiments in which applications were made in summer, liquid manure and dry fertilizer treatments which supplied equal or almost equal amounts of nitrogen and potassium resulted in similar yields of herbage, but the percentages of clover were higher and the yield of clover approximately double with the liquid manure treatments.

In the third experiment substantial increases in herbage yield were obtained from winter applications of liquid manure, and these increases were again similar to those from the dry fertilizer. The responses were different from the six types of sward and also varied from month to month but it was found that dressings of liquid manure applied in February generally had the maximum effect on each sward.

The effect of liquid manure was attributed mainly to its content of nitrogen and potassium. Although the liquid manure had only a very low phosphorus content, supplementing it with dressings of phosphate fertilizer had no effect on yield in the first experiment and gave only small increases at the high levels of nitrogen application in the second experiment. The water content of the liquid manure had no effect in itself on the yield of herbage or of clover, but the pH and the ammonia nitrogen contents of the liquid manure were higher than those of the dry fertilizer and this was suggested tentatively as a possible reason for the different effects that liquid manure and fertilizers had on clover.

Botanical data obtained from the second experiment showed that changes in the clover cover of the sward on plots receiving liquid manure were generally compensated for by changes in the perennial ryegrass cover, and the total area occupied by clover plus ryegrass was similar under all treatments.

The weed cover was decreased considerably by liquid manure applications and there was a corresponding increase in the proportion of bare ground.

Liquid manure had a high potassium to nitrogen ratio and its application resulted in a marked increase in the potassium content of the soil and of the herbage, and a concomitant decrease in the calcium, magnesium, sodium and phosphorus contents of the herbage. This effect tended to be greater than that caused by applications of equivalent or almost equivalent levels of dry fertilizer and might be of considerable practical importance since the ratio of $\frac{K}{Ca + Mg}$ (using milli-equivalents) was increased to a level which in experiments elsewhere has shown a statistically significant correlation with an increased incidence of hypomagnesaemic tetany in dairy cows.

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REVIEW OF LITERATURE

It is not known when the fertilizing properties of the excrement of animals first became appreciated but according to Hall (1948) the value of dung was recognized certainly by Roman times. Throughout the early history of the scientific appraisal of agricultural practice many references are found to the value of dung (see Russell, 1952) but it was only in the nineteenth century with the growth of chemistry that the fundamental principles involved were discovered. Since the nineteenth century many experiments have been made in this country in an appraisal of the fertilizer value of dung when applied to different crops. Technical improvements in methods of handling the dung coupled with detailed knowledge of its beneficial action on plant growth have established its use in modern agricultural practice.

The effect of the urine of animals on plant growth has also been known since early times but despite the fact that urine has a greater potential fertilizer value than dung, its use has not become widespread in this country. Among early investigations was that reported by Rutherford in 1747 with urine collected from two bullocks. He noted that "the grass owing to this kind of manure grew so amazing luxurious that it was considered as marvellous". These isolated early experiments provided a basis for the collection and application of urine in the nineteenth and early twentieth centuries. The use of liquid manure made from urine was described by Turner et al. (1958) as a feature of many Scottish dairy farms at that time. However, the introduction of artificial inorganic fertilizers and the troublesomeness of collecting urine led to a gradual decline in the use of liquid manure in this country. Whereas dung inevitably had to be disposed of under winter housing conditions, urine could be allowed to run to waste unless situations arose where its collection and fertilizer value could be exploited profitably.

In recent years new husbandry practices, legislation to prevent river pollution, appreciation of the losses involved when urine is wasted and new equipment that has now become available have all led to a revival of interest in the fertilizer value of urine.

The economic contingencies of modern agriculture have stimulated the development of new methods of animal production such as the yard and parlour and cubicle systems for dairy cows, and intensive beef and pig rearing on slatted floors. These systems are designed to operate with a minimum amount of straw for bedding and entail the collection and distribution of all the animal excreta as liquid manure or slurry.

Recent legislation in the form of the Rivers (Prevention of Pollution) Acts 1951 and 1961 is intended to protect the wholesomeness of the country's rivers by preventing indiscriminate disposal of farm effluent into rivers, streams and ditches. The conditions embodied in these Acts have been reviewed by Fish (1962) and McGrath & Howse (1962) and the widespread changes which are forecast may result in thousands of farmers retaining farm effluent and applying it to the land.

The potential value of the urine of livestock which runs to waste annually is very great. The losses involved in Britain have been calculated by the present writer (Drysdale, 1962) to be equivalent to one-quarter of the nitrogen fertilizers and one-fifth of the potassium fertilizers used each year. A report by Turner et al. (1958) stated that the 219 million gallons of urine which run to waste annually in Scotland have a fertilizer equivalent of 40,000 tons of sulphate of ammonia and 29,000 tons of muriate of potash.

Improvement in methods of collection and storage has accompanied the renewed interest in liquid manure. New machinery for pumping and spreading it has become quickly available to allow application either by tanker or by pipeline irrigation.

With this renewed emphasis on liquid manure application in Britain, as in a number of other European countries, new husbandry practices may be required. However, even in Switzerland and Germany where liquid manure farming has been practised for over 100 years, Truninger (1930) and Gunhold (1957) have stated that there is need for modern methods in its use and that although much technical knowledge has been gained, scientific knowledge has been neglected.

With the different agricultural practices used in these countries, different forms of organic liquid manure are found and some confusion exists in the nomenclature. In this thesis the terms urine, liquid manure and slurry have the following meanings.

Urine = the fresh undiluted urinary excretion of the animal.

Liquid manure = a mixture of urine, wash water from the cowshed and very small quantities of solid matter, collected and stored for varying periods. (This is the Jauche of continental literature).

Slurry = a mixture of urine with dung and wash water. (This is the Gülle of continental literature).

The effect of urine on the yield of herbage

Much information on the effect of urine on pasture has been obtained from management studies in which the normal pattern of urine distribution made under natural grazing conditions, referred to as the normal return of urine, was simulated. Dale (1961), Mundy (1961), Sears & Newbold (1942), Sears, Goodall & Newbold (1948), Sears & Thurston (1953), Watkin (1954), Wheeler (1958) and others have studied the effects of sheep urine on pasture, and the effects of cattle urine have been investigated by Doak (1952), During & McNaught (1961), Norman & Green (1958) and Thompson & Coup (1943).

The effects of sheep and cattle urine on pasture have been shown by Saunders & Metson (1959) to be similar, and to depend as might be expected on the quantity of fertilizer nutrients applied.

In New Zealand Sears (1956) showed that the combined use of dung and urine on pasture resulted in substantial increases in yield compared with the yields obtained from plots to which no excreta was applied; dung and urine applied separately produced intermediate results. Thus in a 2-year trial reported by Sears et al. (1948) the return of urine resulted in an increase of 15% in the total dry matter production compared with the control plots which gave a yield of 9500 lb dry matter/acre. In Britain

Mundy (1961) found that urine caused an average increase of 56% in dry matter production over untreated plots which yielded only 3200 lb dry matter. However, mainly because of botanical changes, some experiments showed that urine had little effect or even a derogatory effect on yield. Thus Sears & Thurston (1953) found that there was no increase in yield from the natural return of dung and urine, swards with and without animal excreta both yielding 9600 lb dry matter/acre. Watkin (1954) and Wheeler (1958) found that the yield of grass and clover swards was depressed by urine alone but that when fertilizer nitrogen was applied in addition yields were increased.

The effect of urine on botanical composition

Changes in the botanical composition of the sward in the experiments where dung and urine were returned to pasture were pronounced and were important in their influence on the herbage yields. Sears & Newbold (1942), Wheeler (1958) and many others have reported that the main botanical change resulting from the natural or simulated return of urine to a mixed grass and clover sward was a marked reduction in the red and white clover content. This decline in the clover content of pasture was caused by the increased proportion of grass in the sward, especially ryegrass. The antagonism between grass and clover under conditions of nitrogenous fertilizing has been shown repeatedly since the experiments made by Blackman (1938). However, Doak (1954) went so far as to suggest that urine contained a substance which inhibited the growth of clover roots. Where only a single application of cattle urine simulating a urine patch was made, Norman &

Green (1958) reported that this was too small to have any long-term effect on botanical composition. Where clover was depressed by the nitrogen applied in the urine, an increase occurred in the yield of herbage only if there was an increased growth of the grass present in it. Thus the depression of red clover found in the New Zealand experiment of Sears & Thurston (1953) and the depression of white clover in the British experiments of Watkin (1954) and Wheeler (1958) was not sufficiently compensated for by an increased growth of grass. With a very productive sward and a high stocking rate in the experiments of Sears et al. (1948) the increased growth of ryegrass did offset the loss which otherwise would have resulted from the depression of the white clover.

The effect of urine on the mineral status of the soil

The soil nutrient status can affect the response to applications of urine. Mundy (1961), for example, showed that where the potassium content of the soil was low, potassium in the urine increased pasture yields and also maintained the clover content of the sward. A high response to urine applications was not found by Watkin (1954) or by Wheeler (1958) when potassium fertilizer was applied as a basic dressing.

In a mathematical study of the frequency distribution of excreta over a grazed area, Petersen, Woodhouse & Lucas (1956) showed that freely grazing cattle at normal stocking rates were inefficient distributors of fertilizer nutrients and that wastefully high rates were applied on relatively small areas. They calculated that only 16% of the pasture could be expected to be affected by a supply of nitrogen from excreta at one time. Saunders &

Metson (1959) estimated that even under a relatively intensive grazing rate of ⅘ of a cow/acre, only 25% of the area received urine. Similarly MacLusky (1960) calculated that with 200 cow-grazing days/acre only 20% of the pasture received urine. Petersen et al. (1956) concluded that for elements such as phosphorus, that are lost slowly from the soil, intensive stocking for a long enough period could permit a reduction in the amount of phosphate fertilizer applied. With nitrogen, however, and to a lesser extent with potassium, no reduction in the application of these fertilizers was advised and identical applications were needed whether pastures were grazed by animals or cut, i.e. whether excreta was returned or not. The inefficiency of nutrient return under grazing was discussed by Metson & Saunders (1962) in relation to potassium-deficient areas of New Zealand. In these areas, dressings of potassium fertilizer resulted in a luxury uptake by the grass and clover, and subsequently this element was distributed inefficiently in urine patches so that the fertilising effects were short-lived.

Constituents in urine affecting plant growth

The studies that were made on the natural return of dung and urine, either separately or together, emphasized the different roles of the two forms of excreta when applied to pasture. Urine had a greater effect than dung on herbage production and on the botanical composition of the sward. Cooke (1960) reviewing the effects of grazing animals pointed out that urine contains most of the nitrogen and potassium excreted, whereas most of the phosphorus is in the dung. The phosphorus content of urine is approximately 0.01% and this has a negligible fertilizer value. Sears &

Newbold (1942) calculated that of the excreted elements less than 2% of the phosphorus and calcium but some 70% of the nitrogen and 86% of the potassium were in the urine. Similar figures have been given by Ames (1912), Brünner (1958), Mundy (1961), Petersen et al. (1956), Salter & Schollenberger (1939) and many others. Sears (1956) pointed out that the amount of soluble and readily available nitrogen in dung was low and that its full utilization by the plant could be realized only after prolonged action by the soil micro-organisms whereas the urinary nitrogen was available almost immediately. Much of the effect of urine on pasture should be related, therefore, to its content of readily available nitrogen and, where the potassium status of the soil is low, to its content of potassium. Mundy (1961) has gone so far as to suggest that the effect of urine could be explained entirely by its content of nitrogen and potassium.

Little information is available in the literature on the relative efficiencies of urine nitrogen and inorganic fertilizer nitrogen. In a small scale experiment Gisiger (1950) tested the effect of the nitrogen in urine and in different fertilizers on two grasses. With Italian ryegrass (Lolium italicum), ammonium nitrate produced the greatest relative yield, i.e. 118, when that of urine was taken to be 100, while ammonium sulphate gave a yield of 113. With cocksfoot (Dactylis glomerata), ammonium sulphate gave the highest relative yield of 103 compared with 77 from ammonium nitrate and 100 from urine. Normally applications of urine to grassland are associated with serious losses of nitrogen. For example, During & McNaught (1961) reported an apparent net recovery of only 10% of the nitrogen applied in urine. This compares poorly with an average of 50% for fertilizer nitrogen recorded by Holmes & MacLusky (1955). More information is required on the effects of urinary nitrogen in comparison with other nitrogen fertilizers.

The high potassium content of urine has been shown to have smaller and less spectacular effects on herbage than has the nitrogen content. The apparent recovery of potassium in the herbage was 23% of that applied in the urine and 21% of that applied as potassium chloride (KCl) in an experiment reported by During & McNaught (1961), and no difference was found in herbage yields. Saunders & Metson (1959), however, found a higher recovery of potassium from applications of KCl than from applications of urine.

Although the effects of urine have been generally attributed to its content of nitrogen and potassium many observations indicate that other constituents may be involved. Watkin (1954), for example, suggested that the effect of urine might be due in part to its auxin and water contents. Doak (1954) concluded that cow and sheep urine contained a substance which inhibited the root growth of clovers. He inferred the existence of an inhibitor-auxin complex with the auxin of the complex probably being indole-acetic acid. Where the inhibitor portion was inactivated by bacteria, as in the soil and on storage, stimulation of root growth occurred, presumably due to the indole-acetic acid. However, in a field-scale experiment to investigate the existence of a growth-promoting factor in urine, Mundy (1961) found that indole-acetic acid applied to the sward had no effect on the botanical composition or on the production of herbage. As well as indole-acetic acid, Salter & Schollenberger (1939) mentioned creatinine in urine as a plant growth promoter. Sauerlandt (1948) suggested also that the water and hormone contents of urine were important and that to base the value of urine on its nitrogen and potassium contents alone was wrong. He used the growth of yeast to measure the hormone activity of different forms of urine and liquid manure and showed that the number of added yeast cells x 10^3 increased from an initial amount of 87 to 1580 in fresh urine and to 2152 in fermented urine which had been stored for some weeks, i.e. liquid manure. From the results of other experiments Sauerlandt (1948) inferred that the high hormone activity of liquid manure apparently could be further increased by dilution of the liquid manure.

Liechti & Mooser (1906), who were perhaps the first to suggest that urine contained constituents which were harmful to pasture, showed that salts of benzoic acid in fermented urine were damaging to soil bacteria and to plant growth. Schneiter (1958) and Schechtner (1958) studied the breakdown of hippuric acid in urine to benzoic acid and of urea to ammonium carbonate, and discussed the possible harmful effects in the soil of sodium and potassium benzoate on shallow rooted plants such as the cultivated grasses. Phenols and paracresol were also produced when urine fermented (Sauerlandt, 1948; Voigtländer, 1952). The toxic effect of organic acids was found with red clover and shallow rooted plants by Voigtländer (1952), but Schneiter (1958) reported that the deep rooted Rumex spp were little affected. In contrast Voigtländer (1952) showed that benzoic acid in dilute solution had a stimulating effect on plant growth. Doak (1954) eliminated benzoic acid and cresols as being responsible for growth inhibition but found that hippuric acid caused slight root retardation. This, however, was much less than that caused by urinary extracts at equivalent dilutions and indicated that hippuric acid per se was not the root inhibitor in urine.

The benefits of humus in the soil are well known and much has been written about the effects of animal excreta and humus production. Fresh urine, however, contains no humus and it is when dung is mixed with urine that humus formation takes place.

Most of the constituents in urine have been shown, therefore, to be effective in promoting plant growth under certain conditions and only a few have seemed to reduce it. This potential for increasing plant growth largely is wasted because of the inefficient distribution of urine by grazing animals and this has directed attention to the practice of conservation of the urine and its application as liquid manure or slurry.

The effect of liquid manure and slurry on yield

Few experiments have been made to study the effect of urine as a grassland fertilizer in Britain. Hendrick (1915) discussed many aspects of the use of urine as a liquid manure and he investigated the effect of winter applications. Applications of liquid manure to provide 40 lb N/acre were made in January, late February and April, and 6040, 6480 and 5980 lb of hay/acre were obtained compared with 5020 lb/acre from an untreated area. Similar results were reported by Coady & Ratcliffe (1954) in England and by the Director of the Department of Agriculture for

Ireland (1915) where liquid manure was applied on average at 2000 gallons/acre. The use of liquid manure in Britain was reviewed by Turner <u>et al.</u> (1958) but because of the absence of experimental data no information was given of expected increases in yield. Attention has been drawn to the value of liquid manure in New Zealand through the fundamental studies of Sears and others but its collection and use as a fertilizer there are limited since the cows are indoors for only a very small part of the year. Edwards (1957), for example, calculated that in that country only 5% of the urine could be collected for use as a fertilizer. In spite of this disadvantage Blake (1942) in New Zealand has described the very high value of liquid manure and quoted remarkable effects of its application to pasture.

From a large number of experiments conducted in Denmark, Iversen (1955) reported that spring applications of liquid manure produced the largest and autumn applications the smallest increases in yield in the wetter areas, while on the drier areas winter applications had the greatest effect. Where equal amounts of nitrogen were supplied as liquid manure and as fertilizer nitrogen the losses by leaching were greater with the latter. The opposite result was found in experiments in Germany reported by Rheinwald (1934). After a basic dressing of phosphorus and potassium fertilizers on all his plots, he applied 90 lb N/acre as liquid manure in December, February and May and as sulphate of ammonia in November. The hay yields from the four treatments at the first cut in summer were higher than those from the untreated plots by 38, 44, 30 and 52% respectively and there was a further effect at a second cut.

The lower yields from the early dressings of liquid manure were correlated with losses by leaching and evaporation while the lower yields from the May treatment were due to the lateness of the application.

With applications made during the summer growing period, Nevens (1941) found an increase of 44% in the yield of bluegrass (Poa pratensis) pastures with approximately 55 lb N/acre applied as urine. A similar response was found in earlier American investigations reported by Curtiss (1896).

Of these experiments on the fertilizing value of winter and summer applications of urine and liquid manure to grassland, few are comparable because of differences in methods and materials. The conflicting results obtained indicate the need for a greater knowledge of the effects and the relative efficiency of liquid manure applied at different times during the year.

The effect of slurry was reported by Hodgson et al. (1942) as being very small. Over a 4-year period in America they compared pastures treated with slurry during the summer grazing period with untreated pastures. There was a very small increase of 8.4% in the total digestible nutrients from pasture given an average annual application of 214 lb N/acre as slurry. The low response to slurry was attributed to the high fertility of the soil. A higher response was obtained when this experiment was repeated on poorer soil by Wolberg, Spielman & Miller (1945) who found increases of 15% in the total digestible nutrients and 12% in the dry matter resulting from applications of 93 lb N/acre as slurry. Under a system of cutting only, Herriott & Wells (1962) obtained an increase of 23% in dry matter yield with summer applications of slurry; the untreated plots yielding 7500 lb dry matter/acre. In this experiment the slurry was only about 55-60% as effective as inorganic fertilizer nitrogen.

<u>The effect of liquid manure and slurry on botanical composition</u>

Contrary to the depression of clover that occurred where urine was returned to pasture under the simulated or natural grazing conditions, liquid manure and slurry have been reported to increase white clover in many experiments. For example, Hendrick (1915) reported that liquid manure had a very noticeable beneficial effect on clover despite the high amount of nitrogen applied in the liquid manure and this was also observed by Blake (1942) in New Zealand. Similar effects with slurry were described as early as 1887 by Stebler & Schroeter and later by Klapp (1931), Radtke (1934) and Gisiger (1950). Gisiger (1950) emphasized this increase in white clover by stating that thousands of observations have proved that this species was not suppressed but encouraged, although red clover deteriorated. In contrast, a depression of legumes by liquid manure and slurry was reported by Brünner (1954), Dusserre (1933), Schöllhorn (1955) and Voisin (1960). Emphasis on the effects of liquid manure on the clover content of pasture is planned in this thesis in an attempt to explain these conflicting results and to provide further information on the interaction of liquid manure and clover.

Experimental and practical observations on the dicotyledonous weed content of pastures which had liquid manure and slurry applications have also given conflicting results. Schechtner (1958) listed the weeds in pasture that were encouraged by slurry as broad-leaved dock (Rumex obtusifolius), cow parsnip (Heracleum sphondylium), wild chervil (Anthriscus sylvestris), bishopweed (Aegopodium podagraria), buttercup (Ranunculus spp) and dandelion (Taraxacum officinale). Brünner (1954) also indicated that slurry increased the umbelliferous weeds such as Anthriscus sylvestris and Heracleum sphondylium but he noted that they could be controlled by the grazing and treading of animals. Increases in the umbelliferous weeds where liquid manure was applied have been reported by Alten (1952) and in the Ranunculus spp by Koblet (1946). An increase in umbelliferous weeds from 11% before liquid manure applications to 40% after 2 years of application has been quoted by Voisin (1960) who reported also that heavy slurry dressings caused an increase from 6 to 58% in those weeds. Other experiments, by Klapp (1931) using liquid manure and by Stachler (1961) using slurry, showed no weed increases. In Scotland Turner et al. (1958) reported that weed growth was unaffected on some farms but on others Rumex spp and other weeds were greatly increased.

An experiment by Wheeler (1959) showed that seeds of Poa annua were prevented from developing in the soil by applications of sheep urine but where very dilute urine was used the seeds were almost unaffected. Doak (1954) also found that cattle urine killed all the seeds in the soil that were actually wetted with urine and largely prevented the emergence of seedlings. Grass seedlings were less affected than most weeds but clover was extremely sensitive.

Further work appears to be needed to ascertain whether the use of liquid manure as a fertilizer does encourage weeds or whether many of the results quoted reflect poor husbandry methods which in themselves tend to encourage the spread of weeds.

Factors affecting the composition of liquid manure and slurry

The use of liquid manure and slurry is an important factor in the farming economy of parts of Switzerland, Germany and Austria and many of the different systems of collection and application devised result in different proportions of dung, urine and water. Analyses of liquid manure quoted by Gisiger (1950) were 0.7% N, 0.004% P and 1.2% K in a ratio of 175:1:300. Analyses of 266 samples of slurry reported by Schöllhorn (1955) averaged 0.4% N, 0.04% P and 0.6% K, a ratio of 10:1:15. The increase in phosphorus with the addition of dung gave a slurry in which these three elements were present in much the same proportions as in grass dry matter. This balance of fertilizer nutrients in slurry and the fact that the increased quantities of fertilizer obtained could be applied over larger areas have been given by Friedmann (1934), Gisiger (1950) and Schneiter (1958) as reasons for the widespread use of slurry in Alpine areas, but research in these countries has been devoted mainly to technical aspects of collection and storage.

Where slurry was stored for 3 weeks before application as opposed to several months, Brünner (1958) found that a smaller area of pasture was needed per animal with a consequent increase in milk yield/acre. This resulted mainly from lower storage losses. Sauerlandt (1948) emphasized the fact that considerable losses can occur during storage, especially in the nitrogen content. For example, the nitrogen content of fresh urine fell from 0.7% to 0.3% after 2-3 days although the same urine stored under laboratory conditions contained 0.4% N after 15 months. This type of loss of nitrogen was reported also by Schöllhorn (1955) who showed that phosphorus and potassium were little affected. In these areas where slurry is used the average storage time was 41 days.

Dilution with water can lessen the storage losses from the urine by helping to keep the ammonia in solution. Brünner (1958) found that with dilution rates of 2.9 and 4.4 the milk yields from the respective grazing areas were 3285 kg and 5706 kg/hectare. Lutz (1948) suggested a dilution rate of 1.5 or 3 for highest yields but in drier and windier conditions dilution rates of 3 or 6 were better. Schöllhorn (1955) showed that dilution of slurry increased dry matter yields on light soils but had little effect on heavy soils. There was no evidence that the increased yields of herbage on the light soils resulted from a higher water content of the diluted slurry but this irrigation effect has been discussed by Sauerlandt (1948). Schöllhorn (1955) also found, however, that dilution reduced the yield in one experiment probably because of a drop in the soil temperature of 3°C caused by a dressing of slurry equivalent to 15 mm of rain.

<u>The effect of liquid manure on the mineral content of herbage</u>

The application of urine to pasture has a marked effect on the chemical composition of the herbage. This may not be of practical significance under natural grazing conditions where only about 25% of the pasture may be affected even under heavy grazing, but where liquid manure is applied uniformly and in large quantities as a fertilizer changes in the mineral content of the treated pasture are of considerable practical importance to animal health. Nevens (1941) found that urine increased the protein content of the grass at the highest application rate to an average of 17% crude protein compared with 13% in the herbage from control plots. However During & McNaught (1961), Hodgson et al.(1942) and Melville & Sears (1953) found little or no effect of urine or slurry on the protein content of herbage. Dusserre (1933) and Watkin (1954) reported that there was a lower protein content where urine was applied, mainly because of a depression in the clover content of the sward.

When urine is applied to pasture either by grazing animals, as liquid manure or as slurry, there is an increase in the potassium content of the herbage (Geering, 1943; Hodgson et al., 1942; Melville & Sears, 1953; Schiller, 1955; Sears & Thurston, 1953; Truninger & Grünigen, 1935 and others). Since herbage takes up the monovalent potassium ion in preference to the divalent magnesium ion (Head, 1961), there is a decrease in the magnesium content of herbage where urine is applied (Saunders & Metson 1959; Watkin, 1957). This is important because of the apparent relationship between a high potassium and low magnesium content of herbage and hypomagnesaemic tetany in sheep and cattle, reported by Frens (1959) and Kemp & 't Hart (1957). High urine applications have been stated by 't Hart (1956) to be a more serious cause of hypomagnesaemia in Holland than high quantities of conventional nitrogen and potassium fertilizers and because of this the use of liquid manure is reported as declining there. It is noteworthy that Holland is the main source of reference to this effect of liquid manure. In parts of Germany where there is intensive use of liquid manure Brünner (1954) has stated that hypomagnesaemia is not found. The incidence in Holland may be more severe because of the intensive use there of nitrogen fertilizers which results in the pastures having a lower clover content. Clover has been shown by Blaser & Brady (1950) and Melville & Sears (1953) to have a lower potassium content than grass and also a higher magnesium content (Hvidsten et al., 1959; Todd, 1961) although it is not known whether this would hold where liquid manure was being used. In Alpine pastures the high proportion of the sward made up of weeds and herbs with high mineral contents may be the reason for hypomagnesaemia being so uncommon in those areas. The threat of an increased incidence of hypomagnesaemia where liquid manure is used is of considerable scientific and practical importance and stresses the need for further details of the mineral content of pasture receiving liquid manure.

Apart from this incidence of hypomagnesaemia there is no evidence that liquid manure has a deleterious effect on the health of livestock grazing the treated pastures and in fact it may be valuable in increasing dry matter intake. Nevens (1941) in experiments with bluegrass (Poa pratensis) pasture noted that the palatability of the grass on plots treated with urine was greater than that of the grass on the untreated plots, and he suggested that this might be because of the increased protein content of the treated pasture. Blake (1942), Coady & Ratcliffe (1954), Hodgson *et al.* (1942), Mackie (1961) and Norman & Green (1958) noted that where cattle had access to pasture after liquid manure or slurry applications, the treated pastures were at least as well grazed as the untreated areas. No evidence is available in the literature to show that either liquid manure or slurry has any deleterious effect on the acceptability or palatability of the herbage provided that there is no actual contamination of the herbage by solid material when the animals are grazing.

GENERAL INTRODUCTION

The review of literature in the preceding pages has shown that much has yet to be learned about the effects of urine on the yield and botanical composition of pasture. Often the results of experiments were variable and contradictory. For example, urine increased dry matter yields in some experiments but decreased it in others, and clover growth was increased in some but reduced in others. It has been suggested that several substances such as nitrogen, potassium, indole-acetic acid, water and other constituents in urine are responsible for these changes. In general the review emphasized the need for much more detailed and conclusive information on the effects of liquid manure applications on grassland.

The results of three experiments which were made to clarify some of the salient points from earlier investigations and to appraise the fertilizer value of liquid manure are reported here.

Expt 1 was planned as a preliminary study of the effect of liquid manure on the yield and botanical composition of a grass and clover sward, and the value of the liquid manure as a fertilizer was compared with the value of conventional dry fertilizers, and applications of water. This experiment was started in 1958 and continued during 1959 and 1960.

Expt 2, which constitutes the main part of the work described here, was designed to obtain more detailed information of the effect of liquid manure when applied with different levels of nitrogen, phosphate and potash fertilizers on a grass and clover sward. This included a study of the changes in the botanical composition of the sward and the mineral content of the soil, grass and clover fractions. The results for 1961 and 1962 are reported here.

Since capacity for the storage of liquid manure is limited on most farms, it is usual in practice to apply liquid manure in winter or early spring and Expt 3 was planned to study the effectiveness of winter applications. In the winters of 1959/60, 1960/61 and 1961/62, liquid manure was applied to plots in a single dressing in such a way that some plots received it in November, some in December, some in January, some in February and others in March. It was applied to contrasting sward types and the results were compared with those obtained from applications of equivalent levels of dry fertilizers applied on the same dates.

The results from each of these three experiments are discussed separately, and in the last section of the thesis the main points arising from them are collated in a general discussion.

Collection of liquid manure

The liquid manure used throughout this work was collected in an underground storage tank and was composed of the mixed urine from thirty Ayrshire cows. The urine was diluted with wash water (i.e. with some of the water used for hosing the cow shed) and contained a trace of solid material. Separation of the urine from the bulk of the wash water was achieved by the use of a diversion gully at the end of the drainage channels in the cow shed. This allowed only a small proportion of the wash water to enter the storage tank. The liquid manure was collected during the winter months when the cows were indoors and were being fed on conserved grassland products and on a concentrate ration of cereal products and oilcake. When the storage tank was full, generally by the spring, the diversion gully was closed and liquid paraffin was added to form a thin layer of oil on the surface of the liquid manure to lessen the loss of nitrogen caused by the evaporation of ammonia.

When the liquid manure was collected for application in winter, the amount by which the urine was diluted by wash water varied because of the continuous filling. In summer there were losses associated with the evaporation of ammonia in spite of the liquid paraffin and the concentration of nutrients decreased with storage.

The liquid manure was removed by a tractor-operated vacuum tanker from the storage tank after it had been mixed by alternately filling and emptying the tanker which was then used to transport the liquid manure to the site of the experiments where the appropriate quantities were weighed and applied to the plots by a watering can fitted with a fine rose.

EXPERIMENT 1

Object. To make a preliminary study of the use of liquid manure and to compare its effect on grassland with that of conventional dry fertilizers and of water applications. *

EXPERIMENTAL

General

The experiment started in the spring of 1958 in field A of the Hannah Institute farm. The soil was a free draining light to medium loam and the field was about 100 ft above sea level. Soil sampled in January 1958 had the following analysis: pH 6.37; available P_2O_5, 6 mg/100g and available K_2O, 14 mg/100g. These unit values indicate a "medium" P_2O_5 and a "satisfactory" K_2O content according to the classification used by Whittles (1952).

The sward used in this trial was sown in 1955 with 20 lb of meadow fescue (*Festuca pratensis*) and 2 lb of white clover (*Trifolium repens*) per acre, and from 1955 to 1957 it was cut regularly and was also grazed by cattle. At the start of the trial the balance of grass and clover in the sward was good with an even distribution of white clover and few dicotyledonous weeds.

Treatments

The experimental treatments were:

Control

1) No application of liquid manure, dry fertilizers or water.

* This experiment has been published in shorter form by Castle & Drysdale (1962).

Table 1. Date of application (day/month) in Expt 1

Application	1958	1959	1960
1	2/4	25/3	28/3
2	16/5	20/5	25/5
3	18/6	30/6	1/7
4	31/7	6/8	15/8
5	2/9	7/9	8/9

Table 2. The contents of nitrogen and of potassium (g/100 ml) in the liquid manure at each application

	1958		1959		1960	
Application	N	K	N	K	N	K
1	0.35	0.61	0.32	0.60	0.28	0.45
2	0.29	0.56	0.32	0.56	0.24	0.40
3	0.22	0.43	0.23	0.40	0.23	0.36
4	0.16	0.32	0.18	0.32	0.15	0.24
5	0.18	0.35	0.16	0.28	0.08	0.13

Liquid manure

2) Low rate: an amount calculated to supply approximately the nitrogen equivalent of 5 cwt "Nitro-Chalk" (15.5% N)/acre/year.

3) High rate: an amount calculated to supply approximately the nitrogen equivalent of 10 cwt "Nitro-Chalk"/acre/year.

4) Low rate plus phosphate: the same weight of liquid manure as in treatment 2, plus 4 cwt superphosphate (18.5% P_2O_5)/acre/year.

5) High rate plus phosphate: the same weight of liquid manure as in treatment 3, plus 4 cwt superphosphate/acre/year.

Water

6) Low rate: an amount equal to the weight of liquid manure applied in treatments 2 and 4.

7) High rate: an amount equal to the weight of liquid manure applied in treatments 3 and 5.

Dry fertilizer

8) Low rate: 5 cwt "Nitro-Chalk"/acre/year; 1½ cwt muriate of potash (60% K_2O)/acre/year; 4 cwt superphosphate/acre/year.

9) High rate: 10 cwt "Nitro-Chalk"/acre/year; 2½ cwt muriate of potash/acre/year; 4 cwt superphosphate/acre/year.

The superphosphate in treatments 4, 5, 8 and 9 was applied in two dressings, each of 2 cwt/acre, one in early spring and the other in mid-summer. The water and dry fertilizers were applied as five equal dressings each year. The first dressing was made in late March or early April and the remaining ones on the dates shown in Table 1, i.e. after each of the first four cuts. Small variations in the composition of the liquid manure resulted

Table 3. The weights of liquid manure, nitrogen and potassium supplied by liquid manure at each application

Application	Low rate			High rate		
	Liquid manure 100 lb/acre	N lb/acre	K	Liquid manure 100 lb/acre	N lb/acre	K
			1958			
1	50	18	30	100	35	61
2	50	14	28	100	29	56
3	50	11	22	100	22	43
4	75	12	24	150	24	48
5	100	18	35	200	36	70
Total	325	73	139	650	146	278
			1959			
1	50	16	30	100	32	60
2	50	16	28	100	32	56
3	50	12	20	100	23	40
4	100	18	32	200	36	64
5	100	16	28	200	32	56
Total	350	78	138	700	155	276
			1960			
1	50	14	22	100	28	45
2	50	12	20	100	24	40
3	75	17	27	150	34	54
4	100	15	24	200	30	48
5	200	16	26	400	32	52
Total	475	74	119	950	148	239

Table 4. The total weights of nitrogen, phosphorus and potassium (lb/acre) applied in the liquid manure and in the dry fertilizer each year

Treatment	1958	1959	1960	Mean
		N		
Liquid manure				
Low rate	73	78	74	75
High rate	146	155	148	150
Low rate + phosphate	73	78	74	75
High rate + phosphate	146	155	148	150
Dry fertilizer				
Low rate	87	87	87	87
High rate	174	174	174	174
		P		
Liquid manure				
Low rate	0	0	0	0
High rate	1	1	1	1
Low rate + phosphate	36	36	36	36
High rate + phosphate	37	37	37	37
Dry fertilizer				
Low rate	36	36	36	36
High rate	36	36	36	36
		K		
Liquid manure				
Low rate	139	138	119	132
High rate	278	276	239	264
Low rate + phosphate	139	138	119	132
High rate + phosphate	278	276	239	264
Dry fertilizer				
Low rate	70	70	70	70
High rate	140	140	140	140

in slightly different quantities of fertilizer nutrients being applied in the five dressings.

The liquid manure was sampled 2 or 3 days before the date of application and analysed for its content of nitrogen and potassium. From the results of the analyses the quantity to be applied was calculated. The contents of nitrogen and potassium in the liquid manure are shown in Table 2 and the amounts of these applied at each date during the 3-year experimental period are shown in Table 3.

The mean weights of fertilizer nutrients applied in each year of the trial as liquid manure and as dry fertilizer are shown in Table 4. In this preliminary trial the amount of nitrogen applied in the liquid manure treatments was only approximately the same as the amount applied in the dry fertilizer treatments and on average the liquid manure supplied 75 and 150 lb N/acre on the low and high treatments respectively whereas the dry fertilizer supplied 87 and 174 lb N/acre on the low and high treatments.

The ratio of nitrogen to potassium in the liquid manure was on average 1:1.7, and the weight of potassium applied in it was almost twice the amount applied in the dry fertilizer. The phosphorus content of the liquid manure was determined on only two samples, and since the mean content of 0.001% P was considered to be so low as to be negligible, no further phosphorus analyses were made.

The weights of water applied on the two water treatments were equal to the weights of liquid manure applied on the corresponding treatments. As with the liquid manure the water was applied by watering can.

Table 5. Dates of cutting in Expt 1

Cut number	1958	1959	1960
1	16/5	20/5	25/5
2	18/6	30/6	30/6
3	31/7	6/8	15/8
4	2/9	7/9	7/9
5	9/10	15/10	11/10

Experimental design

A randomized block design was used with the nine treatments replicated four times. The plots each measured 18 ft by 5 ft, or $\frac{1}{484}$ acre.

No run-off of liquid manure or water occurred and there were no signs of sub-surface drift of nitrogen or potassium between plots from the liquid manure or dry fertilizer. During & McNaught (1961) calculated that very little transfer of potassium occurred beyond the border of plots at a much higher application rate than used here, and Petersen et al. (1956) stated that the effective area of urine applications was the area actually covered by the urine.

Experimental methods

Yield sampling procedure

The plots were harvested five times each year at intervals of 4 to 6 weeks when the herbage was 6-8 in. tall. Dates of cutting in each year are shown in Table 5.

At each harvest a sample area 18 ft long by 38 in. wide was cut on every plot with an Allen autoscythe set to cut at about 1 in. above ground level. The cut herbage was raked together placed on a hessian sheet and weighed to the nearest ½ lb on a spring balance in the field. After it had been weighed, a random sample of herbage of about 1000 g was placed in a plastic bag and taken to the laboratory.

The herbage on the remainder of the plot on each side of the sample area was then cut and discarded, and the liquid manure, water and dry fertilizer dressings were applied to the appropriate plots at the rates described previously.

In the laboratory a sub-sample of 300 g was dried for approximately 12 h at 100°C in a Blackburn Unitherm Drier to determine the percentage of dry matter in the herbage. The dried sample was then ground through a 0.7 mm mesh sieve in a laboratory mill and stored for chemical analysis. The crude protein content of the herbage was determined on these samples by the Kjeldahl method.

Botanical composition of the sward

In November of each year of the trial the botanical composition of the sward on each plot was determined by a modification of the point quadrat method (Fenton, 1933). Two wooden rails 18 ft long and 2 in. square cross section, the length of the plots, were marked at ten points equidistant from each other and these positions were fixed by wooden blocks. A movable cross bar to fit across the side rails was constructed and measured 5 ft x 2 in. x $\frac{3}{4}$ in. with legs 5 in. long recessed to grip the side rails. Ten pins 6 in. long by 0.2 in. in diameter were inserted at intervals along the centre line of this bar, the outside pins being at $7\frac{1}{2}$ in. centre from the end of the bar and the remainder evenly spaced at 5 in. centres. The cross bar was then placed in turn at each of the ten equidistant positions on the rails and the species touching each of the ten pins at ground level was identified and recorded. Where a pin did not contact a plant at ground level bare ground was recorded. The hundred 'hits' so recorded give an estimate of the proportion of the total area of each plot covered by each plant species at ground level and the results are presented in terms of 'percentage ground cover' for each species.

This method is similar to that described by Reid (1961) who concluded that the even distribution of the points over the total area gave a more representative sampling of the vegetation on each plot than would the random distribution of the points.

Soil analysis

In the autumn of each year four cores of soil were taken from each plot to a depth of 8 in. with a soil sampling device, and the cores mixed to give a composite sample of all the replicates from a treatment. Routine analyses of these samples were made by the Chemistry Department of the West of Scotland Agricultural College. The methods of analysis used were based on those described by Whittles (1952) but modified by Alexander (1963).

Mineral analysis of the herbage

In each year the milled samples of herbage from every cut were bulked to give one composite sample from each treatment. Mineral analyses were made on the bulk samples for each of the 3 years of the experiment.

Potassium and sodium were determined by a flame photometer method, calcium by the micro-method of the Association of Official Agricultural Chemists (1945), magnesium by a modification of the method described by Hunter (1950) and phosphorus by a modification of the method of Allen (1940).

Statistical treatment of results

The data collected were tested by analysis of variance and the standard error of the difference between treatment means, $s_{\bar{d}}$ (Federer, 1955), was determined. Least significant difference values (LSD) have been calculated and these are products of $s_{\bar{d}}$ and the 't' values at the 5 and 1 per cent level, for the appropriate degrees of freedom. The yields of dry matter and crude protein were expressed in hundreds of lb/acre before analysis and rounded to the first decimal place.

Percentage ground cover data were transformed to angles, i.e. arc sin $\sqrt{\%}$ before analysis using tables given by Snedecor (1948). This transformation is appropriate to data associated with a number of occurrences among a definite total counted or percentage of occurrences, and corrects for the regular type of heterogeneity of error variance which usually occurs with such data.

Presentation of results

The results of this experiment for each of the 3 years are presented under the following sub-headings.

1. Mixed herbage dry matter - the total yield for each year.
2. Mixed herbage crude protein - including the total yield for each year and the mean percentage crude protein in the mixed herbage dry matter.
3. Botanical composition of the sward.
4. Soil analysis.
5. Mineral content of the herbage.

The results of these different components are discussed together at the end of the section.

RESULTS

Mixed herbage dry matter

The total yields of dry matter for each year of the trial are shown in Table 6.

The yields of the control plots in 1958 and 1959 were similar, but in 1960 there was a considerable decrease in the yield.

The yields of herbage dry matter from both the low and high water treatments did not differ significantly

Table 6. Mean total annual yield of dry matter (100 lb/acre)

Treatment	1958	1959	1960
Control	63.3	63.2	47.2
Water			
Low rate	62.6	67.0	48.8
High rate	66.0	66.0	46.1
Liquid manure			
Low rate	71.7	89.5	79.0
High rate	82.4	92.0	86.0
Low rate + phosphate	72.2	92.7	81.0
High rate + phosphate	81.1	94.4	87.2
Dry fertilizer			
Low rate	79.8	82.0	76.1
High rate	92.2	89.1	94.4
Level of significance $P <$	0.001	0.001	0.001
$s_{\bar{d}}$	± 2.00	± 3.76	± 3.23
$LSD_{.05}$	4.12	7.74	6.65
$LSD_{.01}$	5.60	10.50	9.04

from the yield of the control treatment in any of the 3 years. The high water treatment received 6500, 7000 and 9500 gallons of water/acre in 1958, 1959 and 1960 respectively. These application rates are equivalent to 0.29, 0.31 and 0.42 in./acre of water. The greatest response to water would be expected in 1959 which was the driest summer period (see Appendix Table 1) and had a rainfall that was much below average. However, in a trial adjacent to this experiment and on the same sward, the effects of supplemental irrigation were reported by Castle & Reid (1960) who showed that the response of herbage per 1 in. of water applied was only 213 lb dry matter/acre in 1959. The high water treatment would have been expected, therefore, to increase the yield by approximately 69 lb/acre which is considerably smaller than the appropriate standard error for the difference between the means in this experiment.

The addition of phosphate to plots which received low and high applications of liquid manure produced no statistically significant increases in yield. There was a tendency for the yields to be slightly higher where superphosphate was applied but even with the heaviest yield of herbage in 1959 the yield resulting from the low rate of liquid manure was increased by only 320 lb and from the high rate by 240 lb dry matter/acre where phosphate was applied. Other experiments at the Hannah Institute in which the effect of superphosphate was studied in conjunction with different levels of fertilizer nitrogen showed no response to phosphate even when 520 lb N/acre was applied (Holmes & MacLusky, 1954).

The yields of dry matter on all the liquid manure treatments were significantly higher than the yields on the control treatment in each of the 3 years ($P<0.01$). For example, the liquid manure applied at the low rate without phosphate resulted in an increase in yield over the control plot of 840 lb/acre in 1958, 2630 lb/acre in 1959 and 3180 lb/acre in 1960, and all the increases were highly significant ($P<0.01$).

The largest difference between the yields from the low and high levels of liquid manure application occurred in the first year of the trial. The yield from the high rate averaged over the phosphate treatments was 980 lb/acre greater than the yield from the low rate ($P<0.01$). In 1959, a strong growth of clover resulted in high yields being harvested from all the plots which received liquid manure, and the difference between the low and high levels was small and not significant. By 1960 when botanical changes were not so marked the high rate of liquid manure again produced a greater yield than the low rate; a difference of 660 lb/acre, which just failed to reach statistical significance.

The dry fertilizer treatments resulted in significantly higher yields than were obtained from the control plots each year ($P<0.01$). In 1958 and 1960 the high rate of dry fertilizer increased yields compared with the low rate ($P<0.01$) but in 1959 this difference was not significant.

The liquid manure treatments supplied less nitrogen and more potassium than the equivalent dry fertilizer treatments and therefore these treatments are not strictly comparable. However, since the lowest application of potassium on plots receiving liquid manure or fertilizer was 70 lb K/acre (the low dry fertilizer treatment), all the plots were relatively well supplied with potassium. The dry fertilizer treatments supplied more nitrogen than the liquid manure treatments, and on the low and high treatments respectively the differences were 12 and 24 lb/acre, which would give extra yields of approximately 250 and 500 lb dry matter/acre if a response of 21 lb dry matter/lb N applied is assumed (see Holmes & MacLusky, 1955). In 1958, the dry fertilizer treatment outyielded the liquid manure treatment at both levels by a margin greater than might be expected from the difference in the amounts of fertilizer nutrients applied. The opposite was found in 1959 when the liquid manure treatments yielded more herbage than the dry fertilizer treatments. The yield increase at the high level of application was 410 lb/acre and at the low level 910 lb/acre despite the lower quantity of nitrogen applied. These differences were caused by an increase in clover on plots receiving liquid manure, particularly at the low level of application, with an associated increase in the total yield of herbage. Similar botanical changes possibly also had an effect in 1960 when the low rate of liquid manure resulted in a slightly higher yield than the equivalent dry fertilizer treatment. At the high rate, the dry fertilizer treatment as in 1958, outyielded the liquid manure treatment. Over the 3-year period, however, the mean total dry matter yields were similar on the liquid manure and dry fertilizer treatments, e.g. 8100 and 7930 lb/acre respectively at the low levels of application and 8720 and 9190 lb/acre at the high levels of application.

Mixed herbage crude protein

The yield of crude protein and the crude protein

Table 7 Mean total annual yield of crude protein, and the crude protein content of the herbage

Treatment	Crude protein 100 lb/acre			Crude protein in the dry matter %		
	1958	1959	1960	1958	1959	1960
Control	11.4	11.5	6.5	17.9	18.2	13.8
Water						
Low rate	11.1	12.8	7.2	17.6	19.2	14.5
High rate	11.7	12.5	6.6	17.8	18.9	14.2
Liquid manure						
Low rate	11.9	17.0	13.2	16.6	19.0	16.8
High rate	13.1	16.4	14.3	15.9	17.7	16.7
Low rate + phosphate	12.2	18.6	13.6	17.0	20.0	16.7
High rate + phosphate	12.8	16.3	14.4	15.8	17.2	16.6
Dry fertilizer						
Low rate	13.4	14.6	11.6	16.8	17.8	15.2
High rate	15.0	14.8	14.8	16.3	16.6	15.6
Level of significance P<	0.001	0.001	0.001	0.001	0.001	0.001
$s_{\bar{d}}$	±0.46	±1.11	±0.67	±0.37	±0.62	±0.71
$LSD_{.05}$	0.95	2.29	1.38	0.76	1.28	1.46
$LSD_{.01}$	1.29	3.11	1.87	1.03	1.74	1.98

percentage in the herbage dry matter are shown in Table 7. The low and high rates of water application and the addition of phosphate had no significant effect on the yield of crude protein in any of the 3 years.

In 1958 the mean yields from both high rates of liquid manure were slightly greater than that from the control plots ($P<0.01$) but significantly less than that from the high level of dry fertilizer ($P<0.01$). In 1959 no significant differences occurred in crude protein yield between the four liquid manure treatments although the two low levels gave the highest crude protein yields. All the liquid manure treatments gave significantly greater yields of crude protein than the control plots ($P<0.01$), and the yields from the low liquid manure treatments were just significantly higher than those from both levels of dry fertilizer. There were no significant differences in crude protein yields between the four liquid manure treatments in 1960, the average yield being 1390 lb crude protein/acre and more than double the yield of the control treatment at 650 lb/acre.

Only small changes in the crude protein percentage of the herbage occurred between treatments in each of the years. In 1958 and 1959 the control, water and low levels of liquid manure gave herbage with approximately similar contents of crude protein, but the high level of liquid manure tended to produce herbage with a slightly lower crude protein content. In 1960 the reverse occurred, herbage from the control and water treatments containing a lower percentage of crude protein than the herbage from plots receiving liquid manure.

Again many of the changes in crude protein resulted from the differences in the botanical composition of the treated plots.

Table 8. Percentage ground cover of the different species in the sward

Treatment	Meadow fescue			White clover			Unsown grass			Weeds			Bare ground		
	1958	1959	1960	1958	1959	1960	1958	1959	1960	1958	1959	1960	1958	1959	1960
Control	34	20	23	31	30	15	12	12	23	8	5	10	16	34	30
Water															
Low rate	26	19	24	34	35	12	12	13	22	6	3	10	22	30	32
High rate	32	18	22	34	29	12	10	16	27	3	4	9	22	34	29
Liquid manure															
Low rate	36	6	14	25	48	34	12	9	18	2	1	2	24	36	32
High rate	30	11	14	19	44	32	20	6	24	0	1	2	30	38	28
Low + phosphate	28	4	14	28	45	34	15	8	22	2	0	0	28	42	30
High + phosphate	40	14	14	12	37	28	20	10	30	2	0	1	26	38	26
Dry fertilizer															
Low rate	33	19	26	24	33	18	17	10	20	3	2	4	22	36	32
High rate	43	24	24	9	29	18	18	17	19	3	1	3	28	30	36

Table 9. Mean percentage ground cover of clover in the sward

Mean percentages

Treatment	1958	1959	1960
Control	31	30	15
Water			
Low rate	34	35	12
High rate	34	29	12
Liquid manure			
Low rate	25	48	34
High rate	19	44	32
Low rate + phosphate	28	46	34
High rate + phosphate	12	37	28
Dry fertilizer			
Low rate	24	33	18
High rate	9	29	18

Mean angular transformations

Treatment	1958	1959	1960
Control	34	33	22
Water			
Low rate	36	36	20
High rate	36	33	20
Liquid manure			
Low rate	30	44	35
High rate	25	41	34
Low rate + phosphate	32	43	36
High rate + phosphate	20	37	32
Dry fertilizer			
Low rate	30	35	25
High rate	17	32	25
Level of significance $P <$	0.001	0.05	0.001
$s_{\bar{d}}$	± 3.06	± 3.63	± 2.84
$LSD_{.05}$	6.30	7.47	5.85
$LSD_{.01}$	8.57	-	7.95

Botanical composition of the sward

The percentage ground cover of the different plant species grouped into five fractions, (1) meadow fescue, (2) white clover, (3) unsown grass, (4) dicotyledonous weeds and (5) bare ground is shown in Table 8. An example of the results for the percentage ground cover of clover and the angular transformations is shown in Table 9. In 1958 the high levels of liquid manure and of dry fertilizer resulted in a significant decrease in the clover cover of the sward ($P<0.01$). Liquid manure and dry fertilizer treatments at the low level also gave a lower clover cover than the control treatment but the differences were not significant. In 1959 the control, water and dry fertilizer treatment plots contained similar levels of clover but there was an increase in clover in all the plots receiving liquid manure. The control and water treatment plots had a clover cover similar to that noted in 1958, but the plots receiving liquid manure had approximately twice the clover cover noted in the first year. The highest cover of clover was on plots receiving the low level of liquid manure ($P<0.05$). It was lower on plots receiving the high level of liquid manure although the high level without phosphate still had a significantly higher clover cover than the control plots. The effect of liquid manure on clover cover was more pronounced in 1960 when all the plots receiving liquid manure had a similar clover cover which averaged 32%. This was significantly higher than the mean clover cover on the control plots ($P<0.01$) or on the plots receiving either of the dry fertilizer treatments ($P<0.01$).

The application of superphosphate at the high level

Table 10. Contents of phosphate and potash (mg/100 g) and the pH of soil samples taken in November of each year

Treatment	P_2O_5			K_2O			pH		
	1958	1959	1960	1958	1959	1960	1958	1959	1960
Control	4	6	9	8	5	7	6.18	6.22	6.08
Water									
Low rate	5	5	8	10	4	6	6.48	6.30	6.17
High rate	4	5	7	6	4	6	6.52	6.20	6.14
Liquid manure									
Low rate	4	5	8	7	5	7	6.32	6.20	6.07
High rate	4	5	7	6	8	10	6.38	6.16	6.15
Low rate + phosphate	3	5	7	6	4	7	6.27	6.03	5.98
High rate + phosphate	5	5	10	11	8	11	6.40	6.04	6.08
Dry fertilizer									
Low rate	5	6	7	8	4	6	6.08	5.99	6.15
High rate	5	5	7	6	5	6	6.36	6.24	6.32

of liquid manure tended to reduce the clover content in all the 3 years. This result was not found at the low level of application.

The ground cover of meadow fescue (Table 8) was significantly affected by treatment in 1959 and 1960 only. In 1959 this fraction was considerably lower where the sward had been treated with liquid manure, especially at the low level ($P<0.01$). Meadow fescue increased slightly in 1960 with the liquid manure treatment at the low level but the percentage ground cover on all the liquid manure treatments was still lower than with the other treatments ($P<0.05$).

The unsown grass and the bare ground fractions tended to be higher with the liquid manure treatments in 1958 but thereafter any changes were inconsistent, and for neither of these fractions was there any significant difference from the corresponding values for the control treatment.

The content of dicotyledonous weeds was lowest on the liquid manure and dry fertilizer plots in each year, and in 1960 the difference between these and the control plots was highly significant ($P<0.01$).

In 1958, therefore, both liquid manure and dry fertilizers caused a decrease in the percentage of clover. Thereafter the plots receiving liquid manure had a higher clover content and a lower meadow fescue and dicotyledonous weed content than the other treatments.

Soil analysis

The main results for soil analysis are shown in Table 10. No marked differences occurred between treatments. The P_2O_5 values were highest in 1960 and the range from 7 to 10 mg/100g has been classified as "medium". No increase in the soil phosphate level with the additional top dressing of superphosphate was detected.

The K_2O values had a wider range than those of P_2O_5 and the classification for potash was "low" to "medium". The K_2O level tended to be lowest in 1959 but rose again in 1960. The plots receiving the highest application of potassium, i.e. the liquid manure high treatments with and without phosphate, showed the highest soil K_2O content on all but one occasion in the 3-year period but no other effects were evident.

There was no effect of treatment on soil pH values but there tended to be a small decrease in soil pH during the experiment. The average decline from 1958 to 1960 on plots of the control and water treatments was 0.27 units and on plots of the liquid manure and of the dry fertilizer treatments it was 0.27 and 0.25 units respectively.

Mineral content of the herbage

The mineral content of the herbage dry matter on each treatment for each year of the trial is shown in Table 11. Marked differences in the content of certain minerals in the herbage were found between treatments, but changes in the mineral content of the herbage occurred also between the 3 years of the trial. These year-to-year changes in mineral content appeared to result partly from variations in the clover content of the herbage.

One of the main effects of liquid manure was to increase the potassium content of the herbage in 1958 and 1960, the high level of liquid manure giving the highest potassium content. For example, in 1960 the

Table 11. The mineral content of the herbage in 1958, 1959 and 1960

percentage in dry matter

Treatment	Potassium (K)			Sodium (Na)			Calcium (Ca)			Magnesium (Mg)			Phosphorus (P)		
	1958	1959	1960	1958	1959	1960	1958	1959	1960	1958	1959	1960	1958	1959	1960
Control	2.23	2.24	1.16	0.21	0.24	0.26	0.89	0.96	0.85	0.28	0.29	0.36	0.42	0.40	0.37
Water															
Low rate	2.29	2.21	1.18	0.19	0.31	0.25	0.89	1.19	0.87	0.27	0.27	0.38	0.42	0.40	0.39
High rate	2.38	2.89	1.05	0.20	0.19	0.25	0.91	1.02	0.86	0.28	0.25	0.35	0.42	0.37	0.37
Liquid manure															
Low rate	2.86	1.79	2.35	0.12	0.29	0.24	0.73	1.14	0.76	0.24	0.24	0.24	0.40	0.42	0.32
High rate	3.11	1.57	2.92	0.11	0.33	0.17	0.64	1.12	0.72	0.24	0.32	0.23	0.39	0.43	0.30
Low rate + phosphate	2.80	1.43	2.09	0.13	0.35	0.28	0.77	1.21	0.80	0.24	0.34	0.26	0.44	0.43	0.35
High rate+ phosphate	3.12	2.96	2.93	0.07	0.17	0.20	0.62	1.00	0.74	0.24	0.25	0.23	0.43	0.39	0.34
Dry fertilizer															
Low rate	2.65	2.47	1.56	0.14	0.27	0.23	0.82	1.06	0.84	0.26	0.27	0.31	0.43	0.38	0.35
High rate	2.87	1.48	2.04	0.09	0.35	0.22	0.64	1.15	0.73	0.27	0.33	0.28	0.42	0.45	0.32

potassium content of the herbage from the control and water treatments averaged 1.13 compared with means of 2.22 and 2.92% K in the herbage from the low and high levels of liquid manure respectively. The increases in the potassium content of the herbage where liquid manure was applied, generally were accompanied by decreases in the sodium, calcium and magnesium contents.

The marked increase in clover growth in 1959 caused a change in the mineral relationship. In that year the herbage from three of the four liquid manure treatments had a lower potassium content than had the herbage from the control plots while an increase was noted in the calcium, magnesium and sodium contents.

A comparison of the results from the treated plots in the different years showed that the calcium content of the herbage was almost double, and the potassium content considerably smaller in 1959 than in 1958 and 1960. The sodium content of the herbage was very low in 1958, averaging only 0.11% Na over the four liquid manure treatments. The magnesium values were more consistent but in 1958 and 1960 the lowest values occurred on the liquid manure treatments.

The phosphorus contents of the herbage were similar for all the treatments and the addition of 36 lb P/acre/year to the liquid manure plots for 3 years resulted in only a very small increase in the phosphorus content of the herbage.

DISCUSSION

The value of liquid manure as a grassland fertilizer has been shown in this preliminary trial. Liquid manure applications increased considerably the yields of herbage dry matter and of crude protein and had a beneficial effect on the clover content of the sward.

The increases in herbage yield noted in this experiment agree with the results of other trials in which urine was used as a fertilizer, notably those of Hendrick (1915), Rheinwald (1934), Nevens (1941) and others. They differ from the results of trials in which the urine came from sheep and cattle as they grazed. For example, Watkin (1954) and Wheeler (1958) found that urine had little effect on pasture yield, a result which was caused by a reduction in the clover content as a consequence of applying nitrogen in the urine without a compensating increase in the yield.

In the present trial, the liquid manure had a marked effect in increasing clover growth and much of the increase in total herbage could be attributed to the excellent yields from the combined effects of clover and grass forming a vigorous sward. This agrees with the results of Blake (1942), Gisiger (1950) and Hendrick (1915) but is contrary to those of Brünner (1954) and Dusserre (1933). In 1959 the herbage from all the liquid manure treatments had a higher clover content than that from any other treatment. In that year the heaviest growth of clover occurred on plots receiving the low level of liquid manure, and this resulted in these plots giving almost the same total herbage yield as plots of the high level of liquid manure which received double the quantity of fertilizer nutrients.

The nitrogen content of the liquid manure appears to have been of little importance in the increased growth of clover since swards treated with the high level of liquid manure providing 150 lb N/acre each year for 3 years averaged 30% of clover cover in the third year compared with 18% on the swards treated with the low level of dry fertilizer providing 87 lb N/acre/year. Potassium has a considerable effect on clover growth and the higher quantities applied in the liquid manure, 132 and 264 lb K/acre in the low and high levels of liquid manure compared with 70 and 140 lb K/acre in the low and high levels of dry fertilizer, may have been partly responsible for these effects. However, 140 lb K/acre applied in the high rate of dry fertilizer had no more effect on the clover cover than had the 70 lb/acre applied in the low rate of dry fertilizer. No explanation for the increased clover growth with liquid manure treatment therefore can be derived from this experiment.

The absence of phosphorus application on the plots receiving liquid manure over the 3 years of intensive management had no obvious effect on the yield of herbage or botanical composition of the sward. Liquid manure composed of urine and water has been criticized by Gisiger (1950) because it is imbalanced, being very low in phosphorus, but the results reported here indicate that on soils which do not respond to phosphorus applications, liquid manure can be used economically without supplementation with superphosphate.

Similarly the lack of response to applications of water showed that the water content of the liquid manure, under the climatic conditions of this area, had a negligible effect on yield.

It may be concluded that the value of liquid manure as a fertilizer is due mainly to its content of nitrogen and potassium but that other factors which have a beneficial effect on clover growth may be present.

Nitrogen and potassium fertilizers have been implicated in the aetiology of hypomagnesaemic tetany, and Frens (1959), Kemp (1958), Kemp & 't Hart (1957) and Wind (1958) have shown that applications of nitrogen and potassium as dry fertilizer or liquid manure increased the potassium content of herbage and decreased the magnesium content. A similar result was found in this trial in 1958 and 1960 when the highest potassium values were recorded in herbage which received the liquid manure dressing at the high rate. This increase in potassium was associated with a fall in the magnesium, sodium and calcium values. The average magnesium content of the herbage from the four liquid manure treatments in both years was 0.24% Mg and this is well above the normal range of 0.09 - 0.16% Mg given by Rook & Wood (1960). The four liquid manure treatments averaged 0.11% Na in 1958 and this is below the level of 0.18% Na which Frens (1959) considered to be a minimum content for herbage to meet the nutritional requirements of the grazing cow.

In 1959 there was a reversal of this pattern and the potassium values were lower than in the other years and the magnesium and sodium values were higher. These changes were apparently caused by the increased clover content in 1959 when swards receiving the liquid manure treatments averaged 44% ground cover of clover. Since legumes are known to have a higher mineral content than grasses any factor which stimulates clover growth should maintain the magnesium, sodium and calcium levels in the herbage but confirmation of this is required.

This trial has suggested the possibility that rather than being a predisposing factor in the aetiology of hypomagnesaemia liquid manure may help to prevent it by encouraging the legume content of pasture and by thus giving a more desirable mineral balance in the herbage. This beneficial effect on clover would be expected to be accompanied by an increase in the yield due to the fertilizer nutrients in the liquid manure.

One of the problems in the management of grass and clover swards is to exploit clover with its associated fixation of atmospheric nitrogen and higher nutritive value and yet to intensify the total production of herbage by the use of nitrogen fertilizers. This trial indicated that liquid manure might be advantageous in this respect since plots treated with it, often gave herbage yields comparable with those from plots treated with nitrogen fertilizer, but at the same time maintained higher clover contents. Applications of liquid manure together with nitrogen fertilizer may therefore combine the advantage of high yields with the presence of clover, a result which has hitherto seldom been possible where high levels of nitrogen were applied.

SUMMARY AND CONCLUSIONS

1) In a trial over the 3-year period 1958-60 a preliminary investigation was made of the main effects of liquid manure, conventional dry fertilizers and water on a meadow fescue and white clover sward.

2) The liquid manure contained on average 0.23% N, 0.40% K and 0.001% P.

3) The liquid manure treatments were - a low rate supplying on average 75 lb N and 132 lb K/acre, and a high rate of 150 lb N and 264 lb K/acre. In two further treatments the same two levels of liquid manure were applied with additional dressings of 36 lb P/acre. The treatments with dry fertilizers were - a low rate of application supplying 87 lb N, 36 lb P and 70 lb K/acre, and a high rate supplying 174 lb N, 36 lb P and 140 lb K/acre. Water treatments were a low and a high

rate supplying the same weight of liquid as in the low and high levels of liquid manure.

4) The yield of herbage dry matter was unaffected by the water treatments and by the application of phosphate with the liquid manure treatments. Liquid manure and dry fertilizer treatments significantly increased the yields in each of the 3 years. The low level of liquid manure resulted in a smaller yield than the low fertilizer treatment in 1958 but in a significantly greater yield in 1959 and 1960. The high level of liquid manure yielded less than the high level of dry fertilizer in 1958 and 1960 but significantly more in 1959. Averaged over the 3 years liquid manure and dry fertilizers resulted in similar dry matter yields.

5) Neither water nor the addition of phosphate affected the yields of crude protein but liquid manure and dry fertilizer increased these yields by greater amounts each year. The low and high levels of liquid manure reduced the crude protein yield in 1958 compared with the low and high levels of fertilizer. In 1959 and 1960 the low level of liquid manure increased the yield but the high level had no significant effect.

6) Many of the changes in the yields of dry matter and crude protein resulted from changes in the clover content of the sward, an overall increase in clover in 1959 having the greatest effect. At the end of the third year, the liquid manure treatments had significantly increased the percentage ground cover of clover and decreased the meadow fescue and dicotyledonous weeds compared with the control. The mean contents of clover in the swards at the end of the experiment were 32, 18 and 15% on the liquid manure, dry fertilizer and control plots respectively.

7) No large or consistent differences in either the pH or phosphate contents of the soil were noted. The average potash content of the soil under the control and water treatments in 1960 was almost half that under the high liquid manure treatment.

8) Mineral analyses of the mixed herbage showed that in 1958 and 1960 the liquid manure treatments increased the potassium content of the herbage and lowered its calcium, magnesium and sodium contents. In 1959 when the clover cover was highest the reverse occurred on three out of the four liquid manure treatments.

EXPERIMENT 2

Object. To study the effect of various levels of liquid manure on the yield and botanical composition of a sward of grass and clover and the interaction of these levels with various quantities of fertilizer nitrogen either with or without phosphate and potash fertilizers.

EXPERIMENTAL

General

The plots used in this experiment were sown in 1960 in field A of the Institute farm and the results from the first 2 years of the experiment, 1961 and 1962, are reported here. Since 1950 the area used had been under grass which was grazed and cut for conservation as hay, dried grass or silage. The average application of fertilizers each year between 1955 and 1960 consisted of 100 lb N, 13 lb P and 75 lb K/acre. During that time no lime was applied.

Establishment of seeds mixture

The area of approximately 0.5 acre to be used for the establishment of the experimental plots was fenced off from the rest of the field in early 1960 and ploughed on 1 March 1960. The ploughed ground was subsequently broken down by a rotary cultivator on 11 April 1960 and a compound fertilizer containing 12% N, 12% P_2O_5 and 18% K_2O was applied at the rate of 5 cwt/acre. Further cultivation by chain harrow and ring roller prepared a firm seed bed.

The seeds mixture was sown on 7 May by hand, harrowed in and rolled by tractor. The seeds mixture was one known to give a productive sward with a good balance of clover and consisted of 20 lb S24 perennial ryegrass and

3 lb S100 white clover/acre. The seed was obtained as stock seed from the National Institute of Agricultural Botany, and it had a purity of not less than 99.6%. The germination of the S24 ryegrass was 96% and of the S100 clover 87% with 12% hard seed remaining.

An even growth of the seeds with a normal amount of annual weeds resulted. The first growth was cut by tractor mower on 21 June with the cutter blade set high. The cut swathe was left lying in the field and grazed by sheep. The cutting and grazing were repeated on 27 July and there was a further grazing in the autumn. This management resulted in an even sward in which there was a good but not excessive development of clover. The initial weed population which had been mainly annual dicotyledons was eliminated by the autumn.

Analysis of the soil from this area in January 1961 showed that it had a pH 5.91, an available P_2O_5 of 6 mg/100 g and an available K_2O of 20 mg/100 g.

Treatments

The treatments applied in this experiment were as follows:

Liquid manure

A weight of liquid manure was calculated to supply nitrogen at the following rates:-

	lb N/acre/year
LM0	No liquid manure
LM1	50
LM2	100
LM3	200
LM4	400

Table 12. Dates of application of liquid manure and dry fertilizers in Expt 2

Application	1961	1962
1	7/4	9/4
2	4/5	9/5
3	13/6	13/6
4	18/7	17/7
5	24/8	24/8

Table 13. The contents of nitrogen and of potassium (g/100 ml) in the liquid manure at each application in Expt 2

Application	1961 N	1961 K	1962 N	1962 K
1	0.35	0.57	0.29	0.48
2	0.32	0.51	0.25	0.43
3	0.32	0.54	0.24	0.42
4	0.31	0.52	0.24	0.40
5	0.29	0.49	0.21	0.39

Table 14. The total weights of liquid manure, nitrogen and potassium supplied by each liquid manure treatment

Liquid manure treatments	1961			1962		
	Liquid manure (100 lb/acre)	N (lb/acre)	K (lb/acre)	Liquid manure (100 lb/acre)	N (lb/acre)	K (lb/acre)
LM0	-	-	-	-	-	-
LM1	158	50	83	205	50	86
LM2	316	100	166	410	100	173
LM3	632	200	332	820	200	346
LM4	1263	400	663	1641	400	691

Fertilizer nitrogen

N0	No fertilizer nitrogen
N1	100 lb N/acre/year applied as "Nitro-Chalk"
N2	200 lb N/acre/year applied as "Nitro-Chalk"

Phosphate

P0	No phosphate
P1	150 lb P_2O_5/acre/year (66 lb P) applied as superphosphate

Potash

K0	No potash
K1	200 lb K_2O/acre/year (166 lb K) applied as muriate of potash

The "Nitro-Chalk" contained 21% N, the superphosphate 20.5% P_2O_5 and the muriate of potash 60% K_2O.

The applications of liquid manure and fertilizers were made in five equal dressings. The first application was in April and thereafter the liquid manure and fertilizers were applied after each of the five cuts except the last. At each date of application the liquid manure treatments were applied first and were followed by the dry fertilizer. The dates of application in 1961 and 1962 are shown in Table 12. Generally these applications took 2 days but only the first date is given in the table.

The liquid manure was weighed and applied by watering can as described on page 23. The analysis of the liquid manure at every application date is shown in Table 13 and the weights of liquid manure applied, and the quantities of nitrogen and potassium supplied in these weights each year are shown in Table 14.

The weight of liquid manure was adjusted to supply the correct quantity of nitrogen but this, of course, entailed also the application of the potassium contained in the liquid manure. It was not feasible to have

Table 15. The total weights of nitrogen and potassium (lb/acre) applied in the liquid manure and in the dry fertilizer each year

Fertilizer treatments	Liquid manure treatments				
	LM0	LM1	LM2	LM3	LM4
	Nitrogen 1961 and 1962				
N0	0	50	100	200	400
N1	100	150	200	300	500
N2	200	250	300	400	600
	Potassium 1961				
K0	0	83	166	332	663
K1	166	249	332	498	829
	Potassium 1962				
K0	0	86	173	346	691
K1	166	252	339	512	857

liquid manure of constant potassium content, and there were consequently small variations in the amounts of potassium applied. For example, in 1962 the EM1 treatment supplied 3 lb K/acre more than in 1961 and this amount became progressively greater as the levels of liquid manure increased.

The combined total weights of nitrogen supplied by the liquid manure and "Nitro-Chalk" are shown in Table 15. Because of the small differences in liquid manure composition, the total weights of potassium supplied by the liquid manure and potash fertilizer treatments are shown separately for each year in this table.

Experimental design

Since this experiment was designed mainly to investigate the interaction of liquid manure with fertilizers, a split-split-plot design was used to obtain increased precision in the estimation of interaction effects (Federer, 1955).

The six possible combinations of the three nitrogen fertiliser treatments and two phosphate treatments were allocated to the main plots within each block. The potash treatments were applied to the sub-plots within each main plot and the five liquid manure treatments to sub-sub-plots within each sub-plot.

Although by this arrangement some precision was lost in the measurement of the nitrogen and phosphate effects, the potash effects were measured more exactly and increased precision was obtained in the measurement of the effect of liquid manure and its interactions with all the other factors. This design was applicable here since in previous experiments at this Institute detailed studies have been made of the response to applications of

Table 16. Dates of cutting in Expt 2

Cut number	1961	1962
1	3/5	9/5
2	12/6	12/6
3	17/7	17/7
4	23/8	22/8
5	18/10	10/10

nitrogen, and it has been repeatedly shown also that on the Institute farm applications of phosphate usually have little effect on herbage yields.

The main-plot treatments were randomized independently within each block, and the sub-plots within each main-plot. The liquid manure treatments in sub-sub-plots were randomized independently within each sub-plot. All possible treatment combinations were replicated three times, giving a total of 180 sub-sub-plots.

The size of each sub-sub-plot was 12 ft by 5 ft. Although no fertility drift occurred in Expt 1 all sub-plots in Expt 2 were separated by paths 3 ft 2 in. wide to avoid any possible risk of this with nitrogen, phosphate and potash fertilizers.

Experimental methods

Yield sampling procedure

All the plots were harvested five times each year. The herbage was cut at a 'grazing' stage which was determined by the rate of growth and not by fixed cutting dates. This resulted in the first four cuts occurring at approximately 5-week intervals, and in the fifth cut in each year being made 7-8 weeks after the fourth.

Limited oven-space for drying the samples made it impracticable to cut all the plots on the same day. On every occasion two blocks totalling 120 plots had to be cut on one day and the remaining block of 60 plots on the following day. The dates of the first cutting days are given in Table 16.

At each time of cutting, the paths surrounding each plot were cut and the grass removed. A sample strip the length of each plot, was cut by an Allen autoscythe which removed an area of herbage 12 ft by 38 in. wide and left a 'discard strip' on each side. The cut herbage was collected, weighed and a random sample taken from each plot as described for Expt 1 (page 27). In the laboratory the sample of herbage from each plot was thoroughly mixed and two sub-samples were taken. One sub-sample of 300 g was dried at 100°C and weighed to determine its dry matter content. These dried samples were ground through a 0.7 mm mesh and retained for analysis of crude protein content as in Expt 1. Samples from two of the three blocks of the experiment were kept for analysis of their crude protein content.

A second sub-sample of approximately 100 g was taken to determine its clover content. It was not possible to hand-separate the 180 herbage samples into grass and clover while they were still fresh so they were dried and stored. The weighed sample of fresh herbage was placed in a small hessian sack (12 in. by 20 in.), and all the sacks were dried together on a commercial tray-type grass drier. The dried samples were stored until they were required for separation during the winter months, when they were carefully separated into clover and a 'grass plus weeds' fraction. The two fractions were then dried in the oven and weighed to two decimal places. Thus the proportion of clover dry matter in the herbage was determined for each cut from every plot.

Botanical composition of the sward

A detailed botanical analysis of the sward on all the plots was made in the second year of the experiment in 1962.

The method used was the same as that described for Expt 1 (page 28) except that with the plot length of 12 ft new rails were constructed. The plant species or bare ground touching each of the ten pins at ground level at each of the ten positions was recorded. The hundred hits so recorded gave a measure of the percentage cover of each species at ground level.

Soil analysis

A number of composite samples of soil were taken from selected treatments as there were too many plots to allow complete sampling. The samples were taken after the first and second years of the experiment in March 1962 and March 1963 from plots representative of the range of treatments, and apportioned in two ways.

(1) Plots receiving liquid manure at 0, 100 and 400 lb N/acre/year (LM0, LM2 and LM4) were sampled where fertilizer nitrogen at 0 and 200 lb N/acre/year had been applied. These six treatments were further represented at each level of potash (K0 and K1) to give twelve treatment combinations. One core of soil was taken from the appropriate sub-sub-plot in each block and the samples bulked. The twelve samples were thus averaged over phosphate treatments.

(2) The effect of phosphate application on the phosphorus content of the soil was studied at two extreme levels of nitrogen application, i.e. at LM0 N0 and LM4 N2. These two treatments were sampled at both levels of potash and at both levels of phosphate to give eight treatment combinations. Here two soil cores were taken from each sub-sub-plot and the replicates were again bulked.

The samples were taken to a depth of 6 in. with a stainless steel soil sampling device or corer and routine analyses of these composite samples were made.

Mineral analysis of the herbage

Certain of the separated fractions of grass and clover were retained for mineral analysis. Twelve treatment combinations were chosen as representative of the range of treatments applied. Herbage samples from all the plots which received liquid manure applications of 0, 100 and 400 lb N/acre/year (LM0, LM2 and LM4), fertilizer nitrogen at 0 and 200 lb N/acre/year (N0 and N2), muriate of potash at 0 and 200 lb K_2O/acre/year (K0 and K1) and no phosphate (P0) were kept.

After being separated into grass and clover fractions, these were weighed and the grass fraction was ground through a 0.7 mm laboratory mill. Since the clover fraction was small compared with the grass sample it was ground by pestle and mortar. The samples from each replicate were bulked and mixed.

There were thus twelve grass and twelve clover samples obtained from each of the five cuts in 1962. These were stored in glass bottles for analysis.

The contents of potassium, sodium, calcium, magnesium and phosphorus were determined by the methods described on page 29.

Statistical treatment of results

Analysis of variance was used to test the significance of the differences between the treatment means. As in Expt 1 all the yield data were expressed in terms of 100 lb/acre.

The data from the point quadrat analysis and also from the percentage clover contribution in the separated samples were transformed into angles (see page 30). Where angular transformations were used, only the transformed data have been tabulated and not the actual percentages.

The standard error of the difference between treatment means ($s\bar{d}$) was calculated for all the main factor effects and is included in all the tables whether the effect was significant or not. Standard errors are given also for all significant interactions, and least significant difference values (LSD) are presented only for the significant main factor and interaction effects. Coefficients of variation are given in each table.

The analyses of variance for mixed herbage yields, clover yields, clover percentage and point quadrat measurements were made with a total of 179 degrees of freedom. Crude protein yields and crude protein percentages were calculated from two replicates only and 119 degrees of freedom were used. An analysis of variance was made for each cut of each set of data, but only a few examples are given in detail here.

Presentation of results

The results of this experiment are reported separately for each year under the following sub-headings:

1. Mixed herbage dry matter - including total yields for the season, and yields at each cut.
2. Clover dry matter - including total yields for the season, yields at each cut, and the percentage of clover in the mixed herbage dry matter at each cut.
3. Mixed herbage crude protein - including total yields for the season, yields at each cut, and the percentage of crude protein in the mixed herbage dry matter at each cut.

In addition the following are reported:

4. Botanical composition of the sward - 1962.
5. Soil analysis - 1961 and 1962.
6. Mineral content of the herbage - 1962.

Table 17. Analysis of variance of total yields of mixed herbage dry matter (100 lb/acre) - 1961

Source of variation	df+	Sums of squares	Mean squares	Variance ratio (F)
Nitrogen (N)	2	21262.66	10631.33	130.67 ***
Phosphate (P)	1	597.50	597.50	7.34 *
N x P	2	725.43	362.71	4.46 *
Replicates	2	4402.52	2201.26	
Error (a)	10	813.62	81.36	
Potash (K)	1	501.84	501.84	8.13 *
N x K	2	18.18	9.09	
P x K	1	26.89	26.89	
N x P x K	2	171.30	85.65	
Error (b)	12	740.88	61.74	
Liquid manure (LM)	4	43988.84	10997.21	344.85 ***
LM x N	8	1668.76	208.60	6.54 ***
LM x P	4	127.62	31.90	
LM x K	4	1357.71	339.43	10.64 ***
LM x N x P	8	275.54	34.44	
LM x N x K	8	332.84	41.60	
LM x K x P	4	102.26	25.56	
Error (c)	104	3316.28	31.89	
Total	179	80430.67		

* $P<0.05$

** $P<0.01$

*** $P<0.001$

\+ degrees of freedom

Table 18. Mean total yields of mixed herbage dry matter (100 lb/acre) 1961

Nitrogen treatments	LM0	LM1	LM2	LM3	LM4	Means
	Liquid manure treatments					
N0	79.0	93.5	96.7	109.5	135.7	102.9
N1	96.5	108.4	113.0	126.2	140.7	117.0
N2	110.6	121.8	128.7	138.4	147.9	129.5
Potash treatments						
K0	88.8	105.1	113.0	125.0	141.9	114.8
K1	102.0	110.7	112.6	124.3	140.9	118.1
Phosphate treatments						
P0	94.7	106.8	110.8	121.8	138.9	114.6
P1	96.0	109.0	114.8	127.6	143.9	118.2
Liquid manure means	95.4	107.9	112.8	124.7	141.4	

Significant effects

LM	***	LM x N	***
N	***	LM x K	***
K	*	N x P	*
P	*		

Coefficient of Variation

Main-plots = 7.8%

Sub-plots = 6.8%

Sub-sub-plots = 4.8%

L S D

Differences between:	$s_{\bar{d}}$ ±	0.05 ±	0.01 ±
LM means	1.33	2.64	3.50
N means	1.65	3.67	5.22
K means	1.17	2.55	-
P means	1.34	3.00	-
LM means within a N	2.30	4.57	6.05
N means within a LM	2.64	5.49	7.49
LM means within a K	1.88	3.73	4.94
K means within a LM	2.05	4.20	5.67
N means within a P	2.33	5.19	-

and vice-versa

* $P<0.05$ ** $P<0.01$ *** $P<0.001$

RESULTS

Mixed herbage dry matter - 1961

The analysis of variance of the yields is given in detail in Table 17 and this layout is typical of the analyses done on other sets of data comprising all three replicates of the experiment.

Total dry matter yields for the main treatments and their interactions are given in Table 18. These are the mean values of grass + clover + weeds from the total of five cuts made in 1961.

Liquid manure increased the yields at each rate of application and all the differences were highly significant ($P<0.01$). Applications of liquid manure which supplied 50, 100, 200 and 400 lb N/acre - the LM1, LM2, LM3 and LM4 treatments - increased yields by 13, 18 31 and 48% respectively when averaged over all the other treatments.

Fertilizer nitrogen also increased the yields by highly significant amounts. Applications of 100 and 200 lb N/acre - the N1 and N2 treatments - increased yields by 14 and 26% respectively when averaged over all the other treatments. Fertilizer nitrogen thus apparently gave a lower increase in yield than the same weight of nitrogen applied in liquid manure.

Potash and phosphate applications increased the yield of herbage by 330 and 360 lb dry matter/acre respectively (about 3%) and these increases were just significant ($P<0.05$).

A highly significant 'liquid manure x nitrogen' interaction ($P<0.001$) indicated that the effect of liquid manure varied with the different levels of fertilizer nitrogen. Where no fertilizer nitrogen was applied the treatments LM1, LM2, LM3 and LM4 increased the yield of dry matter above that of the LMO treatment by 18, 22, 39 and 72% respectively. The corresponding increases became progressively less where fertilizer nitrogen was applied being 12, 17, 31, 46% and 10, 16, 25, 34% with treatments N1 and N2 respectively. The difference in yield between treatments LM1 and LM2 was not significant within the NO treatment but was significant within the N1 treatment ($P<0.05$). All the other increases were highly significant. The LM4 treatment gave a significantly greater increase in yield within the NO treatment than within the N1 or N2 treatments. Within all the liquid manure treatments the dry matter yield increased progressively with each increase in the rate of application of fertilizer nitrogen and most of the differences were highly significant. The response to fertilizer nitrogen was smaller within the LM4 treatment than within the other liquid manure treatments, and the difference between treatments NO and N1 was not significant while that between N1 and N2 was just significant ($P<0.05$).

The 'liquid manure x potash' interaction was also highly significant ($P<0.001$). Within potash treatments liquid manure resulted in a similar response at both levels of potash. However, within the liquid manure treatments, the effect of potash application decreased as the rate of application of liquid manure increased. Thus at LMO the treatment which received additional potash fertilizer outyielded the no potash treatment by 1320 lb dry matter/acre or 15% ($P<0.01$) while at LM1 the difference was only 560 lb dry matter or 5% ($P<0.05$) and for all other levels of liquid manure the yields were not significantly different. Thus the optimum level of potash for yields of approximately 11,000 lb dry matter/acre was more than that supplied by LM1 (83 lb K/acre) but less than that supplied by LM2 (166 lb K/acre).

Table 19. Significance of the effects of treatment on the yield of mixed herbage dry matter at each cut - 1961

Treatment	Cut number				
	1	2	3	4	5
N	NS	***	***	***	***
P	NS	***	NS	NS	NS
K	NS	NS	NS	**	**
LM	NS	***	***	***	***
LM x N	NS	***	***	*	***
LM x K	NS	NS	***	***	**
LM x P	NS	*	NS	NS	NS

NS Not significant

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

The application of phosphate increased the yield of herbage where no fertilizer nitrogen was used ($P<0.05$) but had no effect with N1 and N2.

The yields at each cut in 1961 were analysed in the same way as the total yields, and Table 19 contains a list of the level of significance of the effects of the main treatments and their interactions at each cut. Apart from cut 1 when uniformly high yields were obtained, the overall effect of liquid manure was to produce yields that were highly significantly greater than those from untreated plots at each cut. The LM2 treatment did not give a significantly higher yield than the LM1 treatment at cut 2, and at cuts 4 and 5 there was a small increase with this treatment which was just significant ($P<0.05$). All the other treatment differences were highly significant.

The pattern of response to potash and phosphate differed with the individual cuts. Potash fertilizer increased yields at cuts 4 and 5 only ($P<0.01$). Phosphate, on the other hand, had a highly significant effect at cut 2 only.

The lower response which occurred in the total dry matter yields at the high levels of applied nitrogen was found also at some individual cuts and the 'liquid manure x nitrogen' interaction was highly significant at cuts 2, 3 and 5 ($P<0.01$) and significant at cut 4 ($P<0.05$). At cut 2 the yield was considerably higher with the LM4 treatment than with LM3 where no fertilizer nitrogen was applied ($P<0.01$) but the increase was less with the N1 and N2 treatments ($P<0.05$). This was most noticeable at cut 5, and the plots with the treatment LM4 N0 gave higher yields than those with the higher applications of nitrogen at treatments LM4 N1 and LM4 N2.

At cuts 3 and 4 there were no significant differences between the yields from the LM1 and LM2 treatments where no fertilizer nitrogen was used and where the clover content was high. Where the clover content was lower, with the N2 treatment, LM2 yielded more than LM1 at cut 3 ($P<0.01$) and at cut 4 ($P<0.05$).

The 'liquid manure x potash' interaction became more pronounced as the experiment progressed and was highly significant at cuts 3, 4 and 5 ($P<0.01$). Where no liquid manure was applied, plots receiving potash fertilizer had a significantly higher yield than those receiving none. At LM1 the application of potash fertilizer again increased yields but at none of the cuts was this significant. At the highest level of liquid manure, additional potash fertilizer decreased the yield at all the cuts but this decrease was never significant.

A significant 'liquid manure x phosphate' interaction at cut 2 ($P<0.05$) resulted from the treatments LM3 and LM4 giving higher yields where phosphate was applied than where it was not.

The coefficients of variation calculated from the analyses of variance of total yields of dry matter and yields of dry matter at each cut were low and indicated that a satisfactory degree of precision was obtained.

Clover dry matter - 1961

The mean total yields of clover dry matter from the main treatments and their interactions are shown in Table 20.

Averaged over all other treatments the yield of clover was increased by treatments LM1 and LM2, i.e. where 50 and 100 lb N/acre were applied. The increase

Table 20. Mean total yields of clover dry matter

(100 lb/acre) - 1961

Nitrogen treatments	LMO	LM1	LM2	LM3	LM4	Means
	Liquid manure treatments					
NO	17.9	23.1	20.3	15.1	8.9	17.1
N1	12.2	13.6	12.6	10.3	5.4	10.8
N2	6.3	6.8	5.6	5.0	3.6	5.5
Potash treatments						
KO	7.8	13.0	13.2	11.4	6.7	10.4
K1	16.5	16.0	12.4	8.8	5.3	11.8
Phosphate treatments						
PO	13.2	15.2	12.7	10.6	6.0	11.5
P1	11.1	13.8	12.9	9.6	6.0	10.7
Liquid manure means	12.1	14.5	12.8	10.1	6.0	

Significant effects

LM	***	LM x N	***
N	***	LM x K	***
K	NS	LM x N x K	***
P	NS		

Coefficient of Variation

Main-plots = 82.2%

Sub-plots = 57.6%

Sub-sub-plots = 26.8%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	0.70	1.39	1.84
N means	1.67	3.72	5.29
K means	0.96	-	-
P means	1.36	-	-
LM means within a N	1.21	2.41	3.19
N means within a LM	1.99	4.29	5.98
LM means within a K	0.99	1.97	2.60
K means within a LM	1.30	2.72	3.72

was highly significant with treatment LM1 only ($P < 0.01$). With treatments LM3 and LM4 the yields of clover were depressed ($P < 0.01$).

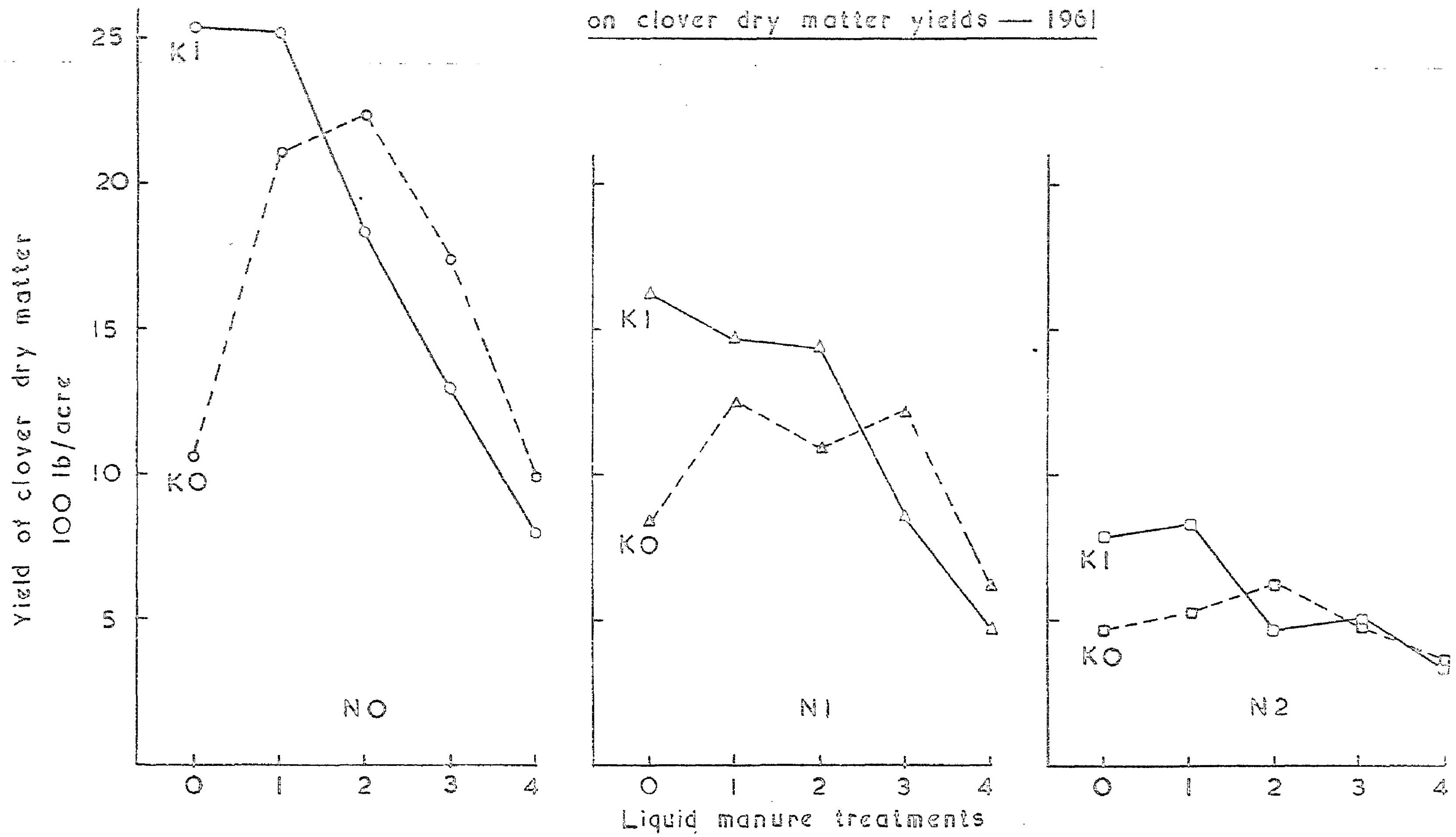
Nitrogen fertilizer caused a reduction in the mean yield of clover at each level of application ($P < 0.01$).

Neither the overall potash nor phosphate effects were significant although potash tended to increase and phosphate to decrease clover yields.

The variations in clover yield with applications of liquid manure were modified by the level of fertilizer nitrogen, and the 'liquid manure x nitrogen' interaction was highly significant ($P < 0.001$). Although the clover yield from treatment LM1 was higher than that from treatment LMO at all the nitrogen levels the difference was significant only at the NO level ($P < 0.01$). There was also an appreciable increase in clover yield from treatment LM2 NO compared with treatment LMO NO but this just failed to reach significance. The decreases in clover yield with treatments LM3 and LM4 were greater at the NO level, i.e. where the mean clover yield was highest, than at the N1 and N2 levels. Within liquid manure treatments increasing the level of fertilizer nitrogen reduced the clover yield. These differences were significant within LMO and LM3 ($P < 0.05$) and within LM1 and LM2 ($P < 0.01$) but with the low mean yield of clover within the LM4 treatment the differences were small and not significant.

The 'liquid manure x potash' effect was also highly significant ($P < 0.001$). Increasing levels of application of liquid manure caused progressive reductions in the yield of clover where potash fertilizer was applied, the reductions being highly significant between treatments LM2, LM3 and LM4 ($P < 0.01$). Without

Fig. 1. Effect of 'liquid manure x nitrogen x potash' interaction on clover dry matter yields — 1961



potash fertilizer, however, the yields of clover were highly significantly greater with LM1, LM2 and LM3 than with LM0. Within treatment LM0 the yield of clover dry matter increased by 870 lb/acre or 112% with potash fertilizer ($P<0.01$) while within treatment LM1 the corresponding increase was 300 lb/acre or 23% ($P<0.05$). Within all other levels of liquid manure, clover yields were lower where potash was applied than where it was not, but none of the differences was significant.

In the analysis of variance of clover dry matter yields the 'liquid manure x nitrogen x potash' interaction was highly significant and this is illustrated graphically in Fig. 1. The general effect of potash in increasing or maintaining clover is the most important point to observe, and the higher the yield of clover the greater the effect of the treatment. Where no liquid manure was used the increased yields caused by applications of potash fertilizer at N0, N1 and N2 were 1476, 781 and 332 lb clover dry matter/acre respectively. With treatment LM1 the corresponding increases were 412, 206 and 301 lb. Thereafter at higher levels of liquid manure the clover yields declined, although at each level of fertilizer nitrogen the clover yields were generally higher in the plots receiving liquid manure and no potash fertilizer than in plots with additional potash fertilizer.

Within the N0 level the application of potash fertilizer increased the clover yields from treatments LM0 and LM1 by 1476 and 412 lb dry matter/acre, but decreased those from treatments LM2, LM3 and LM4 by 414, 431 and 201 lb/acre respectively. Thus the optimum dressing of potassium at the highest yield of clover was

Table 21. Significance of the effects of treatment on the yield of clover dry matter at each cut - 1961

Treatment	Cut number				
	1	2	3	4	5
N	NS	*	**	***	***
P	NS	NS	NS	NS	NS
K	NS	NS	NS	*	**
LM	NS	*	***	***	***
LM x N	NS	NS	**	***	***
LM x K	NS	*	***	***	***
LM x N x K	NS	NS	***	***	***

Table 22. Significance of the effects of treatment on the percentage of clover dry matter - 1961

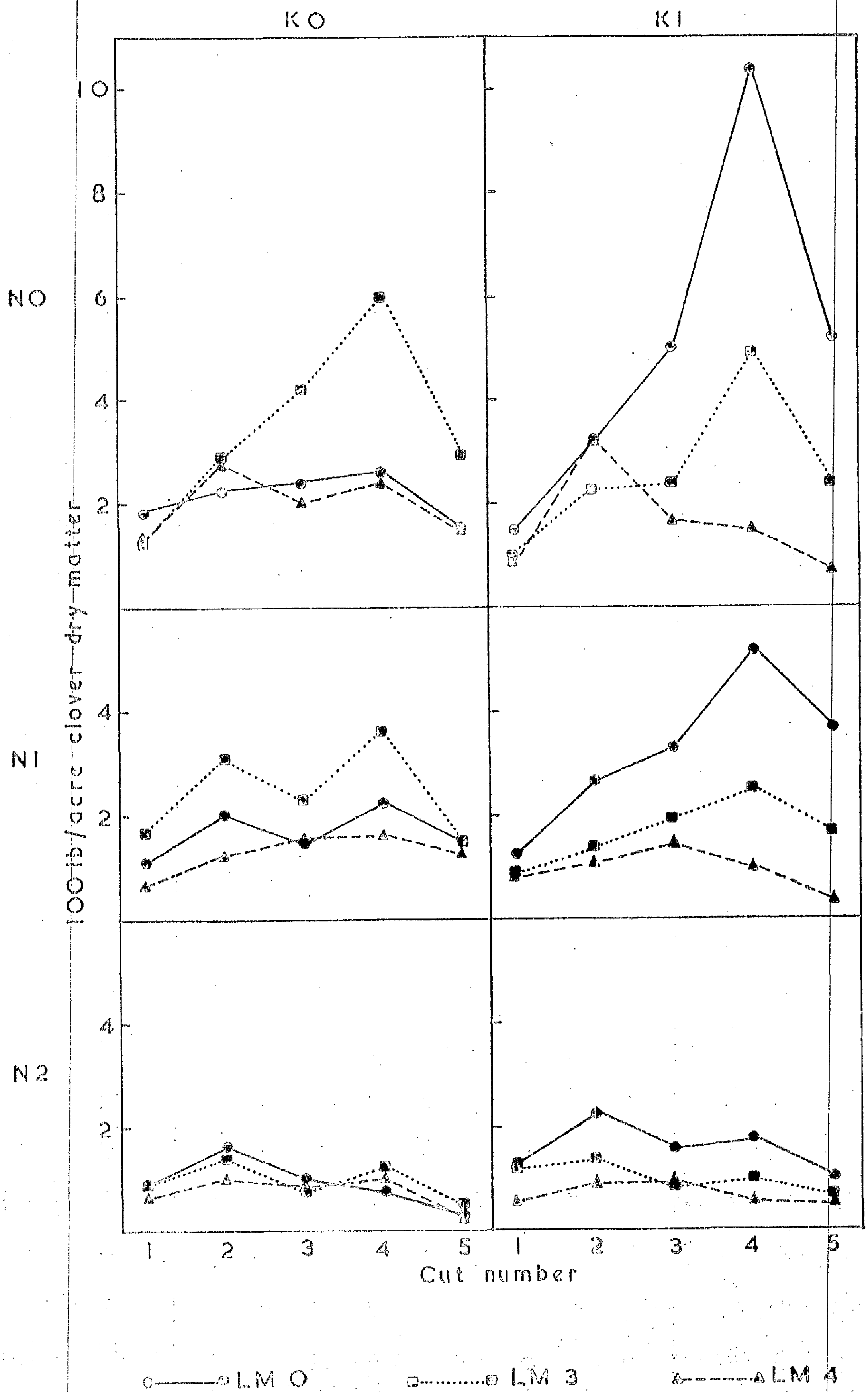
Treatment	Cut number				
	1	2	3	4	5
N	NS	**	***	***	***
P	NS	NS	NS	NS	NS
K	NS	NS	NS	*	NS
LM	**	***	***	***	***
LM x N	NS	NS	***	***	***
LM x K	NS	**	***	***	*
LM x N x K	NS	NS	*	*	NS

between that supplied by treatments LM1 and LM2, i.e. between 83 and 166 lb K/acre. This was similar to the optimum level indicated for the production of the total yield of mixed herbage.

Liquid manure depressed the yield of clover dry matter and the percentage of clover in the mixed herbage less than the equivalent level of fertilizers. Treatment LM2 N0 K0 which supplied 100 lb N and 166 lb K/acre entirely from liquid manure gave a yield of 2237 lb clover dry matter compared with 1609 lb from treatment LM0 N1 K1 which supplied 100 lb N and 166 lb K/acre as fertilizer. The corresponding weighted mean percentages of clover in the mixed herbage were 23 and 16%. Where the treatments supplied 200 lb N (LM3 N0 K0 and LM0 N2 K1) the corresponding figures were 1727 and 799 lb clover dry matter/acre and 16 and 7% clover. This effect was found also where liquid manure and fertilizer nitrogen applications were combined. For example the yield and the percentage of clover from the combined applications of 200 lb N from liquid manure + 100 lb N from fertilizer (LM3 N1 K0) were 1220 lb/acre and 10% clover whereas with 100 lb N from liquid manure + 200 lb N from fertilizer (LM2 N2 K1) the figures were only 475 lb/acre and 4% clover; the potassium applied in each treatment being 332 lb K/acre.

The significant treatment effects which occurred with clover dry matter yields at each cut in 1961 are given in Table 21. At cuts 1 and 2 there was little effect of treatment but at cuts 3, 4 and 5 the yields were affected highly significantly and followed the same trend as described for the total yields of clover and the 'liquid manure x nitrogen', 'liquid manure x potash', and 'liquid manure x nitrogen x potash' interactions were

Fig. 2. Effect of liquid manure, nitrogen and potash on the yield of clover dry matter at each cut — 1961



all highly significant ($P < 0.01$).

The distribution of yields over the season is shown in Fig. 2 for some of the treatments only. For clarity the results of only three liquid manure treatments, supplying 0,200 and 400 lb N/acre are shown in this figure. The greatest treatment effects occurred at cut 4 which had the heaviest yield of clover. Where no fertilizer nitrogen or potash was applied, the clover yields at cuts 2, 3,4 and 5 from the LMO treatment were markedly lower and from the LM1 treatment (not shown) slightly lower than the clover yields from the same treatments with potash fertilizer. The LM2, LM3 and LM4 treatments at these four cuts nearly always yielded more clover where no potash fertilizer was applied. At the N1 and N2 levels all these differences became less evident.

All significant effects from the angular transformations of percentage clover at each cut in 1961 are included in Table 22. The effects of treatments were similar to those found with the yield of clover except that there was a lower level of significance of the three factor interaction.

Because of sampling errors the coefficients of variation with the yield of clover data were high compared with those found with the total herbage data.

<u>Mixed herbage crude protein - 1961</u>

Since the samples from only two of three replicates were analysed for crude protein content the analysis of variance differed from that of the mixed herbage dry matter. The full analysis for the total crude protein yield is given in Table 23 and is typical of the analyses made on data of the yield and percentage of crude protein. The mean total yields of crude protein in the mixed herbage

Table 23. Analysis of variance of total yields of crude protein in the mixed herbage (100 lb/acre) - 1961

Source of variation	df	Sums of squares	Mean squares	Variance ratio (F)
Nitrogen (N)	2	386.16	193.08	26.88**
Phosphate (P)	1	0.08	0.08	
N x P	2	8.46	4.23	
Replicates	1	5.87	5.87	
Error (a)	5	35.91	7.18	
Potash (K)	1	24.54	24.54	9.52*
N x K	2	2.05	1.02	
P x K	1	0.02	0.02	
N x P x K	2	1.89	0.94	
Error (b)	6	15.46	2.58	
Liquid manure (LM)	4	1363.53	340.88	355.60***
LM x N	8	14.12	1.76	
LM x P	4	6.28	1.57	
LM x K	4	78.35	19.59	20.43***
LM x N x P	8	5.80	0.72	
LM x N x K	8	18.26	2.28	2.38*
LM x K x P	4	4.42	1.11	
Error (c)	56	53.68	0.96	
Total	119	2024.88		

Table 24. Mean total yields of crude protein in the mixed herbage (100 lb/acre) - 1961

	Liquid manure treatments					
	LMO	LM1	LM2	LM3	LM4	Means
Nitrogen treatments						
NO	11.4	14.3	14.7	16.0	20.6	15.4
N1	12.6	15.0	15.8	18.2	23.1	16.9
N2	15.4	17.7	18.6	21.2	25.9	19.8
Potash treatments						
KO	11.2	15.1	16.6	18.5	23.3	16.9
K1	15.2	16.2	16.2	18.4	23.1	17.8
Phosphate treatments						
PO	13.4	15.8	16.1	18.6	22.9	17.4
P1	13.0	15.5	16.7	18.3	23.5	17.4
Liquid manure means	13.2	15.7	16.4	18.4	23.2	

Significant effects

LM	***	LM x N	NS
N	**	LM x K	***
K	*	LM x N x K	*
P	NS		

Coefficient of Variation

Main-plots	=	15.4%
Sub-plots	=	9.3%
Sub-sub-plots	=	5.6%

L S D

Differences between:	$s_{\bar{d}}$ ±	0.05 ±	0.01 ±
LM means	0.28	0.57	0.75
N means	0.60	1.54	2.42
K means	0.29	0.72	-
P means	0.49	-	-
LM means within a K	0.40	0.80	1.07
K means within a LM	0.46	1.16	1.80

for 1961 are shown in Table 24.

Liquid manure increased the yield of crude protein at each level of application. The increase was small between treatments LM1 and LM2 ($P < 0.05$) but all the other differences were highly significant. Averaged over all the levels of fertilizer treatment, the LM4 treatment yielded 1000 lb crude protein/acre more than the LM0 treatment.

The average response of crude protein to fertilizer nitrogen was small and not significant at N1 but at N2 the increase was greater and differed significantly from N0 and N1 ($P < 0.01$).

Potash fertilizer caused a small but significant increase ($P < 0.05$) whereas the application of phosphate gave no increase in yield.

Liquid manure increased the yield of crude protein by similar amounts at each level of fertilizer nitrogen and the interaction therefore was not significant, and when liquid manure and fertilizer nitrogen were applied together the increases were additive.

There was a highly significant 'liquid manure x potash' interaction ($P < 0.001$). Where there was no additional potash fertilizer the yield of crude protein increased progressively and significantly as the rate of application of liquid manure increased ($P < 0.01$). Where potash was applied the crude protein yield was higher and liquid manure had less effect. Within liquid manure treatments, potash fertilizer had a highly significant effect where no liquid manure was applied ($P < 0.01$) but with all the other levels of liquid manure it had no effect.

The combined effect of potash and liquid manure on crude protein yield varied with the fertilizer nitrogen level, and the 'liquid manure x nitrogen x potash'

Table 25. Significance of the effects of treatment on the yield of crude protein at each cut - 1961

Treatment	Cut number 1	2	3	4	5
N	***	***	*	NS	**
P	NS	NS	NS	NS	NS
K	NS	NS	*	*	**
LM	***	***	***	***	***
LM x N	NS	NS	**	***	NS
LM x K	NS	NS	***	***	***
LM x P	NS	*	NS	NS	NS
N x P	**	NS	NS	NS	NS
LM x N x K	NS	NS	NS	***	NS

Table 26. Significance of the effects of treatment on the percentage of crude protein in dry matter - 1961

Treatment	Cut number 1	2	3	4	5
N	***	*	*	***	**
P	NS	NS	NS	NS	NS
K	NS	NS	NS	NS	*
LM	***	***	**	***	**
LM x N	NS	***	***	***	***
LM x K	NS	NS	**	***	**
LM x N x K	NS	NS	NS	***	NS

interaction was significant ($P < 0.05$). Where potash fertilizer was applied the relative increases in crude protein yield were similar at each level of liquid manure and fertilizer nitrogen. Without potash fertilizer the LM1 treatment resulted in a greater increase in protein at N0 than at N1 and N2.

The significance of the effects of treatment on the yield of crude protein and on the percentage of crude protein in the dry matter at each cut are shown in Tables 25 and 26. Liquid manure increased the crude protein percentage and the yield of crude protein at each cut ($P < 0.01$), and the main interaction effects occurred at cuts 3, 4 and 5. Although the 'liquid manure x nitrogen' interaction was not significant for the total yield of crude protein, it was highly significant at cuts 3 and 4 ($P < 0.01$). At cut 3, only the LM4 treatment showed a significant increase in the yield of crude protein with fertilizer nitrogen at N1 ($P < 0.05$), and a further increase at N2 ($P < 0.05$). This was more evident at cut 4 when the treatments LM0, LM1 and LM2 caused a decrease in the yield of crude protein at the N1 and N2 levels compared with the N0 level, whereas the treatments LM3 and LM4 gave an increase, although this was significant only with the LM4 N2 treatment ($P < 0.01$).

The crude protein percentage at cuts 3, 4 and 5 was high at LM0, LM1 and LM2 where no fertilizer nitrogen was used and where the clover contribution was high, but applications of fertilizer nitrogen decreased it. At LM3 and LM4 clover growth was less and the percentage of crude protein where no fertilizer nitrogen was applied was much the same as the percentage where fertilizer nitrogen was applied with the low levels of liquid manure. Thus the higher yields of crude protein at the LM4 level

Table 27. Analysis of variance of total yields of mixed herbage dry matter (100 lb/acre) - 1962

Source of variation	df	Sums of squares	Mean squares	Variance ratio (F)
Nitrogen (N)	2	7233.98	3616.99	27.92***
Phosphate (P)	1	2115.29	2115.29	16.33**
N x P	2	749.56	374.78	
Replicates	2	944.86	472.43	
Error (a)	10	1295.57	129.56	
Potash (K)	1	1935.33	1935.33	64.07***
N x K	2	61.49	30.74	
P x K	1	143.77	143.77	4.76*
N x P x K	2	204.84	102.42	
Error (b)	12	362.46	30.20	
Liquid manure (LM)	4	34305.16	8576.29	416.99***
LM x N	8	1379.04	172.38	8.38***
LM x P	4	246.94	61.74	3.00*
LM x K	4	5683.14	1420.78	69.08***
LM x N x P	8	241.61	30.20	
LM x N x K	8	220.53	27.57	
LM x K x P	4	114.09	28.52	
Error (c)	104	2138.98	20.57	
Total	179	59376.64		

Table 28. Mean total yields of mixed herbage dry matter (100 lb/acre) - 1962

Nitrogen treatments	Liquid manure treatments LMO	LM1	LM2	LM3	LM4	Means
NO	57.7	80.5	85.8	96.6	108.1	85.7
N1	73.4	90.5	96.4	105.8	112.5	95.7
N2	80.2	98.9	105.2	108.7	112.0	101.0
Potash treatments						
KO	56.5	86.6	94.1	105.4	111.8	90.9
K1	84.4	93.4	97.4	102.0	109.9	97.4
Phosphate treatments						
PO	68.8	87.2	92.4	99.2	106.0	90.7
P1	72.1	92.8	99.1	108.2	115.7	97.6
Liquid manure means	70.4	90.0	95.8	103.7	110.9	

Significant effects

LM	***	LM x N	***
N	***	LM x K	***
K	***	LM x P	*
P	**	P x K	*

Coefficient of Variation

Main-plots	=	12.1%
Sub-plots	=	5.8%
Sub-sub-plots	=	4.8%

Differences between:	$s_{\bar{d}}$ ±	L S D 0.05 ±	L S D 0.01 ±
LM means	1.07	2.12	2.81
N means	2.08	4.63	6.58
K means	0.82	1.78	2.50
P means	1.70	3.78	5.38
LM means within a N	1.85	3.67	4.86
N means within a LM	2.66	5.67	7.86
LM means within a K	1.51	3.00	3.97
K means within a LM	1.58	3.22	4.33
LM means within a P	1.51	3.00	-
P means within a LM	2.17	4.63	-
K means within a P	1.16	2.52	-
P means within a K	1.88	4.18	-

were caused mainly by the greater yields of herbage dry matter from the treatments rather than by an increase in the percentage of crude protein.

The 'liquid manure x potash' effect was the same as observed with the total yield data. At cuts 3, 4 and 5 the yield and percentage of crude protein were not significantly affected by potash fertilizer where liquid manure was applied, but in the LMO treatment potash significantly increased the yield and percentage of crude protein.

The coefficients of variation for crude protein yields were slightly higher than those for total herbage yields but they were acceptable for data of this type.

Mixed herbage dry matter - 1962

The analysis of variance of the total dry matter yields in 1962 is given in Table 27, and the mean total dry matter yields of the main treatments and their interactions are shown in Table 28.

Where no liquid manure, nitrogen and potash were applied, the mean yield of herbage dry matter was 4060 lb in 1962 compared with 7090 lb/acre in 1961 and because the yields of the untreated plots were so much lower in 1962 than in 1961, the responses to some of the fertilizer treatments in 1962 appeared to be greater.

Liquid manure again gave highly significant increases in yield ($P < 0.001$). The mean increases in total yield obtained from the treatments LM1, LM2, LM3 and LM4 were 28, 36, 47 and 58% respectively. Apart from the greater overall increase in 1962 than in 1961, the main change was a smaller difference between the LM3 and LM4 treatments.

Fertilizer nitrogen had a highly significant effect on dry matter yield ($P < 0.001$). The overall effect of 100 and 200 lb N/acre was to increase the yield by

12 and 18% respectively. These increases were smaller than those noted in 1961. The difference between N1 and N2, however, was still significant ($P < 0.05$).

On average, applications of potash increased the yield by 650 lb dry matter/acre. This increase was larger, and the level of significance ($P < 0.01$) higher, than in 1961. Phosphate also showed a pronounced effect ($P < 0.01$) and the overall increase of 690 lb dry matter/acre where phosphate was applied was almost twice that obtained in 1961.

The 'liquid manure x nitrogen' interaction was again highly significant ($P < 0.001$) although the responses were different from those observed in 1961. Where no fertilizer nitrogen was applied the treatments LM1, LM2, LM3 and LM4 increased yields by 40, 49, 67 and 87% respectively over treatment LM0. The corresponding increases within treatments N1 and N2 were 23, 31, 44, 53% and 23, 31, 36, 40%. These increases at each increment of liquid manure were all highly significant within N0 and N1 but there was a lower response within the N2 level and the LM3 treatment did not differ significantly from the LM2 or the LM4 treatment. Further evidence of a low response to fertilizer nitrogen was found within liquid manure applications, e.g. where 400 lb N/acre were applied as liquid manure, additional fertilizer nitrogen caused no significant increase in yield. Similarly where 200 lb N/acre were applied as liquid manure there was no significant increase in yield when fertilizer nitrogen was applied at 200 lb N/acre compared with when it was applied at 100 lb N/acre. The ability of the sward to increase yields with these high levels of nitrogen was therefore less in 1962 than in 1961.

The 'liquid manure x potash' interaction was highly significant ($P < 0.001$) and the differences were more extreme than in 1961. Within the potash treatments all the applications of liquid manure increased yields ($P < 0.01$), the increase between treatments LM0 and LM1 being greater where no potash was applied than where it was applied ($P < 0.01$). Within liquid manure treatments potash fertilizer gave a highly significant increase of 2790 lb dry matter/acre at LM0, more than double the increase in 1961. With treatment LM1 the increase due to additional potash fertilizer was 680 lb ($P < 0.01$) and with LM2 it was 330 lb dry matter/acre ($P < 0.05$). With higher applications of liquid manure, yields were reduced by applying additional potash fertilizer; this reduction was just significant with treatment LM3 ($P < 0.05$) but not with LM4. Thus the optimum dressing of potassium in 1962 for approximately 10000 lb dry matter/acre was more than that supplied by treatment LM2 but less than that supplied by treatment LM3, i.e. more than 173 lb K but less than 346 lb K/acre.

The 'liquid manure x phosphate' interaction was significant ($P < 0.05$) in 1962 but not in 1961, and an increasing response to phosphate occurred as the application rate of liquid manure increased, being significantly greater with LM3 and LM4 than with LM0. The effect of phosphate was shown also in the interaction 'phosphate x potash' ($P < 0.05$). Phosphate increased the yield of dry matter by a significantly greater amount where potash fertilizer was applied than where no potash was used.

The levels of significance for the treatment effects on dry matter yields at the individual cuts in 1962 are given in Table 29.

At cut 1 only small increases in yield occurred with

Table 29. Significance of the effects of treatment on the yield of mixed herbage dry matter - 1962

Treatment	Cut number				
	1	2	3	4	5
N	***	***	NS	***	***
P	***	NS	NS	**	NS
K	NS	***	*	***	***
LM	***	***	***	***	***
LM x N	***	***	**	***	***
LM x K	**	***	***	***	***
LM x N x K	NS	**	NS	*	NS

the treatments LM1, LM2 and LM3 compared with LM0. The LM4 treatment resulted in a decrease of 441 lb dry matter/acre ($P < 0.01$) compared with the treatment which had no liquid manure. The LM4 treatment had noticeably less plant cover in the early spring and this would account for the lower yield at cut 1. Increasing levels of liquid manure significantly increased the yield of dry matter at all the other cuts in 1962.

Fertilizer nitrogen also decreased the yield of dry matter at cut 1 but the only significant difference was that between N0 and N2 ($P < 0.01$). Fertilizer nitrogen increased the yields at the other four cuts but these increases were not always significant.

The overall effect of potash fertilizer was negligible at cut 1 but small though significant increases were found at the remaining cuts; the largest increase being 217 lb dry matter/acre at cut 4 ($P < 0.01$). Phosphate application showed a small response at each cut but it was significant only at cuts 1 and 4 ($P < 0.01$).

The 'liquid manure x nitrogen' interaction was highly significant at each cut ($P < 0.01$). The effects at cut 1, however, were different from those at the other cuts. At cut 1 the treatments receiving application rates greater than about 200 lb N/acre showed a marked reduction in yield. Thus each increment of nitrogen supplied by the liquid manure or fertilizer nitrogen above that applied on treatments LM1 N2, LM2 N1 and LM3 N0 resulted in a decrease in yield ($P < 0.01$). The remaining cuts showed that within the fertilizer nitrogen treatments most of the levels of liquid manure increased yields, but there was a significant decrease in response to the LM4 treatment at the high rate of application of fertilizer nitrogen as reported for the data on total yield.

Table 30. Mean total yields of clover dry matter

(100 lb/acre) - 1962

Nitrogen treatments	Liquid manure treatments LMO	LM1	LM2	LM3	LM4	Means
NO	17.3	27.5	24.6	17.1	10.1	19.3
N1	12.7	16.7	14.4	14.8	11.8	14.1
N2	5.2	6.0	6.8	5.2	8.2	6.3
Potash treatments						
KO	3.7	13.8	14.7	12.9	11.3	11.3
K1	19.8	19.6	15.9	11.9	8.8	15.2
Phosphate treatments						
PO	11.6	16.4	15.5	12.6	11.3	13.5
P1	11.9	17.1	15.0	12.2	8.7	13.0
Liquid manure means	11.7	16.7	15.3	12.4	10.0	

Significant effects

LM	***	LM x N	***
N	***	LM x K	***
K	***	LM x N x K	***
P	NS		

Coefficient of Variation

Main-plots = 90.9%

Sub-plots = 35.8%

Sub-sub-plots = 29.3%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	0.91	1.80	2.39
N means	2.19	4.88	6.94
K means	0.71	1.55	2.17
P means	1.79	-	-
LM means within a N	1.58	3.13	4.15
N means within a LM	2.61	5.63	7.85
LM means within a K	1.29	2.56	3.39
K means within a LM	1.35	2.75	3.70

The 'liquid manure x potash' interaction was highly significant at each cut ($P<0.01$) and showed the same trend as did the total yield. Where no liquid manure was applied at each cut, potash fertiliser increased yields over the treatments receiving no potash ($P<0.01$). At the LM1 treatment the effect of potash was less pronounced, but the yield was still increased where potash was applied at cuts 2, 4 and 5 ($P<0.01$).

Clover dry matter - 1962

The mean total yields of clover dry matter are shown in Table 30. The yields were slightly higher in 1962 than in 1961 on most treatments.

The response to liquid manure as measured against the yields of the untreated plots was also greater than in 1961. Thus, averaged over all other treatments, increased yields of clover were obtained with treatments LM1 and LM2 ($P<0.01$) and, although not statistically significant, from LM3. The yield from treatment LM4 was smaller than that from LM0 but not significantly so. The mean increase between LM0 and LM1 amounted to 500 lb clover dry matter/acre but thereafter there was a progressive decrease which was significant between each of the treatments LM2, LM3 and LM4 and there was little difference between the yield of clover where no liquid manure, and where 400 lb N/acre from liquid manure were applied.

The overall effect of fertilizer nitrogen was similar to that in 1961 and there were progressive decreases in clover yield with the treatments N1 ($P<0.05$) and N2 ($P<0.01$).

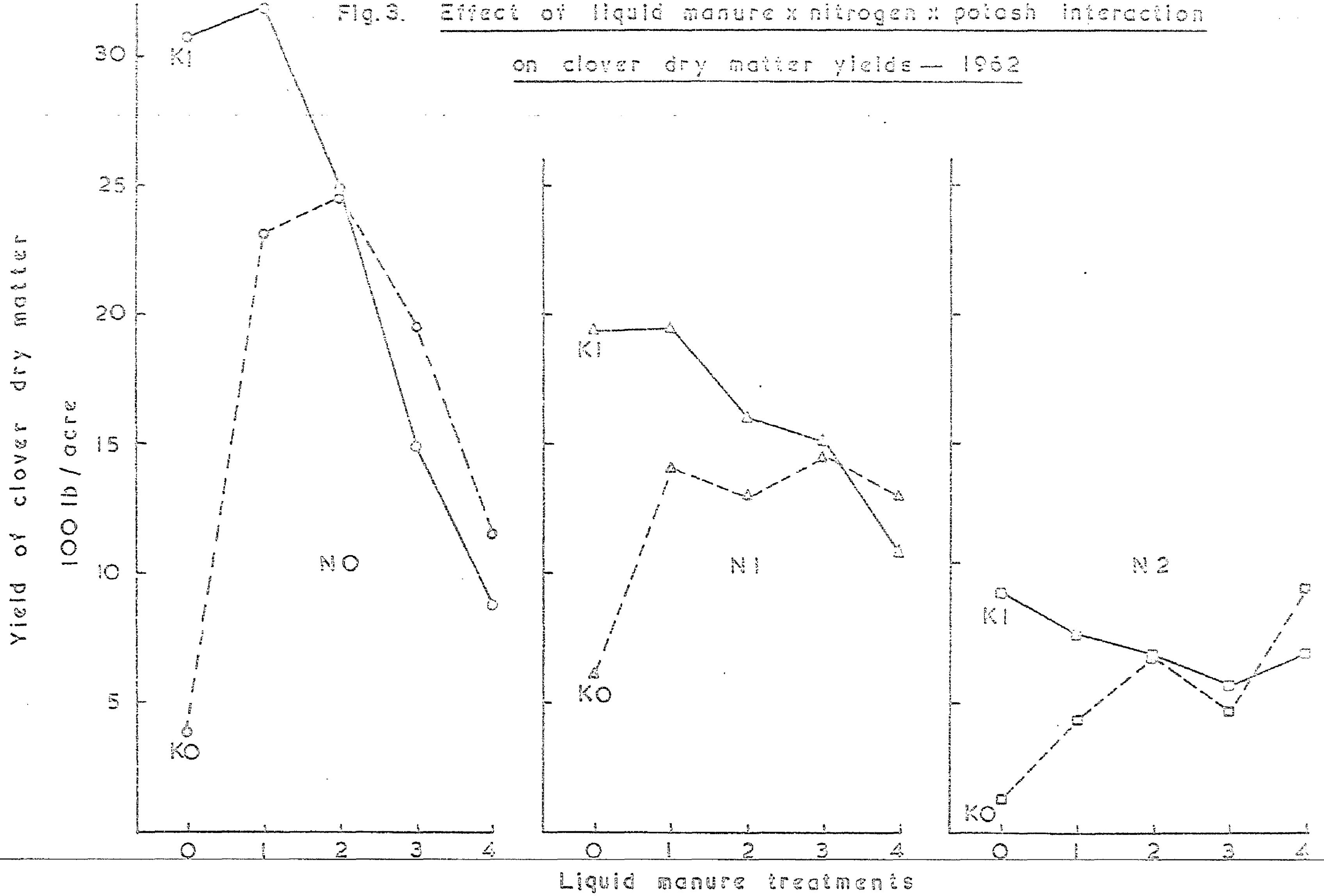
Phosphate application tended to decrease the clover yield as in 1961 but the overall decrease was far from being statistically significant. Potash fertilizer, however, had a marked effect and increased yields in

1962 ($P<0.001$) compared with a small non-significant effect in 1961. Averaged over all treatments which included high levels of potassium in the liquid manure, there was a highly significant increase of 390 lb clover dry matter/acre where potash fertilizer was applied.

The 'liquid manure x nitrogen' interaction had a highly significant effect as in 1961, liquid manure giving greater increases in the total yield of clover within treatment N0 than within treatments N1 and N2. The LM1 and LM2 treatments increased clover yields by 1020 and 730 lb/acre respectively where no fertilizer nitrogen was applied ($P<0.01$), but by only 400 and 170 lb/acre where 100 lb fertilizer nitrogen were applied ($P<0.05$). Within the N0 level where there was the greatest clover growth, only the LM4 treatment significantly reduced the yield of clover compared with the LM0 treatment. The clover yield within the N2 level was low and was not significantly affected by liquid manure treatments, although here the LM4 treatment yielded 300 lb clover dry matter/acre more than the LM0 treatment. This difference was almost statistically significant. Within liquid manure treatments increasing levels of fertilizer nitrogen generally reduced clover yields. This was greatest within treatments LM1 and LM2 where most of the differences were highly significant. Within LM0 and LM3 the decreases were smaller being significant between the N1 and N2 levels but not between N0 and N1. The decreases were smallest and none was significant within the LM4 treatment. However, the yield of 820 lb clover dry matter/acre from treatment LM4 N2 was higher than that from any other liquid manure treatments within the N2 level.

The 'liquid manure x potash' interaction was again

Fig. 3. Effect of liquid manure x nitrogen x potash interaction on clover dry matter yields — 1962



highly significant ($P < 0.001$). Where potash fertilizer was applied treatment LM1 had no effect compared with treatment LM0 but the yield of clover subsequently was reduced by treatments LM2, LM3 and LM4 ($P < 0.01$). Where no potash was applied treatments LM1 and LM2 increased the clover yields by 1010 and 1100 lb/acre respectively ($P < 0.01$). Thereafter treatments LM3 and LM4 reduced the yield slightly although the clover yields from all the treatments were highly significantly greater than those from treatment LM0. Within liquid manure treatments the addition of potash fertilizer increased the yields of clover dry matter by 1610, 580 and 120 lb/acre within treatments LM0, LM1 and LM2 respectively. Within treatments LM3 and LM4 the addition of potash fertilizer caused small non-significant decreases in the clover yield.

The 'liquid manure x nitrogen x potash' interaction ($P < 0.001$) is shown graphically in Fig. 3. The shapes of the curves were similar to those obtained in 1961 but the differences between them were greater. The increases in clover yield resulting from potash fertilizer applied on the LM0 treatment were 2692, 1330 and 797 lb clover dry matter/acre at the N0, N1 and N2 levels respectively. With treatment LM1 the corresponding increases were 879, 543 and 326 lb/acre but with treatment LM2 potash fertilizer increased clover yield at the N1 level only. All these increases were approximately double those found in 1961. Clover yields were not affected by potash fertilizer at any of the other fertilizer nitrogen-liquid manure combinations.

Additional dressings of potash fertilizer gave increases at the N0 level of 2692, 879 and 39 lb clover dry matter/acre with treatments LM0, LM1 and LM2 respectively

Table 31. Significance of the effects of treatment on the yield of clover dry matter at each cut - 1962

Treatment	Cut number				
	1	2	3	4	5
N	***	***	**	***	***
P	NS	NS	NS	NS	NS
K	**	**	**	***	***
LM	***	***	***	***	***
LM x N	***	***	***	***	***
LM x K	***	***	***	***	***
LM x N x K	***	***	***	NS	*
LM x N x P	*	NS	NS	NS	**

Table 32. Significance of the effects of treatment on the percentage of clover dry matter - 1962

Treatment	Cut number				
	1	2	3	4	5
N	***	***	***	***	***
P	NS	NS	NS	NS	NS
K	*	**	**	***	***
LM	***	***	***	***	***
LM x N	***	***	***	***	***
LM x K	***	***	***	***	***
LM x N x K	**	*	*	NS	NS
LM x N x P	NS	NS	NS	NS	*

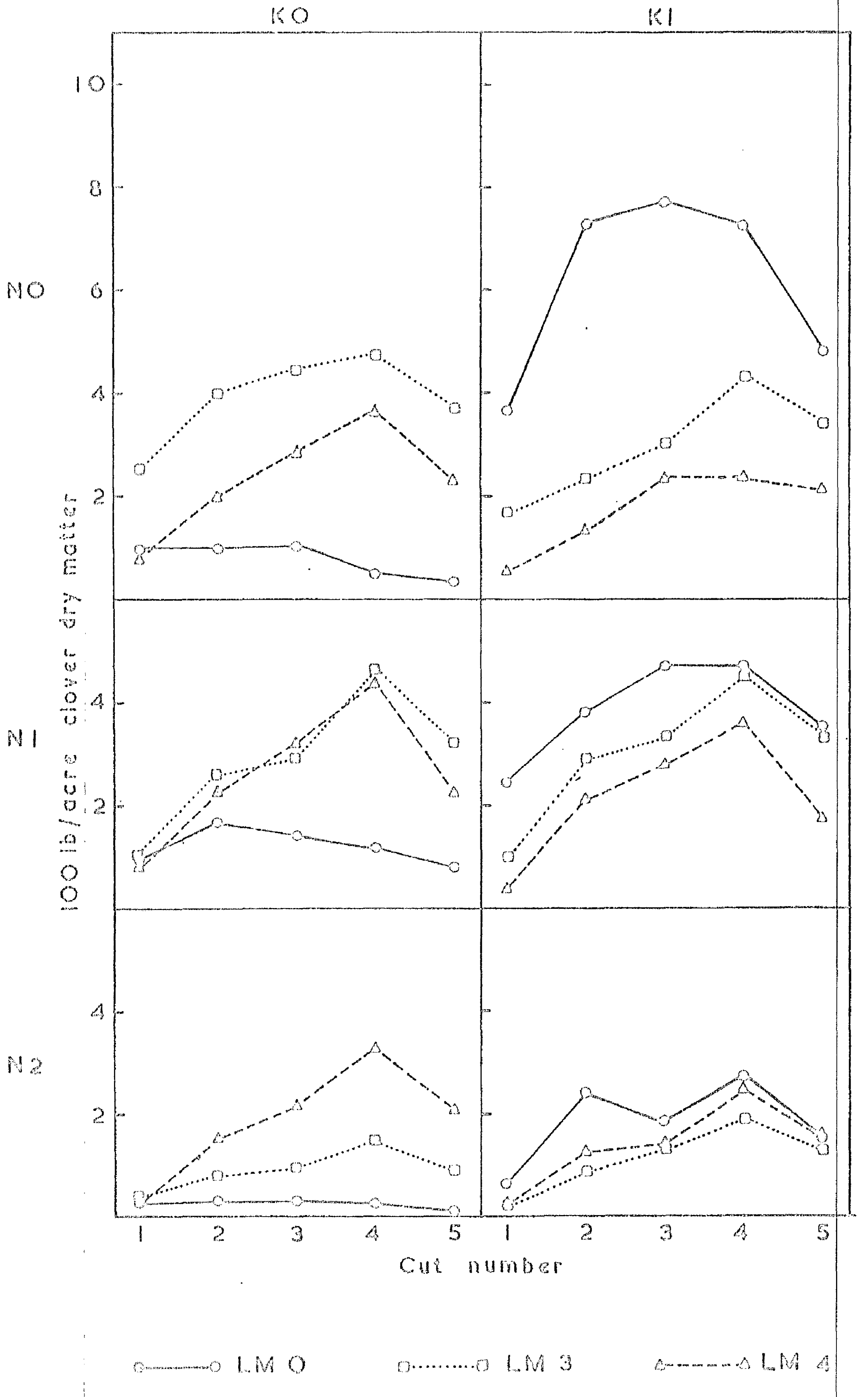
and thereafter they gave lowered yields. Thus the optimum dressing for clover growth where liquid manure was applied was close to the amount of potassium applied by the liquid manure in treatment LM2, i.e. 173 lb K/acre, which is higher than the optimum indicated by the 1961 results. This requirement of potassium was little affected by the amount of fertilizer nitrogen applied.

As in 1961 fertilizers had a greater depressing effect on clover yield, and the percentage of clover in the mixed herbage, than had equivalent levels of liquid manure. Where 100 lb N/acre were applied as liquid manure or as fertilizer, both supplying the same quantity of potassium, the yields of clover dry matter were 2443 and 1935 lb/acre respectively and the corresponding figures for clover percentage were 29 and 23%. With 200 lb N/acre the respective figures were 1947 and 922 lb/acre; 20 and 10%. Combined applications of liquid manure and fertilizer nitrogen likewise had a similar effect on clover, higher yields being dependent on the ratio of liquid manure to fertilizer.

The significance of treatment effects on clover dry matter yields at each cut in 1962 are given in Table 31. In 1962 the effects were similar to those noted at the last three cuts in 1961 when substantial changes in the composition of the sward had taken place. The 'liquid manure x nitrogen x potash' effect, however, decreased in significance at cuts 4 and 5 in 1962. This effect appeared to be due to an increase in the experimental error associated with these cuts since the treatment differences were of a similar magnitude to those for the first three cuts.

The interaction 'liquid manure x nitrogen x phosphate'

Fig. 4. Effect of liquid manure, nitrogen and potash on the yield of clover dry matter at each cut — 1962



was significant at cut 1 ($P < 0.05$) and at cut 5 ($P < 0.01$). At the N0 level, phosphate applications increased the yield of clover within each level of liquid manure. At the N1 and N2 levels, however, the opposite effect was noted, phosphate applications decreasing clover yield. These effects were seen mainly within treatments LM2, LM3 and LM4. Although not significant the same pattern was observed with the total yield of clover.

The significant effects of treatments shown by the transformed clover percentages are listed in Table 32. These results were similar to those noted for clover dry matter yield, only the 'liquid manure x nitrogen x potash' and the 'liquid manure x nitrogen x phosphate' interactions showing lower levels of significance.

Fig. 4 shows the distribution of the clover yields over the 1962 season, and this was somewhat different from that noted in 1961. In 1962 the yields were on average higher, except at cut 4, but the differences attributable to the treatments were smaller than in 1961. Without potash fertilizer, the yield and distribution of clover from the LM0 and LM4 treatments showed little variation with the level of fertilizer nitrogen application. With all the other liquid manure treatments the clover yields decreased with increasing fertilizer nitrogen. Where potash fertilizer was applied at the N0 level, the clover yield from the LM1 treatment (not shown) was greater than that from LM0 at cuts 4 and 5.

The coefficients of variation calculated from the results for clover were slightly higher in 1962 than in 1961. This was due probably to the fact that the overall difference in the treatment means for clover were greater.

Table 33. Mean total yields of crude protein in the mixed herbage (100 lb/acre) - 1962

	Liquid manure treatments					Means
Nitrogen treatments	LMO	LM1	LM2	LM3	LM4	
NO	9.6	14.4	15.0	15.7	18.2	14.6
N1	11.6	14.7	14.9	17.4	20.5	15.8
N2	13.3	15.3	16.7	18.5	21.6	17.1
Potash treatments						
KO	8.8	14.0	15.2	17.4	20.1	15.1
K1	14.2	15.6	15.9	17.0	20.2	16.6
Phosphate treatments						
PO	11.2	14.5	15.4	16.8	19.6	15.5
P1	11.8	15.0	15.7	17.6	20.6	16.1
Liquid manure means	11.5	14.8	15.6	17.2	20.1	

Significant effects

LM	***	LM x N	**
N	NS	LM x K	***
K	**	LM x N x K	***
P	NS		

Coefficient of Variation

Main-plots	=	30.2%
Sub-plots	=	9.6%
Sub-sub-plots	=	7.0%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	0.31	0.62	0.83
N means	1.07	-	-
K means	0.28	0.68	1.02
P means	0.87	-	-
LM means within a N	0.54	1.08	1.44
N means within a LM	1.17	2.90	4.46
LM means within a K	0.44	0.88	1.18
K means within a LM	0.48	1.04	1.45

Mixed herbage crude protein - 1962

The mean total crude protein yields in the mixed herbage are shown in Table 33. The yields were slightly lower in 1962 than in 1961 but the general response was similar.

Liquid manure increased the crude protein yield significantly at each level of application. Treatment LM4 yielded 860 lb crude protein/acre more than treatment LM0, a smaller increase than in 1961.

Fertilizer nitrogen increased the yield of crude protein at each level but the differences were not significant.

The effect of potash fertilizer was slightly greater than in 1961 and was highly significant ($P < 0.01$), but phosphate again had no significant effect.

Within fertilizer nitrogen treatments applications of liquid manure had a similar overall effect, the increased yields between treatments LM0 and LM4 being 860, 890 and 830 lb crude protein/acre for treatments N0, N1 and N2 respectively. However, within the N2 level each increment of liquid manure increased the yield significantly whereas within the N0 and N1 levels many of the differences in crude protein yield between liquid manure treatments were small and not significant.

The 'liquid manure x potash' interaction was again highly significant ($P < 0.001$) and the effects were more pronounced than in 1961. Where no potash fertilizer was applied the crude protein yield with treatment LM0 was 880 lb/acre and this increased significantly at each level of liquid manure to 2010 lb/acre with the LM4 treatment. With potash fertilizer yields were higher and the corresponding increase was from 1420 to 2020 lb/acre. Within liquid manure treatments potash

Table 34. Significance of the effects of treatment on the yield of crude protein at each cut - 1962

Treatment	Cut number				
	1	2	3	4	5
N	NS	**	NS	*	NS
P	NS	NS	NS	NS	NS
K	NS	**	*	**	**
LM	***	***	***	***	***
LM x N	**	***	NS	***	**
LM x K	***	***	***	***	***
LM x P	*	NS	NS	NS	NS
N x K	*	NS	NS	*	NS
LM x N x K	NS	*	NS	NS	*

Table 35. Significance of the effects of treatment on the percentage of crude protein in the dry matter - 1962

Treatment	Cut number				
	1	2	3	4	5
N	**	NS	NS	NS	NS
P	NS	NS	NS	NS	NS
K	NS	NS	*	**	NS
LM	***	***	***	***	*
LM x N	***	***	***	***	***
LM x K	NS	NS	*	**	NS
N x K	NS	*	*	***	*
LM x N x K	***	***	***	***	***

significantly increased the yield of crude protein where no liquid manure was applied, as noted in 1961, but in 1962 a similar effect was noted within the LM1 level ($P < 0.01$) doubtless due to the higher yield of clover.

The 'liquid manure x nitrogen x potash' interaction was highly significant ($P < 0.001$). The yield of crude protein was lowest at LM0 N0 and the addition of potash fertilizer increased the yield by 849 lb/acre, the corresponding increases at LM0 N1 and LM0 N2 being 576 and 193 lb/acre. The effect of potash became progressively smaller as the rate of application of liquid manure increased, and the treatments LM3 and LM4 showed no effect of the addition of potash fertilizer.

The significance of treatment effects on the yield and the percentage of crude protein at each of the five cuts in 1962 are given in Tables 34 and 35. With few exceptions most levels of application of liquid manure increased the crude protein yield at each cut. This was due largely to increases in the yield of herbage dry matter since the percentage of crude protein showed little variation with liquid manure application. An exception was the LM4 N2 treatment at the first four cuts where there was a highly significant increase in the percentage of crude protein in the herbage compared with the corresponding values from the LM0 N0 treatment.

Fertilizer nitrogen gave small increases in the yield of protein but again this was caused mainly by increases in the dry matter yields since the percentage of crude protein tended to rise with increasing levels of fertilizer nitrogen at cuts 1 and2 but to decrease at the remaining cuts.

At each cut, (Table 35), the percentage of crude protein in the herbage tended to be lowest where about the same level of nitrogen was applied, i.e. LM1 N2, LM2 N1 and LM3 NO. A highly significant effect of the 'liquid manure x nitrogen x potash' interaction ($P < 0.001$) on the percentage of crude protein was noted at each cut in 1962 and the effects of treatment at each cut were similar. The main effect was that without potash fertilizer the crude protein percentage between LMO and LM1 increased considerably at the NO level, increased slightly at N1 but declined markedly at N2. Where potash fertilizer was applied the fertilizer nitrogen treatments caused little change in the crude protein percentage between LMO and LM1. At higher application rates of liquid manure, potash fertilizer had no effect. This occurred at each cut for the percentage data but not for the yield of crude protein which was influenced more by the yield of herbage than by the percentage of crude protein in the herbage with the result that the three-factor interaction showed low significance for the yield of crude protein at each cut.

There were a number of other significant effects involving the potash factor; at the low levels of either liquid manure or fertilizer nitrogen greater yields or higher percentages of crude protein occurred where potash fertilizer was applied than where it was not.

Botanical composition of the sward - 1962

A detailed point quadrat analysis of all the plots was made in November 1962, and the results were recorded as percentage ground cover. The results of statistical analyses of the percentages after transformation to angles are presented separately for the components

Table 36. Effect of treatment on the botanical composition of the sward - perennial ryegrass 1962

Mean angular transformations

	Liquid manure treatments					
Nitrogen treatments	LM0	LM1	LM2	LM3	LM4	Means
N0	25.4	24.4	24.4	30.6	31.2	27.2
N1	30.3	28.6	30.2	28.8	28.4	29.2
N2	32.3	33.2	30.6	31.9	27.2	31.0
Potash treatments						
K0	30.8	30.1	27.9	29.3	28.2	29.3
K1	27.8	27.4	28.8	31.6	29.6	29.0
Phosphate treatments						
P0	29.1	28.5	28.8	29.4	29.6	29.0
P1	29.6	29.0	28.0	31.5	28.3	29.3
Liquid manure means	29.3	28.7	28.4	30.4	28.9	

Significant effects

LM	NS	LM x N	***
N	**	LM x K	*
K	NS	N x P	*
P	NS		

Coefficient of Variation

Main-plots = 16.0%

Sub-plots = 17.5%

Sub-sub-plots = 13.6%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	0.94	-	-
N means	0.85	1.90	2.71
K means	0.76	-	-
P means	0.70	-	-
LM means within a N	1.62	3.22	4.27
N means within a LM	1.69	3.45	4.66
LM means within a K	1.33	2.63	-
K means within a LM	1.41	2.88	-
N means within a P	1.21	2.69	-

and vice-versa

(1) perennial ryegrass, (2) white clover, (3) weeds and (4) bare ground. The weed component included the unsown grasses, mainly *Poa* spp, *Agrostis* spp and *Holcus lanatus*, and dicotyledonous weeds, mainly daisy (*Bellis perennis*), dandelion (*Taraxacum officinale*), speedwell (*Veronica* spp), chickweeds (*Cerastium vulgatum* and *Stellaria media*) and sheep's sorrel (*Rumex acetosella*).

The untransformed percentage ground cover data for the four components are presented graphically in Fig. 5 (facing page 81) and are discussed at the end of this section.

Perennial ryegrass. The means of the angular transformations of the percentage ground cover contributed by perennial ryegrass are shown in Table 36 for the main treatments and their interactions.

The main effects of liquid manure, potash and phosphate were not statistically significant. The overall effect of increasing fertilizer nitrogen application was to cause a small increase in the ryegrass cover. For example, the ryegrass cover was significantly greater with the N1 and N2 treatments than with the N0 treatment. Fertilizer nitrogen modified the effect of liquid manure on the ryegrass cover as shown by the 'liquid manure x nitrogen' interaction ($P < 0.001$). Where no fertilizer nitrogen was applied, the ryegrass cover was increased by treatments LM3 and LM4 ($P < 0.01$), but within nitrogen treatments N1 and N2, where the ryegrass cover was on average higher, it was little affected by liquid manure. However, within the N2 level the ryegrass cover was lower in treatment LM4 than in treatment LM0 ($P < 0.01$).

The effect of liquid manure was modified slightly by potash and the interaction was just significant ($P < 0.05$). Without potash fertilizer the ryegrass cover was highest at the low levels of liquid manure and then declined at the

Table 37. Effect of treatment on the botanical composition of the sward - white clover 1962

Mean angular transformations

Nitrogen treatments	LM0	LM1	LM2	LM3	LM4	Means
	Liquid manure treatments					
N0	23.7	32.4	31.1	23.9	22.5	26.7
N1	20.3	26.6	24.6	23.5	23.8	23.8
N2	13.0	17.4	19.8	16.5	22.3	17.8
Potash treatments						
K0	9.8	23.2	25.4	21.4	22.4	20.4
K1	28.2	27.8	24.9	21.2	23.3	25.1
Phosphate treatments						
P0	19.7	25.2	25.2	23.0	24.0	23.4
P1	18.3	25.8	25.2	19.6	21.8	22.1
Liquid manure means	19.0	25.5	25.2	21.3	22.9	

Significant effects

LM	***	LM x N	***
N	**	LM x K	***
K	**		
P	NS		

Coefficient of Variation

Main-plots = 52.1%

Sub-plots = 33.6%

Sub-sub-plots = 23.6%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	1.27	2.52	3.34
N means	2.17	4.83	6.87
K means	1.14	2.49	3.49
P means	1.77	-	-
LM means within a N	2.20	4.37	5.78
N means within a LM	2.93	6.21	8.56
LM means within a K	1.80	3.57	4.72
K means within a LM	1.97	4.04	5.46

high levels, whereas with potash fertilizer the opposite effect was found. The differences between LM1 and LM2 were significant, there being a decrease without potash and an increase when potash fertilizer was applied ($P < 0.05$).

White clover. The mean transformed data for white clover cover are shown in Table 37. Averaged over all other treatments the mean clover cover was higher on plots receiving liquid manure ($P < 0.001$) than where none was applied. The untransformed data, i.e. the percentage of ground cover on the treatments LMO, LM1, LM2, LM3 and LM4 were respectively 11, 18, 18, 13 and 15%. The percentage on the LM3 treatment was the only one not significantly different from that on the LMO treatment. The similarity between the clover cover on treatments LM1 and LM2 resulted in recurring non-significant differences between these treatments, reported previously for dry matter and crude protein yields.

Fertilizer nitrogen had the opposite effect to liquid manure, the clover cover decreasing as the level of nitrogen increased. This was most apparent with the N2 treatment ($P < 0.01$). Potash fertilizer had a highly significant effect, and increased the clover considerably ($P < 0.01$), but phosphate again showed no effect.

The 'liquid manure x nitrogen' interaction was highly significant ($P < 0.001$). The increase in clover cover between treatments LMO and LM1 was greatest at the NO level ($P < 0.01$), intermediate at N1 ($P < 0.01$) and lowest at N2 ($P < 0.05$). As the liquid manure rate increased above the LM1 level the clover cover decreased. This effect was most apparent where no fertilizer nitrogen was applied, i.e. where the clover cover was highest. There was an unexpected increase in clover cover between treatments LM3 and LM4 when these treatments were applied with the highest level of fertilizer nitrogen ($P<0.01$). Within liquid manure treatments, except for LM4, there was a significant decrease in the clover cover as the nitrogen application rate increased from treatment N0 to treatment N2. The mean percentage clover cover on plots receiving no liquid manure and no fertilizer nitrogen was 16%, compared with 14% on plots of the treatment combination LM4 N2 where 600 lb N/acre/year were applied for 2 years.

The high ground cover percentages of clover where liquid manure was applied can be attributed largely to a potash effect, and the 'liquid manure x potash' interaction was highly significant ($P<0.001$). Where no potash or liquid manure was applied the clover cover was very low but it increased markedly with treatment LM1 ($P<0.01$) and still further, but not significantly, with treatment LM2. Where potash was applied to these treatments increasing applications of liquid manure gradually decreased the clover. With treatments LM3 and LM4 the percentage ground cover of clover was much the same whether potash was applied or not. The increase in clover cover resulting from applications of potash fertilizer was significant within treatment LM0 ($P<0.01$) and LM1 ($P<0.05$) but not significant at the other levels of liquid manure.

The treatment effects which were significant for the clover ground cover were significant also for the percentage clover in the total herbage at each cut in 1962.

Weeds. The mean transformed data for weeds are shown in Table 38. Liquid manure reduced the weed cover at each level of application and most of the differences were highly significant ($P<0.01$). Fertilizer nitrogen had a

Table 38. Effect of treatment on the botanical composition of the sward - weeds 1962

Mean angular transformations

	Liquid manure treatments LMO	LM1	LM2	LM3	LM4	Means
Nitrogen treatments						
NO	36.9	27.3	24.7	22.1	16.0	25.4
N1	29.2	23.5	21.5	15.6	12.1	20.4
N2	28.9	20.0	20.2	15.8	13.4	19.7
Potash treatments						
KO	39.8	25.1	22.7	17.2	13.2	23.6
K1	23.5	22.2	21.6	18.5	14.5	20.0
Phosphate treatments						
PO	32.8	25.3	22.0	16.4	12.1	21.7
P1	30.5	21.9	22.3	19.3	15.6	21.9
Liquid manure means	31.7	23.6	22.1	17.8	13.8	

Significant effects

LM	***	LM x N	NS
N	**	LM x K	***
K	**	LM x P	*
P	NS	LM x N x K	**

Coefficient of Variation

Main-plots	= 34.4%
Sub-plots	= 31.8%
Sub-sub-plots	= 24.9%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	1.28	2.54	3.36
N means	1.37	3.05	4.34
K means	1.04	2.26	3.16
P means	1.12	-	-
LM means within a K	1.81	3.59	4.76
K means within a LM	1.92	3.92	5.29
LM means within a P	1.81	3.59	-
P means within a LM	1.97	4.06	-

smaller effect than liquid manure but significantly decreased the weed cover where it was applied ($P<0.01$). Potash applications also reduced the weed cover ($P<0.01$) but phosphate had no effect.

The effect of liquid manure on the weed cover did not vary with the fertilizer nitrogen treatment but was modified by the potash treatment ($P<0.001$). Without potash, the weed cover was high on plots of treatment LM0 and was reduced considerably by the LM1 treatment ($P<0.01$). With potash fertilizer, however, the weed cover was much less on the LM0 treatment, and the LM1 treatment had no effect. At higher levels the effects of liquid manure on weed cover were much the same whether or not potash was applied. Potash fertilizers caused a highly significant decrease in the weed cover within treatment LM0 but had no significant effect within the other liquid manure treatments.

The 'liquid manure x phosphate' interaction was significant ($P<0.05$) and where phosphate was applied the weed cover was lower and decreased less as the level of liquid manure increased than where no phosphate was applied.

The 'liquid manure x nitrogen x potash' interaction was highly significant ($P<0.01$). Potash fertilizer reduced the weed cover on plots receiving the LM0 and LM1 treatments, most at the N0 level, to an intermediate degree at the N1 level and least at the N2 level. The higher application rates of liquid manure gave a lower weed cover and with these treatments potash fertilizer had little effect.

The ground cover percentages of unsown grasses and dicotyledonous weeds are shown separately in Table 39. These percentages were not analysed statistically and this

Table 39. Percentage ground cover of dicotyledonous weeds and unsown grasses - 1962

Dicotyledonous weeds

	Liquid manure treatments					
	LMO	LM1	LM2	LM3	LM4	Means
Nitrogen treatments						
NO	23.2	7.5	4.7	1.7	0.7	7.5
N1	11.8	5.2	2.7	0.5	0.7	4.2
N2	11.8	5.5	2.3	0.8	0.2	4.1
Potash treatments						
KO	24.3	8.6	4.7	0.9	0.6	7.8
K1	6.9	3.6	1.8	1.1	0.4	2.8
Phosphate treatments						
PO	17.9	8.1	4.2	1.2	0.6	6.4
P1	13.3	4.0	2.2	0.8	0.4	4.2
Liquid manure means	15.6	6.0	3.2	1.0	0.5	

Unsown grasses

	Liquid manure treatments					
	LMO	LM1	LM2	LM3	LM4	Means
Nitrogen treatments						
NO	13.8	14.2	14.0	13.2	7.5	12.5
N1	13.5	11.2	11.2	7.8	5.7	9.9
N2	12.2	6.8	10.3	7.0	6.3	8.6
Potash treatments						
KO	16.7	10.3	11.1	8.4	6.1	10.5
K1	9.4	11.1	12.6	10.2	6.9	10.4
Phosphate treatments						
PO	12.5	10.9	10.9	8.2	5.2	9.6
P1	13.8	10.6	12.8	10.4	7.8	11.1
Liquid manure means	13.2	10.7	11.8	9.3	6.5	

Table 40. Effect of treatment on the botanical composition of the sward - bare ground 1962

Mean angular transformations

Nitrogen treatments	Liquid manure treatments LMO	LM1	LM2	LM3	LM4	Means
NO	28.8	33.9	37.4	40.0	44.2	36.8
N1	35.4	39.3	40.9	45.9	47.1	41.7
N2	38.9	43.6	44.4	48.1	49.2	44.8
Potash treatments						
KO	30.7	38.4	40.6	46.2	47.9	40.8
K1	38.0	39.4	41.1	43.1	45.8	41.5
Phosphate treatments						
PO	33.5	38.3	40.6	44.9	46.0	40.6
P1	35.2	39.6	41.2	44.4	47.8	41.6
Liquid manure means	34.4	38.9	40.9	44.6	46.9	

Significant effects

LM	***	LM x N	NS
N	***	LM x K	***
K	NS	N x P	**
P	NS		

Coefficient of Variation

Main-plots = 11.3%

Sub-plots = 10.3%

Sub-sub-plots = 9.6%

Differences between:	$s_{\bar{d}}$ ±	LSD 0.05 ±	LSD 0.01 ±
LM means	0.93	1.85	2.45
N means	0.84	1.88	2.68
K means	0.63	-	-
P means	0.69	-	-
LM means within a K	1.32	2.62	3.46
K means within a LM	1.34	2.71	3.64
N means within a P and vice-versa	1.19	2.66	3.78

table shows the untransformed means. Some differences between these separate fractions and the total weed analysis were found. The dicotyledonous weeds were reduced to a greater extent by liquid manure than were the unsown grasses, whereas fertilizer nitrogen affected both fractions similarly. That this may have been due to the potassium content of the liquid manure is suggested by the lower percentage of dicotyledonous weeds where potash fertilizer was used. Potash fertilizer had less effect on the unsown grasses.

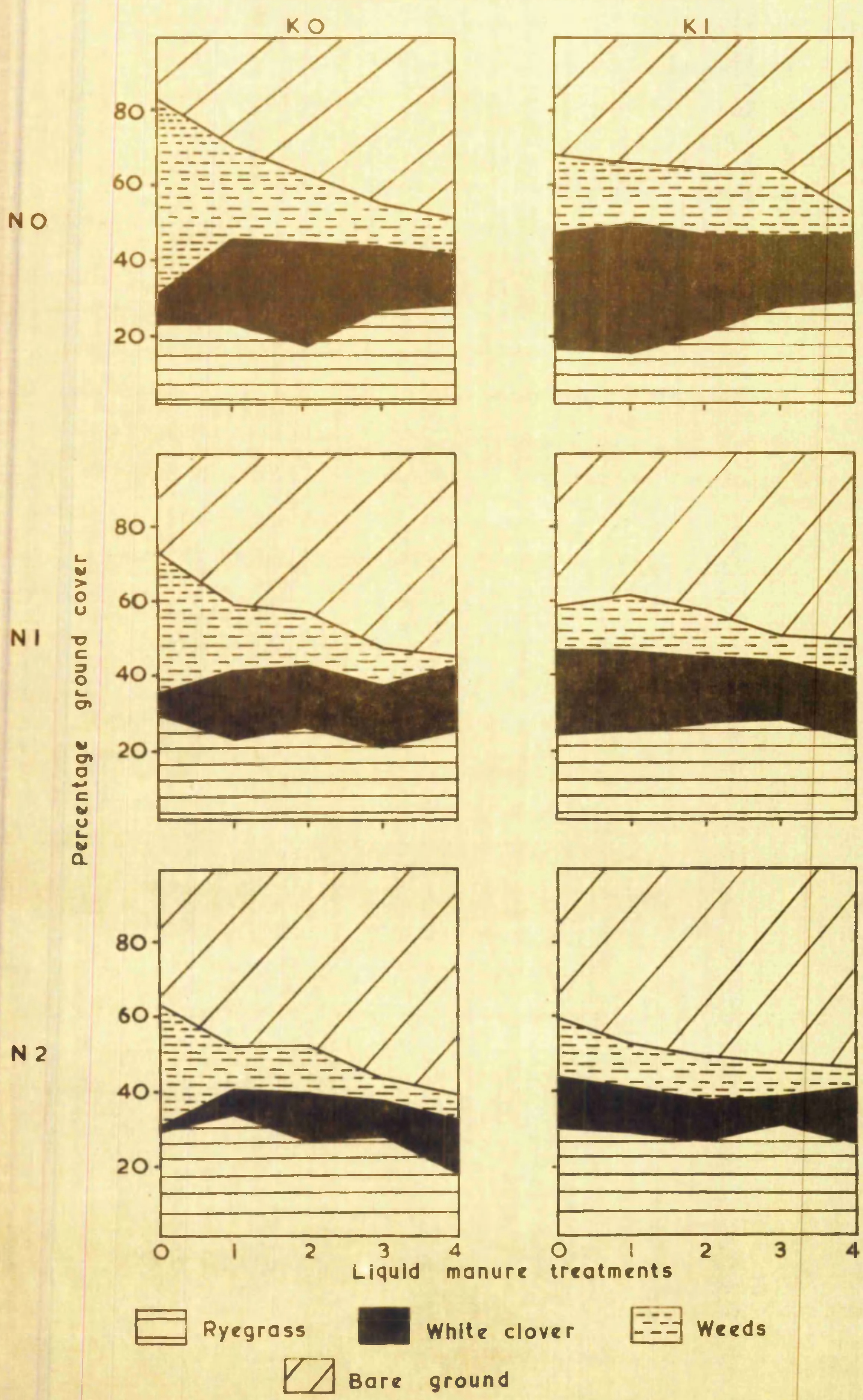
Bare ground. The mean transformed data for bare ground are shown in Table 40. Each increase in the rate of application of liquid manure and fertilizer nitrogen resulted in a significant increase in the bare ground fraction. The increases were generally additive and the effect of liquid manure was similar at each level of fertilizer nitrogen. Potash and phosphate tended to increase the proportion of bare ground but never significantly.

The 'liquid manure x potash' interaction had a highly significant effect on the proportion of bare ground ($P < 0.001$). Where no liquid manure was applied, plots without potash fertilizer had significantly less bare ground than plots with potash. With increasing levels of liquid manure the proportion of bare ground increased by greater amounts where no potash fertilizer was applied than where it was applied, but the differences were rarely significant.

The amount of bare ground increased also as the level of fertilizer nitrogen rose and this increase was greater without phosphate than with it ($P < 0.01$).

Total percentage ground cover. Composite graphs of the

Fig. 5. Effect of liquid manure, nitrogen and potash on sward botanical composition — 1962



untransformed percentage ground cover data are shown in Fig. 5. The main treatment effects are shown in the figure and each section of it illustrates the variation in the sward botanical composition after 2 years' application of the different levels of liquid manure with varying levels of nitrogen and potash fertilizer, averaged over the phosphate treatments. In each section of the figure percentage ground cover is shown on one axis and the application rates of liquid manure on the other. The four components - perennial ryegrass, white clover, weeds (including unsown grasses) and bare ground are shown in ascending order from the basal axis. Thus the first curve shows the effect of increasing rates of liquid manure on the ryegrass fraction, the other fractions being graphed separately but cumulatively above this.

Where no nitrogen fertilizer was applied there was less ryegrass and considerably more clover at the low than at the high application rates of liquid manure particularly where potash was applied. Where fertilizer nitrogen treatment N1 was applied the ryegrass and clover ratios were fairly uniform over the liquid manure treatments and the total cover of ryegrass plus clover was only slightly smaller than with treatment N0. With fertilizer nitrogen treatment N2, the clover percentage was very low where no liquid manure or potash was used but increased appreciably where treatment LM2 was applied without potash or LM0 was applied with potash, i.e. where the average potassium application rate was 166 lb K/acre. Also at the N2 level there was a further increase in clover with treatment LM4 whether potash was applied or not, and the ryegrass level decreased.

The cumulative total ground cover percentages of ryegrass plus clover were relatively uniform over the

Soil analysis

Table 41. Available potash (K_2O) in air dry soil (mg/100 g)

Nitrogen treatments	LM0		LM2		LM4	
	K0	K1	K0	K1	K0	K1
	1962					
N0	7	9	12	17	32	38
N2	6	8	8	16	24	33
	1963					
N0	6	13	14	28	47	67
N2	6	9	9	21	42	54

Table 42. Available phosphate (P_2O_5) in air dry soil (mg/100 g)

Nitrogen treatments	LM0		LM2		LM4	
	K0	K1	K0	K1	K0	K1
	1962					
N0	6	5	5	5	6	5
N2	5	5	6	5	5	6
	1963					
N0	6	7	6	6	5	6
N2	6	6	6	6	6	6

different levels of liquid manure and decreased only slightly from the lowest to the highest level of nitrogen fertilizer.

One of the most noticeable effects was in the weed fraction. Where no potash fertilizer was applied, the weed content of the sward receiving no liquid manure was high but that of the sward receiving treatment LM1 was considerably lower, and further reductions though smaller ones, occurred in swards receiving treatments LM2, LM3 and LM4. This was found at all nitrogen levels where no potash was applied, but the weed cover remained fairly constant in all the plots that received additional potash fertilizer. The increase in bare ground with increasing liquid manure applications was more marked at K0 than at K1 and generally resulted from the decrease in the weed fraction rather than from a decrease in the sown species.

Soil analysis - 1961 and 1962

Analysis of the soil samples taken by the second method described on page 51, from plots that had and had not received phosphate fertilizer, showed that the application of phosphate had very little effect on either the pH or the potash status of the soil, and that the available phosphate content increased from 4 to only 8 mg. after phosphate had been applied for 2 years. Thus only the values obtained from the first method of sampling, showing changes in the soil content of available potash and phosphate where liquid manure, nitrogen and potash fertilizers were applied are given in Tables 41 and 42.

Available potash. Over the first year all the application rates of liquid manure and potash fertilizer increased the content of potash in the soil. Within

Soil analysis

Table 43. Acidity (pH in water)

Nitrogen treatments	LM0		LM2		LM4	
	K0	K1	K0	K1	K0	K1
			1962			
N0	6.02	6.10	6.21	6.07	6.37	6.10
N2	6.22	6.12	6.14	6.08	6.24	6.12
			1963			
N0	6.11	6.13	6.20	6.20	6.50	6.18
N2	6.10	6.08	6.20	6.21	6.13	6.01

all treatments the potash content of the soil was always higher at the N0 level than at the N2 level. The potash content was 7 mg where no liquid manure, nitrogen or potash fertilizer was applied, 9 mg where 166 lb K/acre were applied in potash fertilizer, and 12 mg where 166 lb K/acre were applied in liquid manure. The highest level, 38 mg, occurred at the highest level of liquid manure plus potash fertilizer on the N0 treatment. These plots received a total of 829 lb K/acre each year. After 2 years of the experiment, the potash content had increased considerably but the effects of the treatments on the soil potash content remained the same as in the first year. Without liquid manure or potash fertilizer the soil content was 6 mg, with 166 lb K/acre as fertilizer it was 13 mg and with 173 lb K/acre as liquid manure it was 14 mg. The highest level, 67 mg, again occurred at the highest application rate of liquid manure and potash fertilizer.

Available phosphate. The soil phosphate level was 6 mg on the untreated area. Varying the amounts of liquid manure or potash fertilizer applied had no apparent effect on soil phosphate content in either year of the experiment.

Acidity. The pH measurements of the soil and water extracts are given in Table 43. Where liquid manure was applied the pH tended to rise but only where the liquid manure was not accompanied by potash fertilizer. For example, in the first year where no fertilizer nitrogen or potash was given the mean pH of the soil was 6.02 with treatment LM0, 6.21 with treatment LM2 and 6.37 with treatment LM4. The effect was less consistent where fertilizer nitrogen was applied. Where potash fertilizer

Table 44. Effect of liquid manure, nitrogen and potash on the weighted mean percentage of potassium in the grass and clover

GRASS

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.98	2.24	3.29	2.17	2.53	K0 2.04
	K1	2.30	2.81	3.57	2.89		
N2	K0	0.63	1.84	3.27	1.91	2.32	K1 2.80
	K1	1.86	2.65	3.66	2.72		
Liquid manure means		1.44	2.38	3.45	Grass mean		2.42

CLOVER

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.83	1.90	3.32	2.02	2.39	K0 1.98
	K1	2.08	2.71	3.50	2.76		
N2	K0	0.93	1.64	3.25	1.94	2.27	K1 2.68
	K1	1.75	2.51	3.55	2.60		
Liquid manure means		1.40	2.19	3.40	Clover mean		2.33

was given the pH values were lower and did not vary with the liquid manure treatment. After 2 years there was greater variation in the values but the same general trends were observed. Without nitrogen and potash fertilizers the pH values at LMO, LM2 and LM4 were 6.11, 6.20 and 6.50 respectively but where nitrogen, potash or phosphate fertilizers were used the differences were inconsistent.

Mineral content of the herbage - 1962

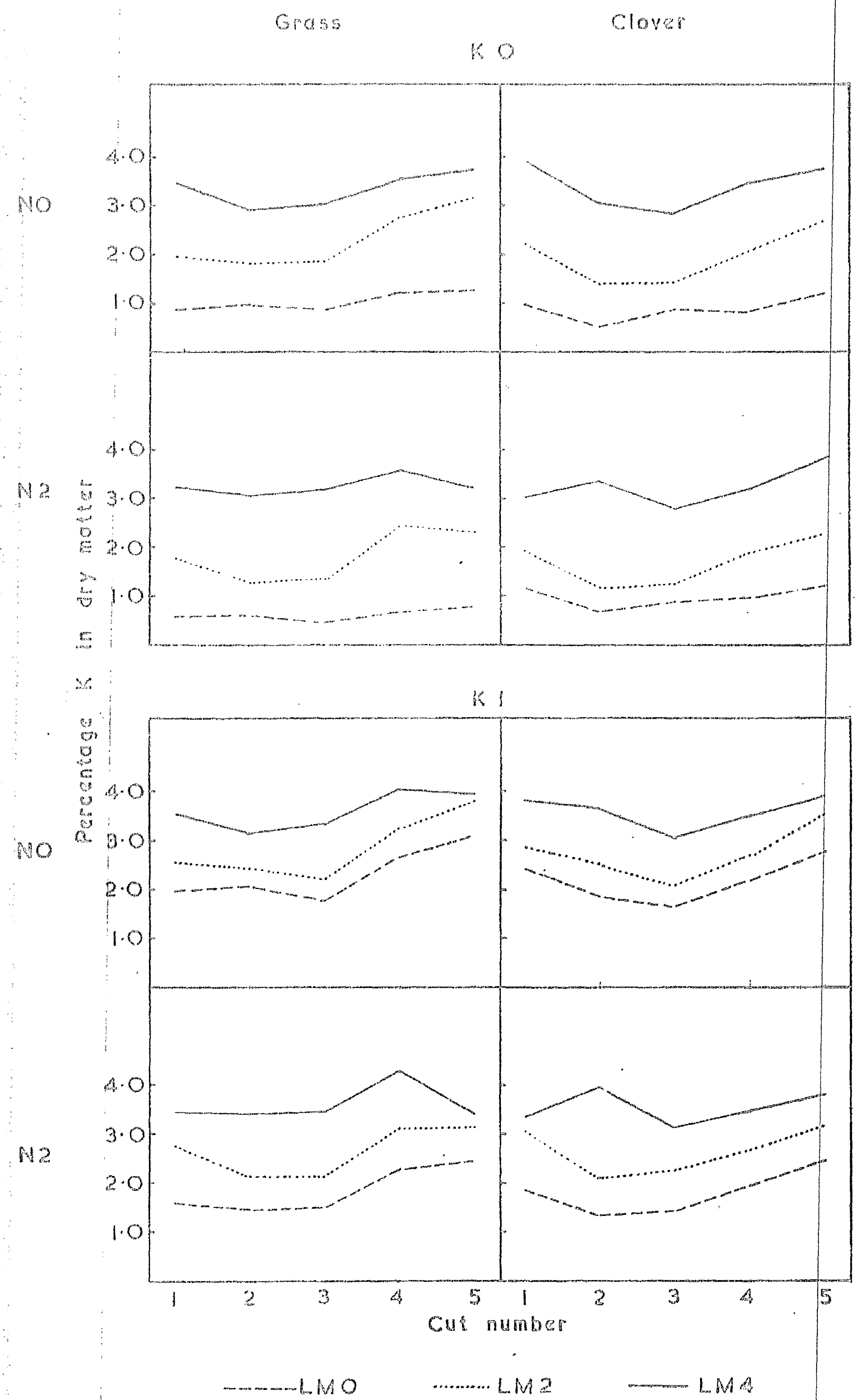
Samples of both grass and clover fractions obtained from the botanical separations at each cut were retained from selected treatments which represented the extreme applications of liquid manure and fertilizers.

(a) Potassium. The weighted mean percentages of potassium (%K) in the grass and the clover fractions from each of the selected treatments, calculated from the data for the individual cuts, are shown in Table 44. The difference between the potassium content of the grass and that of the clover was small, the overall mean percentages being 2.42 and 2.33% K respectively.

Applications of potassium either in liquid manure or in fertilizer increased the potassium content of the herbage. Where the potassium was applied in liquid manure and without fertilizer nitrogen, the grass from the LMO, LM2 and LM4 treatments contained 0.98, 2.24 and 3.29% K. Where potash fertilizer was applied in addition there was an increase to 2.30, 2.81 and 3.57% K respectively. Potash fertilizer had a similar effect on clover as it had on grass, the difference between the means of the KO and K1 treatments being 0.76% K for grass and 0.70% K for clover.

The potassium in the liquid manure apparently increased the potassium content of the grass more than did the potassium in the potash fertilizer. Thus the

Fig. 6. Potassium content of grass and clover — 1962



grass from treatment LM2 NO KO, which supplied 100 lb N and a mean of 170 lb K/acre as liquid manure contained 2.24% K, whereas the grass from the treatment LMO N2 K1 which supplied 200 lb N and 166 lb K/acre in the form of fertilizer, contained 1.86% K. This latter treatment supplied more nitrogen than the other, but since fertilizer nitrogen was observed to reduce the potassium content, this fact further emphasized the difference. Similar effects on the potassium content of grass and to a lesser extent on that of clover were found at other levels where equivalent applications of potassium were made in liquid manure and fertilizer.

Fertilizer nitrogen generally reduced the potassium content of both grass and clover. Exceptions to this did, however, occur in the grass and clover with the LM4 K1 treatment where the highest application rate of nitrogen and potassium was applied, and also in the clover with the LMO KO treatment. However, the latter treatment resulted in such a small sample of clover as to be unrepresentative of the treatment. Where no liquid manure or potash fertilizer was applied the potassium content of the grass decreased when fertilizer nitrogen was applied from 0.90 to 0.63% and by the end of 1962 signs of "yellowing" at the leaf tips of the grass were observed under this treatment.

The potassium contents in the grass and the clover at each cut are shown in Fig. 6. Overall it appears that irrespective of the rate or time of application liquid manure has much the same effect on the potassium content of clover as of grass. In grass and clover the potassium content tended to be higher at the first and last cuts than at the three mid-season cuts. The effects of liquid manure, nitrogen and potash fertilizer

Table 45. Effect of liquid manure, nitrogen and potash on the weighted mean percentage of sodium in the grass and clover

GRASS

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.98	0.50	0.39	0.62	0.50	K0 0.78
	K1	0.52	0.33	0.33	0.39		
N2	K0	1.28	0.92	0.59	0.93	0.76	K1 0.50
	K1	0.78	0.61	0.42	0.60		
Liquid manure means		0.89	0.59	0.43	Grass mean		0.63

CLOVER

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.85	0.59	0.37	0.60	0.50	K0 0.58
	K1	0.47	0.41	0.31	0.40		
N2	K0	0.62	0.65	0.42	0.56	0.52	K1 0.44
	K1	0.56	0.51	0.36	0.48		
Liquid manure means		0.62	0.54	0.36	Clover mean		0.51

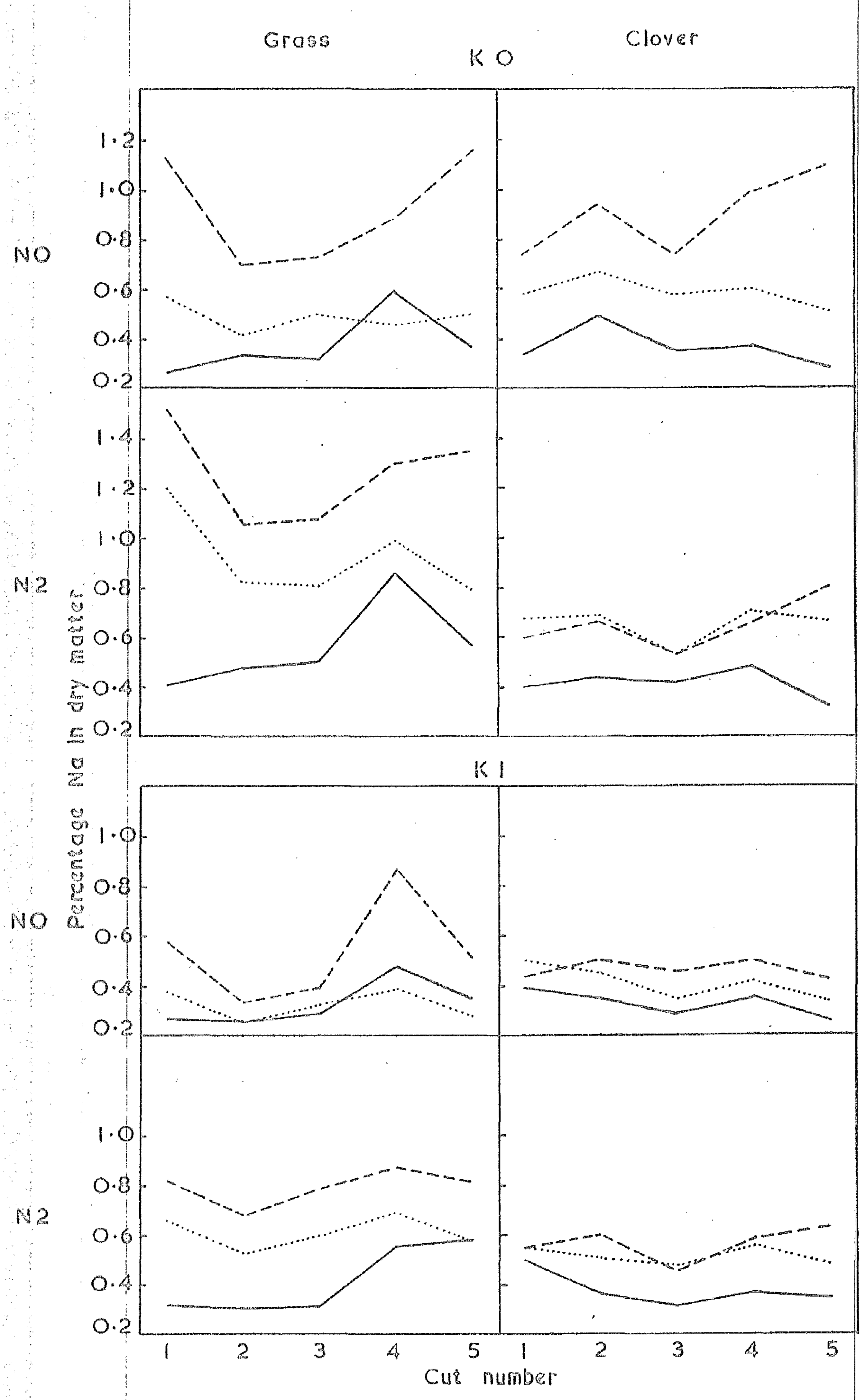
treatments on the potassium content at each cut were similar to those described previously for the weighted mean potassium content, and these treatment effects were often considerably greater than the seasonal effects.

(b) Sodium. The weighted mean percentage of sodium in the grass and clover fractions from the same treatment samples are shown in Table 45. The overall sodium content of the grass was slightly higher than that of the clover, the respective mean values being 0.63 and 0.51% Na. Liquid manure applications lowered the mean sodium content in grass, the values on the LMO, LM2 and LM4 treatments being 0.89, 0.59 and 0.43% respectively. Potash fertilizer also lowered the mean sodium content from 0.78 to 0.50%, and when applied with liquid manure the effect was additive.

In clover, the average sodium content was lower than in grass and the range of values under the liquid manure applications was less extreme. Thus increasing applications of liquid manure gave sodium contents of 0.62, 0.54 and 0.36%.

The potassium in liquid manure apparently reduced the sodium content of grass more than did the equivalent potash fertilizer treatment, the respective values on the LM2 NO KO and LMO N2 K1 treatments being 0.50 and 0.78% Na. This latter figure may have been influenced, however, by additional nitrogen which tended to increase the sodium content of grass. For example, the overall effect of fertilizer nitrogen was an increase of 0.26% Na in the grass.

With clover, as with grass, potash fertiliser lowered the sodium content. Fertilizer nitrogen, however, had little effect on the sodium content of clover, the results



Grass
Clover
K O
K I
NO
N2
NO
N2
Percentage Na in dry matter
Cut number
LM O
LM 2
LM 4

where nitrogen was applied being higher by only 0.02% Na. On the LMO KO treatment, fertilizer nitrogen reduced the sodium content, but as discussed previously this may have been an artifact associated with the smallness of the sample.

The distribution of sodium in the grass and clover at each cut is shown in Fig. 7. The fluctuations at each cut were more evident than those observed with potassium. For the grass fraction the untreated plots had the highest sodium contents at cuts 1 and 5 with lower contents in mid-season. Where liquid manure or potash fertilizer was applied, cuts 1 and 4 often gave the highest results. An exception was the LM4 treatment at cut 1 which had a sodium content as much as 1% Na lower than the LMO treatment and showed an increase only at cut 4. Fertilizer nitrogen did not alter the relative effects of the other treatments at each cut.

The effects of the treatments on the sodium content of clover were smaller than those found with grass, and less extreme variations occurred between cuts. The sodium content of clover tended to be lower at cuts 1 and 3 than at the other cuts, although where liquid manure or potash fertilizer was applied cut 5 also had a lower sodium content.

Throughout this experiment the sodium contents of the samples were all considerably higher than were found in Expt 1.

(c) Magnesium. The weighted mean percentages of magnesium in the grass and clover fractions are shown in Table 46. The mean content of magnesium was lower in grass than in clover, 0.16% compared with 0.20% Mg. In general the effect of treatment was small. With both

Fig. 8. Magnesium content of grass and clover—1962

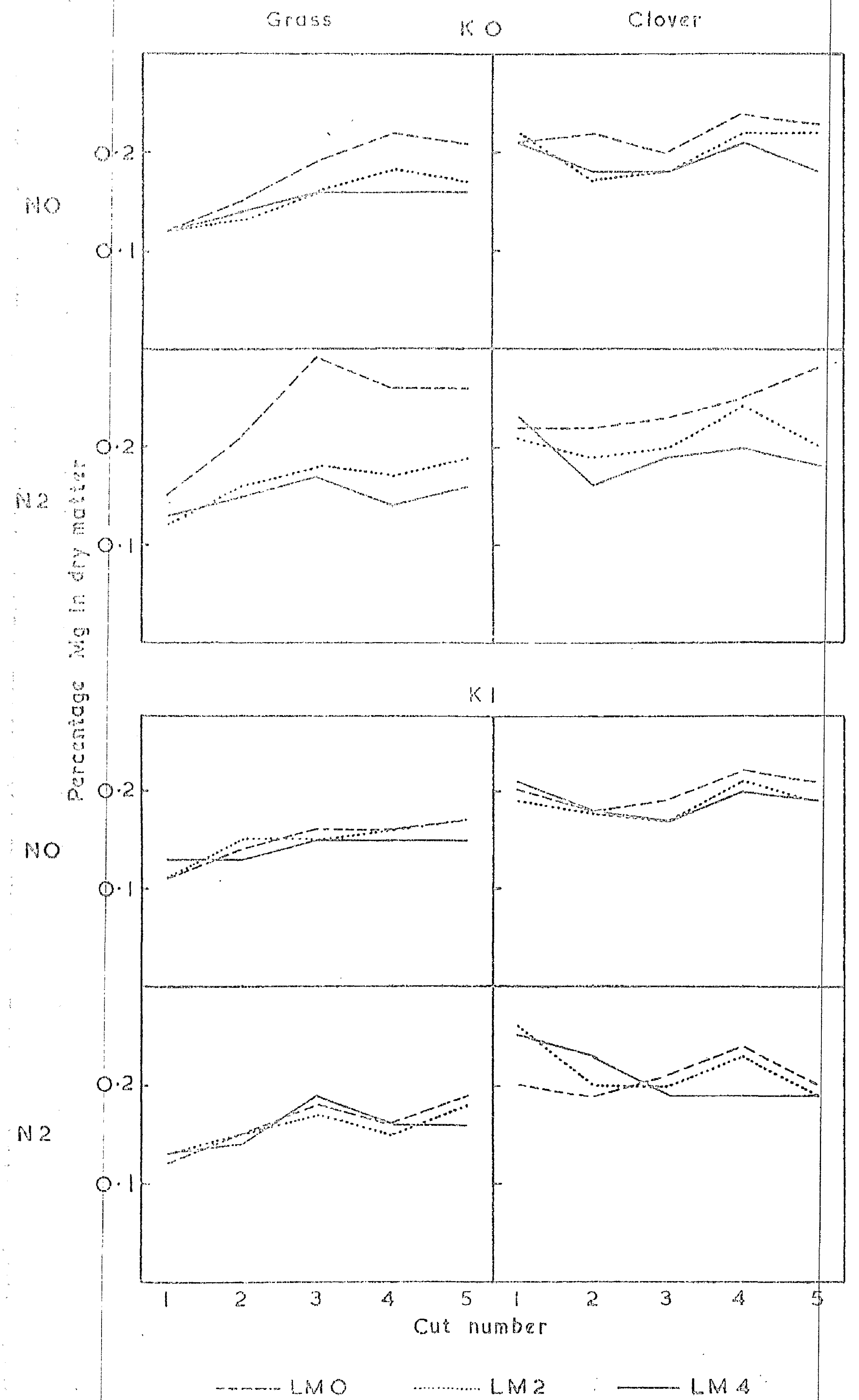


Table 46. Effect of liquid manure, nitrogen and potash on the weighted mean percentage of magnesium in the grass and clover

GRASS

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.16	0.14	0.15	0.15	0.14	K0 0.16
	K1	0.14	0.14	0.14	0.14		
N2	K0	0.22	0.16	0.15	0.18	0.17	K1 0.15
	K1	0.16	0.16	0.16	0.16		
Liquid manure means		0.17	0.15	0.15	Grass mean		0.16

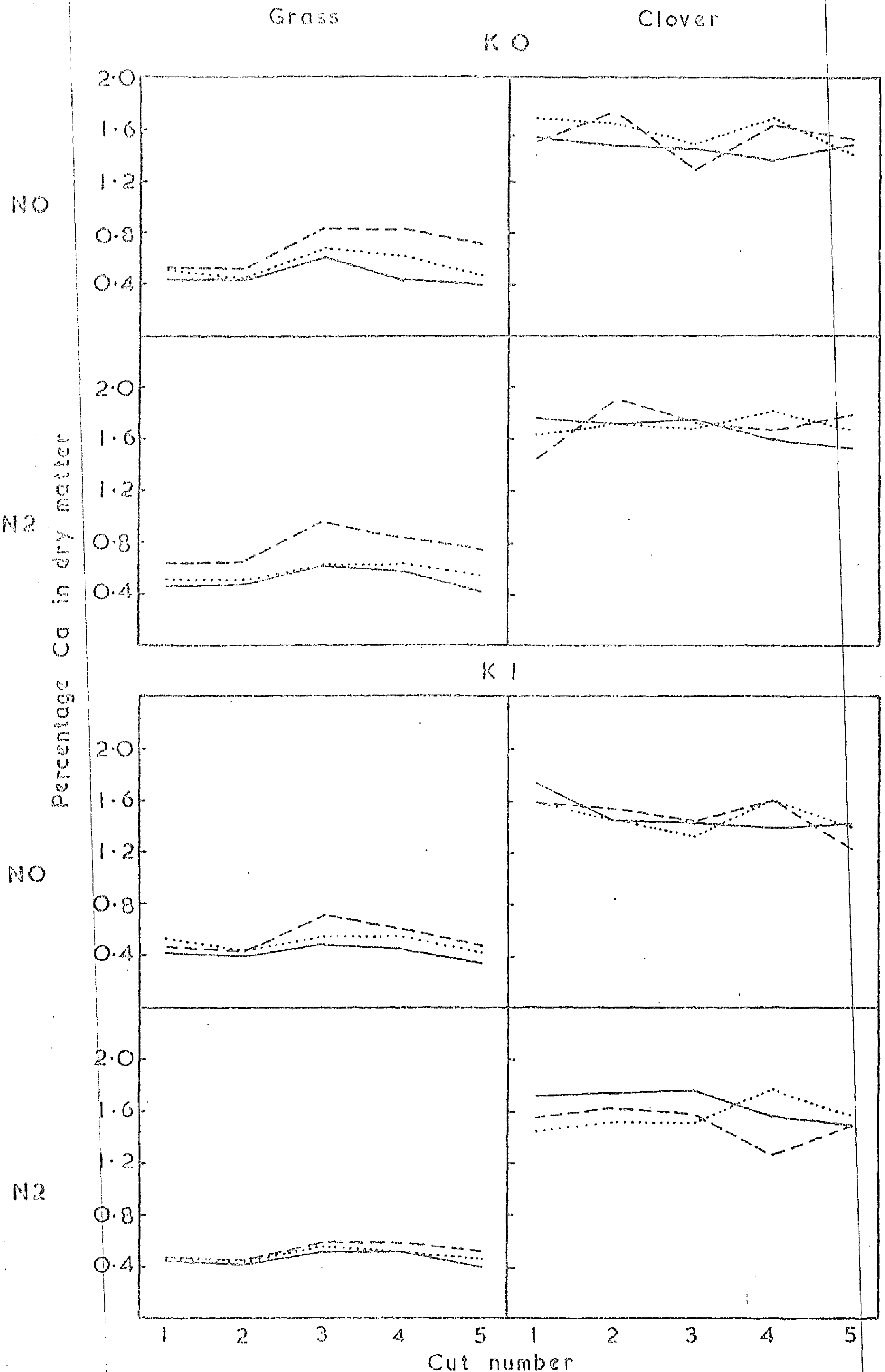
CLOVER

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LM0	LM2	LM4	Mean	N	K
N0	K0	0.22	0.20	0.19	0.20	0.20	K0 0.21
	K1	0.20	0.19	0.18	0.19		
N2	K0	0.24	0.21	0.19	0.21	0.21	K1 0.20
	K1	0.21	0.21	0.20	0.21		
Liquid manure means		0.22	0.20	0.19	Clover mean		0.20

grass and clover, applications of liquid manure reduced the magnesium content where no potash fertilizer was applied but had little effect where there was a basal dressing of potash fertilizer since this source of potassium had depressed the magnesium to a uniformly low level within most treatments. Where fertilizer nitrogen but no potash fertilizer was applied the magnesium content was highest, and liquid manure had the largest effect, the magnesium values decreasing between the treatments LMO and LM4 by 0.07 and 0.05% Mg in the grass and clover respectively. When liquid manure and potash fertilizer treatments were applied the magnesium content was less and the effect of fertilizer nitrogen was small. Liquid manure showed a tendency to decrease the magnesium more than fertilizers although the difference was only 0.02% Mg, e.g. the LM2 NO KO and LMO N2 K1 treatments contained 0.14 and 0.16% Mg respectively.

The magnesium contents of grass and clover at each cut are shown in Fig. 8. In grass receiving no fertilizer nitrogen, the magnesium content increased at each cut on all the liquid manure treatments until cut 4 and then it tended to fall. With fertilizer nitrogen the highest magnesium level occurred at cut 3 followed by a decrease at cut 4 and an increase at cut 5. Within each nitrogen treatment where no potash fertilizer was applied, the LMO treatment gave grass with a higher magnesium content at each cut than did the LM2 and LM4 treatments, but with potash applications the magnesium content did not vary appreciably with the level of liquid manure. This higher magnesium content on the LMO treatment was more apparent at the N2 level than at the NO level and the differences became more pronounced as the season advanced.

Fig. 9. Calcium content of grass and clover — 1962



——LMO .... LM2 —— LM4

Table 47. Effect of liquid manure, nitrogen and potash on the weighted mean percentage of calcium in the grass and clover

GRASS

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LMO	LM2	LM4	Mean	N	K
NO	KO	0.61	0.52	0.45	0.53	0.50	KO 0.57
	K1	0.50	0.49	0.42	0.47		
N2	KO	0.75	0.56	0.51	0.61	0.55	K1 0.48
	K1	0.52	0.49	0.46	0.49		
Liquid manure means		0.60	0.52	0.46	Grass mean		0.52

CLOVER

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LMO	LM2	LM4	Mean	N	K
NO	KO	1.53	1.58	1.44	1.52	1.50	KO 1.60
	K1	1.49	1.47	1.44	1.47		
N2	KO	1.71	1.71	1.63	1.68	1.62	K1 1.51
	K1	1.47	1.58	1.62	1.56		
Liquid manure means		1.55	1.58	1.53	Clover mean		1.56

The magnesium content of the clover was about 0.10% Mg higher than that of the grass at cut 1 and, in contrast to the values for the grass, it declined after cut 1 but increased again at cut 4 and fell at cut 5. At cut 5 there was little difference between the content of magnesium in the clover and grass, emphasising the greater, and more important difference at the first cut. As with grass the highest magnesium content of clover occurred on the LM0 treatment without potash fertilizer.

(d) Calcium. The weighted mean percentages of calcium in the grass and clover fractions are shown in Table 47. The overall calcium content of grass was 0.52 compared with 1.56% Ca for clover. Liquid manure had less effect on the calcium contents of grass and clover than it had on the potassium or sodium contents. Increasing rates of liquid manure decreased the calcium slightly but this was only evident in grass. For example in the LM0, LM2 and LM4 treatments the grass contained 0.60, 0.52 and 0.46% Ca; while the corresponding contents in the clover were 1.55, 1.58 and 1.53% Ca. Potash fertilizer, however, lowered the mean percentage calcium in grass and clover by 0.09% Ca and this effect was greater at the LM0 level than where liquid manure was applied.

Fertilizer nitrogen increased the calcium in grass at each level of liquid manure especially where no potash fertilizer had been applied. A similar but more pronounced effect was noted in the clover.

The calcium contents of the grass and clover at each cut are shown in Fig. 9. Although the clover had a much higher calcium content than had the grass at each cut the effect of treatment was small. In grass at all rates

Fig. 10. Phosphorus content of grass and clover — 1962

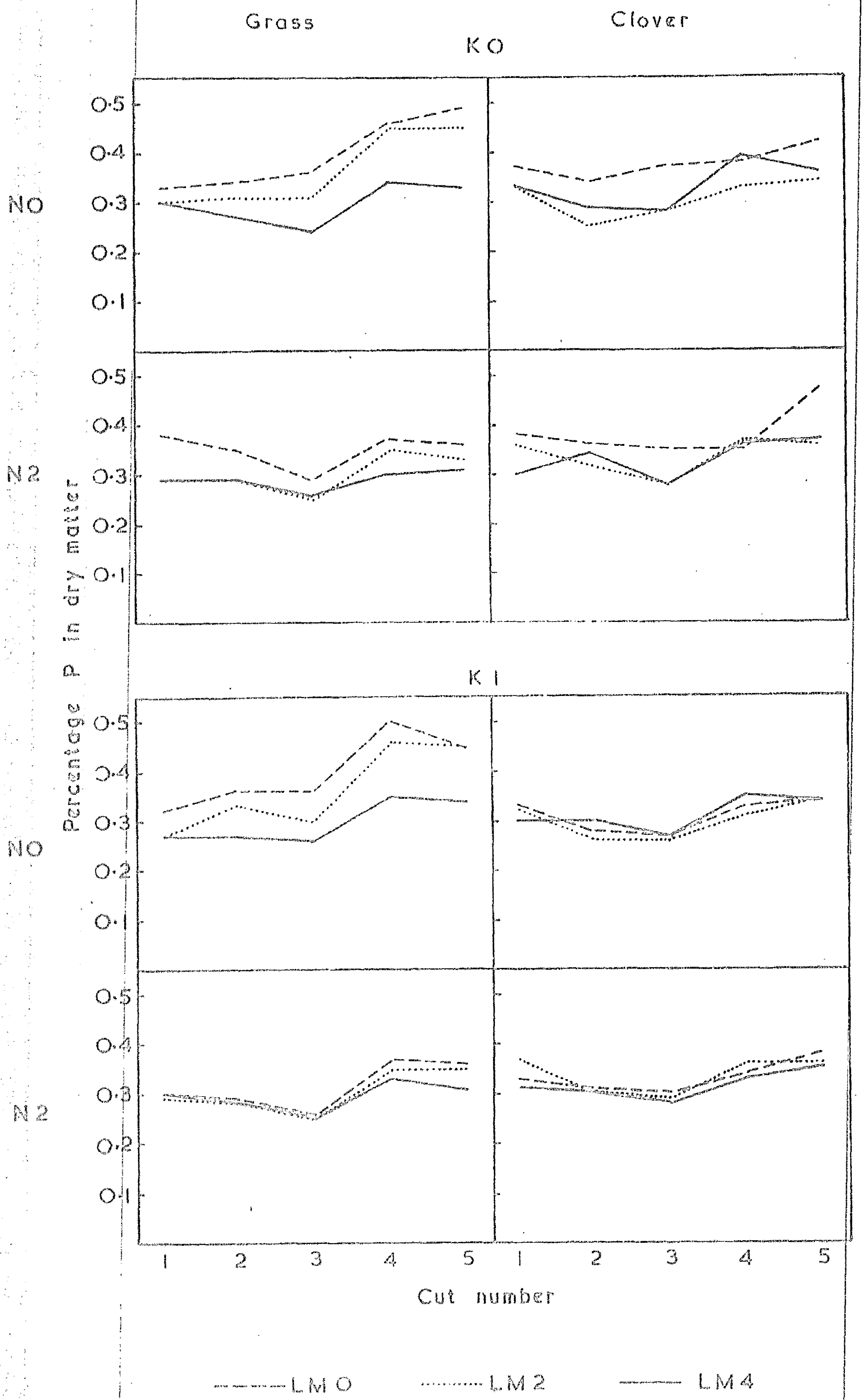


Table 48. Effect of liquid manure, nitrogen and potash on the weighted mean percentage of phosphorus in the grass and clover

GRASS

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LMO	LM2	LM4	Mean	N	K
NO	KO	0.38	0.35	0.29	0.34	0.34	KO 0.32
	K1	0.38	0.35	0.30	0.34		
N2	KO	0.35	0.30	0.29	0.31	0.31	K1 0.32
	K1	0.32	0.31	0.30	0.31		
Liquid manure means		0.36	0.33	0.30	Grass mean		0.33

CLOVER

Fertilizer treatments		Liquid manure treatments				Fertilizer means	
		LMO	LM2	LM4	Mean	N	K
NO	KO	0.37	0.30	0.34	0.34	0.32	KO 0.34
	K1	0.30	0.30	0.31	0.30		
N2	KO	0.38	0.33	0.34	0.35	0.34	K1 0.32
	K1	0.33	0.33	0.32	0.33		
Liquid manure means		0.34	0.32	0.33	Clover mean		0.33

of liquid manure application calcium tended to increase to cut 3 and then decreased slowly, the LMO treatment giving the highest percentage throughout. The differences between the liquid manure treatments were greater at each cut where no potash fertilizer was applied. There were fluctuations in the calcium content of clover at each level of liquid manure and no seasonal trend was discernible.

(e) Phosphorus. The weighted mean percentages of phosphorus in the grass and clover fractions are shown in Table 48. There was no difference in the phosphorus contents of grass and clover, the mean value for each being 0.33% P. In both grass and clover phosphorus tended to be higher where no liquid manure was used and to decrease as the level of liquid manure increased but the differences were small.

Potash fertilizer had no overall effect on the phosphorus content of grass or clover, but it did cause a small decrease in the phosphorus content of clover within the LMO treatment.

There was very little effect of fertiliser nitrogen on the phosphorus content of the herbage, the tendency being for a decrease to occur in the grass and an increase in the clover.

The effect at each cut is shown in Fig. 10. The treatment effects on phosphorus content were small compared with those on the contents of the other minerals. In grass the phosphorus content tended to rise during the season, each liquid manure treatment having relatively the same effect at each cut. With clover there was little difference in phosphorus content between cuts and considerable fluctuation occurred although the tendency was for a slight decrease in mid-season.

DISCUSSION

The response to liquid manure was modified considerably by the application of nitrogen and potash fertilizers. On the other hand the effect of phosphate was small and rarely modified the effect of liquid manure. Apart from the section in which the low response to phosphate is discussed, all the results have been averaged over phosphate treatments.

The response to liquid manure alone

The mean increases in dry matter yield, where liquid manure alone supplied 50, 100, 200 and 400 lb N/acre, were 56, 73, 101 and 134% respectively, above the yields of the untreated plots. Perhaps equally important was the beneficial effect which liquid manure had on the percentage and yield of white clover in the sward. At cut 1 in 1961 the highest percentage of clover was in the plots that did not receive liquid manure, whereas throughout 1962 the clover percentage was higher than from the untreated plots, where 50, 100 and 200 lb N/acre were applied and even plots receiving 400 lb N/acre from liquid manure contained more clover than plots without liquid manure at cut 5. The highest content of clover, where liquid manure was the only source of fertilizer nutrients, was found consistently in the treatment receiving 50 lb N/acre and this treatment usually gave herbage with the highest percentage of crude protein. However, the yield of crude protein was influenced more by the dry matter yield than by the percentage of crude protein the herbage contained, and the highest yield of crude protein occurred with the heaviest application of liquid manure of 400 lb N/acre.

There are no comparable experiments on the use of liquid manure as a fertilizer in the literature. Nevens (1941) reported that undiluted cow urine increased the yield and protein content of the herbage and that the heaviest applications had the greatest effect. Similar results were described with diluted urine by the Director of the Department of Agriculture for Ireland, 1915, Hansen, 1893 and Hendrick, 1915. In most of these experiments the quantity of nitrogen applied in the liquid manure was low and where comparisons were made with conventional dry fertilizers, the liquid manure often produced a greater response in the yield of herbage.

Applications of slurry tend to have less effect than the equivalent amount of fertilizers (Herriott & Wells, 1962). This is in agreement with a suggestion by Gisiger (1950) and also with the results of an experiment being made at this Institute, that the response to liquid manure and slurry is mainly dependent on the content of ammonia nitrogen. Since in the liquid manure used here over 95% of the nitrogen was present as ammonia and the liquid manure also supplied potassium to a soil inherently low in potassium, the response to liquid manure must be considered as being near to the maximum response that could be obtained.

Where the sward received urine from grazing sheep, Watkin (1954) and Wheeler (1958) showed that the yield of herbage was reduced by 10% and that this resulted partly from a depression in the content of clover in the sward. Sears (1956) over a number of years found that the return of urine under grazing conditions increased the yield of herbage but lowered the clover content. This result was similar to that reported by Mundy (1961). In contrast During & McNaught (1961) found increased yields together with a higher clover content where cow urine was applied, but their conditions differed in that urine was applied uniformly to plots measuring only 420 sq in.

Many of the differences in the results from these grazing studies probably are due to the different proportions of pasture covered by urine patches. During & McNaught (1961) calculated that a cow urine patch received the fertilizer equivalent of 330 lb N and 590 lb K/acre, and Petersen et al. (1956) estimated that 40 to 75% of the area of a pasture might receive no urine. This situation under grazing conditions is completely different from that prevailing where uniform application of diluted urine is made as liquid manure.

In this trial the low potash status of the soil enhanced the fertilizer value of liquid manure because of its high content of available potassium. It is not surprising therefore that liquid manure encouraged the growth of clover. Similar results were reported from the field observations of Gisiger (1950), Hendrick (1915) and others.

In contrast to liquid manure, conventional fertilizer nitrogen depressed the growth and yield of clover. Without liquid manure or fertilizers the mean yield of clover dry matter/acre was 720 lb, with applications of 400 lb N/acre as liquid manure it was 1070 lb and with 200 lb N/acre as fertilizer nitrogen it was only 300 lb. In other trials at this Institute, e.g. Holmes & MacLusky (1955) and elsewhere (Linehan & Lowe, 1960), the clover contribution to herbage yield was negligible where approximately 200 lb fertilizer nitrogen/acre were applied.

After 2 years without liquid manure or fertilizers the sward contained 17% unsown grasses and 36% dicotyledonous weeds. Increasing the level of liquid manure depressed the weed content of the sward and at the highest rate of application there were only 9% unsown grasses and 1% dicotyledonous weeds. There was no indication of an ingress of 'liquid manure weeds' such as the Umbelliferae and Rumex spp, as reported by Alten (1952), Koblet (1946) and Schechtner (1958). The restriction of the invasion of unsown grasses confirmed the results from the experiments made by Doak (1954), Wheeler (1959) and Wind & de Vries (1954).

At the high levels of liquid manure application where the ground cover of clover was less than at low levels, the decrease in the weed content was not compensated for by an increase in any other component of the sward with the result that at the highest rate of liquid manure only 50% of the ground surface was covered by plant growth. This more open sward where liquid manure was applied was very noticeable at cut 1 in 1962 after the first year of the trial, and the yield of dry matter where 400 lb N/acre were applied as liquid manure was lower than that from plots receiving no liquid manure. Thereafter this treatment outyielded all the others but the low plant cover would no doubt have severely curtailed subsequent production if further applications of liquid manure had not been made. If liquid manure encouraged weeds as has often been asserted, the very open sward at the high level of application would provide excellent conditions for weed infestation. That this did not happen indicates that it is not liquid manure per se which stimulates the growth of weeds but rather bad husbandry practices. These allow weed infestation with consequent transport of weed seeds in or on the animal and eventual passage of these seeds to the liquid manure storage tank. Many trials with liquid manure in which the weed content of pasture increased were made in Alpine areas where there was a large indigenous flora of herbs and weeds. Under these conditions the circulation of weed seeds in liquid manure is an important factor.

The response to liquid manure and potash fertilizer

There is little doubt that the potassium content of the liquid manure was responsible for much of the response in yield, clover growth and botanical changes observed in this trial. For example, where the mean dry matter yields from plots which received increasing rates of application of liquid manure were compared with those from plots which received no liquid manure but which did have a potash dressing of 166 lb K/acre, increases of 2, 13, 30 and 52% respectively were obtained. When these same dry matter yields were compared with yields from plots which received neither liquid manure nor potash fertilizer the increases were 56, 73, 101 and 134%. The addition of potash fertilizer had an extra effect only at the low levels of application of liquid manure, and the potash fertilizer often decreased the yield of plots receiving the highest levels of liquid manure.

Potassium is, of course, essential for clover growth, and where none was applied in this experiment either as liquid manure or fertilizer, clover growth was poor. Where an average dressing of 170 lb K/acre was made, the conditions were about optimum for clover growth. This figure agrees with that reported by Brown & Munsell (1956) who found an increase in the growth of clover with 166 lb but a decrease with 250 lb K/acre.

Where potash dressings were adequate liquid manure acted like fertilizer nitrogen in that each increment reduced the percentage of clover in the sward and also the total yield of clover dry matter. These results suggest that the contradictory evidence on the effect of liquid manure on clover growth as reported from other trials, resulted from whether or not potassium was a limiting factor in the growth of clover. In the New Zealand experiments of Sears (1953), for example, the potassium content of pasture was generally high and potash fertilizer was not used. Under these conditions the potassium in urine was superfluous and caused a luxury uptake in the herbage but had no beneficial effect on clover growth since the nitrogen in urine encouraged the growth of grass but suppressed the clover. In Britain it is apparent that, where the levels of potash and phosphate in the soil are adequate, there is little or no effect of urine returned by grazing sheep on the yield of herbage, and clover is reduced, but where potash is a limiting factor the increase in response is marked (Herriott & Wells, 1962; Mundy, 1961; Watkin, 1954; Wheeler, 1958). It can be concluded that, where potassium is not a limiting factor for clover growth, liquid manure will decrease the content of clover in the pasture and generally also the yield of clover.

The decrease in the weed content of the pasture, where liquid manure was applied alone, was not observed where there was also a basal dressing of potash fertilizer. Competition from the increased growth of clover where 166 lb K/acre were applied in potash fertilizer, reduced the weed content to 21% compared with 53% where no potash was applied. With this basal potash dressing, liquid manure reduced the weed content at the highest rate of application only. Since the ryegrass fraction was unaffected by the high rate of liquid manure it was not competition from the grass but some factor in the liquid manure which reduced the growth of the weed component. This observation agrees with those made by Doak (1954) and Wheeler (1959).

The response to liquid manure and fertilizer nitrogen

Over most levels of application the increased yields resulting from liquid manure and fertilizer nitrogen applied together were additive. In 1961, however, the response was slightly reduced once the total application rate of nitrogen exceeded 400 lb N/acre and in 1962 there was little additional response to dressings above 300 lb N/acre, irrespective of the source of nitrogen. This combined effect of liquid manure and fertilizer nitrogen was not significantly affected by applications of potash fertilizer. These results differed from those reported by Wheeler (1958). In a grazing study he found that urine had no effect on the yield unless fertilizer nitrogen was used with it; the maximum benefit of urine occurring where a fertilizer dressing of 312 lb N/acre was applied in addition to the urine. Where slurry has been used further increases in yield with additional fertilizer nitrogen have often been observed. For example, Brünner (1958) emphasized that large quantities of fertilizer nitrogen could be utilized economically although 120 lb N/acre were said to be high. Staehler (1961) reported that the application of 120 lb N/acre as fertilizer significantly increased yields compared with single applications of slurry supplying from 80 to 520 lb N/acre and that the extra fertilizer nitrogen had no adverse effect on the botanical composition of the sward. Another approach to the use of liquid manure and slurry was made by Schiller (1955) who suggested that rather than apply excess potash, liquid manure should apply the right quantity of potash, the deficiency of nitrogen being made up with fertilizer nitrogen. As well as making the most efficient use of potassium in the liquid manure, such a method could be of considerable importance where a luxury uptake of potassium caused a mineral imbalance in the herbage.

Fertilizer nitrogen in most circumstances depresses clover growth and this was found in the present experiment even where potash additions were adequate. Despite this reduction in clover the yield of crude protein increased with increasing levels of fertilizer nitrogen and the responses in yield within each level of liquid manure were similar. Generally, however, the percentage of crude protein was lower where fertilizer nitrogen was used in addition to liquid manure. This effect was particularly marked in mid-season when clover growth was at a maximum.

<u>The effect of liquid manure and dry fertilizers on clover</u>

One of the most impressive results noted in this experiment was that the depression of clover where liquid manure was applied was always less than where the equivalent weights of nitrogen and potassium were applied in fertilizers. Thus where 100 lb N and a mean of 170 lb K/acre were applied in liquid manure the yield of clover dry matter increased by an average of 568 lb or 32% over that from treatments receiving 100 lb N and 166 lb K/acre in fertilizers. As the level of total nitrogen applied increased, the difference between the effect of liquid manure and dry fertilizers became progressively greater and with applications of 200 lb N/acre the corresponding mean increase with the liquid manure treatment was 114%. Where liquid manure and fertilizer nitrogen were applied on the same plots the yield of clover was dependent on the ratio of liquid manure to fertilizer. Thus with 100 lb fertilizer nitrogen + 200 lb liquid manure nitrogen the yield of clover dry matter was 2672 lb compared with 1156 lb from 200 lb fertilizer nitrogen + 100 lb liquid manure nitrogen, both treatments supplying a mean of 338 lb K/acre; an increase of 135%.

It has been shown by Blackman & Templeman (1938) and Wilson (1962) and it is generally accepted that the decrease in clover where fertilizer nitrogen is applied is due to the increased shading of the clover by the grass and not to a direct effect of fertilizer nitrogen. However, in this experiment the opposite occurred since equivalent levels of nitrogen and potassium in liquid manure and dry fertilizers resulted in almost identical yields of dry matter and consequently a similar effect of shading under each treatment, yet there was a marked difference in the yield of clover. Evidently some constituent in liquid manure ameliorated the suppression of clover.

Constituents in liquid manure which may influence the growth of clover

Potassium. The potassium in liquid manure had a marked beneficial effect on clover growth which was emphasized by the low potash status of the soil but potassium was apparently not responsible for the different effects of liquid manure and of dry fertilizers on clover. First, the differences between liquid manure and fertilizers occurred where the amount of potassium applied was the same, and During & McNaught (1961) concluded that the potassium in urine and in muriate of potash had a similar effect. Second, even if there was a greater availability of the potassium in the liquid manure than in the potash fertilizer this would have little effect once the optimum level of potassium was applied and it was above the optimum levels of potassium and at high levels of applied nitrogen that the greatest differences in clover yield occurred.

Nitrogen. When liquid manure is stored, as in this trial, the nitrogen which was excreted mostly as urea is converted to ammonia and analyses made at intervals showed that ammonia nitrogen comprised 95-100% of the total nitrogen in the stored liquid manure. In comparison the fertilizer nitrogen ("Nitro-Chalk" 21% N) contained only 52% of its total nitrogen in the form of ammonium salts.

Since the initial ammonia content of the soil may be increased over a hundred-fold by urine applications (Thompson & Coup, 1943) before being gradually converted to nitrate nitrogen, applications of liquid manure at intervals of 5 weeks would be expected to maintain a higher ammonia nitrogen content in the soil throughout the growth period than where fertilizer nitrogen of a lower ammonia nitrogen content was used. Thus the highest clover contents which were on the liquid manure treatments were where the highest amounts of ammonia nitrogen were applied. This is different to the results of Doak (1954) and Walker (1956) which indicated that fertilizers high in ammonia nitrogen were inferior to fertilizers consisting mainly of nitrate nitrogen because they suppressed clover to a greater extent. In most studies of ammonia nitrogen, sulphate of ammonia generally is used as a source of the ammonia nitrogen and the associated increase in soil acidity which occurs when this fertilizer is used may be responsible for the clover depression reported elsewhere when fertilizers consisting of ammonia nitrogen are used.

Acidity. In this trial the pH of the soil was higher where high rates of liquid manure were applied than where dry fertilizers were applied or the plots were untreated. For example, at the end of the second year of the experiment the soil pH was 6.11 on the untreated plots, 6.10 on the plots receiving 200 lb N/acre as fertilizer nitrogen and 6.50 on the plots receiving 400 lb N/acre as liquid manure.

Raising the pH on acid soils favours the stoloniferous growth of clover but differences in the figures for the optimum pH of the soil for maximum clover growth have been reported. Thus McNeur (1953) calculated an optimum pH of 5.4 for white clover. A higher value was suggested by Sprague (1952) who claimed that the optimum pH for legumes was 6.5 to 6.9. Dilz & Mulder (1962) found that there was an increase in the yield of clover when the pH was raised from 5.8 to 6.4, and that sometimes there was a further increase in the yield when the pH rose to 6.8. The higher pH of 6.50 in the soil of the plots receiving liquid manure might therefore be important in the different effect that liquid manure and dry fertilizers had on the growth of clover in this experiment. Consequently the high pH of the liquid manure may be of greater importance in more acid soil conditions than those prevailing in the soil on which the present experiment was made.

Other constituents. The result might also support earlier suggestions made by Doak (1954) and Sauerlandt (1948) that urine contains a hormone beneficial to herbage growth.

It can be concluded that the greater benefit liquid manure had on clover growth and yield compared with the equivalent weight of nutrients in dry fertilizers was most likely to be related to either the higher content of ammonia nitrogen or the higher pH of the liquid manure.

The response to liquid manure and phosphate fertilizer

As expected from previous trials on the same soil type at this Institute, phosphorus played a relatively small part in the fertilization of grassland. The yields of herbage were increased slightly throughout by phosphate applications. The increases were greatest at the highest levels of liquid manure and fertilizer nitrogen applications but were seldom either statistically significant or of practical importance. It is important to note that the response to phosphate fertilizers was low in spite of the fact that the available phosphate content of the soil was low, and it was found that applications equivalent to 7 cwt superphosphate/acre each year had apparently very little effect on the available phosphate content of the soil. Holmes (1951) discussed the inability to detect added phosphate on this particular soil and suggested that at least part of the 'fixed' phosphate could be utilized. Since liquid manure is very low in phosphorus and has a high nitrogen and potassium content it is natural to regard it as being imbalanced for grass production. In areas where the phosphorus content of the soil is low and applied phosphate brings an increase in yield, the phosphorus deficiency in liquid manure would require to be corrected. The results from this trial indicate, however, that on the type of soil that exists at the Hannah Institute farm the application of phosphate fertilizer is not necessary for the efficient use of liquid manure.

Mineral content of the herbage

As might be expected in an experiment where the nutrients supplied ranged from nil to a maximum of 600 lb N and 850 lb K/acre, large variations in the mineral content of the herbage were noted. The effect of liquid manure was considerable, the potassium content of grass showing a range of values from 0.4% where no liquid manure was applied to 4.3% K at the highest rate of application. The latter figure was higher than those quoted from other trials but resulted in the present experiment from the extremely high amounts of potassium applied. Urine increased the potassium content of pasture in experiments reported by Hemingway (1963), Melville & Sears (1953), Metson & Hurst (1953), Saunders & Metson (1959), Sears & Thurston (1953) and Watkin (1957) and these increases were similar to those found by other workers using potash fertilizer.

The increase in potassium and the decrease in other minerals, mainly sodium, calcium and magnesium, where liquid manure and fertilizers were used has been identified in some instances with an increased incidence of hypomagnesaemic tetany in dairy cattle, and this was discussed in Expt 1. In this disease the blood magnesium level is low but the incidence of tetany has seldom been directly related to a low content of magnesium in the herbage and other minerals have been implicated. For example, a statistically significant correlation between the incidence of tetany and the mineral ratio $\frac{K}{Ca + Mg}$ (the amount of each element being expressed in milli-equivalents), was found in two large surveys - one in Holland by Kemp & 't Hart (1957) and another in Scotland by Butler (1963). A similar correlation between tetany and the ratio $\frac{K}{Ca + Mg}$ was reported by Verdeyen (1953) and Hvidsten *et al.* (1959) in other countries. However this correlation was not found by Rahman, McDonald & Simpson (1960) or by Rook & Wood (1960). The ratio $\frac{K}{Ca + Mg}$

Table 49. Effect of liquid manure and dry fertilizers on the ratio $\frac{K}{Ca + Mg}$* in the mixed herbage (grass + clover) and in grass alone (Cut 1, 1962)

Fertilizer treatments		Liquid manure treatments LM0	LM2	LM4
		Grass + clover		
N0	K0	0.56	1.17	2.61
	K1	1.15	1.54	2.64
N2	K0	0.34	1.22	2.32
	K1	1.15	2.00	2.57
		Grass		
N0	K0	0.60	1.42	2.80
	K1	1.55	1.82	2.84
N2	K0	0.34	1.27	2.44
	K1	1.22	2.06	2.65

*To calculate this ratio m-equivalents were used can be little more than an indication of the potential of a pasture to cause hypomagnesaemia because of the many anomalies associated with the disease but the significant correlation of this ratio with tetany in Holland has prompted its use in advisory work there.

The mineral composition and the dry matter yields of the grass and clover fractions from some treatments in this experiment have been used to calculate the potassium, calcium and magnesium contents in the mixed herbage and also in grass alone. These values have been converted into milli-equivalents and from them $\frac{K}{Ca + Mg}$ ratios have been calculated for the mixed herbage and also for the grass fraction alone. These ratios are shown in Table 49 for the herbage at cut 1 in early May, and thus slightly past the period when the highest incidence of tetany usually occurs.

In pastures where tetany occurred Kemp & 't Hart (1957) found that the mean $\frac{K}{Ca + Mg}$ ratio was 2.37 compared with 1.67 on normal pastures; the corresponding figures given by Butler (1963) in Scotland being 2.03 and 1.62. In the trial reported here four treatments had a ratio higher than 2.03; all were where the highest level of liquid manure was applied. With the high level of liquid manure alone the ratio in the mixed herbage was 2.61, decreasing to 2.32 where fertilizer nitrogen was added. With additional potash fertilizer the respective values at the high level of liquid manure were 2.64 and 2.57.

A reduced sodium content has also been found where tetany occurred in the experiments of Kemp & 't Hart (1957) and Butler (1963) and in the experiment reported here the sodium content of grass and clover was markedly reduced by applications of liquid manure. At cut 1, for example, the mean sodium content of grass where the highest level of liquid manure was applied was 0.34% but this was considerably higher at a mean of 1.32% Na where no liquid manure or potash fertilizer was applied.

Clover is usually reported to have a higher content of minerals than grass and in this experiment this was true of calcium, to a lesser extent of magnesium, but potassium was slightly higher in the grass. The small amount of clover that was in the sward in spring, although having a higher magnesium content than of grass, had little effect on the magnesium content of the mixed herbage and thus confirmed the results reported by Todd (1961). However, the high content of calcium in clover did affect the $\frac{K}{Ca + Mg}$ ratio. Thus in the herbage produced on the LM2 treatment without fertilizers and containing 13% clover, the ratio was 1.17 in the mixed herbage but 1.42 in grass alone. Where the amount of clover was small in the four high liquid manure treatments (2%) the ratios were 2.54 in the mixed herbage and 2.68 in the grass alone. Whether the reduction of the $\frac{K}{Ca + Mg}$ ratio because of the high calcium content of clover would have a significant effect on the incidence of tetany was unfortunately beyond the scope of this trial. However, it is important to record that O'Moore (1960) found the only difference in the mineral content of normal pastures and of pastures where tetany occurred was a significantly higher calcium content of the normal pastures.

Liquid manure has been quoted by 't Hart (1956) as a more important causative agent of tetany than nitrogen and potash fertilizers. In this trial the potassium in the liquid manure tended to increase the potassium in the grass and clover and to decrease the sodium and the magnesium in the grass more than did the equivalent weight of potash fertilizer. The $\frac{K}{Ca + Mg}$ ratios for grass alone (Table 49) on the treatments which supplied 166 lb K/acre were higher with liquid manure (1.42) than with fertilizer (1.22). Since in the mixed herbage, the clover contents were 12 and 4% on these respective liquid manure and fertilizer treatments, the ratio in grass alone from the liquid manure treatment decreased more than did the ratio from the fertilizer treatment, and both treatments were then similar at 1.17 and 1.15 respectively. It can be concluded from this experiment that because of the higher clover contents, the liquid manure treatments would tend to decrease the $\frac{K}{Ca + Mg}$ ratio and by inference to decrease the incidence of hypomagnesaemia more than would the equivalent fertilizer treatments. If, however, the clover content was negligible, liquid manure might be a greater predisposing factor than conventional fertilizers.

SUMMARY AND CONCLUSIONS

1) In an experiment conducted in 1961 and 1962 on a ryegrass and white clover sward a split-split plot design was used to investigate the effects of liquid manure and its interactions with various levels of nitrogen, phosphate and potash fertilizers on the yield and on the botanical and mineral composition of the herbage.

2) The liquid manure contained on average 0.28% N and 0.48% K and had an average pH of 8.5.

3) The liquid manure treatments were planned to supply 0, 50, 100, 200 and 400 lb N/acre/year and supplied in addition a mean of 0, 85, 170, 340 and 680 lb K/acre. The fertilizer nitrogen treatments were 0, 100 and 200 lb N/acre; the potash treatments were 0 and 166 lb K/acre and the phosphate treatments 0 and 66 lb P/acre.

4) All the levels of liquid manure increased the yields of herbage and crude protein, but the overall response of these yields to liquid manure was modified by the rate of application of nitrogen and potash fertilizers but rarely by phosphate.

5) Liquid manure considerably increased the yield of herbage at each level of application. Additional potash fertilizer resulted in a further increase in the yield of plots receiving the low levels of application of liquid manure but tended to decrease the yields at the high levels. Where fertilizer nitrogen was applied, liquid manure increased the yields at each level of application but the response became smaller where a total application of more than 400 lb N/acre was made.

6) The application of liquid manure alone increased the percentage and yield of clover at all except its highest level of application and this was shown to be due mainly to the potassium in the liquid manure. With the addition of fertilizer nitrogen the clover was reduced and liquid manure had less effect. Liquid manure applications alone or in combination with fertilizer nitrogen resulted in a higher clover percentage and approximately double the yield of clover in comparison with the equivalent weight of nutrients applied as nitrogen and potash fertilizers. This differential action may be related to the high pH value or to the high ammonia nitrogen content of the liquid manure.

7) The percentage of crude protein in the mixed herbage was influenced by the proportion of clover in the sward and the total amount of nitrogen applied, being highest either where the clover was at a maximum or where over 400 lb N/acre were applied, and lowest where low levels of fertilizer nitrogen depressed the clover. The yield

of crude protein was influenced more by the yield of total herbage than by its crude protein content and was increased at each increment of liquid manure.

8) The proportion of bare ground in the sward increased as the application rates of liquid manure increased. This resulted mainly from a marked reduction in the dicotyledonous weeds. Ryegrass cover also increased with increasing liquid manure rate, but when fertilizer nitrogen was applied with the highest rate of liquid manure the ryegrass cover was reduced. Clover was maintained in swards receiving liquid manure, and with an annual dressing of 400 lb N from liquid manure plus 200 lb N/acre from fertilizers for 2 years, clover contributed 14% of the ground cover.

9) The available soil potash content was increased from 7 to 47 mg/100 g after 2 years by the highest level of liquid manure but no change in the available phosphate content was recorded. An increase in the pH of the top 6 in. of soil was also noted.

10) Liquid manure supplied an excess of potassium leading to a luxury uptake of this element in the grass and clover and a consequent depression in the calcium, magnesium, sodium and phosphorus contents. Liquid manure was indicated as a more serious predisposing factor in hypomagnesaemic tetany than equivalent fertilizer dressings on grass only swards but it was suggested that the higher clover content on mixed swards receiving liquid manure may alleviate this effect.

Table 50. The botanical composition of the control plots at cut 1 from each sward

(Percentage contribution on a dry matter basis)

Constituent	Swards A	B	C	D	E	F
Ryegrass	38	75	0	97	61	34
Cocksfoot	12	0	96	0	0	22
Timothy	0	0	0	0	18	4
Clover	17	0	0	0	20	4
Unsown grass	32	19	4 (unsown grass and weeds)	3 (unsown grass and weeds)	1	35
Weeds	1	6			0	1
Year sown	1950	1959	1956	1960	1960	1940

EXPERIMENT 3

Object. To study the effect of winter applications of liquid manure on contrasting sward types and to compare the response of herbage yield with the response obtained by using conventional dry fertilizers. *

EXPERIMENTAL

General

Two similar experiments were conducted on established grass swards in each of the three winters 1959/60, 1960/61 and 1961/62. The following six different types of pasture were used:

A A general purpose ryegrass sward with clover.

B A 2-year ley of Italian and perennial ryegrass.

C A long ley of S37 cocksfoot.

D A 2-year ley of S22 Italian ryegrass.

E A long ley of perennial ryegrass, timothy and white clover.

F A permanent pasture.

Swards A and B were harvested in 1960, C and D in 1961 and E and F in 1962. These pastures were located within half-a-mile of one another at this Institute on the same soil type.

Experimental swards

The botanical composition of each sward was estimated from hand separations made on the herbage from the control plots at cut 1 in May each year, and details of these separations are given in Table 50.

The crop rotation in the various fields during the 4-year period preceding the experiment are given in Table 51, and the mean annual fertilizer dressings in the

* This experiment has been published in a shorter form by Drysdale (1963).

Table 51. Previous 4-year rotation on the experimental area

Sward	1956	1957	1958	1959	1960	1961
A	Grass	Grass	Grass	Grass		
B	Grass	Grass	Oats	Oats		
C		Grass	Grass	Grass	Grass	
D		{Kale {Fodder beet	Kale	Grass	Grass	
E			Barley	Barley	Grass	Grass
F			Permanent pasture			

Table 52. Fertilizer applications in the preceding 2-year period (lb/acre)

$N: P_2O_5: K_2O$

Sward	1958	1959	1960	1961
A	136:39:54	83:12:36	-	-
B	27:40:27	{27:40:27 {20 tons dung	-	-
C	-	106:47:67	141:47:134	-
D	-	78:81:74	141:47:0	-
E	-	-	70:67:34	0:46:136
F	-	-	0: 0:67	0:23:0

previous 2 years are shown in Table 52. Further details of the six swards used are given below.

Sward A. This sward was sown with 20 lb S23 perennial ryegrass + 2 lb S100 white clover/acre in 1950. Thereafter it received liberal fertilizer dressings and was alternately grazed and cut for silage, hay and dried grass. Volunteer cocksfoot plants together with other unsown grasses, mainly Poa spp and Agrostis spp, contributed 44% of the total herbage dry matter in the sward as shown in Table 50. Management of the sward was such that clover growth was reduced, and in May clover contributed only 17% of the total herbage dry matter. The varied composition of the sward resulted in rather uneven growth due mainly to the clumps of cocksfoot plants.

Sward B. A crop of oats grown in this field in 1958 was badly laid at harvest time. The sward was sown under a second oat crop in 1959. The grass mixture used was:

	lb/acre
Italian ryegrass (Irish)	16
Perennial ryegrass (S24)	5
Perennial ryegrass (Leafy Lurcan)	5
	26

The rate of fertilizer application was low and much of the residual fertility from the previous grass and clover sward probably was removed by the two oat crops. The resulting low fertility coupled with undersowing resulted in a rather open sward with a rough stubble remaining from the oat crop.

Sward C. This area was sown broadcast with S37 cocksfoot at 14 lb/acre in 1956 and an excellent establishment resulted. The field received liberal fertilizer dressings and was grazed and cut for silage each spring and summer. Each autumn further fertilizer applications were made to promote a good growth of grass for winter grazing during the winter months in 1958/59 and 1959/60. In autumn 1960 the area used for the experiment was fenced off and no fertilizer was applied. The area was cut over with an Allen autoscythe after being enclosed and an even sward resulted, but because of the heavy crops removed during 1960 the sward showed signs of nitrogen deficiency. The aggressiveness of cocksfoot resulted in a minimum of other species, cocksfoot contributing 96% of the herbage harvested, as shown in Table 50.

Sward D. The field in which sward D was sown had previously been used for short leys of Italian and perennial ryegrasses and root crops. This field was sheltered and situated near the farm buildings and was used generally for the first grazing in spring. To achieve this early varieties of grass and liberal manuring were used. Since an electric fence was used to maximize the use of the herbage grown, the return of excreta was particularly large in this field. Consequently an accumulation of residual fertility had occurred over a period of years. A direct reseed was made in 1960 with S22 Italian ryegrass sown at 40 lb/acre. The experimental area was fenced off from the rest of the field in autumn and the herbage cut with the Allen autoscythe. Further growth occurred after this cut because of the high inherent fertility of the field, and during the winter there was an appreciable cover of herbage on the area. As with the cocksfoot sward the strong growth inhibited weed development.

Sward E. After 2 years in barley the following mixture was sown directly in 1960:

	lb/acre
Perennial ryegrass S24	10
Timothy S48	10
White clover S100	3
	23

No fertilizer nitrogen was used during 1961 and the management aimed at securing a good clover balance. The clover growth throughout 1961 was strong and this was maintained, the clover contributing 20% of the herbage dry matter in May 1962.

Sward F. This permanent pasture was sown about 1940 and since then the field had been grazed and cut for silage, dried grass and hay. The experiment was located on an area of the field which received a basal potash and phosphate dressing annually but no nitrogen fertilizer during a long-term trial which started in 1954. As shown in Table 50 the pasture contained 35% unsown grasses (mainly *Poa* spp and *Agrostis* spp), 56% perennial ryegrass and cocksfoot but only 4% clover. This sward had a dense mat of the low-growing, fine-leaved grasses. In autumn 1961, the area was cut over with the Allen autoscythe and this cleared off much of the accumulated debris of the matted sward.

Treatments

The liquid manure treatment supplied 69 lb N/acre which was equivalent to the nitrogen in 4 cwt "Nitro-Chalk" (15.5% N)/acre. The liquid manure was applied in a single dressing at the end of November, December, January, February or March. At the same time as each monthly application of liquid manure was made conventional dry fertilizers were applied to other plots. The dry fertilizers used were "Nitro-Chalk" (15.5% N) and muriate of potash (60% K_2O), and they supplied the same quantities of nitrogen and potassium as the liquid manure application. There were thus five liquid manure treatments, five fertilizer treatments and a control in which no liquid manure or dry fertilizer was applied.

Table 53. Dates of application of liquid manure and dry fertilizers in Expt 3

Month of treatment	1959/60 Swards A and B	1960/61 Swards C and D	1961/62 Swards E and F
November	27/11	29/11	1/12
December	23/12	4/1	*
January	27/1	1/2	25/1
February	26/2	3/3	1/3
March	31/3	31/3	5/4

* no application

Table 54. Content of nitrogen and potassium (g/100 ml) in the liquid manure at each application in Expt 3

Month of treatment	1959/60		1960/61		1961/62	
	N	K	N	K	N	K
November	0.12	0.24	0.35	0.51	0.26	0.44
December	0.22	0.43	0.34	0.44	*	*
January	0.26	0.47	0.32	0.42	0.27	0.43
February	0.22	0.40	0.33	0.55	0.28	0.44
March	0.28	0.45	0.35	0.57	0.29	0.48

Table 55. Weights of liquid manure and potassium supplied by an application of 69 lb N/acre

Month of treatment	Liquid manure 100 lb/acre			Potassium lb/acre		
	1959/60	1960/61	1961/62	1959/60	1960/61	1961/62
November	581	198	266	139	101	117
December	315	203	*	136	90	*
January	266	218	256	125	92	110
February	315	210	247	126	116	108
March	247	198	240	111	113	115
Mean	345	205	252	127	102	112

* No application

The dates of application of the liquid manure and dry fertilizers in each year are shown in Table 53. On a number of occasions the application was delayed owing to weather conditions, and there were consequently small deviations between the intended and actual months of application.

The liquid manure was collected throughout the winter period and was similar to that used in the two previous experiments. The fluctuations in the composition of the monthly samples are shown in Table 54. The range was from 0.12 to 0.35% N and from 0.24 to 0.57% K. To apply 69 lb N/acre entailed different weights of liquid manure at each application and these are shown in Table 55. Although the amount of nitrogen applied was the same at all times the variation in the composition of the liquid manure resulted in a small fluctuation in the amount of potassium applied in it each month. The average applications are shown in Table 55 and were 127, 102 and 112 lb K/acre in 1959/60, 1960/61 and 1961/62. No phosphate fertilizer was applied in this experiment.

Experimental design and methods

The plan was to have a randomized block design with four replications of the eleven treatments. On sward A, however, dry fertilizers were applied only in March and there were thus only seven treatments; on swards E and F frozen ground prevented December applications and there were only nine treatments.

The plots measured 18 ft by 5 ft and an Allen autoscythe was used to harvest a sample area 18 ft long by 38 in. wide on each plot. The herbage was cut to a height of approximately 1 in. above ground level. Two cuts were taken in early summer from all the plots. Cut 1 was made when it was estimated by visual observation that the period of maximum growth had been reached, and all the plots were cut on the same day in any one year. Dates for cut 1 were 12 May 1960, 16 May 1961 and 24 May 1962. Cut 2 was made to determine any residual effects of the treatments and was harvested on 24 June 1960, 29 June 1961 and 23 July 1962. The 1962 cuts were late due to the cold spring and because a slightly longer period was needed to reach the correct stage for cutting. After cutting, the herbage from the sample strip on each plot was weighed and a random sample of 1000 g was taken. A 300 g sub-sample from each sample was dried at 100°C to determine the percentage of dry matter in the herbage. The dried sub-samples were then ground in a laboratory mill and the crude protein content was determined by the Kjeldahl method.

In addition a sub-sample of 100 g was taken from the fresh herbage sample from each control plot. These sub-samples were separated into the main component species to provide an estimate of the botanical composition of the swards. The results of this determination are shown in Table 50. On sward E differences in the clover contents of the plots were apparent at cut 2, and sub-samples from each plot were separated to determine the clover content under each treatment.

Rainfall and the temperature of the soil at a depth of 4 in. were recorded daily at 9 a.m. (Table 56).

The results for the yields of dry matter and crude protein and for the percentage of dry matter in the herbage and for crude protein in the dry matter from

Table 56. Rainfall and temperature data

Rainfall during the experimental periods (in./month)

Month	1959/1960	1960/1961	1961/1962
November	4.24	5.34	4.96
December	4.89	5.43	3.00
January	4.10	2.24	5.92
February	2.79	3.08	2.63
March	2.00	2.12	1.44
April	2.44	3.05	2.20
May	1.64	0.94	2.25
June	1.82	1.78	1.65
Total	23.92	23.98	24.05

The number of days with the soil temperature * above 42^{o} and 47^{o} F in the period 1 December to 1 April

Number of days above	1959/60	1960/61	1961/62
42^{o}	38	40	15
47^{o}	0	11	0

The date on which the soil temperature* consistently remained above 42^{o} and 47^{o} F

	1960	1961	1962
42^{o}	April 1	April 5	April 4
47^{o}	April 17	April 9	April 21

*Measured at 9.00 a.m. GMT at a depth of 4 in.

individual plots for each cut were analysed by standard methods of analysis of variance.

RESULTS

In any experiment on the effects of winter applications of liquid manure and fertilizers the influence of rainfall and soil temperature are of major importance (Iversen, 1955) since these factors control the degree of leaching and nitrification in the soil. These data are shown in Table 56. Total rainfall in the 8-month period November to June varied little from year to year being 23.92, 23.98 and 24.05 in. in 1959/60, 1960/61 and 1961/62.

In 1959/60 it was early January before the soil temperature dropped to 42°F and it remained below that fairly consistently until 1 April. After 17 April the temperature remained above 47°F. The winter of 1960/61 was colder than the previous one and the soil temperature was below 42°F at the beginning of December and remained low until February but increased quickly thereafter giving a longer potential growing period in late winter. Although the soil temperature on many days in February was over 42°F it was 5 April before it remained over this reading and 9 April before 47°F was consistently exceeded. The soil temperature was lower in 1961/62 than in the other years and growth was late in spring since the temperature did not consistently exceed 47°F until 21 April.

Mixed herbage dry matter

The yields of herbage dry matter are given in Table 57. The overall effect of treatment was significant on each sward ($P < 0.01$) but the effects of liquid manure and dry fertilizers separately, were

Table 57. Mean yields of dry matter (100 lb/acre)

Treatment	Sward A	B	C	D	E	F
	Cut 1					
Control	24.0	15.2	16.8	54.5	26.1	20.6
Liquid manure applied						
November	29.0	24.0	27.2	58.0	29.2	28.5
December	26.8	25.1	29.6	51.5	*	*
January	31.5	38.2	29.1	51.2	38.7	38.4
February	39.5	37.7	33.0	56.4	44.6	38.9
March	33.8	37.9	32.3	54.2	42.6	36.2
Dry fertilizer applied						
November	*	26.8	26.2	55.4	28.1	28.8
December	*	30.0	32.5	58.4	*	*
January	*	38.0	35.4	56.7	40.7	40.6
February	*	43.2	38.8	60.3	45.0	38.0
March	32.5	35.6	33.7	53.4	44.4	37.0
$s_{\bar{d}}$	±2.06	±3.09	±1.45	±2.20	±3.41	±1.59
Level of significance $P <$	0.001	.001	.001	.01	.001	.001
	Cut 2					
Control	13.2	10.6	7.5	20.4	12.5	29.6
Liquid manure applied						
November	13.7	11.2	8.6	22.8	11.6	23.1
December	13.8	10.8	8.2	25.0	*	*
January	14.0	9.9	7.7	28.8	10.8	24.2
February	13.2	10.6	8.4	29.5	13.4	25.4
March	13.0	9.8	9.3	26.7	13.2	22.0
Dry fertilizer applied						
November	*	11.8	8.0	23.6	14.4	21.9
December	*	11.6	8.1	33.0	*	*
January	*	10.8	8.4	27.6	11.6	31.5
February	*	11.0	7.6	29.4	11.7	31.2
March	13.9	11.0	9.2	25.5	13.2	30.6
$s_{\bar{d}}$	±1.28	±1.11	±0.48	±3.01	±1.88	±5.14
Level of significance $P <$	NS	NS	.01	.01	NS	NS

NS Not significant * Treatments ommitted

different from month to month. At cut 1 swards B, C and F showed a significant increase in yield with all the liquid manure treatments, irrespective of the date of application ($P < 0.01$). Yields from swards A and E were increased by the January, February and March applications ($P < 0.01$) but the yield from sward D was not significantly affected by applications of liquid manure. This latter sward of S22 Italian ryegrass produced a very high yield of 5450 lb dry matter/acre at cut 1 even when no liquid manure was applied.

An important aspect of the results was the effect of application in early winter. On swards B, C and F the yields of herbage from plots receiving the November dressing were respectively 58, 62 and 38% higher ($P < 0.01$) than they were from the control plots. These three swards contained no clover, whereas on sward A which contained 17% clover the yield was increased by only 21% ($P < 0.05$) from the November application, and sward E which contained 20% clover showed no statistical significant increase from this treatment. Larger increases in yield resulted from the applications made in later months. The yields from the January, February and March applications did not always differ significantly from each other, although the highest yields were obtained from the February dressings on swards A, C, E and F and from the January dressings on sward B; the yield increases being 65, 96, 71, 89 and 151% respectively.

At cut 2 which was planned to measure any residual effects of the liquid manure, only swards C and D were affected significantly. On sward C there were small yield increases from the November and March treatments. The yields from sward D were increased significantly by

Table 58. Mean yields of crude protein (100 lb/acre)

Treatment	Sward A	B	C	D	E	F
			Cut 1			
Control	3.46	1.23	1.70	5.70	3.21	2.34
Liquid manure applied						
November	3.80	1.74	2.97	6.30	3.38	3.24
December	3.80	1.83	3.16	6.20	*	*
January	4.91	3.03	2.96	6.48	4.48	4.44
February	5.78	2.92	3.56	6.84	4.64	4.59
March	5.80	3.89	3.91	7.28	4.88	4.44
Dry fertilizer applied						
November	*	1.98	2.95	6.22	3.13	3.31
December	*	2.30	3.46	7.94	*	*
January	*	3.01	3.88	7.17	4.67	4.94
February	*	3.67	4.10	7.32	4.96	4.66
March	5.81	4.34	4.55	6.88	5.16	4.65
$s_{\bar{d}}$	±0.37	±0.28	±0.20	±0.31	±0.36	±0.20
Level of significance $P <$	0.001	.001	.001	.001	.001	.001
			Cut 2			
Control	1.38	0.90	0.80	1.44	1.62	2.93
Liquid manure applied						
November	1.48	0.92	0.96	1.57	1.49	2.36
December	1.53	0.88	0.91	1.73	*	*
January	1.65	0.81	0.86	2.08	1.58	2.36
February	1.50	0.82	0.93	1.96	1.69	2.51
March	1.42	0.76	1.01	1.92	1.72	2.26
Dry fertilizer applied						
November	*	0.95	0.86	1.63	1.84	2.30
December	*	0.98	0.93	2.16	*	*
January	*	0.89	0.95	1.85	1.59	3.12
February	*	0.88	0.89	2.01	1.11	2.91
March	1.50	0.87	1.02	1.76	1.74	3.01
$s_{\bar{d}}$	±0.23	±0.10	±0.20	±0.20	±0.31	±0.49
Level of significance $P <$	NS	NS	NS	0.05	NS	NS

NS Not significant * Treatments ommitted

the January, February and March applications, whereas these treatments had no statistically significant effects at cut 1 on this sward.

The overall significant effects of the dry fertilizer on herbage yields at cut 1 were similar to those from the liquid manure but the differences between treatments were greater. On swards B, C, and F, with every monthly application of dry fertilizer, significantly higher yields were obtained than from the control plots ($P<0.01$). On sward E higher yields resulted only from the January, February and March applications and on sward D there was a response only to the February dressing ($P<0.05$). A direct comparison of the results for dry fertilizer with those for liquid manure applied in the same month showed that only on sward C in January and February ($P<0.01$) and on sward D in December ($P<0.01$) and January ($P<0.05$) did the dry fertilizers give significantly higher yields than liquid manure although there was a similar trend on the other swards at the highest levels of production.

The residual effect of the dry fertilizers at cut 2 was similar to that from the liquid manure. Sward C showed a slight effect due to the March dressing and sward D again responded to residual fertilizer nutrients from the December, January and February applications.

Mixed herbage crude protein

The yields of crude protein from the various treatments are presented in Table 58. The overall effect of liquid manure was to increase the yield of crude protein at cut 1 by highly significant amounts on all the swards ($P<0.001$). However, small differences in yield were found between the monthly applications on the different

Table 59. Mean content of dry matter in the mixed herbage (%)

Treatment	Sward A	B	C	D	E	F
	Cut 1					
Control	27.3	25.9	23.2	19.3	21.6	22.6
Liquid manure applied						
November	27.4	26.1	20.9	19.4	21.4	22.3
December	26.6	26.1	20.6	18.0	*	*
January	22.7	24.4	20.4	18.0	19.7	20.7
February	24.5	22.8	19.6	19.1	20.3	19.8
March	22.5	21.1	20.7	17.6	18.2	20.0
Dry fertilizer applied						
November	*	26.1	20.7	19.2	20.6	21.8
December	*	25.2	20.3	18.4	*	*
January	*	22.8	19.6	18.3	19.7	19.4
February	*	20.6	18.8	19.5	19.5	19.5
March	21.2	18.6	18.2	17.4	18.5	19.1
$s_{\bar{d}}$	±1.15	±1.29	±0.80	±0.85	±0.86	±0.47
Level of significance P <	0.001	.001	.001	NS	.01	.001
	Cut 2					
Control	34.8	29.7	34.1	30.4	23.0	25.8
Liquid manure applied						
November	32.4	29.3	32.4	31.4	21.7	28.1
December	34.0	29.6	31.9	29.9	*	*
January	31.2	29.8	31.4	29.9	20.0	28.4
February	31.0	30.8	31.4	30.0	22.3	27.0
March	34.1	31.4	30.6	30.2	21.1	27.2
Dry fertilizer applied						
November	*	30.2	32.0	30.2	21.0	28.7
December	*	29.0	30.6	29.3	*	*
January	*	30.0	31.4	30.3	20.4	25.6
February	*	29.8	30.7	29.5	26.2	26.0
March	32.5	30.7	31.2	29.9	22.1	25.9
$s_{\bar{d}}$	±2.05	±1.05	±1.02	±1.17	±1.38	±1.47
Level of significance P <	NS	NS	NS	NS	0.01	NS

NS Not significant   * Treatments ommitted

swards and not all were significantly higher than the control plots. Liquid manure significantly increased crude protein yields on swards C and F with all dressings ($P < 0.01$) and on swards A, B, D and E with the January, February and March applications (mostly with $P < 0.01$). The residual effects at cut 2 were very small and only the January, February and March dressings on sward D gave an increased yield of crude protein ($P < 0.05$).

Plots receiving dry fertilizers, apart from the November applications on swards D and E, gave significantly higher yields of crude protein than the untreated plots at cut 1 (mostly with $P < 0.01$). This form of fertilizer was slightly more effective than liquid manure and when compared with it, generally resulted in greater yields of crude protein on swards B, C, D, E and F, although not always significantly so.

Percentage of dry matter and of crude protein

The percentages of dry matter and of crude protein in the dry matter at each cut are shown in Tables 59 and 60.

With a few minor exceptions the liquid manure and the dry fertilizer treatments decreased the dry matter percentage of the herbage at cut 1, but in general these decreases were significant only with the late winter applications. Only on sward C was the dry matter percentage significantly decreased by the November application ($P < 0.01$). Sward D at its high level of production had the lowest average dry matter percentages and none of the differences between the plots was significant.

At cut 2 only sward E showed a statistically significant overall effect of treatment on dry matter

Table 60. Mean content of crude protein in the dry matter (%)

Treatment	Sward A	B	C	D	E	F
			Cut 1			
Control	14.3	8.3	10.2	10.4	12.4	11.3
Liquid manure applied						
November	13.1	7.3	10.9	10.9	11.7	11.4
December	14.2	7.4	10.6	12.1	*	*
January	15.6	8.0	10.2	12.7	11.7	11.6
February	14.6	7.8	10.8	12.1	10.4	11.8
March	17.2	10.3	12.1	13.4	11.5	12.2
Dry fertilizer applied						
November	*	7.4	11.2	11.2	11.1	11.5
December	*	7.7	10.6	13.6	*	*
January	*	7.9	11.0	12.6	11.5	12.2
February	*	8.5	10.6	12.2	11.0	12.3
March	17.9	12.2	13.5	12.9	11.6	12.6
$s_{\bar{d}}$	±0.72	±0.62	±0.39	±0.60	±0.92	±0.42
Level of significance $P <$	0.001	.001	.001	.001	NS	.05
			Cut 2			
Control	10.4	8.4	10.6	7.1	12.9	10.0
Liquid manure applied						
November	10.5	8.2	11.1	6.9	12.7	10.1
December	11.0	8.0	11.1	6.9	*	*
January	11.7	8.2	11.1	7.2	14.6	9.7
February	11.3	7.8	11.2	6.7	12.7	9.8
March	10.9	7.7	10.8	7.2	13.5	10.3
Dry fertilizer applied						
November	*	8.1	10.8	6.9	13.0	10.6
December	*	8.3	11.5	6.6	*	*
January	*	8.1	11.4	6.8	13.4	9.9
February	*	7.8	11.8	6.8	9.4	9.4
March	10.6	7.9	11.1	6.9	12.8	9.9
$s_{\bar{d}}$	±0.88	±0.32	±0.22	±0.26	±1.05	±0.33
Level of significance $P <$	NS	NS	.01	NS	.01	NS

NS Not significant *Treatments ommitted

percentage ($P<0.01$). Here there was an increase in the dry matter percentage compared with the control plots where fertilizers were applied in February ($P<0.05$) whereas all the other liquid manure and fertilizer treatments caused a decrease although this was significant only where liquid manure was applied in January ($P<0.05$). These changes at cut 2 were related to changes in the clover content of the sward.

A highly significant increase in crude protein percentage (Table 60) resulted at cut 1 from the March dressing of both liquid manure and dry fertilizers on swards A, B, C and D, the increase being from an average of 10.8% on the control plots to an average of 13.7% crude protein. Sward D differed from swards A, B and C in that the December, January and February liquid manure and dry fertilizer treatments also gave a higher crude protein content than the control treatment. On sward E, with a high clover content, a reduction in the crude protein content occurred with all the treatments.

At cut 2, the main effects of the treatments were a slight increase in crude protein percentage with dry fertilizer applied in the late winter months on sward C, and a marked reduction in crude protein content with the February dressing of dry fertilizer on sward E.

Recovery of nitrogen

The yield of N/acre from the control plots was deducted from the yield of N/acre from the treated plots and the increase in the yield of N/acre so obtained for each treatment was divided by the amount of N/acre applied, and in this way a figure for the percentage recovery of nitrogen was obtained. These recovery figures, shown in Table 61, were calculated for cut 1 and

Table 61. Recovery of nitrogen in the herbage as a percentage of the nitrogen applied in the liquid manure and fertilizers

Treatment	Sward					
	A	B	C	D	E	F
			Cut 1			
Liquid manure applied						
November	7.7	11.6	29.1	13.8	3.9	20.8
December	7.8	13.9	33.8	11.6	*	*
January	33.5	41.6	29.0	17.9	29.3	48.6
February	53.6	39.0	42.8	26.1	32.9	52.0
March	54.0	61.4	50.8	36.3	38.3	48.2
Mean for all months	31.3	33.5	37.1	21.1	26.1	42.4
		Mean for liquid manure 32.0				
Dry fertilizer applied						
November	*	17.3	28.8	12.0	-1.9	22.5
December	*	24.6	40.6	51.6	*	*
January	*	41.1	50.3	33.9	33.6	59.9
February	*	56.2	55.3	37.3	40.3	53.6
March	54.2	71.6	65.7	27.2	45.0	53.3
Mean for all months	*	42.2	48.1	32.4	29.2	47.3
		Mean for dry fertilizer 39.8				
			Cuts 1 and 2			
Liquid manure applied						
November	10.2	12.2	32.8	16.8	0.9	7.6
December	11.4	13.4	36.3	18.4	*	*
January	39.9	39.4	30.3	32.7	28.5	35.4
February	56.5	37.1	45.6	38.2	34.7	42.3
March	55.0	58.2	55.5	47.3	40.6	32.8
Mean for all months	34.6	32.1	40.1	30.7	26.2	29.5
		Mean for liquid manure 31.7				
Dry fertilizer applied						
November	*	18.4	30.2	16.4	3.2	7.9
December	*	26.5	43.5	68.3	*	*
January	*	40.8	53.7	43.4	33.0	64.4
February	*	55.8	57.3	50.6	28.5	53.0
March	57.1	71.0	70.7	34.6	47.7	55.2
Mean for all months	*	42.5	51.1	42.7	28.1	45.1
		Mean for dry fertilizer 41.9				

*Treatments ommitted

should account for most of the nitrogen recovered. They were calculated also for the total of cuts 1 and 2 which should show the overall effect including any residual effect at cut 2.

The recovery of nitrogen from the liquid manure treatments measured at cut 1 generally increased from the November to the March application over all the swards although within each sward the range of values varied. For example, the nitrogen recovery on sward B rose from 12% for the November treatment to 61% for the March treatment although on sward D the increase was only from 14 to 36%. The average value for all the liquid manure plots within one sward type was lowest on sward D at 21% and highest on sward F at 42% with an overall nitrogen recovery from the six swards of 32%. This latter figure is the same as the overall value calculated for the total of cuts 1 and 2. However, although this average value suggests no residual effect at cut 2, liquid manure treatments which at cut 1 on sward D had the lowest recovery (21%), had a residual effect at cut 2 on that sward which increased the recovery to a total of 31% from both cuts. Sward F had the highest recovery at cut 1 of 42% but this was reduced after cuts 1 and 2 to 30% because of the relatively higher recovery of nitrogen from the control plots than from the treated plots at cut 2.

The recovery of nitrogen from the plots receiving the dry fertilizer at cut 1 showed the same pattern from November to March as that from the plots receiving liquid manure but the overall recovery from the five swards was 40% compared with 32% from the plots treated with liquid manure. The efficiency of recovery of nitrogen

Table 62. Dry matter response expressed as lb dry matter/ lb N applied

Treatment	Sward A	B	C	D	E	F
	Cut 1					
Liquid manure applied						
November	7.2	12.6	14.9	5.0	4.5	11.4
December	4.0	14.3	18.5	-4.3	*	*
January	10.8	33.2	17.6	-4.7	18.2	25.7
February	22.4	32.5	23.2	2.7	26.7	26.4
March	14.2	32.8	22.2	-0.4	23.7	22.4
Mean for all months	11.7	25.1	19.3	-0.3	18.3	21.5
	Mean for liquid manure 16.7					
Dry fertilizer applied						
November	*	16.7	13.5	1.3	2.9	11.8
December	*	21.3	22.6	5.6	*	*
January	*	32.8	26.8	3.2	21.0	28.8
February	*	40.3	31.7	8.4	27.2	25.1
March	12.2	29.4	24.4	-1.6	26.4	23.6
Mean for all months	*	28.1	23.8	3.4	19.4	22.3
	Mean for dry fertilizer 19.4					
	Cuts 1 and 2					
Liquid manure applied						
November	7.9	13.5	16.5	8.5	3.2	2.0
December	4.9	14.6	19.5	2.3	*	*
January	12.0	32.2	17.9	7.3	15.8	17.9
February	22.4	32.5	24.5	15.8	28.0	20.4
March	13.9	31.6	24.8	8.6	24.7	11.5
Mean for all months	12.2	24.9	20.6	8.5	17.9	13.0
	Mean for liquid manure 17.0					
Dry fertilizer applied						
November	*	18.4	14.3	5.9	5.6	0.7
December	*	22.8	23.5	23.8	*	*
January	*	33.1	28.1	13.5	19.7	31.6
February	*	40.9	31.8	21.3	26.1	27.4
March	13.2	30.0	26.8	5.8	27.4	25.1
Mean for all months	*	29.0	24.9	14.1	19.7	21.2
	Mean for dry fertilizer 21.8					

* Treatments ommitted

applied as dry fertilizer on sward E was lower than on the other swards and this was possibly related to a higher content of clover and its depression by the fertilizer on this sward.

The total of cuts 1 and 2 when compared with cut 1 showed a small mean residual effect resulting from the dry fertilizers, the recovery of nitrogen being 42% compared with 40% from cut 1. This higher value was due largely to sward D which showed a substantial response to dry fertilizers at cut 2, as shown by the difference between cut 1 and the total of cuts 1 and 2. In contrast sward E showed a much lower recovery from the February application of dry fertilizer at cut 2 compared with cut 1. This was due to a depression in clover content at cut 2 and was not observed with the application of liquid manure in February.

Dry matter response

The dry matter responses in terms of lb dry matter/ lb N applied are shown for cut 1 and the total of cuts 1 and 2 in Table 62. Apart from sward D, the response to all the dressings of liquid manure was high at cut 1 and the maximum effect generally resulted from the February dressing. On swards A and E which contained clover the response tended to be lower than that on swards B, C, and F. The response to dry fertilizer at cut 1 was slightly greater than that to liquid manure but the overall mean difference between them was only 2.7 lb dry matter/lb N applied. This increased effect of dry fertilizer tended to be lower on swards E and F than on swards B and C.

The difference between the overall mean for cut 1 and the mean for cuts 1 and 2 showed that on average the

Table 63. <u>Mean percentage clover dry matter in Sward E at cut 2</u>

Treatment	Mean percentage clover	Mean angular transformation
Control	33.6	34.8
Liquid manure applied		
November	33.3	35.2
January	42.5	40.7
February	31.4	33.7
March	33.8	35.4
Dry fertilizer applied		
November	35.7	36.6
January	34.3	35.6
February	15.0	22.1
March	29.4	32.5
$s_{\bar{d}}$	-	± 4.58
Level of significance	-	$P < 0.05$

liquid manure had no residual value at cut 2 but that the dry fertilizer had a small positive carry-over effect. However on Sward D the carry-over effects of liquid manure and dry fertilizer were marked. For example, at cut 1 on this sward the control treatment yielded higher than the treatments which received liquid manure, and the mean response was -0.3 lb dry matter/lb N applied. At the total of cuts 1 and 2 the mean response was increased to 8.5 lb dry matter. In contrast at cut 1 on sward F the mean response to liquid manure was 22 lb dry matter/lb N applied whereas with the total of cuts 1 and 2 the mean response was 13 lb dry matter. This was because of higher yields from the control than from the treated plots at cut 2. The mean responses for liquid manure and fertilizers were similar to the responses described by Holmes & MacLusky (1955) from trials made in summer with relatively heavy dressings of fertilizer nitrogen.

Botanical composition of the sward

The mean percentage clover dry matter in sward E at cut 2 together with the angular transformations are shown in Table 63. The error variance was large owing to variations between plots and only the extreme effects of treatment proved significant ($P<0.05$). There was a marked reduction in the percentage of clover compared with the control plots where dry fertilizers had been applied in February ($P<0.05$). Plots receiving this treatment contained 15% clover compared with 31% for plots on the corresponding liquid manure treatment. There was 34% clover on the plots on which dry fertilizers had been applied in January compared with 42% on the equivalent liquid manure treatments but this difference was not quite statistically significant. The high clover content on plots which received liquid manure in January, resulted in a significantly lower dry matter percentage whereas the low clover content resulting from the dry fertilizers applied in February caused a significant increase in the dry matter percentage but a decrease in the crude protein percentage. No other swards contained sufficient clover to show any differential effects of liquid manure or dry fertilizer.

DISCUSSION

The results show that liquid manure applications made during the winter months, even as early as November, can give substantial increases in the yield of herbage and crude protein on a wide variety of swards and with only slightly less efficiency than conventional fertilizers. There was also an indication that applications of liquid manure maintained clover in the sward whereas fertilizer containing inorganic nitrogen reduced it; a result discussed earlier in Expts 1 and 2 where the applications of liquid manure were made in summer.

In a study of the "degree of earliness" of pasture in spring, Blackman (1936) showed that this was governed by such factors as the number of days with soil temperature in the 42 - 47^{o}F range, the botanical composition, nitrogen fertilizing and previous grazing or cutting treatments. Here the term "degree of response" is used to describe the effect of liquid manure as influenced by these factors. Thus on sward D with S22 Italian ryegrass under excellent fertility conditions and with soil temperatures above 47^{o}F for 11 days during the winter period together with a quick rise in the spring, growth started early and the herbage was luxurious. Neither liquid manure nor dry fertilizers increased the yields of dry matter from this sward and consequently the "degree of response" was low. In contrast, the mixture of Italian and perennial ryegrasses in sward B which was undersown in poorer conditions and experienced a cold winter had a high "degree of response" to liquid manure. Swards C and F also showed a high "degree of response" because of the presence of later growing grasses and because of the poorer fertility conditions.

Pastures with an appreciable clover content such as swards A and E gave proportionately higher yields on the control plots because of the benefit of mixed grass and clover and consequently the difference between the control and the treated plots tended to be smaller and the "degree of response" lower than on the other swards.

From these results it can be concluded that the "degree of response" to winter applications of liquid manure is inversely related to the "degree of earliness" of the sward.

Although the different swards showed varying "degrees of response" most of them gave their highest yields from the February dressing of liquid manure with the January and March applications yielding slightly less. The response to dressings of liquid manure in winter has been described by Rheinwald (1934) who found that December and February applications supplying 90 lb N/acre gave increases at a first cut of hay of 38 and 44% respectively. Hendrick (1915) applying 40 lb N/acre found yield increases of 20 and 29% from applications made in January and late February. These increases were lower than those obtained in the present experiment where the five swards which responded to liquid manure applications gave 33 and 89% higher yields with the December and February applications than the control plots. Rheinwald (1934) and Hendrick (1915) discussed the high responses to liquid manure and concluded that the breakdown of the urea in urine resulted in the formation of ammonia which would be fixed in the soil under winter conditions. Similarly Volk (1961) has shown that when urea is converted to ammonia it is readily absorbed by the base exchange complex of the soil and the leaching loss is relatively low. This fixed ammonia is nitrified and becomes available in the spring when plant growth starts thus explaining the high efficiency of winter applications of liquid manure. It also explains why the response of herbage yield to nitrogen applied during the winter was comparable with that obtained from summer applications. In summer, nitrate production is rapid (Doak, 1952; Rheinwald, 1934) but the soil is subject to leaching and most of the nitrogen lost from British soils is due to this leaching of nitrate (Russell, 1952). The average dry matter response of herbage yields to liquid manure applied in January was 21 lb dry matter/lb N applied which agrees exactly with the response to summer applications of "Nitro-Chalk" obtained by Holmes & MacLusky (1955) on a large number of swards.

The similarity in the rainfall of each year of the experiment minimized the differences due to leaching. Iversen (1955) has shown that leaching can affect the result of liquid manure application considerably, spring applications producing the largest and autumn applications the smallest increases in yield in a wet area. Winter applications occupied an intermediate position in the wet area whereas in a drier area they gave the largest yield. Iversen (1955) also showed that leaching losses were greater with nitrate nitrogen in fertilizer than with the ammonia nitrogen in liquid manure, since ammonia nitrogen is fixed in the soil as described previously and not leached as is much of the nitrate fraction. Under the conditions of this trial, rainfall was not heavy and the date of application of liquid manure would be therefore less crucial than in a wetter area.

The excellent responses to winter applications of liquid manure are further emphasized by the January dressing, where the recovery of applied nitrogen varied from 29 to 49% over all the swards except sward D. Walker (1956) has suggested that a 60% recovery means that there is in fact almost a complete recovery since the root system contains nitrogen as well as the part of the plant that is harvested.

The high efficiency of the utilization of urine nitrogen was shown by the large response at the first cut and its similarity with the total response calculated from cuts 1 and 2. This liquid manure, consisting of cow urine diluted with water, is known to be used with a higher efficiency than dung nitrogen (Gisiger, 1950). The responses to liquid manure quoted in this experiment will therefore be higher than they would have been if the same amount of nitrogen had been applied as a slurry containing dung and urine. In addition to this difference, the efficiency of liquid manure applied during the winter may also be reduced where dung or straw is added because of the high organic matter content of these and an associated decrease in the availability of the nitrogen in the urine (Gisiger, 1950). Schuppli (1934) has suggested that urine collected during the winter should be kept separate from solid material and have water added to it to reduce the loss of nitrogen. Practical considerations will determine the type of collecting system to be used, but where it is possible to keep dung and urine separate a more efficient use can be made of the nitrogen in urine and results comparable with those observed with inorganic nitrogen can be obtained.

SUMMARY AND CONCLUSIONS

1) The effect of applications of liquid manure during the winter months was studied and compared with the application of conventional dry fertilizers on six different types of sward in two experiments in each of the years 1960, 1961 and 1962.

2) The liquid manure contained on average 0.28% N and 0.45% K and had an average pH of 8.6.

3) The liquid manure supplied an average of 69 lb N and 114 lb K/acre at each application and plots received one dressing only, applied in November, December, January, February or March. Further treatments consisted of applying conventional dry fertilizers supplying the same weight of nitrogen and potassium as the liquid manure and applied on the same day. A control plot received no added fertilizer or liquid manure.

4) All plots were cut in May and a second cut was made 8-10 weeks later to measure the residual effects of the treatments.

5) The maximum increases in dry matter yields at cut 1 generally occurred with the February application

although the January and March applications gave only slightly lower yields. The dry matter yield/lb N applied even from the November treatment on some swards was comparable with the response obtained from applications of fertilizer nitrogen made in summer in earlier experiments by other workers.

6) The production of crude protein followed a similar pattern to that of the dry matter, and the maximum increase was from the March application.

7) With similar rainfall conditions but different winter soil temperatures, a mixture of Italian and perennial ryegrasses growing in conditions of average fertility gave the highest response to liquid manure, followed by the later growing cocksfoot sward and the permanent pasture, on both of which yields were increased by all the monthly applications of liquid manure. The two swards containing grass and clover mixtures showed a response to the later dressings only, whereas the vigorous Italian ryegrass sward grew so well in the mild winter of 1961 that it did not respond to treatment.

8) Conventional dry fertilizers produced slightly higher yields of dry matter and crude protein than did liquid manure and the overall recovery of applied nitrogen in the herbage was greater. However, the difference in herbage yield between the dry fertilizer and the liquid manure treatments was statistically significant only on the cocksfoot sward from the January and February dressings and on the Italian ryegrass sward from the December and January dressings.

9) The residual value of liquid manure at the second cut was negligible compared with a slight positive carry-over effect from the dry fertilizer although the difference was too small to be of statistical significance.

GENERAL DISCUSSION AND CONCLUSIONS

The excreta of livestock is the most common type of organic manure used in farming. However, despite the much higher response in crop yield obtained with urine compared with dung, the anomalous situation exists in Britain that virtually all the dung produced is returned to the land whereas the urine produced during winter runs to waste. This waste of urine constitutes an important loss of plant nutrients but in addition causes a pollution problem in the national water courses. Legislation was introduced in 1961 to prevent such pollution, and the logical solution is the return of the urine to the land.

The three experiments which have been reported here were designed to investigate different agronomic aspects of the fertilizer value of urine when diluted and used as a liquid manure on grassland. In this section the main results are collated and an evaluation of liquid manure is made.

Many of the contradictions among the results from other trials in which the effect of urine on pasture was studied have been explained by these three experiments. Although the results presented are strictly applicable to one specific soil type only, many of the observations are fundamental and generally applicable.

In each experiment the yield of herbage from plots treated with liquid manure was similar to the yield from other plots which received normal commercial fertilizers supplying the equivalent or almost the equivalent level of plant nutrients. For example, in Expt 1 yields of 8100 and 8720 lb dry matter/acre were obtained from areas treated with the low and high rates of liquid manure and were comparable to the yields of 7930 and 9190 lb/acre from plots dressed with the low and high rates of dry fertilizer. In Expt 2, where more precise comparisons were possible, it was shown that liquid manure which supplied 100 lb N and a mean of 170 lb K/acre resulted in a yield of 9140 compared with 9320 lb dry matter/acre where the same weight of nutrients was supplied in dry fertilizers. In the same experiment when liquid manure and fertilizers were applied together, 200 lb N from liquid manure plus 100 lb N/acre from fertilizer resulted in a yield of 11610 lb compared with 11780 lb dry matter/acre from 100 lb N from liquid manure plus 200 lb N/acre from fertilizer; a mean of 338 lb K/acre being applied on each treatment. Furthermore, when winter applications were made in Expt 3, different grass swards gave much the same yield when treated with liquid manure as when they received dry fertilizers containing equivalent levels of plant nutrients, irrespective of the time of application.

The similarity of the responses in these experiments is unexpected for a number of reasons. First, high losses of nitrogen by evaporation are expected where ammonia or related products are applied to grassland. Volk (1961), for example, showed that the loss of ammonia where urea was applied on the soil surface was as high as 41% whereas with ammonium nitrate it was only 4%. Second, it is generally quoted that "animal nitrogen" is less efficient than "fertilizer nitrogen", although such reports have generally originated from grazing or simulated urine return studies or from experiments in which a slurry of dung and urine was applied. Third, leaching might be expected to cause a greater decrease in the effect of a liquid than of a granular fertilizer in summer and winter.

Fourth, many studies of the composition of urine have indicated the presence of substances with toxic effects on grassland.

It is evident, however, that none of the above observations is wholly applicable to the form of liquid manure used here. The urine was diluted by three or four times its weight of water, and this would reduce the loss of ammonia by evaporation and assist in its uptake by the soil; a different situation from that described by Volk. In summer, where five applications of liquid manure were made, there would be a more or less continuous balance between the fixed non-leachable ammonia nitrogen and the nitrate nitrogen in the soil which would provide a ready supply of available nitrogen for the grass. In winter the fixed ammonia nitrogen would be less affected by leaching than nitrate nitrogen. By diluting urine toxic effects are minimized and in fact some substances may become stimulatory (Voigtländer, 1952; Doak, 1954).

Substances in liquid manure to which its effect on pasture could be attributed include water, nitrogen, potassium, phosphorus and other constituents. In Expt 1 it was shown that the quantity of water applied in the liquid manure, apart from its usefulness in diluting the urine, did not affect the yield of the herbage. Larger amounts of water were applied in Expt 2, and the water content of the highest level of liquid manure was equivalent to 14000 gallons/acre. Since an irrigation experiment on a similar sward at this Institute indicated that in 1961 and 1962 this volume of water would be expected to increase the yield by only 60 lb dry matter/acre (Reid, 1963), it can be concluded that the amount of water in the liquid manure had a negligible effect on the yield of herbage.

Although liquid manure has a very low phosphorus content, the addition of phosphate fertilizer with liquid manure in Expt 1 had no effect on herbage yield. In Expt 2 phosphate occasionally caused significant increases in yield, but these increases were small relative to the quantity of phosphate fertilizer applied.

As stated previously, in each experiment the nitrogen in the liquid manure and that in the dry fertilizer affected yields similarly. However, one reason suggested for the higher clover content after liquid manure applications than after fertilizer applications was the higher ammonia nitrogen content of the liquid manure.

The large response in yield which can be caused by the potassium in liquid manure was shown clearly in Expt 2. The potassium content of the soil was low, and the grass and clover from untreated plots contained 0.98 and 0.63% K respectively compared with optimum levels of 1.8 and 1.6% K quoted by McNaught (1958). Signs of potassium deficiency were in fact observed. In this work applications of liquid manure alone caused an extremely large increase in the yield of grass and an appreciable increase in the yield of clover. For example, in 1962 the highest level of liquid manure resulted in a mean yield of 10930 lb herbage dry matter/acre compared with 4060 lb where no liquid manure was applied; the respective clover dry matter yields being 1150 and 380 lb/acre. Plots which received no liquid manure but had a dressing of potash fertilizer yielded 7480 lb dry matter and 3080 lb clover dry matter/acre. Although the response to liquid manure was attributable in the main to its nitrogen and potassium content, its high pH was suggested as a possible reason for the different effects of liquid manure and fertilizer on the percentage and yield of clover.

Averaged over all treatments, the herbage dry matter in Expt 2 had a ratio of nitrogen to potassium of 1:0.9 in 1962. Even where the highest level of liquid manure was applied and the herbage contained well over 3% K this ratio was only slightly different at 1:1.1. Liquid manure contained nitrogen and potassium in a ratio of 1:1.7 and therefore supplied potassium in a quantity well above that required for normal growth. Since this ratio cannot be adjusted where liquid manure is applied alone, continual applications will result in the accumulation of some potassium in the soil. After applying 400 lb N and a mean of 677 lb K/acre as liquid manure for 2 years the soil potassium content was 47 mg compared with 8 mg on the untreated plots. Such application rates averaging 14000 gallons of liquid manure/acre are becoming more common in practice, and similar accumulations of potassium in the soil also might occur if smaller quantities of liquid manure were applied over many years. The application of fertilizer nitrogen with liquid manure to give a better balance of nitrogen to potassium has been proposed by Schiller (1955) and others but in Expt 2 even where fertilizer nitrogen was used in addition, the soil potassium content at the highest level of liquid manure was only slightly lower, 42 mg compared with 47 mg. The increase in soil potassium that may occur is apparently one of the main disadvantages that may arise from the use of liquid manure as a fertilizer. Where liquid manure was applied the herbage contained between 3 and 4% K in the dry matter with a concomitant decrease in the sodium, magnesium, calcium and phosphorus contents. This effect tended to be more severe with liquid manure than it was when nitrogen and potassium were applied in the form of conventional fertilizers. The resulting mineral imbalance has been associated in other experiments with an increased incidence of hypomagnesaemic tetany in dairy cows. To combat a tendency towards a high incidence of the disease in spring, it has recently been recommended that potash fertilizer should be applied in summer rather than in early spring (O'Moore, 1960; Wolton, 1961). The apparent correlation between the incidence of tetany and the potassium content of herbage has possibly influenced the use of potash fertilizers. Whereas sales of nitrogen and phosphate fertilizers increased by 16 and 11% respectively in 1961/62, potash sales increased by only 0.4% (1962 Fertilizer Statistics, 1963). Because of storage difficulties liquid manure is applied in winter or early spring and therefore supplies potassium just before the highest incidence of tetany is expected. No mineral analyses of the herbage were made in Expt 3 in which liquid manure was applied in winter, but the results from Expt 2 indicate the potential danger. In Expt 2 fertilizer nitrogen slightly reduced the potassium content of grass but also reduced the calcium content of the mixed herbage where clover was originally present. If the ratio $\frac{K}{Ca + Mg}$ (using milli-equivalents) is taken as an indication of the tendency of a pasture to cause tetany, it could be inferred that the higher the clover content and hence the higher the calcium content in the sward receiving liquid manure, the lower is the chance of tetany.

The principal conclusions which can be drawn from the results of the experiments described in this thesis can be summarized as follows:-

(1) The value of liquid manure as a fertilizer depended mainly on its content of nitrogen and potassium.

(2) Compared with conventional fertilizers supplying equivalent weights of nitrogen and potassium, liquid manure resulted in similar increases in herbage yield but greater increases in the yield of clover and in the percentage of clover in the sward.

(3) Applications of liquid manure increased the potassium content of the soil and of the herbage and decreased the sodium, magnesium, calcium and phosphorus contents of both grass and clover.

(4) It can be concluded that liquid manure is an important source of plant nutrients with considerable value as a fertilizer for grassland.

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APPENDIX

Table 1. Rainfall (in./month) in 1958 - 62

Month	Mean 1931-55	1958	1959	1960	1961	1962
January	3.77	3.72	1.52	4.10	2.24	5.92
February	2.41	3.38	1.70	2.79	3.08	2.63
March	2.11	0.72	2.02	2.00	2.12	1.44
April	2.08	1.18	2.04	2.44	3.05	2.20
May	2.10	2.68	1.44	1.64	0.94	2.25
June	2.54	2.84	3.66	1.82	1.78	1.65
July	3.36	4.72	4.58	3.03	3.18	3.24
August	3.08	4.60	0.69	3.78	5.47	6.13
September	3.64	3.98	1.51	3.09	6.57	7.46
October	4.09	3.68	5.60	2.61	6.24	1.56
November	3.63	1.53	4.24	5.34	4.96	1.92
December	3.79	3.74	4.89	5.43	3.00	4.04
Total	36.60	36.77	33.89	38.07	42.63	40.44