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PLANT NUTRIENT AND ECONOMIC VALUE OF ANIMAL MANURES^{1,2}

S. R. Wilkinson³

SUMMARY

Animal manures have economic value as plant nutrient sources and as amendments for soils whose physical properties can be improved by adding organic matter. Their value as fertilizer per metric ton applied is generally inverse to their water and carbon contents. Plant nutrient concentrations in animal manures are highly variable, thereby introducing uncertainty into meeting plant nutrient needs for crop production. Where manure has been applied for several years, however, little or no additional fertilizer phosphorus (P) and potassium (K) are needed for crop production. Animal manures were ranked in decreasing order as to replacement fertilizer value (dollars) as follows: broiler litter; hen litter; hen droppings; beef feedlot, swine and dairy solid manures; poultry slurry; and other classes of livestock manure slurries. Storage conditions and degree of dilution mainly determine the fertilizer value of liquid manure. Liquid manures have little potential economic value as fertilizer outside the farm where produced. Relative efficiencies of manure nitrogen (N) as compared to commercial fertilizer N range from less than 30% to greater than 100%. Manure N applications that are immediately incorporated have produced yields equal to those produced by fertilizer N for many different crops. The representative plant nutrient contents selected from the literature suggest that replacement fertilizer value can exceed waste management costs, thus changing manure from a waste to a resource.

(Key Words: Animal Manures, Nitrogen,

Phosphorus, Potassium, Fertilizer Use Efficiency, Economic Value of Manure.)

INTRODUCTION

In 1975, farmers spent more for fertilizers and lime than for hired labor (Hargett, 1977 and figure 1). The price of ammonia (NH₃) increased approximately 2.5 fold from 1973 to 1975; labor costs have also risen rapidly. This trend in expenditures suggests that we should reexamine our management practices, including a reevaluation of plant nutrient use efficiency and increased efforts to use plant nutrients in animal manures. The CAST report (1973) indicates that the largest single energy input for corn production is the production and application of the N fertilizer. Nitrogen fertilizer production consumes approximately 87% of the total energy used to produce the primary plant nutrients; 5% is used for P production, and 8% for K. Increasing prices of natural gas and fossil fuels likely will continue to increase price and decrease availability of nitrogen and other fertilizers.

Prior (1975) estimated that the maximum percentages of total animal waste generated by all animals in confinement were 44.8 for beef cattle, 33.4 for dairy cows, 11.5 for swine and 9.7% for chickens. Based on 1974 estimates, this amounts to 167.8, 127, 43.5 and 36.3 million metric tons of waste produced annually in confinement for beef, dairy, swine and poultry, respectively. These wastes correspond to 1,352, 1,393 and 1,844 thousand tons of N, P₂O₅ and K₂O, considered recoverable annually. These figures are based on the assumption that 50% of N and 90% of P and K in animal wastes are recoverable. These amounts of estimated recoverable primary plant nutrients are approximately equal to 16% of the total N fertilizer sold in 1974, and 30 and 40% of the P₂O₅ and K₂O sold in 1974, respectively. Expressed in such terms, the plant nutrients in wastes from animals raised in confinement can be important in meeting food and fiber production goals. Prior (1975) estimates that one-half to two-thirds of this waste is already being returned to the land.

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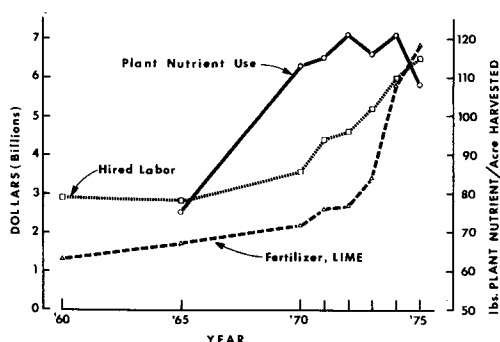


Figure 1. A comparison of farm expenditures for fertilizers, lime, and labor, and plant nutrient use per acre harvested (Hargett, 1977).

Lauer (1975) calculated that if all the potentially available manure (manure produced in confinement) were spread on cropland, about 42% of the N, 29% of the P, and 57% of the K in fertilizer could be replaced by manure. These were considered maximum potentials and neither distribution losses nor management problems by the individual farmer in effectively utilizing the plant nutrients in manure were considered.

In this report, I will:

1. Review the form and availability of primary plant nutrients in animal manures.
2. Illustrate representative total plant nutrient contents for animal manures.
3. Illustrate their fertilizer value in relation to that of commercial fertilizers for corn, grain sorghum, small grains, grasslands, and vegetable production.
4. Show that animal manures are valuable as soil amendments and discuss various considerations in the use of animal manures in crop production.
5. Give examples of relative economic value in terms of fertilizer replacement value and in terms of crop return.

ANIMAL MANURES AS PLANT NUTRIENT CARRIER

Manure as a fertilizer has several characteristics that must be recognized and accepted if it is to be successfully used in crop production:

- a) Manure varies widely in water and plant nutrient content.
- b) Manure generally has a low plant nutrient content as compared to commercial fertilizers.
- c) Manure contains a high percentage of carbon, which may be food for small animals

and microorganisms in the soil. (It also may be a source of food for other nonsoil animals as is discussed elsewhere).

d) Because of the high water and carbon contents and their consequent bulk, costs for handling and spreading per unit of plant nutrients applied are higher for manures than for commercial fertilizers.

FORM AND AVAILABILITY OF PLANT NUTRIENTS

The proportion of total N excreted by sheep and cattle in the urine increases as dietary N increases (Henzell and Ross, 1973). Although, the N content in feces increases with increasing N concentration in the feed, the two are not closely related. Mason (1969) reported that 45 to 65% of the total N excreted in feces was alpha-amino-N. The chief nitrogenous constituent of urine in sheep and cattle on high protein diets is usually urea, with some ammonia, allantoin, creatinine and creatine (Church, 1969). Much of the N excreted in feces requires mineralization before it becomes available for crop growth. In contrast, up to 61% of the nitrogen excreted by poultry is uric acid, which is readily converted to urea and NH_4 salts (White *et al.*, 1944).

Nitrogen in urine and uric acid is readily available since much of it is already in inorganic, highly soluble form. Losses of N through volatilization are large when urine additions to soil are allowed to evaporate (Stewart, 1970). Such N losses from manure are greatly reduced if evaporation is slow, and the manure N is incorporated into the soil. Ammonium and urea forms of N are about as available for plant uptake as is the N in inorganic fertilizers, whereas in old cattle wastes more than half of the N may exist in slowly mineralizable organic forms.

Manure storage may also affect the form of N present. Manure storage usually takes one of three basic forms: Storage in piles, aerobic liquid treatment, and anaerobic liquid treatment. There are N losses under all systems. In a laboratory study (Hensler *et al.*, 1970), reported N losses for fermented, piled steer manure were 27%; for anaerobic liquid, 32%; and for aerobic liquid, 30%. During aerobic digestion, N loss occurs partly as volatilized NH_3 ; and, if organic carbon substrate is available, considerable N can be denitrified (Chang *et al.*, 1971). Hensler *et al.* (1970) reported nutrient recoveries were lowest from aerobic liquid cow manure. Storage

stabilized manure N forms. However, crop response is generally good from fermented and anaerobic liquid forms.

Phosphorus is usually contained in the feces of ruminant animals. Barrow and Lambourne (1962) indicated that about .06 g organic P is excreted per 100 g of feed eaten; the remainder is excreted as inorganic P. Generally, only trace amounts of P are excreted in the urine. The higher the P content of feed the higher the inorganic P content of the feces. Gerritse and Zugec (1977) found that pig slurry contains 1 to 2% P of dry matter of which 10 to 30% was in organic molecules and 2 to 3% in microorganisms. About 10 to 20% of the organic P was in solution. The amount of inorganic P in solution was 10 to 100 mg/l at low Ca/P ratios in the feed. Gerritse and Zugec (1977) concluded that all organic phosphates in pig slurry are of microbial origin and that feed composition had little influence on the organic P of the slurry. The inorganic phosphate in sheep feces is probably present as calcium hydrogen phosphate ($\text{Ca}(\text{HPO})_2 \cdot 2\text{H}_2\text{O}$). Phosphorus forms in stored manures from different animal origins probably approaches a similar equilibrium with 15 to 25% of the total P in organic form. From 36 to 58% of the P in various samples of animal manure was water soluble (Bear, 1942). Parker *et al.* (1959) found 94% of the P in broiler

manure was available, as compared with 88% in hen manure (by AOAC procedures).

Most of the K in animal manures is water soluble and readily available. Water soluble K contents of various manures have ranged from 75 to 97% (Bear, 1942). Jackson *et al.* (1975) found that essentially all of the K from broiler house litter spread at disposal rates on the soil surface had been leached after 1 year. Most of the K excreted by cattle is in the urine. Sulfur (S) excretion was reported as about .1 g S excreted in feces with 100 g of feed eaten with the remainder of S excreted in urine after retention by the animal. The other elements having plant nutrient value are mainly associated with feces, except for boron (B), which is mostly excreted in the urine. Those nutrients primarily excreted in feces will likely have lower availabilities for crop production than those excreted in the urine.

Losses and transformations of plant nutrients during storage is the subject of another paper in this symposium.

PLANT NUTRIENT CONCENTRATION

The plant nutrient content of animal manures varies with animal species and among animals of the same species. Consequently, only through chemical analyses is it possible to predict

TABLE 1. PRIMARY NUTRIENT CONTENT OF ANIMAL MANURES FROM FROM VARIOUS WASTE MANAGEMENT SYSTEMS (REPRESENTATIVE VALUES)

Type of livestock	Waste system	Dry matter	Primary N	plant P_2O_5	nutrient K_2O
		%	kg/metric ton (wet basis)		
broiler ^a	solid with litter	75	30	26	18
hens ^a	with litter	75	21	33	17
hens ^b	battery	29	17	14	7
turkeys ^b	litter	58	19	15	9
swine ^a	farmyard manure (FYM)	23	6	6	4
beef ^a	feedlot	52	11	10	15
dairy ^b	FYM	23	6	3	7
			kg/1000 liters		
poultry ^b	liquid slurry	8	6	5	2
swine ^b	slurry	4	4	2	2
beef ^c	oxidation ditch	3	3	2	5
dairy ^b	slurry	4	3	1	3

^aBarnett *et al.* (1977).

^bLoehr, 1974.

^cSutton *et al.* (1975).

accurately the plant nutrient input from a given application of animal manures to the land. The following factors may affect the mineral composition of animal manure and influence its efficiency of use as a fertilizer on cropland or pasture: 1) animal size and species; 2) housing and rearing management; 3) ration fed; 4) storage, hauling, and spreading methods; 5) rate of manure applied; 6) crop species grown; 7) soil type; 8) crop cultural management, including supplemental irrigation, fertilization, and harvesting; and 10) climate. Even though multiplicity of factors and their possible interactions make the prediction of fertilizer value of animal manures without chemical analysis very uncertain, this should not prevent us from using them in crop production.

Primary nutrient concentrations of solid and liquid manures considered representative from different animal species and manure management systems are shown in table 1. The wide variations encountered in primary nutrient content of these manures make the use of such values tentative for situations requiring precision; however, they are useful in developing relative values for use of animal manures in crop production. Poultry manures, both solid and slurries, are higher in plant nutrient concentrations than are those from other types of livestock. Nitrogen contents for undiluted poultry slurry of 19.9 kgN/1000 ℓ were reported by Gowan (1972) while 6 kgN/1000 ℓ was reported as a median value by Loehr (1974). Powers *et al.* (1975) reported minimum and maximum values on a dry basis of 1.9 to 9.0% N, 1.8 to 5.1% P, 3.4 to 19% K for beef, dairy

and swine undigested slurry. Tunney and Molloy (1975) found that dry matter was significantly correlated with N, P, and Mg contents of pig slurry. They also found that farmyard manure and pig manure had similar and lower N contents than poultry slurry. Deep litter from broilers was much higher in N content than layer slurry (25.6 kg/M³ vs 14.2 kg/M³). Levels of P and K were much higher in the deep litter. The data in table 1 illustrates clearly the impact of dry matter content of manures on their fertilizer content per unit of volume or mass.

Representative values of calcium (Ca), Mg, and S in various animal manures on a wet basis are shown in table 2. On a unit weight basis, poultry manures have higher levels of Ca, Mg, S than do other manures. At land application rates normally used to optimize plant nutrient use (up to 25 metric tons/ha/yr), the addition of these elements would likely have little effect on crop response except where a soil is deficient in one or more of these elements. Since such deficiencies are specific to soil situations and localities, it was considered not appropriate to assign a fertilizer or dollar value to these elements. Nevertheless, they do have maintenance value, and in deficiency situations are good sources of secondary plant nutrients.

Micronutrient contents of animal manures likewise may have significant fertilizer value where the particular micronutrient is deficient in the soil. Broiler litter contains 41 and 191 ppm copper (Cu) and zinc (Zn), respectively (Perkins and Parker, 1971). We found in certain lots of broiler manure an average concentration

TABLE 2. CALCIUM, MAGNESIUM, AND SULFUR CONTENTS OF VARIOUS ANIMAL MANURES (REPRESENTATIVE VALUE)

Type of livestock	Waste system	Dry matter	Secondary Ca	plant Mg	nutrient S
		%	kg/metric ton (wet basis)		
broilers ^a	with litter	75	14	4	3
hens ^a	with litter	63	22	3	3
beef cattle ^b	feedlot	52	11	4	...
swine ^b	FYM	18	4	4	...
poultry ^c	slurry	8.1	.6	.2	...
hog ^c	slurry	2.6	.4	.2	...
dairy ^c	slurry	8.6	.4	.2	...

^aWilkinson, S. R., unpublished, as well as Perkins and Parker, 1971.

^bBarnett *et al.*, 1977 (In press).

^cMurphy and Walsh, 1971.

of 435 ppm Cu, which was about 10-fold more than Cu levels normally found in broiler manure. This roughly agrees with about the same relative increase in Cu for swine wastes when Cu was added to the ration. Overcash *et al.* (1975) indicate reliable values for raw swine waste of .50 mg Zn and .10 mg Cu total dry solids. The Cu rises to 1.2 mg/g total dry solids when Cu has been added to the ration. Batey *et al.* (1972) reported the Cu content in the dry matter of three pig manure slurries ranged from 643 to 1575 ppm. Kornegay *et al.* (1976) also reported that about 80 to 95% of the dietary Cu, and about the same percentage of added Zn and iron (Fe) were excreted in the manure. Animal manures contain other nutrients essential for plant growth, and ranges reported in the literature are reviewed by Powers *et al.* (1975).

Animal manures contain salts which could become a problem in areas where evapotranspiration exceeds rainfall on an annual or growing season basis. When manure is applied at rates that prevent accumulation of nitrate in the soil or do not exceed crop N requirements, there is little evidence that salinity problems result. However, long-term effects of low manure rates on soil salinity have not been defined, although long-term rotation treatments receiving manure have not indicated a problem. Horton *et al.* (1975) found that as salt (NaCl) additions to the ration increased, Na concentrations of the manure increased, but Ca, Mg and K concentrations remained relatively constant.

COMPARATIVE CROP RESPONSE

The relative efficiency of fertilizer use from manures may be obtained by comparing the yield increase with that produced by a standard inorganic fertilizer. Because manure contains more than one plant nutrient and because interactions between nutrients occur it is difficult to estimate its nutrient efficiency relative to inorganic fertilizer unless other nutrients are supplied at the same ratio, or at a level that minimizes the potential response to or interaction with the element not under study. The most reliable results are obtained when several rates of the element under study are applied as well as equivalent rates of the standard fertilizer. This is a relatively simple method, but it is only approximate. When only one rate of manure N, or the standard fertilizer is applied, then the result is called relative

increase in yield, and is less precise and more ambiguous. Nevertheless, these are useful estimates of the effectiveness of manure plant nutrients in crop production.

The efficiency and effectiveness of manure N are of primary concern. Where manures have been used for a long time, the soil supply usually is adequate for P, K and other plant nutrients and N is the plant nutrient limiting crop production. Jones *et al.* (1973) analyzed soil samples from pastures where poultry manure had been used, and where it had not been used. Poultry-manured pastures had 92% higher soil P levels and 74% higher soil test K levels than pastures that had not been poultry manured. Soil test Mg levels were also higher on the pastures receiving poultry litter, but Ca levels were similar on both pastures. Soil pH levels were lower on the pastures not fertilized with poultry litter. In the short term, P efficiency may be low, but with continued application, animal manures can be expected to be quite effective P sources. Potassium solubility is high and little difference in efficiency of K relative to inorganic K would be expected. Adams (1974) reported an exception that K in slurries was less effective than fertilizer K in maintaining K content of herbage. He believed, but did not verify that the massive applications of K in solution in a wet climate may have resulted in K leaching below the zone of greatest plant uptake in the top layer of soil.

Salter and Schollenberger (1939) illustrated that losses of N fertilizer value were quite large when manures were not immediately incorporated into the soil. Approximate values widely used for such losses are shown in Table 3. Conditions after the manure is broadcast will influence the degree of N volatilization loss. If manure application is followed by leaching rain, then losses will be small. On the other hand, if the weather is hot and dry following surface applications without incorporation into soil, then much of the manure N in uric acid, ammonium and easily mineralized nitrogenous compounds may be lost by volatilization before nitrification can occur. Incorporation of manure applied to grasslands is not usually possible, and volatilization losses may be large. There is evidence, however, that a growing grass canopy is effective in recycling ammonia -N volatilized from the nitrogen-rich soil surface of a grass-clover pasture (Denmead *et al.*, 1976). Consequently, volatilization losses might be expected to be less than where manure is

TABLE 3. SOME GENERALIZED N LOSSES TO THE AIR AS AFFECTED BY METHOD OF APPLICATION FOR CROP PRODUCTION (FROM SUTTON *ET AL.* 1975)

Method of application	Type of waste	Nitrogen loss, % ^a
broadcast without cultivation	solid	21
	liquid	27
broadcast with cultivation	solid	5
immediately after application ^b	liquid	5
knifing	liquid	5
irrigation	liquid	30

^aPercent of total N applied lost within 4 days of application.

^bThe rapidity with which surface applied manure dries out affects the actual loss. Warm, dry conditions result in greater losses than cool, wet conditions.

applied to bare soil.

The efficiency of N use from manure is also influenced by the crop and its requirement for N. Selected results from studies of efficiency of manure N use for different crops follow.

Relative Efficiency of Manure N for Corn, Grain Sorghum and Cotton. Perkins *et al.* (1964) conducted several studies to evaluate broiler or hen manure as a source of fertilizer for corn (*Zea mays* L.) in the Coastal Plains, Southern Piedmont, and Mountain regions of Georgia. Based on their yield data, relative efficiencies of poultry manure for corn production were 44 to 67% that of commercial fertilizer. Harper *et al.* (1978) evaluated the effectiveness of broiler litter as a fertilizer for corn no-till planted in killed strips of Kentucky-31 tall fescue sod. The relative efficiency of broiler manure N for the corn crop was approximately 77%. The experiment was irrigated, however, which probably improved overall efficiency of manure N use by leaching soluble N into the soil. Herron and Erhart (1965) broadcast and immediately incorporated beef cattle manure into calcareous Colby silt loam before planting grain sorghum, (*Sorghum vulgare*) and followed this application by 3 years of cropping without manure to measure the residual N effect. The relative efficiency of manure N in producing grain sorghum was 71% over the 4-year period. During the first year the manure N equivalent was 5.5 kg/metric ton, or approximately one-third of the total N. Another 5.5 kg/metric ton became available during the 3 subsequent years of cropping. Spurgeon *et al.* (1975) obtained the same cotton (*Gossypium hirsutum* L.) yields from 130 kg N/ha contained in 54 metric tons/ha of liquid beef cattle wastes injected into Dubbs silt loam in Mississippi as

were obtained with 135 kg N/ha from liquid commercial N. The same amount of manure surface broadcast produced significantly less lint cotton yield than did either the inorganic N or injected beef cattle wastes. Perkins *et al.* (1964) obtained excellent cotton yields from application of broiler manure up to 5.6 tons/ha per year over a 4-year period.

Relative Efficiency of Manure N for Small Grains. Broiler litter broadcast and mixed with Cecil clay loam 2 weeks before planting produced a rye (*Secale cereale* L.) grain response superior to that produced by inorganic N (Perkins *et al.*, 1964). This soil had very low fertility. In another study (S. R. Wilkinson, *unpublished*) rye seed was applied with broiler litter or with approximately equivalent N-P-K fertilizer on the surface of dormant Coastal bermudagrass without tillage and harvested for grain the following spring. Rates of broiler litter applied were 4.5 and 9.0 metric ton per hectare. Rye yields were higher with the broiler litter because the mulching effect of the litter resulted in a superior stand. Rates of N considered equivalent to that in the broiler manure were 135 and 270 kg N per hectare, respectively. Stewart (1970) found that cow slurry was 85% as efficient and pig slurry was 97% as efficient as nitrochalk when applied to the surface of barley (*Hordeum vulgare* L.) seedbeds. Davies (1970) applied pig slurry to the soil surface at different times from mid-winter to barley sowing time, and found that the relative N use efficiency varied from 25% for midwinter application to 75% for application at sowing time.

Relative Efficiency of Manure N for Production of Forages and Grassland. Broiler litter applied during the growing season to Coastal

bermudagrass produced yields similar to those obtained with inorganic N (Wilkinson *et al.*, 1976). Broiler litter surface applied for 3 years in early fall to Kentucky-31 tall fescue gave a relative efficiency of N use of 43% compared to split applications of inorganic fertilizer. When all treatments were cropped an additional year without N fertilizer or broiler litter, N use efficiency of broiler manure increased to 53%. Lund *et al.* (1975) applied solid dairy manure or liquid dairy manure to Coastal bermudagrass in six equal applications during the year, and its efficiency relative to N applied during the growing season was 28 and 35% for solid and liquid manures over a 3-year period, respectively. Yields of Coastal bermudagrass were increasing on the manured plots receiving 22.4 metric tons/ha rate, indicating an accumulation of available N. In a study where liquid and solid dairy manures were incorporated each spring and followed by a crop of millet and rye, nearly equivalent N use efficiency was achieved (Doss *et al.*, 1976). Montgomery *et al.* (1975) compared average daily gains of dairy heifers and total carrying capacity of orchardgrass pastures receiving 56 kg N/ha from liquid dairy manure or from fertilizer. Average daily gains of dairy heifers were the same for the N sources. In the first year the total carrying capacity of the pasture receiving 56 kg N/ha as liquid manure was 67% of that of inorganic N, and in the second year the total carrying capacities were equivalent. McKell *et al.* (1970) applied poultry litter to annual rangeland in California and found similar N response to that obtained with inorganic fertilizers.

Much work has been done overseas with the use of slurries and gulle (feces, urine, litter diluted with water) on grasslands. Davies (1970) reported relative efficiencies of N-use of 18% for dairy cow slurry applications in December and 56% for applications in March. In another experiment, Davies and Chumbley (1970) reported a relative efficiency of N use of 68% for poultry slurry with no difference in efficiency between winter and spring applications. Nitrogen-use efficiency for mixed cow and poultry slurry applied in October was approximately 50%, whereas relative efficiency of N use from February applications of mixed slurry was similar to that from inorganic N.

In figure 2, N use efficiency is presented as the units of forage produced per unit of N applied. Nitrogen use efficiency normally declines with increasing N rate. The curve

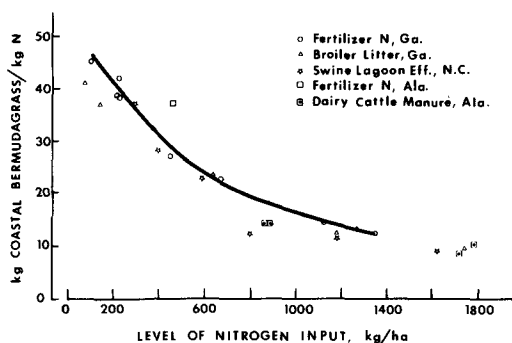


Figure 2. A comparison of Coastal bermudagrass production per unit of Nitrogen from animal manures or fertilizer nitrogen. (Solid line represents inorganic fertilizer response at Watkinsville, GA).

represents results from N fertilizer (NH_4NO_3) applied in split applications to irrigated Coastal bermudagrass (*Cynodon dactylon* L. Pers.) in the Southern Piedmont. The data points represent the units of forage produced per unit of N applied from various animal manures. One advantage of this type of analysis is that it represents an output/input relationship and permits determination of gross economic return. If Coastal bermudagrass hay sells for \$70/metric ton (\$.07/kg), and if N is \$.463 per kilogram then the point at which costs of N inputs no longer exceed value of product output is about 7 kg forage per kilogram N. Based on this analysis, the product return from applying 1,185 kg N per ha from swine lagoon effluent still exceeded the fertilizer replacement cost. However, this amount of N resulted in excessive accumulation and loss of N below the root zone of Coastal bermudagrass (Cummings *et al.*, 1975). The scatter of points for manure N suggest that manure N was less efficient than commercial fertilizer, but it still produced a good product return for unit N input. Because of a reduction in N recovery and probable N losses in soil water percolate; 672 kg N/ha/yr is near the top N rate to apply to Coastal bermudagrass swards.

Relative Efficiency of Manure N for Other Crops. The relative efficiency of broiler manure N relative to commercial fertilizer in growing cabbage (*Brassica oleracea capitata*) was about 44% (calculated from Perkins *et al.*, 1964). However, each ton of broiler manure at the 9 metric ton rate produced an additional 1.5 metric tons of cabbage. Although the efficiency was low, the broiler manure was cost effective

in producing cabbage. Ware and Johnson (1968) found each metric ton of broiler manure returned \$768 worth of tomatoes and turnips in a study where manure was applied for 2 years, and residual effects were measured for 3 years (based on recent prices). Measure of N-use efficiency was not possible in this study because additional N-P-K fertilizer was applied before and after each crop. This was an extremely intensive system and broiler manure may have provided some of its benefit as a soil amendment. Garner (1970) summarizes the manure N equivalence of kiln-dried poultry manure as about 53% for potatoes increasing to nearly equivalent to $(\text{NH}_4)\text{SO}_4$ for sugar beets and broccoli. Moberly and Stevenson (1971) demonstrated equivalent yield response of sugarcane to broiler manure as to commercial fertilizer when the broiler litter was applied in a furrow about 20-cm deep.

OTHER CONSIDERATIONS IN USING MANURES AS FERTILIZERS AND SOIL AMENDMENTS

Animal manures also can improve soil physical properties. Whether manures are beneficial or not depends on the individual soil's physical properties and the crop's tolerance of these properties. The organic matter in manures can improve water infiltration rates (Mazurak *et al.*, 1955), reduce water runoff on a fallow soil because of the mulching effect (Barnett *et al.*, 1969), and reduce soil losses by wind erosion (Mazurak *et al.*, 1953). Manure can also improve ease of tillage, improve the tilth of the seedbed, and reduce impedence to seedling emergence and root penetration. Soil organic matter is a source of inorganic plant nutrients and of food for soil microorganisms; is an ion exchange material, chelating agent and buffer; and is an important factor in soil aggregation, and crop rooting depth and distribution (Allison, 1973). The value of manure in restoring productivity to eroded soils, soils with topsoil removed, and generally marginal, low fertility soils has been recognized for sometime (Salter and Schollenberger, 1939; Whitney *et al.*, 1950). Specific dollar returns from soil improvements that might result from manure applications have not generally been estimated. Modern crop production with readily available inorganic N fertilizers is now less dependent on soil organic matter for available N. Mulch tillage and no-till farming with unharvested plant residues and ample N fertilization may supply the soil's requirement

for organic matter additions. Organic matter additions may be more important for some crops than others because of the variable amounts of organic residues likely to be returned with different crops and because of different tolerances of different crops to soil physical conditions.

Animal manures can also be very beneficial in alleviating micronutrient deficiencies in soils. Manure may supply or give rise to chelating agents which might aid in the solubilization of insoluble micronutrients in soil and thereby render them more available in plants. Miller *et al.* (1969) found that the organic fraction in poultry manure was important in rendering Zn and Fe more available to plants. Chesin and Anderson (1975) found that annual manuring increased the amount of available Zn to a depth of 8 inches in a Tripp sandy loam (western Nebraska).

Whether cow slurry application would affect herbage production, intake, and grazing behavior of cattle was investigated by Pain *et al.* (1974). Grassland plots were dressed with cow slurry at rates up to 100 tons/ha in January and March and grazing trials were begun in late April. Herbage intake by cattle was not affected, but behavior of heifers was modified during the first 8 weeks after plots had been dressed with 75 or 100 tons/ha in March and grazing trials were begun in late April. Herbage intake by cattle was not affected, but behavior of heifers was modified during the first 8 weeks after plots had been dressed with 75 or 100 tons/ha in March. Grazing periods were shortened at the highest rate of the March application from a median of 28 sec to 20 sec and lying-down times were shortened from an average of 38% on light treatments to 28% on the 75 tons/ha and 27% on the 100 tons/ha March treatment. Apparently, the slurry formed a mat that the grazing heifers detected and found objectionable.

Stuedeman *et al.* (1975) reported several animal health problems associated with broiler litter fertilization of tall fescue pastures. These problems—fat necrosis, grass tetany, and nitrate accumulation in pasture forage did not involve animal manures *per se*, but involved effects of high rates of plant nutrient input, particularly N and K. They can be appropriately described as being rate and plant species dependent and similar problems from commercial fertilizers would be expected.

Investigations on internal parasite problems

associated with broiler litter fertilization indicated that pasture condition was the dominant factor in level of parasitism rather than use of broiler litter (Stuedemann *et al.*, 1975). Splisteser and Frick (1973) suggested that if coprological investigations indicate parasite contamination of liquid manure that prophylactic measures are necessary to prevent parasitological problems from occurring from the use of liquid manures on grassland.

Two studies reveal that potential phytotoxic substances can occur in animal manures. Costa *et al.* (1974) showed that manure from cows consuming forage contaminated with the herbicide, picloram was toxic to tomatoes. Picloram is not considered toxic to men and animals. Minchinton *et al.* (1973) reported on poultry manure phytotoxicity in Australia caused by an impurity, 4-amino-3, 4 dichloro-2, 6-lutidine, in the coccidiostat, clopidol. The increased potency of the impurity after poultry ingestion indicated that the impurity was metabolized to 4-amino-3, 5-dichloro-6 methyl picolinic acid. Interestingly, this metabolite is similar to picloram which is 4-amino-3, 5, 6-trichloro picolinic acid. These examples illustrate the possibility that herbicides can pass through an animal's digestive system and retain phytotoxic properties, or that a compound can be metabolized to have phytotoxic properties. Fortunately, this has not been a problem associated with the use of manure in crop production in this country.

Arsenicals are used in feeds to promote growth of poultry and swine. Isaac *et al.* (1978) and Liebhardt (1976) showed that the arsenic (As) residues in poultry manure were not sufficient to cause problems in pasture plant growth or in concentrations of As in corn grain when high rates of poultry manures were applied to these crops. These researchers indicate that, when applied at fertilization rates animal manures containing As residues should present no hazard to the soil, plant, animal environment or to water quality.

ECONOMICS OF ANIMAL MANURES AS FERTILIZER

Animal manures have soil amendment and plant nutrient values. However, it is unrealistic to believe that their value would exceed that from equivalent levels of plant nutrients from modern, high analysis fertilizers. Their value as fertilizer in the market place depends on the availability and price of commercial fertilizers.

The point should be made, however, that manure dumped or disposed has only negative value.

Based on 1977 spring prices paid by farmers for ammonium nitrate, superphosphate (46% P_2O_5) and muriate of potash (60% K_2O) (Source; Agricultural Prices, March 1977, Crop Reporting Board, SRS, USDA), the ranking of animal manures for their primary nutrient content and fertilizer value was as follows: broiler litter, hen litter, battery hens, beef feedlot, solid farmyard manure and poultry slurry, and other slurries (table 4). These dollar values are based on total nutrients potentially available for crop production and do not take into account losses in spreading and field application, nor differences in availability of plant nutrient sources.

The economic value of manures for farmers without livestock may be best approximated by estimates of their efficiency relative to commercial fertilizer sources. Reasonable relative efficiency estimates with excellent manure and agronomic crop management are .7 for N, .8 for P_2O_5 and .9 for K_2O . Based on these relative efficiency estimates, the dollar values of animal manures were changed from those shown in table 4 to those shown in table 5. From values such as these the farmer may decide whether it is economically wise to haul and spread manures from their source to his field or to purchase commercial fertilizers. In addition, he must consider the need for all elements in the soil. If N is the only nutrient needed, the economics of paying for unneeded plant nutrients is very questionable.

For the livestock producer who also produces crops and has adequate land, the value of manure as a replacement for commercial fertilizers is obvious. For the livestock producer who does not produce crops or for the farmer who does not have livestock, the question becomes what is its value in the market place? In Georgia, broiler manure typically sells for \$11 per metric ton at the broiler house with a hauling and spreading charge of about \$.65/km. For an average truckload hauled 16 km this cost becomes \$13.77 per metric ton which is competitive with commercial fertilizers. This is roughly half its total dollar value of plant nutrients (table 4).

Some costs estimates for various poultry waste management systems are given in table 6. Land disposal is the lowest cost poultry waste management system and this cost can be

TABLE 4. DOLLAR VALUE OF PRIMARY NUTRIENTS FROM SELECTED ANIMAL MANURES AND HANDLING SYSTEMS

Type of livestock	Waste system	N	Dollar value of plant nutrient in waste ^a		Total
			P ₂ O ₅	K ₂ O	
dollars per metric ton					
broiler litter	solid	13.89	9.18	3.17	26.24
hen litter	solid	9.72	11.65	2.99	24.36
hens	battery	7.87	4.94	1.23	14.04
swine	FYM	2.78	2.12	.70	5.60
beef	feedlot	5.09	3.53	2.64	11.26
dairy	FYM	2.78	1.06	1.23	5.07
dollars per 1000 liters					
poultry	slurry	2.78	1.77	.35	4.90
swine	slurry	1.85	.71	.35	2.91
beef	oxidation ditch	1.39	.71	.88	2.98
dairy	slurry	1.39	.35	.53	2.27

^aBased on a per kilogram total N value of \$.463/kg N, .353/kg P₂O₅, and .176/kg K₂O.

further reduced if 12.5% dried layer waste (DLW) is refeed for 50,000- to 80,000-layer operations (Economic Research Service, 1974). This report concludes that it was not economical to feed DLW at the 25% level, nor was it economical to feed DLW for operations having 10,000 layers. Calculations of the amounts of manure produced by a layer during 1 year, and its probable value based on representative primary plant nutrient content suggests greater fertilizer value than waste management costs. Gaerde *et al.* (1972) pointed out this positive

value for all classes of poultry waste for Massachusetts except layers when fertilizer nitrogen was valued at \$.28 per kilogram. Valuing N at \$.46 per kilogram likely would have changed negative values to positive values for layer manure as well as manure from other classes of livestock.

Ashraf *et al.* (1974) compared the economics of spreading dairy cattle manure daily, stacking, and using liquid manure systems. Average fixed investment costs for stacking systems were two to three times larger than for

TABLE 5. ADJUSTED DOLLAR VALUE OF PRIMARY NUTRIENTS FROM SELECTED ANIMAL MANURES AND HANDLING SYSTEMS

Type of livestock	Waste system	N	Dollar value of plant nutrient in waste ^a		Total
			P ₂ O ₅	K ₂ O	
dollars per metric ton					
broiler litter	solid	9.72	7.34	2.85	19.91
hen litter	solid	6.80	9.32	2.69	18.81
hens	battery	5.51	3.95	1.11	10.57
swine	FYM	1.95	1.70	.63	4.28
beef	feedlot	3.56	2.82	2.37	13.03
dairy	FYM	1.95	.85	1.11	3.91
dollars per 1000 liters					
poultry	slurry	1.95	1.42	.27	3.69
swine	slurry	1.30	.57	.32	2.19
beef	oxidation ditch	.97	.57	.79	2.33
dairy	slurry	.97	.28	.48	1.73

^aBased on a per kilogram total N value of \$.463/kg N, .353/kg P₂O₅, and 9.176/kg K₂O. Total plant nutrient content adjusted to available plant nutrient content by .7 for N, .8 for P₂O₅ and .9 for K₂O.

TABLE 6. ANNUAL COST PER BIRD FOR POLLUTION ABATEMENT USING ALTERNATIVE POULTRY WASTE MANAGEMENT SYSTEMS IN THE UNITED STATES (AGRICULTURE ECONOMIC REPORT 254 ERS-USDA)

Management system	Annual cost per bird
Composting	\$.50
Incineration	.50
Oxidation ditch	.25 ^a
Aerobic lagoon	.25 ^a
Anaerobic lagoon	.18 ^a
Anaerobic-aerobic lagoon	.35 ^a
Drying	.40
All manure returned to land	.10
60% returned to land, 40% in feed	.06 ^b

^aIncludes land disposal costs.

^bFor 50,000 to 80,000 layer operations, feeding 12.5% DLW. Not economical to feed DLW at 25.0% level, nor was it economical to feed DLW for 10,000 layer operation.

daily spreading systems, and the average fixed investment cost for liquid systems was three to five times that of daily spreading. Labor time for spreading was highly concentrated for liquid or stacking systems, but was well distributed for daily spreading. Ashraf *et al.* (1974) suggested that the manure disposal problem may be alleviated by avoiding dairy confinement systems and by acquiring additional acreage for forage production. Daily spreading on forage land does not permit maximum plant nutrient use efficiency from the manures. It may also present pollution hazards from runoff when applied to snow-covered or frozen ground. The daily application of manures at fertilizer rates to growing grass swards in humid climates may not result in as large a N volatilization loss as supposed. However, this aspect has not been adequately researched.

The economic picture improves considerably for the crop producer whose livestock furnish the manure since the return from the manure's fertilizer value reduces either his fertilizer bill or his waste management cost. It must be reemphasized that manure plant nutrient content is so variable that local knowledge and chemical analyses are necessary for precise estimates of fertilizer replacement value of manures.

Manures must be managed safely from an environmental point of view. We now realize that disposal in either air or water is not environmentally acceptable. We hope that this same viewpoint can be acceptable as far as the soil is concerned, i.e., utilization without environmental degradation.

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