NUTRIENT MANAGEMENT OF HUMID, TEMPERATE REGION FORAGES: RECOMMENDATIONS AND PRACTICES

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ABSTRACT

Proper nutrient management is critical for economically and environmentally sustainable perennial forage production, but we have inadequate information about actual on-farm practices. In this paper, I discuss philosophies of fertilization, review current recommendations of public soil testing laboratories in the USA, and provide the first report of statewide nutrient management practices on dairy farms in the North Central USA. Nitrogen fertilizer recommendations generally are based on yield goal (and implicitly on soil N mineralization capacity), with highest amounts recommended for high-yielding warm season grasses in the humid South. Phosphorus and K recommendations are related to soil test levels and occasionally to yield goals. Nutrient recommendations for pastures typically are smaller or are similar to mown forages, unless management intensity differs. Nearly all states recommend that nutrient credits be taken for manure application, and many make detailed recommendations concerning proper manure management. Site specific farming techniques are beginning to be used with perennial forages in some areas. Soil tests are the most important source of infity of nutrient management systems on contemporary dairy farms, and suggest that, for the case of Minnesota, USA, information on improved approaches should be directed to fertilizer dealers to achieve most rapid transfer to dairy farmers.

KEYWORDS

Alfalfa (*Medicago sativa* L.), fertilizer recommendations, fertilizer application, information sources, manure management, nutrient management, plant analysis, soil testing

INTRODUCTION

Many of the traditional approaches to nutrient management on temperate region forages have been covered in well known texts, such as those by Mays (1974), Heath et al. (1985), and Whitehead (1995). In this paper, I review different fertilization philosophies, present current recommendations provided by some of the public soil testing laboratories in the USA, and summarize results of a survey of Minnesota dairy farmers that reveals how farm characteristics (size, productivity, location, etc.) are related to fertility practices used on perennial forages. The companion paper by Graeme Blair in this volume concentrates on fertility management of tropical and subtropical forages.

Most Minnesota farms that produce only crops apply fertilizer N within about 10% of University of Minnesota recommendations (Bruce Montgomery and Denton Bruening, Minnesota Department of Agriculture, personal communication, 1996). In contrast, farms with livestock enterprises applied more fertilizer than needed, based on manure availability and nutrient content. I found no recent statistical data of fertilizer use on forages in the USA, and similarly, although there are thorough descriptions of manure use on major annual crops (e.g., Nowak et al., 1995), there are few data on use of stored livestock manure on forages.

Insufficient N credits often are given for manure or legume crops grown in rotation with corn (*Zea mays* L.) (Daberkow et al., 1988), but the constraints faced in actually managing manure, along with all the other tasks associated with livestock production, are significant (Nowak et al., 1995). To help farmers calibrate their equipment and to improve their ability to evaluate the resulting manure application, Extension Service personnel in Wisconsin have published color photographs of how typical rates appear after application (Combs et al., 1993) and have measured actual manure application rates on farms. This approach is being used in many states to improve on-farm nutrient use.

Nutrient management plans are being offered by public agencies and the private sector in several countries, at low cost to the farmer (Beegle, 1994; Kuipers, 1994; Weissbach, 1994; Daniel et al., 1996). Several computer software tools are available to help consultants and farmers plan the distribution of manure and fertilizer. Available software varies in objective, audience, complexity, and ease of use. The Manure Application Planner (Schmitt et al., 1997) is designed to develop viable manure application plans, subject to user-selected agronomic or environmental constraints, whereas the Cornell Nutrient Management Planning System (Tylutki and Klausner, 1995) helps the user calculate a mass nutrient balance for the farm, develop a crop rotation scheme, and determine an animal feeding program, in addition to developing a nutrient management plan. In most programs, soil test results are important inputs. Although most soil testing is done by commercial laboratories, public soil testing laboratories often play major roles in method development, quality control of methodologies, and dissemination of fertilizer recommendations.

PUBLIC SOIL TESTING LABORATORIES

Objectives and recommendation philosophies. There are at least four different objectives for fertilizing perennial forages:

1) to increase total yield in cases of mown forages and when pasture production is too low for the animal numbers present;

2) to increase yields during specific times of the year (Narasimhalu et al., 1981);

3) to improve persistence of desirable species (Wilkinson and Lowrey, 1973); and

4) to improve forage quality (Munson, 1995).

Nutrient recommendations are made using one or more of several approaches, or philosophies. One is to “feed the plant,” where nutrient additions are recommended to optimize plant response, based on nutrient availability as indicated by a soil extraction. This also is referred to as the “sufficiency level” approach. Recommendations generally are modified by the crop yield goal. This method is used by most public soil testing laboratories in the USA.

Another approach is to “feed the soil,” where nutrient additions are recommended to replace those removed by the crop and to increase the supply of nutrients in the soil to an optimum level, also referred to as the “buildup and maintenance” approach. This approach generally includes soil analyses, but can be based solely on estimated or measured crop removal rates. A third approach, related to the “feed the soil” philosophy, defines an optimum balance of cations (particularly Ca, Mg, and K). A few public laboratories in the USA use these latter two approaches in making recommendations.

There are appealing arguments for the ideas of maintaining or balancing the nutrient supplying capacity of the soil, but the scientific bases of these approaches have been questioned (see Haby et al., 1990) and costs for fertilizer are almost always considerably higher, with little or no gain in crop yield (Olson et al., 1982).

Several public soil testing laboratories in the USA responded to a 1996 survey with information regarding fertilization of temperate perennial forages. The percentage of soil samples received from forage fields (Fig. 1) is related to the relative use of land for hay vs. all crops (Fig. 2). *Providing* the public laboratories are representative of all soil testing laboratories in the types of samples they are asked to analyze, this relationship indicates that, in general, soil testing is used as much for forages as for other crops.

Declines in the proportion of soil samples from forage fields have occurred during the last 5 to 10 yrs in public soil testing laboratories in Illinois, Michigan, New York, and Ohio. Increases have occurred in Georgia, Iowa, Kentucky, Minnesota, Nebraska, Rhode Island, and Wisconsin, but some of that increase was attributed to declines in other types of samples.

Nutrient requirements also can be assessed by measuring nutrient concentrations in plant tissue. Although forage testing is a widespread practice to determine feed quality, forage plant analysis to determine nutrient needs appears to be little used. Only Nebraska, Vermont, and Wisconsin reported that forages comprised more than 10% of the plant samples analyzed in their laboratories. Where plant analyses are offered, the “critical level” approach usually is used, in which fertilization is recommended for those elements that fall below a minimum value deemed sufficient for optimum growth (Kelling and Matocha, 1990). Some states offer evaluations based on the Diagnosis and Recommendation Integrated System (DRIS). In the DRIS approach, the nutrient concentration ratios are compared to optimum ratios, and the most limiting nutrients are then identified (Kelling and Matocha, 1990).

Whether plant tissue or soil samples are analyzed, nutrient recommendations for both mown forages and pastures generally have been developed based on plant yield response, rather than response in livestock weight gain or milk production. Noller and Rhykerd (1974) described the difficulty faced by researchers in defining all relevant components of animal response. Pastures have become an increasingly important source of feed in the USA through the use of intensive rotational grazing systems. There is a need for animal response studies to inorganic and organic nutrient source additions under contemporary management systems, so that sound economic analyses can be performed.

Public laboratory recommendations. Nitrogen recommendations generally are directly related with yield goal, rather than soil test results, and are smaller for stands with legumes. Highest rates are recommended in the humid South, where a long growing season and well adapted species [e.g., *Cynodon dactylon* (L.) Pers. and *Paspalum notatum* Flugge] often produce dry matter yields in excess of 20 Mg/ha (Robinson, 1996). Fertilizer N recommendations generally decrease in states to the North because of decreasing growing season length and to the West because of declining water supply, both of which limit yield potential.

Under similar management levels, N recommendations are smaller for pastures than for mown forages in about one-half of the states, whereas the other half recommend similar N rates. States also differ in how pasture management affects N recommendations. For example, Michigan recommends annual applications of 67 kg N/ha on intensively grazed pastures and 112 kg N/ha on extensively grazed pastures (unless >50% legumes are present, when no N fertilizer additions are recommended) (Christenson et al., 1992). In contrast, Minnesota recommends 168 kg N/ha for rotational grazing and 112 kg N/ha for continuous grazing under adequate rainfall conditions (Rehm et al., 1994). Georgia also recommends higher N rates with increased grazing intensity or stocking rate. Given the slim economic margin under which most livestock producers operate, these differences substantiate the need for further research on animal response to fertilizer addition under various pasture management intensities.

Management intensity typically must increase to take advantage of plant yield and quality responses to N application in pastures or mown forages. Livestock or milk producers should carefully consider the marginal cost of N fertilizer versus the marginal income derived from the animal product. Although most of the nutrients ingested by grazing animals are excreted in the pasture (including non-utilized nutrients from supplemental feeds, such as grains and silage), uneven nutrient distribution in pastures may result in large areas that are responsive to fertilizer addition. In general, application of N and K should be avoided near watering sites, and P additions should be avoided where animals camp (in shade or areas protected from wind) (Peterson and Gerrish, 1996; Mathews et al., 1996).

In contrast to N, recommendations for P and K usually are based on soil test results in most states. Some states (e.g., Iowa, Michigan, Oklahoma, South Dakota, Vermont) recommend more P for pure stands of alfalfa than for other forages grown under the same conditions, because legumes are relatively less efficient in absorbing P than are grasses. There is no difference in P recommendations for alfalfa versus grasses in Maryland, but more P is recommended for clover (*Trifolium* spp.) and clover-grass mixtures than for alfalfa at similar soil test levels.

Nearly all states recommend higher K rates for pure stands of alfalfa than for other forages grown on soils at the same test level and yield potential. Illinois recommends K based on yield potential of all forage crops, without regard to species. Topdressed K recommendations for a 13.4 Mg/ha yield of non-irrigated alfalfa on a soil testing 100 mg K/kg are highest in the North Central and Northeastern regions of the country (Fig. 3), presumably because of relatively low soil K supply, a buildup and maintenance philosophy in several of the states, and higher K requirements for optimum winterhardiness.

Maximum forage yield and quality usually require nutrient inputs, but there are distinct disadvantages to over-fertilization in forages. The first disadvantage is the added cost that is not covered by improved returns. Forage quality can be reduced, and some states (e.g., Arkansas) have based their recommendations in part on this possibility. For example, excess N application can result in forage with toxic nitrate concentrations, and excessive K application can result in poor Mg uptake by the plants, resulting in possible hypomagnesemia in ruminants. Potential environmental contamination by nutrients applied in excess of the crop-animal system requirements also can result from over-fertilization.

Different approaches may be needed to evaluate soil nutrient status where environmentally adverse impacts are possible. Dissolved reactive P concentration in runoff water from forage fields is related to the level of P extracted from the uppermost 2 cm of soil (Pote et al., 1996), rather than the 0-7.5 or 0-15 cm increments used for most soil testing applications. With regard to nitrate, ground water supplies may be protected by including moderately to deeply rooted perennial forages in the cropping system (Stewart et al., 1968; Russelle and Hargrove, 1989; Randall et al., 1993). However, all systems can be overwhelmed by nutrient addition, and nitrate leaching losses can occur when water supplies also exceed crop demand (Walther, 1989; King et al., 1990; Parsons et al., 1991). Deep sampling is required to determine the potential for nitrate loss, and should occur near the end of active plant growth. Farmers and their consultants should be educated about the need for specialized sampling procedures in those cases where such information is needed.

Site specific recommendations. The fact that perennial forages are grown for more than one year increases the likelihood that nutrient supply will have cumulative effects on yield, persistence, and quality, and thereby on the stability and economics of crop production. Consequently, site specific farming techniques may be quite economic for forages grown in fields having variable soil conditions.

A survey of people on two e-mail lists (FORAGE-MG and SOILS-L) in early 1997 indicated that intensive site specific management of nutrients on perennial forages is not widely practiced at present in the Canadian Prairies, New Zealand, California, Wisconsin, Minnesota, western New York state, Oklahoma, Oregon, Kansas, or Nebraska. A few exceptions and interesting ideas follow.

Use of site specific application of lime is being tested in Wisconsin in 1997 (D.J. Undersander, University of Wisconsin, Madison, personal communication, 1997). In New Zealand, James Crush (AgResearch, personal communication, 1997) and colleagues are planning to apply differential fertilizer P rates, depending on pasture plant species presence. Under their conditions, three times more P is needed to maintain white clover (*Trifolium repens* L.) in a clover/perennial ryegrass (*Lolium perenne* L.) pasture than for maximum yield of either in monocultures. At least one private company I heard from has begun grid sampling alfalfa fields for macro- and micronutrients and will begin detailed yield monitoring this year.

One requirement of site specific farming is the need to measure yields within the field to determine response to the variable input. Machinery for forages has been lacking, but some equipment has been developed recently by university researchers in Germany, Nebraska, and Wisconsin. Private firms also have developed forage yield monitoring equipment and nutrient applicator control equipment that will assist farmers in implementing site specific farming techniques with forages.

In addition to yield, however, forage quality is of concern to producers. Forage quality influences livestock performance and hay price, but also may affect insect pest activity. Preliminary data indicated that a 20% variation in crude protein concentration across an alfalfa field in Pennsylvania was positively correlated with potato leafhopper (*Empoasca fabae* Harris) populations (D.A. Emmen, A.A. Hower, and S.J. Fleisher, Pennsylvania State University, personal communication, 1997). Thus, knowledge of spatial variation in forage quality may allow site specific management of insect pests, in addition to site specific management of other inputs. “On-the-go” detectors of total N (crude protein) concentration based on reflectance of light of various wavelengths (e.g., Everitt et al., 1985; Stone et al., 1996) may provide a means of detecting quality, but also of adjusting fertilizer N applications to grass forages at scales much smaller than can be afforded through soil sampling (S.L. Taylor and W.R. Raun, Oklahoma State University, personal communication, 1997). Because spectral reflectance can be used to assess pasture composition (Haggar et al., 1984), this technology also may allow producers to map areas where differential fertilization of other nutrients (P, K, etc.) is needed.

Optimizing supplies of macro- and micronutrients may have larger economic impacts on perennial forages (Moore, 1996). Recommendations for N already are based on general soil and rainfall conditions in some countries and states. In the United Kingdom, fields are classified into one of five “grass growth classes,” depending on average rainfall in April to September and on soil depth and texture (Baker et al., 1991). Such information could be adapted to the variable soils typically found in permanent pastures. Many fields "near the barn" have a history of repeated manure application; at least one laboratory in Ontario, Canada, recommends grid sampling to determine the extent of high fertility soils (T.W. Bruulsema, Potash and Phosphate Institute, Guelph, Ontario, personal communication, 1996).

Livestock manure. Nutrients can be utilized particularly well when manure applications are made before establishing perennial forages. Schmitt et al. (1993) showed that alfalfa can benefit from preplant manure applications, even when soil test levels of P and K appeared to be adequate. Part of this benefit may arise from N and micronutrients in the manure, or perhaps from other factors not related to nutrient availability. An important caveat is that stands can suffer when application equipment causes soil compaction (Schmitt et al., 1993). Topdressing manure on established alfalfa can reduce stands because of crown damage in wheel tracks, smothering, salt damage, increased competition from grasses, and introduction of weed seeds in the manure. Best results occur when manure is applied within a few days of mowing (Lory, 1993).

As in most states, Vermont recommendations suggest that farmers reduce fertilizer applications to hay fields or pastures based on the estimated availability of nutrients in topdressed manure (Jokela, 1993). These recommendations provide estimates of N availability from organic N contained in topdressed manure, but assume complete loss of ammonium N. About 80% of total manure P and 90-100% of manure K are considered to be available from manure during the first season of application.

Many states consider runoff potential in their manure recommendations. For example, Wisconsin prohibits manure application to any areas where surface water accumulates or flows, such as grassed waterways, terrace channels, or open surface drains (Madison et al., 1995). Many recommendations are soil-specific, regardless of soil test levels. For example, in areas of Wisconsin where soils are underlain by fractured bedrock, the state recommends that no manure be applied on soils less than 20 cm deep, and that applications are limited to 56 Mg/ha or 84 m^3/ha on soils between 20 and 40 cm deep. Arkansas researchers and Extension personnel are promoting site specific application of livestock waste to avoid areas of high runoff potential (C.P. West, University of Arkansas, Fayetteville, personal communication, 1997). This has been based more on landscape features than soil test results to date. Location and management of rotational grazing also is being done in consideration of site specific characteristics. Cumulative effects of manure on soil nutrient status and physical properties suggest that site specific management could yield important benefits.

Minnesota dairy farmer practices

In the USA, there is relatively little information available on a state-wide basis regarding fertility management of perennial forages by dairy farmers. Manure and fertilizer use is known for smaller areas or counties, but this information often relates to practices on corn acres. To learn what practices are being used on dairy farms and what characteristics relate to these practices, I conducted a survey by mail of Minnesota dairy farmers during August and September 1996, generally following the recommendations of Salant and Dillman (1994). The questionnaire was mailed to 1007 Minnesota dairy farmers selected randomly by the Minnesota Agricultural Statistics Service from within a stratified database of operations that had reported milking 30 or more dairy cows. About 10% of the 9357 operations with 30 to 199 head and 48% of the 139 operations with 200 or more head were sent the questionnaire.

A total of 354 surveys were deemed suitable for statistical analysis, representing a 35% return of surveys mailed to farms with less than 200 milking cows (3.6% of all farms in this category) and a 24% return from farms with 200 or more milking cows (11.5% of all farms in this category). Because the sampling intensity varied between these two categories, specific farm characteristics (such as size, productivity, etc.) do not accurately reflect overall conditions in Minnesota. Relationships between farm characteristics and behavior (such as whether or not manure is topdressed on established forages) likewise may be limited to the group of respondents.

I divided the state into three generalized soil areas (Fig. 4A). The Mollisol area is mostly neutral to calcareous soils derived from glacial till or lacustrine sediments and developed under prairie species. The cold Alfisol area is characterized by neutral to acidic glacial till and outwash materials vegetated mainly by brush and by evergreen and deciduous forests; the warm Alfisol area is largely neutral to slightly acidic loess over bedrock or glacial till, which was vegetated by deciduous forest, brush, and prairie. A chi square test indicated that the distribution of responses among these areas (Fig. 4B) was not different than would be expected by random sampling.

Distributions of many individual farm characteristics were skewed, so both the median and mean are presented. After establishing categories for all explanatory variables, I chose to include only the four best significant variables produced by stepwise selection using logistic regression (SAS, 1990). In this paper, I will discuss only the *direction* of effects, rather than the magnitude, since the latter is a more difficult concept with categorical than with continuous variables. As with normal regression techniques, statistical significance among variables does not necessarily imply cause and effect.

Farm size and management. Numbers of cows milked each year ranged from 20 to 400, with a median (P_{50}) of 51 and a mean (x) of 69. Numbers of replacement heifers ranged from none to 300 (P_{50} = 24, x = 34). Rolling herd averages reported by the farmers ranged from 4000 to 11,800 kg milk (P_{50} = 8200 kg, x = 8400 kg). Most farmers also raise steers and heifers, 9% raise swine, some raise sheep and other species, and a few raise up to several hundred thousand poultry.

Dairies ranged in size from about 6 to 600 ha of farmed land (P_{50} = 120 ha, x = 150 ha). The most prevalent perennial forage was alfalfa hay, reportedly harvested on 95% of the farms from between 2 and 120 ha, and grass pasture was the second most prevalent, ranging from 1 to 100 ha on 58% of the farms. Smaller areas of other legume, grass, and mixed grass-legume hay and alfalfa, other legume, and mixed pastures were reported.

Fertilizer and lime management. The percentage of forage land fertilized is greater in the cold Alfisol region of Minnesota, and when farmers use soil tests. In contrast, less forage land is fertilized where manure is topdressed on established alfalfa and on those farms with permanent grass-legume mixtures. Only small numbers of respondents provided estimates of fertilizer rate; therefore, the following relationships between farm characteristics and nutrient application rate should be considered tentative.

About 14% of respondents apply P before seeding perennial forages. Reported rates range from about 5 to 70 kg P/ha (P_{50} = 18 kg P/ha, x = 23 kg P/ha). About 23% of respondents apply K before seeding forages, at rates ranging from 25 to 225 kg K/ha (P_{50} = 112 kg K/ha, x = 116 kg K/ha). Greater amounts of K are incorporated before seeding when farmers get information from fertilizer dealers and from the Extension Service, and as the proportion of fertilized forage land increases. The rate is smaller in the Mollisol region, which has higher native soil K availability than the rest of the state.

Lime is incorporated before seeding perennial forages on about 28% of the farms, with rates ranging from about 0.65 to 17.9 Mg/ha (P_{50} = 6.7 Mg/ha, x = 6.3 Mg/ha). The lowest reported rate was based on using a highly soluble, finely ground lime source. More lime is used on larger farms and when fertilizer rate information is obtained from fertilizer dealers and farming magazines, while less is applied, as expected, to farms in the calcareous Mollisol area.

About 16% of the farmers reported that they apply N fertilizer on alfalfa, with rates ranging from about 5 to 70 kg N/ha (P_{50} = 20 kg N/ha, x = 24 kg N/ha). Application rates were likely to be higher when farmers depended on farming magazines for fertilizer rate information and when greater proportions of forage land are fertilized on a farm. Topdressed N applications on alfalfa are smaller with larger herds. More Minnesota farmers reported that they apply N to established forages when crop species was not mentioned. These farmers apparently topdress N in one or two applications, predominantly in the spring (March-June) (Fig. 5).

Fertilizer P is topdressed at rates ranging from about 5 to 80 kg P/ha (P_{50} = 21 kg P/ha, x = 27 kg P/ha) on 26% of the farms. Phosphorus rates are higher in the Mollisol region, on farms where a large percentage of forage land is fertilized, and when information on fertilizer rates is obtained from the Extension Service.

Nearly one-half (47%) of Minnesota dairy farmers topdress K on alfalfa. Reported rates range from about 15 to 390 kg K/ha (P_{50} = 128 kg K/ha, x = 139 kg K/ha). Relatively little variation in applied K could be explained by farm characteristics, but rate tends to increase with the relative importance of manure pack in livestock housing and decreases with the relative importance of daily or frequent hauling. Presumably the practice of K application to established alfalfa has been adopted by farmers with a wide variety of dairy operations.

Topdressed S is applied to alfalfa by about 10% of dairy farmers, and about 5% apply topdressed B. Sulfur rates range from about 7 to 100 kg S/ha and B rates range from 1 to 5.5 kg B/ha. Fertilizers other than N are applied almost entirely during the growing season (Fig. 5) and are spread all at once or in a simple split. Applications tend to be later than N, and a significant number of farmers apply non-N fertilizer in September and October.

Farmers were asked to include results of a recent soil test, but only 21% of the respondents provided soil pH, extractable soil P, and exchangeable K. Nearly all of the soil tests reportedly were taken from alfalfa fields (Fig. 6). About 17% of these tested fields were more acidic than pH 6.5, which is the minimum soil pH recommended for alfalfa in Minnesota (Rehm et al., 1994). Tests may have been taken in preparation for seeding alfalfa, in which case lime may have been added after receiving the test results. However, farmers should be made aware that soil pH is an important factor in maximizing alfalfa yield and persistence.

Almost 80% of the reported soil tests were in excess of 20 mg P/kg, above which no additional P is recommended by the University of Minnesota, and several tests exceeded 120 mg P/kg. Higher soil P levels were associated with manure storage in a pack and with higher percentages of forage land that was fertilized. Lower soil P concentrations are characteristic of farms in the Mollisol region and occurred on farms with daily or frequent haul manure systems. About one-half of the reported soil K tests were greater than 160 mg K/kg, the level at which no K fertilizer is recommended. Soil K concentrations were related positively to pack and lagoon manure storage systems, with increasing proportion of forage land fertilized, and with increasing acreage of permanent grass forages. Pack and lagoon manure handling systems tend to conserve K, which is excreted in urine.

It appears from these results that many Minnesota dairy farmers apply commercial fertilizer to alfalfa and other forages. To some extent, the results indicate that native soil characteristics are taken into account when making decisions on liming and nutrient addition, but the large number of high P and K soil tests confirm reports that these nutrients are often in excess on contemporary farms (Lanyon, 1992). Established stands of alfalfa rarely respond to N addition, except when soil pH is low or when nonlegumes have become dominant. It is not clear from this survey whether either of these was the case, whether N was simply part of the fertilizer mix sold to the farmers, or whether N actually was desired or recommended.

Manure management. Farmers were asked to describe their manure management systems. The two systems ranked as most typical were daily or frequent hauling and lagoon storage of liquid manure (Fig. 7). Dairy farmers apparently rely more on daily or frequent manure hauling in the warm Alfisol area of the state, as the percent of forage land that is fertilized increases, and as fertilizer dealers serve as more important sources of information on nutrient needs. This latter point also might be interpreted that farmers who rely on daily or frequent hauling are less likely to employ independent consultants than to rely on personnel at the fertilizer distributor. Daily hauling is less likely as alfalfa land area increases.

Reliance on lagoon storage of liquid manure is more likely as herd size and rolling herd average increase, and is less likely in the warm Alfisol region and when information is obtained from farming magazine articles. Other manure handling systems rarely were listed as most typical, but were employed on many farms (Fig. 7). Overall, Minnesota dairy farmers reported that manure storage facilities need to be emptied an average of twice a year, with a range of 1 to 26 times per year.

About one-half (53%) of the respondents reported that they apply manure on perennial forages. These dairy farmers are more likely to spread manure before seeding perennial forages when the typical manure source is manure pack in livestock facilities. Manure application either before seeding or as a topdressing on established forage stands is more likely when the farms have larger herds and are in the cold Alfisol area of state. Farmers are less likely to apply manure to perennial forages when a larger percentage of their forages received commercial fertilizer. This implies that farmers are distributing manure and fertilizer nutrients to the various crops grown on the farm, and substituting one for the other to some extent. Topdressing manure is less likely the more farmers rely on independent consultants for information on recommended fertilizer rates. Topdressing manure on established grasses is less likely at higher rolling herd averages.

Although the question was not specifically posed, about 7% of all respondents said they routinely apply manure to old forage stands before rotating to the next crop. Farmers should recognize that, although these old fields are handy places to apply manure, this practice may be environmentally detrimental, if N fertilizer rates to the following crop are not reduced based on reasonable N credits for the manure and the previous forage crop (Lory et al., 1995).

Only 41% of those who apply manure to forages (at any time) answered the question about whether they reduced subsequent N, P, or K fertilizer additions after manure application, and 87% of these replied “yes.” Over two-thirds of these asserted that they reduced application of all three nutrients, while the remainder reduced application of one or two of these nutrients.

About 10% of the respondents indicated that they topdressed at least a portion of their manure on forages during winter (Fig. 5), but at least twice as many spread manure only during the growing season. Spreading manure on frozen soil can lead to serious surface water contamination during snow melt or early spring rains. Farmers should be aware of this potential problem, and select fields for winter spreading to reduce the chance of runoff.

The most frequently given reasons in support of topdressing manure on established perennial forages included the opportunity to spread manure in summer and to make good use of nutrients (Table 1). In contrast, at least 20% of the respondents said that lack of time, lack of uniformity in spreading manure, increased weed problems, and lack of manure (due to use on other crops) were reasons for *not* topdressing manure on all perennial forage fields.

Information sources. When asked what their regular sources of information on recommended fertilizer rates were, over 60% of the respondents reported that they use soil test results as one form of information (Fig. 8). Nearly one-half of the respondents reported that they depend on personnel from fertilizer dealerships for nutrient recommendations. Minnesota dairy farmers rely more on fertilizer dealers when they have more grass pasture, typically use a daily or frequent haul system for manure, and fertilize a higher proportion of their forage land. However, those who said pasturing their livestock is a typical way of managing manure are less likely to depend on employees of a fertilizer dealership for fertilizer recommendations. Similarly, farmers are more likely to use information from independent crop consultants when they fertilize a larger proportion of their forage land, but also when they have larger herds. Those dairy farmers who spread manure on established forage stands are less likely to use an independent crop consultant for fertilizer recommendations.

About one-half (56%) of farmers using soil test results do not rely on other sources of information for nutrient management decisions. For the remainder, soil tests appear to be interpreted mostly using information from personnel at fertilizer dealerships (61%), with far fewer farmers relying on private consultants (24%), Extension (16%), or farming magazine articles (16%) for help in interpreting these tests. Of those farmers who rely on fertilizer dealers for nutrient management recommendations, 15% also use independent consultants, 12% use Extension, and 21% use farming magazines as other, and sometimes primary, sources of information. Only a small proportion of those who rely on independent consultants get nutrient management information from Extension (3%) or farming magazines (6%). Although Extension does not appear to be a primary source of nutrient management information for many Minnesota dairy farmers, it is part of the mix of information sources for about 11% of the respondents. Many farmers who rely on Extension (37%) also get information from farming magazine articles.

CONCLUSION

Better knowledge of on-farm forage fertilization practices is needed to direct our future research and education efforts. As with all research, results of this survey should be verified by follow-up work in Minnesota and other states, and other areas where temperate forages are grown. This survey has helped establish some of the relationships among farm characteristics and farmer behavior. It confirms earlier reports that many dairy farms have high soil test levels for P and K. Very high soil P concentrations may be reason to limit application of manure on these fields, in order to preserve or improve surface water quality. At the same time, improved awareness of nutrient needs should increase the yield, persistence, and quality of perennial forages and improve the viability of livestock farming. Because fertilizer dealers are the most important source of nutrient recommendations to dairy producers in Minnesota, providing them with the latest information on nutrient management likely will result in the most rapid transfer of this information to farmers.

ACKNOWLEDGMENTS

I never realized how much work a survey of farm practices would be. Initial drafts of the survey instrument and cover letter were vastly improved by critical reviews by Michael Schmitt, Bruce Montgomery, Keith Kelling, Craig Sheaffer, Tom Bruulsema, Harold Reetz, Peter Nowak, and Regula Russelle. I am particularly grateful for the time and effort that six farmers (Jack Miller, Joe Molitor, Dick Popp, Vernon and Jack Quaal, and Doug Young) provided in reviewing the survey instrument, and for the many farmers who completed and returned the survey. George Howse, Deputy State Statistician for the Minnesota Agricultural Statistics Service, provided enthusiastic support and firm guidance in conducting the survey. Discussions with Gian Trepp stimulated some of the analyses. Thanks, too, to Karena Schmidt, who helped stuff hundreds of envelopes, and provided nearly error-free data entry and good humor throughout the project. The farm survey research was partially funded by the Foundation for Agronomic Research. I also appreciate the responses I received from many public soil testing laboratories to my questionnaire.

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Figure 1
Percentage of soil tests for which recommendations are requested for forage crops (as the first or only crop choice), according to a 1996 survey of state soil testing laboratories. Four classes of response are indicated: 0-14%, 15-29%, 30-44%, and >44%. Humid climates are found in the eastern one-half and along the West Coast, and are approximately delineated by the North-South lines.

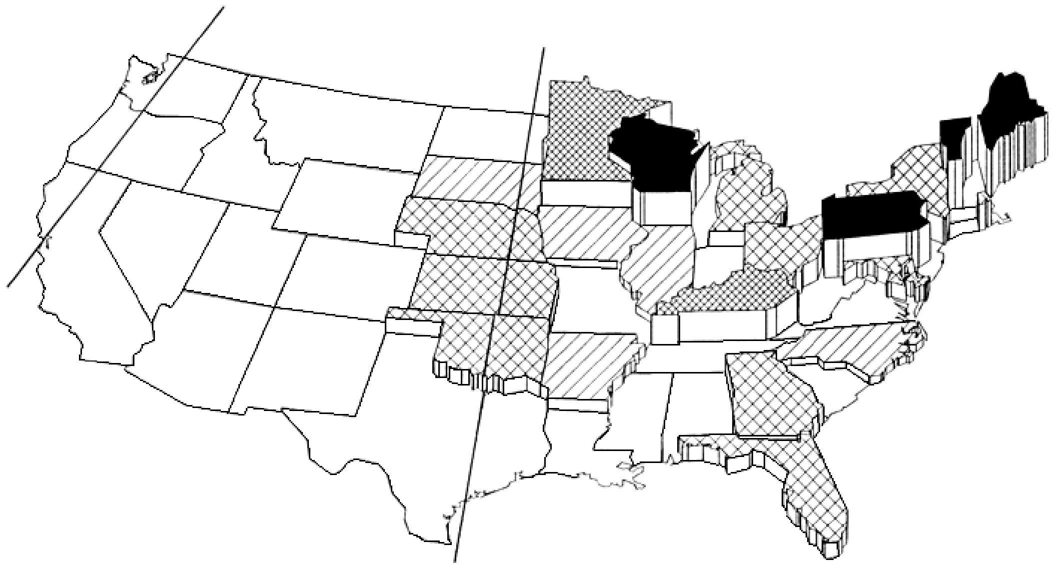

Figure 2
Relationship between the proportion of land in hay crops versus all cropland and the proportion of soil samples from forage fields to all soil samples analyzed in 21 public soil testing laboratories in the USA (USDA-National Agricultural Statistics Service, 1994; and results of a 1996 survey by the author).

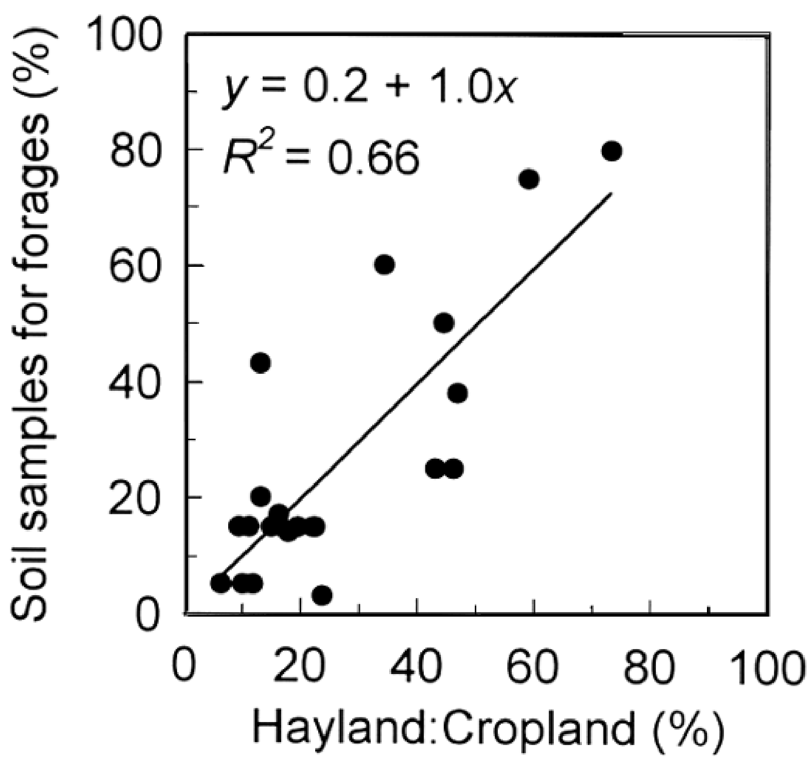

Figure 3

Estimated K_2O recommendations for a yield goal of 13.4 Mg/ha in established, nonirrigated alfalfa on a soil testing 100 mg K/kg. Some values are from Brown (1996). The three rate increments indicated are 0-149 kg/ha (light shading), 150-299 kg/ha (medium shading), and >299 kg/ha (dark shading). Example rates are 45 (Nebraska), 90 (Oklahoma), 200 (North Carolina), 335 (Missouri), and 450 kg K_2O/ha (Illinois). Humid climates are found in the eastern one-half and along the West Coast, and are approximately delineated by the North-South lines.

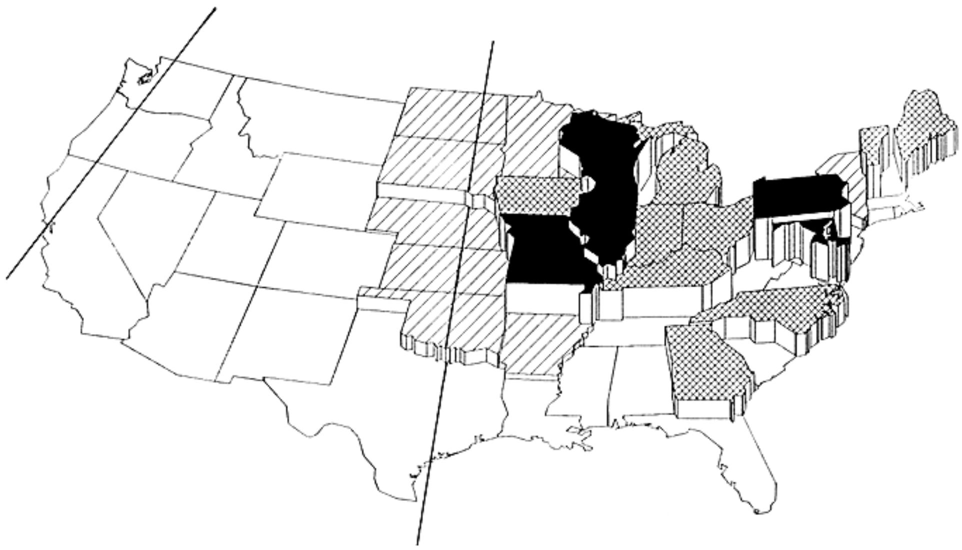

Figure 4

A. Three generalized soil areas of Minnesota, delineated by county boundaries: the Cold Alfisol region (no shading); the Warm Alfisol region (darkest shading); and the Mollisol region (medium shading). B. Survey return rate by county: 0 (no shading); 1-5 farms (light shading); 6-15 farms (medium shading); and >15 farms (darkest shading).

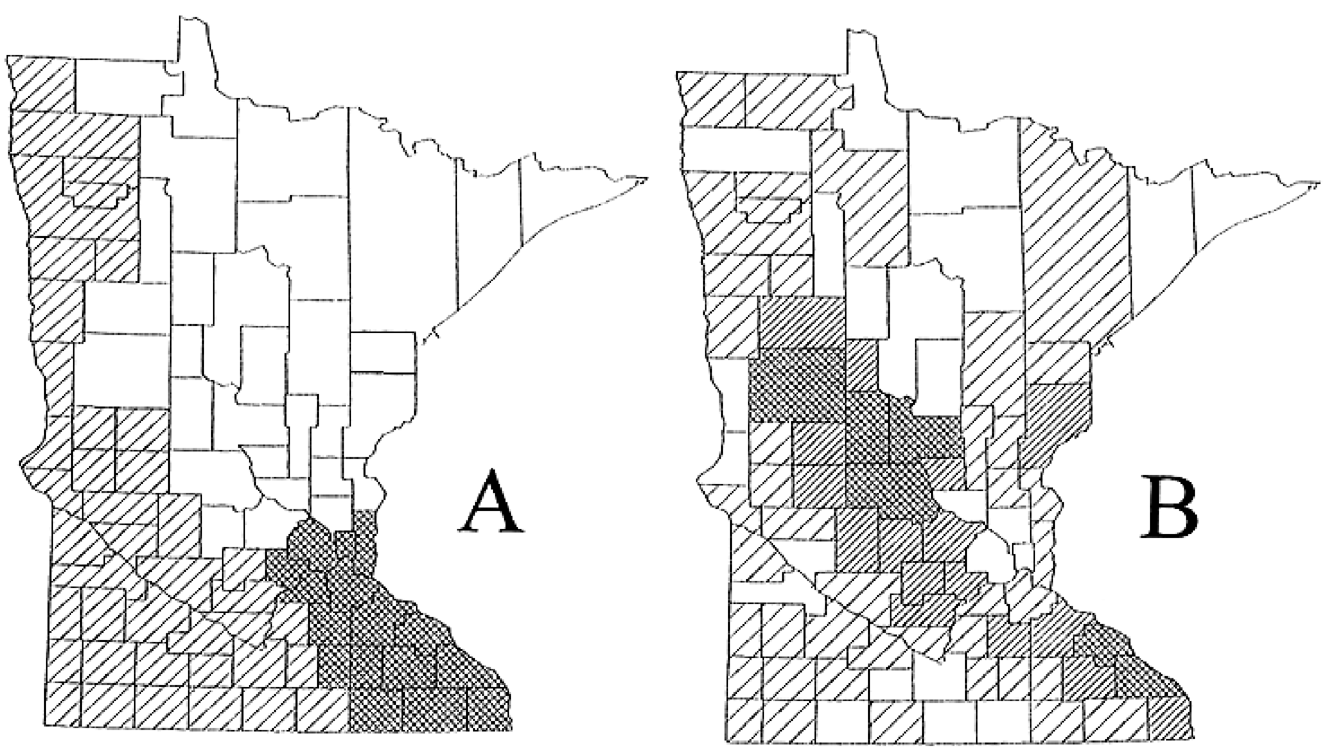

Figure 5

Percent of total manure or fertilizer applied as a topdressing to established forages on Minnesota dairy farms during two-month periods of the year. Midpoints of each interval are indicated. Daily or frequent manure hauling is represented by the 10-20% interval; application of all fertilizer or manure within a two-month period is indicated by the 90-100% interval. Total number of respondents in each case is noted. Results of a 1996 survey, with 354 valid returns.

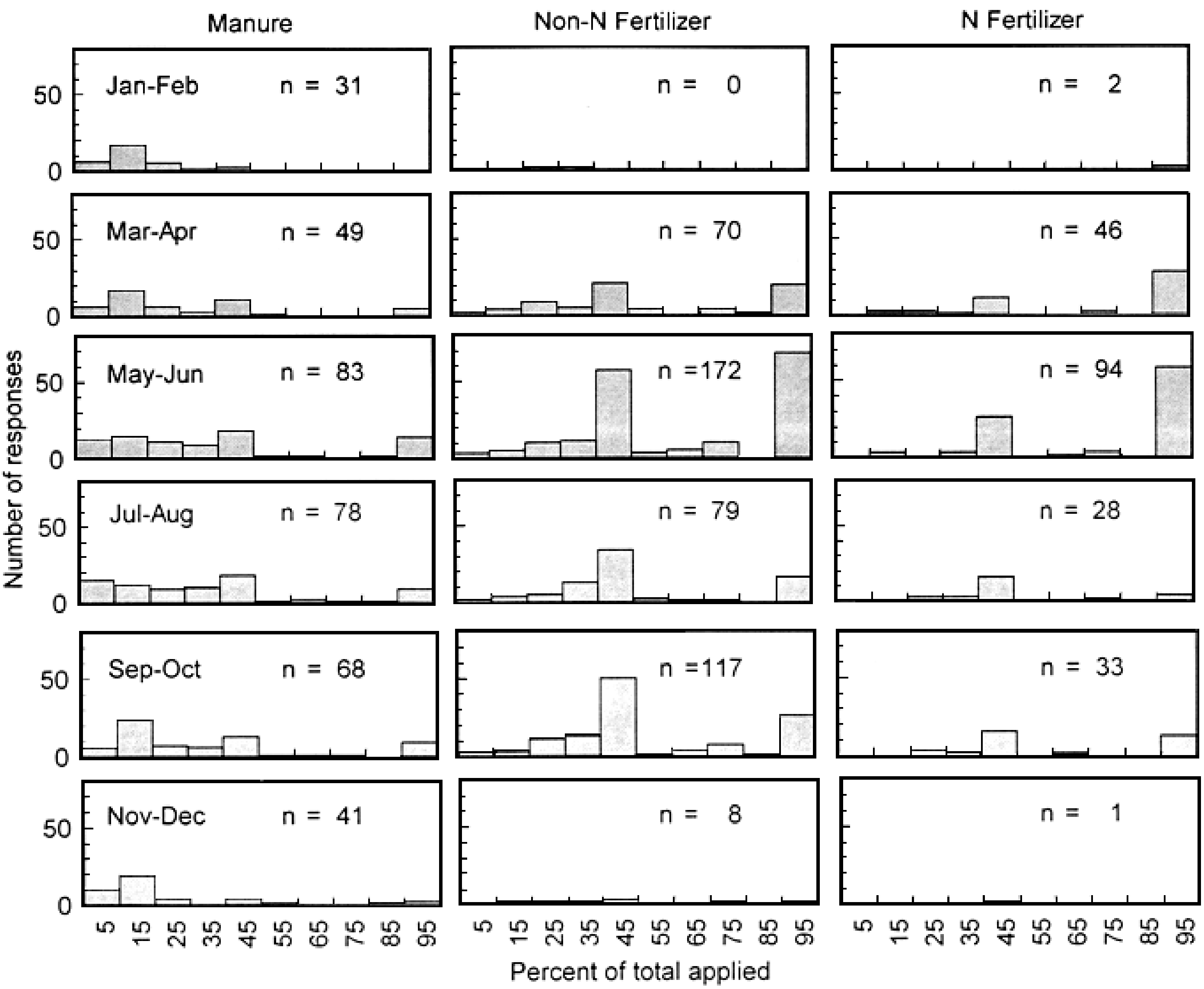

Figure 6
Soil test results as reported by Minnesota dairy farmers in a 1996 survey. Midpoints of each interval are indicated, with the median (P_{50}) and mean (x) of the distributions. Valid survey returns totaled 354.

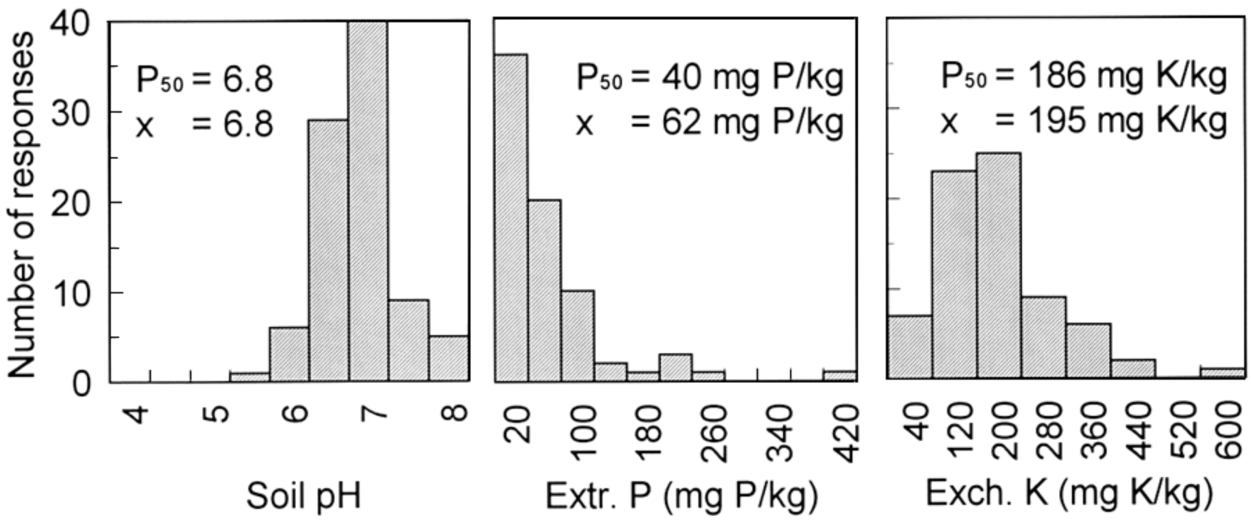

Figure 7
Primary, or most typical, (dark bars) and secondary (gray bars) types of manure management used on Minnesota dairy farms. Results of a 1996 survey, with 354 valid returns.

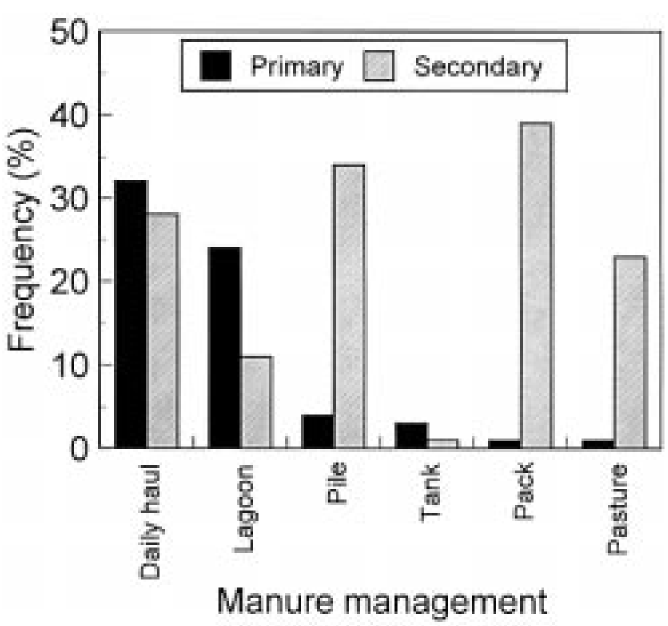

Figure 8
Sources of information on fertilizer recommendations on Minnesota dairy farms. Dark bars represent the sources the respondents said were most important; gray bars represent other regular sources of information. Results of a 1996 survey, with 354 valid returns.

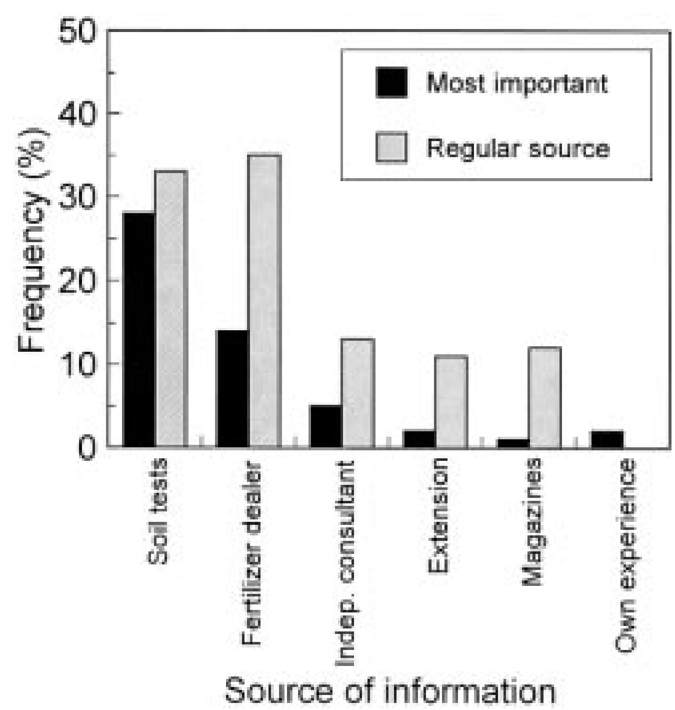

Table 1
Reasons given by Minnesota dairy farmers for topdressing livestock manure on established perennial forages, and reasons for not doing so on all available fields. Results of a survey conducted in summer 1996. Multiple answers were accepted for both questions.

Reason given	**Frequency of response (%)**
For topdressing manure:	
Opportunity to spread manure during summer	25
Good place to use nutrients	25
Need to empty manure storage	11
Fields are close to manure storage	8
For not topdressing all fields:	
Lack of time	30
Lack of uniformity in spreading manure	27
Increased weed problems	23
Manure is used on other crops	21
Fields are not close enough	16
Manure or traffic damages the stand	10
Neighbors are too near	3
Surface water quality may be impaired	2
Decreased feed quality	6