6-15-1996

Feasibility Exploration: "Perfectly" Integrated Crop-Livestock Production

Donald Taylor
South Dakota State University

Diane H. Rickerl
South Dakota State University

FEASIBILITY EXPLORATION: "PERFECTLY" INTEGRATED CROP-LIVESTOCK PRODUCTION

DONALD C. TAYLOR AND DIANE H. RICKERL*

ECONOMICS RESEARCH REPORT 96-1

JUNE 1996

*Donald C. Taylor and Diane H. Rickerl are Professors of Agricultural Economics and Plant Science, respectively; South Dakota State University, Brookings, S.D.

FEASIBILITY EXPLORATION: "PERFECTLY" INTEGRATED CROP-LIVESTOCK PRODUCTION

LIST OF TABLES and FIGURES

ACKNOWLEDGMENTS

We wish to thank (1) the eight South Dakota cow-calf producers who provided information about their farms/ranches that was used in the research covered in this report; (2) Larry Janssen, Agricultural Economist, and James Smolik, Plant Scientist--both at SDSU--for their very helpful review comments on an earlier draft of this manuscript; (3) Verna Clark for her competent typing of the tables; and (4) the South Dakota Agricultural Experiment Station for the funds required to undertake the research reported in this study. While acknowledging that the reactions of the manuscript reviewers were insightful and constructive, we accept responsibility for any errors of fact or interpretation that may remain in the report.

Donald C. Taylor   Diane H. Rickerl

June 25, 1996

FEASIBILITY EXPLORATION: "PERFECTLY" INTEGRATED CROP-LIVESTOCK PRODUCTION

Donald C. Taylor and Diane H. Rickerl

SUMMARY AND CONCLUSIONS

In this research report, the following question is examined. Can individual integrated crop and cow-calf operations be simultaneously "balanced" from the standpoints of (1) amounts of manure produced "matching" (plus or minus 10%) the soil fertility needs of producers' cropland and rangeland and (2) amounts of feedgrains and roughages produced matching (plus or minus 10%) the nutrient needs of producers' livestock? Answers to the question were sought through examination of livestock manure production and utilization and livestock feedstuff production and consumption on eight South Dakota integrated crop-livestock case farms.

On-farm livestock manure production and utilization

In examining livestock manure production and utilization, (1) amounts of nitrogen (N) and phosphorus (P) available to crops and grass in the manure produced by livestock on the respective case farms at the time of application to cropland and rangeland were estimated and then compared with (2) estimated amounts of N and P required to meet the fertility needs of the crops and rangeland grasses produced on the respective case farms.

Livestock manure N and P production. Estimating plant-available N and P in livestock manure involved taking into joint account (1) amounts of solid manure ("spreader dry matter") available for application to farmland, from different categories and weights of cattle and hogs, during periods of time within a year that animals are present in farmers' herds; (2) proportions of total manure available for application to farmland assumed to be scraped, collected, and spread on cropland versus dropped on rangeland; (3) N and P nutrient content of manure produced by cattle and hogs; and (4) percentages of total N and P present in manure assumed to be available for plant use. Values for these parameters--based on reviews of literature--were applied to the animals comprising the cow herds and supplementary livestock enterprises on the respective case farms.

Estimated whole-farm livestock manure N produced on the eight case farms available for use by plants on cropland ranges from 0.91 to 4.25 tons/farm and averages 2.35 tons/farm. Analogous data for rangeland manure N are a range of 2.19 to 15.43 tons and an average of 7.53 tons. Thus, the average whole-farm amount of N available for grass on rangeland is 3.2 times as much as the average whole-farm amount of N for various crops on the farms. Amounts of plant-available N as ratios to plant-available P in livestock manure produced on the various case farms (i.e., "N-to-P ratios") range from 2.32 to 2.40.

Crop and grass production N and P needs. The fertility needs of crops and rangeland grasses produced on the respective case farms were estimated with yield and acreage information from case farmers and "fertilizer recommendation" equations and tables from Gerwing and

Gelderman (1996, pp 3-16), with attention to legume N credits to crops following alfalfa. Because farmer-specific information on (1) yield goals against which to fertilize and (2) farmland soil test nitrogen (STN) and phosphorus (STP) levels were not obtained from individual case farmers, two yield goals regarding cropland N fertility needs (namely, 1.0 and 1.25 times 1993 yields, adjusted for abnormal weather conditions that year) and two STP levels ("medium" and "low") were examined. Similarly, two residual STN levels for rangeland were examined ("STN = 0" and "STN = 20 lb/acre").

Two types of analysis were undertaken. In the "baseline" analysis, (1) stipulated proportions of total livestock manure produced were assumed to be applied to cropland versus to rangeland and (2) livestock manure was assumed to be applied to only those crops for which fertilizer is normally applied. In a follow-up "threshold" analysis, restrictions on the allocation of manure between cropland and rangeland were removed and any manure not needed for fertilizing crops was allowed to be applied to CRP and fallow land. The threshold analysis was undertaken to explore possibilities for manure produced in excess of farmers' crop and grass production fertility needs to be managed (without processing) so as not to become a possible threat to the farmers' soil and water quality.

Estimated per-acre N and P needs determined through the above considerations were multiplied by the respective acreages of each crop and the rangeland operated by the respective case farmers. Resulting from these calculations was determination of the estimated total whole-farm N and P needs for crop and grass production for the various yield goal, STP, and STN conditions for each case farmer.

On-average for the eight case farms, baseline per-acre **cropland** N needs for farmers with yield goals of 1.25 times ("1.25 YG") their "1993" yield-levels are 54% greater than for farmers with yield goals just equal to "1993" yields ("1.0 YG"). Case farmers with low STP levels on-average require 63% more P to meet crop fertility needs as farmers with medium STP levels. On-average, whole-farm **rangeland** N needs for farmers with "STN = 0" are 3.33 times those for farmers with "STN = 20 lb/acre." The eight case farmers with low STP levels require on the average 2.17 times as much P to meet crop fertility needs as farmers with medium STP levels.

Farmland N-to-P need ratios differ greatly among farmers depending on individual farmers' (1) yield goals against which fertilization levels are determined; (2) soil test nitrogen and phosphorus levels; (3) fertilization needs for cropland versus for rangeland; and (4) for cropland, particular combinations of crops raised. For example, N-to-P need ratios are highest for rangeland under the condition of "STN = 0" and a medium STP (ranging among the eight farms from 4.73 to 7.10 and averaging 5.41) and lowest under the condition of "STN = 20 lb/acre" and a low STP (range = 0.44 to 1.53; average = 0.75). Cropland N-to-P need ratios are generally intermediate in magnitude.

"The match" between manure production and utilization. Under the baseline analysis, whole-farm N needs on-average for the eight farms with **cropland** N "1.25 YG" are 5.1-fold whole-farm N production. Under cropland N "1.0 YG," the manure N need-production difference is 3.3-fold. On-average for the eight farms and under a low STP cropland level, whole-farm P needs are 5.7-fold whole-farm P production. Under a medium STP cropland level, the manure P need-production difference is 3.5-fold.

On-average for the eight farms with **rangeland** "STN = 0," whole-farm N needs are 2.7-fold whole-farm N production. Under "STN = 20 lb/acre," however, the manure N need is 20% less than manure N production. On-average for the eight farms with a low STP rangeland level, whole-farm P needs are 2.6-fold whole-farm P production. Under a medium STP cropland level, the manure P need is 18% more than manure P production.

Thus, current manure N and P needs on-average for the eight farms generally exceed current manure N and P production, with margins of difference greater for cropland than for rangeland. Under one rangeland condition considered ("STN = 20 lb/acre"), the current average manure N need for grass production for the eight farms is less than that for manure currently dropping on rangeland.

Under the threshold analysis, estimated whole-farm amounts of N needed on-average for the eight farms are 3.7% to 9.4% more, and whole-farm amounts of P needed are 6.3% to 7.4% greater than for corresponding conditions under the baseline analysis.

If total estimated manure production was either less or more than total estimated crop and grass production fertility needs under particular yield goal and soil test conditions, sensitivity analysis was undertaken to determine how much the farm's livestock population could be expanded or would need to be contracted until its manure production would just match its crop and grass production fertility needs.

Numbers of cows that would allow whole-farm manure production to be matched with current whole-farm manure N and P needs under each case farm N and P situation examined vary widely, depending on the crop and grass nutrient need criterion. For example, under the baseline analysis, Northwest Farmer 1 would need only 66 cows to meet his rangeland N need under "STN = 20 lb/acre," but would require 13.1 times as many (863) cows to meet his crop production manure N needs under the cropland N "1.25 YG" criterion. This margin of difference is least for Northwest Farm 2. But even for it, 5.5 times as many cows are required under a rangeland low STP condition as under a rangeland "STN = 20 lb/acre" condition. Under the threshold analysis, these margins of difference are less (ranging among the six conditions examined from 1.8 to 5.6), but are still substantial.

On-farm livestock feedstuff production and consumption

To assess livestock feedstuff production-consumption balances, amounts of total digestible nutrients (TDN) (1) produced on the case farms and (2) required by the livestock on the respective farms were first estimated and then reconciled with each other.

Crop and grass TDN production. To determine the tons of TDN produced on each case farm, acreages of crops (including alfalfa) and grass raised on each farm were multiplied by (1) various crop and grass yields obtained by the respective farmers and (2) amounts of TDN contained per unit of production for each type of crop and grass raised. Separate attention was given to produced TDN in livestock feedstuffs versus in cash crops.

Average estimated total TDN production for the eight farms is 832 tons per farm, 66% of which is in the form of potential livestock feedstuffs grown on cropland, 19% cash crops, and 15% rangeland grass. On individual farms, total TDN production ranges among farms from 645 tons to 1,186 tons.

While rangeland accounts for 62% of total farmland acreage, it accounts for only 15% of TDN produced. TDN production is far more intensive on cropland used for producing livestock feedstuffs (18% of total acreage contributes 66% of total TDN produced) than on cropland for producing cash crops (11% of total acreage contributes 19% of total TDN produced).

Livestock TDN and protein requirements. Annual TDN and protein requirements for various types of cattle in the herd of each case farmer were determined according to (1) weights of mature breeding cattle and average weights over respective feeding periods for growing cattle, (2) rates of gain, and (3) numbers of days on feed for each producer's mature brood cows, herd sires, replacement heifers, backgrounded animals, and finishing steers.

Estimated whole-farm livestock TDN requirements range among farms from 131 tons to 673 tons and average 350 tons. On average, brood cows require 71% of total TDN, replacement heifers 17%, herd sires and hogs 4% each, and backgrounded cattle and slaughter cattle 2% each.

"The match" between livestock feedstuff production and consumption. In determining the match between amounts of TDN in (1) livestock feedstuffs produced and (2) feedstuffs required by livestock on the respective farms, the following general strategy in formulating rations was pursued. Livestock TDN requirements were met first through rangeland and crop residues. Once grazing resources were exhausted, TDN needs were assumed to be met first by corn and/or sorghum sudan silage and then by various types of hays. Unless cattle protein needs were unfulfilled with native hay, millet hay, and oat hay, the supplies of these hays were used up before alfalfa hay was assumed to be used.

In meeting whole-farm livestock nutrient needs, all corn and sorghum sudan silage and all oat and millet hay produced on the case farms were found to be fed to livestock on the farms. On two of the four farms producing native hay, all the hay produced is fed. On one of the eight farms producing alfalfa hay, all alfalfa produced is fed. One farmer feeds only 50% of his native hay produced and two farmers feed as little as 14% of the alfalfa they produce. In general, percentages of home-raised grains produced fed to farmers' own livestock are lower than for home-raised roughages.

The percentage of TDN in total home-raised livestock feedstuffs produced fed to farmers' own livestock ranges among farms from 25% to 81% and averages 60%. The average percentage of feedstuffs produced fed to farmers' own livestock is much higher for grass (98%) than for crops (51%).

On-farm balance between livestock manure production-utilization and livestock feedstuff production-consumption

In reconciling case farm manure and feedstuff balances, "tons of TDN per cow" required to meet total whole-farm livestock nutrient needs on each farm were determined. Tons of TDN that would be required for herd sizes determined to be just matched in manure production-utilization under various yield goal, STN, and STP conditions were estimated. These tonnages of TDN required to meet livestock nutrient needs were compared with tonnages of TDN in livestock feedstuffs currently produced on each of the eight farms.

Particular attention was given to whether the respective tonnages were approximately equal (within 10% of each other). If so, the manure production-utilization balance would be interpreted to be balanced with the feedstuff production-consumption. This analysis was repeated for each of the eight baseline conditions and each of the six threshold conditions considered in the study.

In 4 of the 64 (6%) baseline analysis situations (eight baseline conditions for eight case farms), the herd size allowing for matched manure production-utilization simultaneously allows for matched (plus or minus 10%) feedstuff production-consumption. Each such instance involves rangeland. However, no case farm matched in manure production-utilization and in livestock feedstuff production-consumption on rangeland is simultaneously matched in a similar way on cropland, thus resulting in "perfect ecological balance."

In 6 of the 48 (12%) threshold analysis situations, the herd size allowing for matched manure production-utilization simultaneously allows for matched (plus or minus 10%) feedstuff production-consumption. Five of these situations involve nitrogen, and one phosphorus. However, no one farm is simultaneously balanced for both nitrogen and phosphorus.

Assumptions and limitations

Assumptions for the following items were common for all eight case farms: (1) manure production rates per 100 lb of liveweight for beef cattle and per day for hogs; (2) proportions of manure assumed to be spread on cropland versus dropped on rangeland (this assumption was relaxed in the post-baseline "threshold" analysis); (3) manure N and P nutrient content; (4) percentages of total manure N and P applied assumed to be available to crops and grasses produced; (5) manure "dry matter" at the time of its application to farmland; (6) TDN content in produced feedstuffs; (7) TDN requirements of various types of cattle and hogs; and (8) storage, shrinkage, and feeding losses for various feedstuffs.

Case farmers were also assumed to follow sound management practices in handling, storing, applying, and incorporating manure in their farming operations. Manure was assumed to be applied uniformly over all cropland receiving spread manure applications and to drop uniformly over all rangeland in the respective farming operations. Further, all case farmers were assumed to meet livestock TDN requirements first through rangeland and crop residues; second by corn and/or sorghum sudan silage; third by native hay, millet hay, and oat hay; and fourth by alfalfa hay--subject to TDN requirements for animals at certain critical growth and reproductive stages being met by grains and supplemental protein sources.

While these assumptions are somewhat unrealistic, research resources were inadequate to permit gathering and use of farmer-specific information on these variables. Thus, this study must be considered as a "feasibility exploration," not as a report of "definitive research results."

Conclusion

Results from this study of eight case farms show no situation in which a case farm is either balanced (plus or minus 10%) for both livestock manure production-utilization on cropland and rangeland and livestock feedstuff production-consumption with (1) its current farmland acreage and livestock population, or (2) simulated contracted or expanded livestock populations and current farmland acreages in which livestock manure production-utilization is in just matched. The primary explanation underlying this conclusion is a very low probability of the N-to-P ratio in the livestock manure produced on a farm being identical with the N-to-P ratios needed in manure for spreading on cropland and manure dropped on rangeland. Thus, while the notion of crop and livestock nutrient requirements being met internally on diversified farms is desirable, it appears that full realization of the concept in particular current real-world farm situations is difficult. If current basic farming systems were altered rather dramatically, however, it is conceivable that livestock manure production-utilization and livestock feedstuff production-consumption could be brought into balance with one another.

Although these results are somewhat discouraging relative to closing of the nutrient cycle on the farms studied, they do indicate positive possibilities for meeting the goals of decreased risk of water quality degradation and decreased off-farm nutrient inputs.

In dealing with these inherently complex issues, we encourage creative use of nutrient budgets to further evaluate agroecosystems and identify areas for improvement patterned after studies such as the following. Complete nutrient budgets for Australian agroecosystems containing legumes as a major component showed closely balanced systems and the importance of balancing nutrients on a farm basis (Loomis and Connor, 1992). In Central America, Berish and Ewel (1988) achieved the natural ecosystem function of nutrient cycling by replacing naturally occurring species with morphologically similar food crops. Approaches which mimic natural ecosystems have also been investigated in the U.S. Researchers at the Land Institute in Kansas are using the prairie as a model for agriculture in the Midwest (Soule and Piper, 1992). This includes the use of perennial grains and polycultures to couple plant and animal interactions and complete nutrient cycles. Regardless of the approach taken, the next step is to study and develop agroecosystems which tighten the nutrient cycle.

FEASIBILITY EXPLORATION: "PERFECTLY" INTEGRATED CROP-LIVESTOCK PRODUCTION

Donald C. Taylor and Diane H. Rickerl

INTRODUCTION

The notion that integrated crop and livestock operations are generally more ecologically sound than operations specialized in only crops or in only livestock is well-established in the literature (Baker and Raun, 1989, pp 120-122; Caneff, 1993, p iii; Koepf, 1985, pp 34-35; Power and Follett, 1987). Baker et al. (1990, p 37) describe the essence of the crop-livestock ecological relationship as follows:

> The interaction of animals and plants with the nonliving parts of the environment such as soil and climate creates an ecosystem. If the ecosystem involves primarily domesticated animals and plants under human management or direction, it is called an agroecosystem... There is both competition for and synergism in the use of resources in agroecosystems. In many instances a stable or sustainable biotic community (a balance among animals and plants) is established. This balance involves the cycling of carbon, nitrogen, and mineral matter and the flow of energy through the soil, plants, and animals. Surplus plant material becomes food for animals, and animal wastes or by-products become plant food material.

While the nature of a "sustainable biotic community" can be readily grasped conceptually, determining what is represented empirically in such a community is rather challenging. Odum (1984) presents structural and functional differences between natural ecosystems and agroecosystems. Nutrient cycles in a natural system are closed, while nutrient cycles in agroecosystems are open or linear rather than cyclic. Closing the nutrient cycle in agroecosystems offers the following benefits: decreased risk of water quality degradation, increased soil quality, and decreased off-farm nutrient inputs (Altieri, 1995).

Soil and water management is often viewed as "resource management." Environmental concerns relative to agricultural resource management need to be dealt with at a farm/field scale (Shuyler (1994) and sometimes even at a smaller scale (Kincheloe, 1994). This report is devoted to an empirical exploration of the feasibility of the nutrient requirements for crop and livestock components of individual farms/ranches being met internally.

The specific research question examined is the following: Can individual integrated crop and cow-calf operations be simultaneously "balanced" from the standpoints of (1) amounts of manure produced "matching" (plus or minus 10%) the soil fertility needs of producers' cropland and rangeland and (2) amounts of feedgrains and roughages produced "matching" (plus or minus 10%) the nutrient needs of producers' livestock? Research resource limitations constrained the exploration to an examination of manure-feedstuff balances--not a formal investigation of carbon, nitrogen, mineral, and/or energy cycling--on eight South Dakota farms/ranches.[1]

---

[1]While beef cattle are produced on each case farm studied, the production units are heretofore described simply as "farms," rather than as "farms/ranches."

RESEARCH METHODOLOGY

Case farm selection

The research project underlying this article was originally designed to explore possibilities for "organic" beef production in South Dakota. Organic beef production was defined in terms of organic beef standards available as of June 1993 from eight organic certification "sources" (Taylor et al., 1996). One was represented by the broad standards specified in the Organic Food Production Act of 1990 (OFPA). Two were statements of standards considered by the National Organic Standards Board (NSOB) in charge of implementing OFPA. The other five involved then current standards for five private organic certification agencies: California Certified Organic Farmers (CCOF), International Federation of Organic Agriculture Movements (IFOAM), Northern Plains Sustainable Agriculture Society (NPSAS), Organic Crop Improvement Association (OCIA), and Organic Food Producers Association of North America (OFPANA).

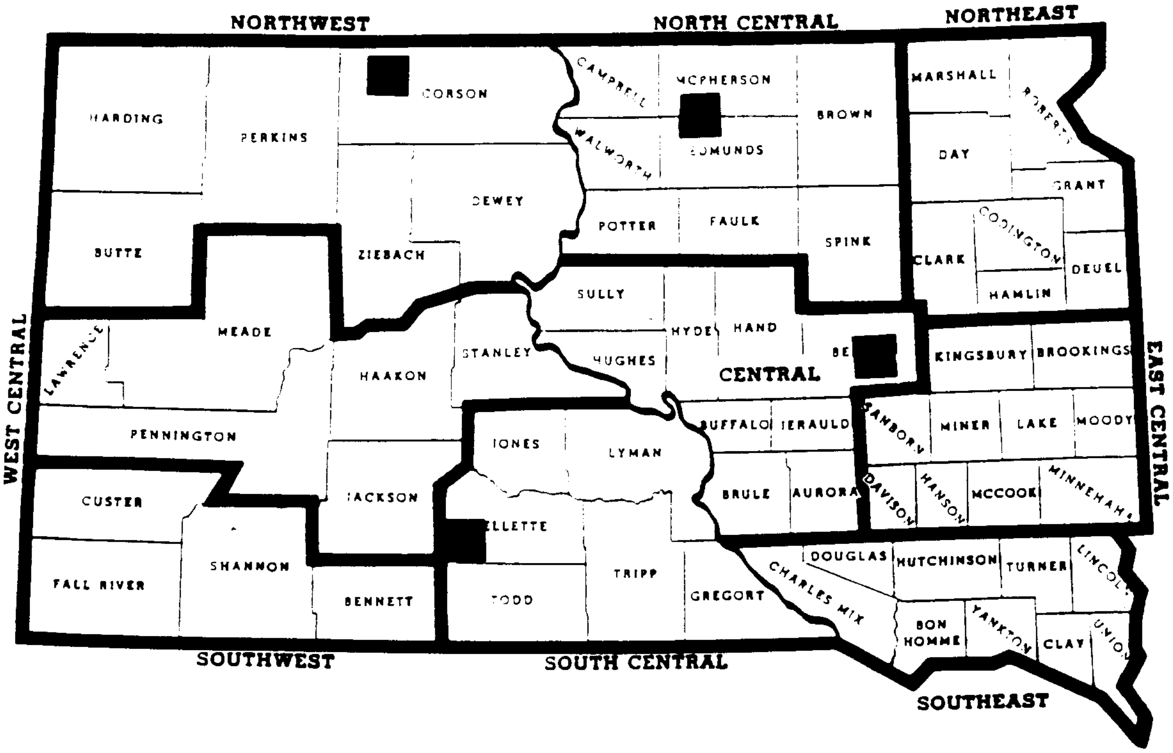
In the component of the organic beef production study underlying results reported in this report, farm resource and management data for four matching pairs of "near-organic" and "mainstream" integrated crop and cow-calf producers in South Dakota were gathered and analyzed. Producers were termed "near-organic," rather than "organic," because none of the original 70 cow-calf operators for which data were available completely adhered to the organic standards from the above sources. The 70 farms consisted of 62 respondents to a randomly selected winter 1992-93 mail survey of South Dakota cow-calf operators (Taylor and Feuz, 1992), plus 8 additional producers who we had come to know prior to the mail survey as having definite interest in organic production methods.

Based on evaluation of the management practices followed by the 70 cow-calf operators, the 17 producers determined to most closely follow "organic" production standards were initially selected for possible further study (Guan, 1994). Thirteen of the 17 were dropped for one or more of the following reasons: producer's name and address not available, producer not willing to participate in proposed case study research, producer had no cropland (the study was limited to integrated crop-livestock farms), producer fed some "non-organically-produced" feedstuffs, and selection of producer would detract from a widespread geographic distribution of case farms within the state. The four near-organic case farmers ultimately selected for study were from Corson County in the Northwest, Mellette County in the South Central Region, McPherson County in the North Central Region, and Beadle County in the Central Region (Figure 1).

A "nearby" mainstream cow-calf operation was then sought to match each near-organic case farm. Operations were selected so as to be as similar as possible to their respective matching near-organic counterparts in (1) acreage and quality of cropland and pasture, (2) size of herd and type of cattle, and (3) overall farm business management ability.

The personal interview questionnaire covered rather detailed information on case farm managers' resources, crop and livestock production management practices, and crop and livestock performance. The general time frame of reference for data was 1993. However, for case farmers experiencing abnormal production conditions in 1993 (e.g., unusual wetness in

Figure 1. Locations, by region, four matching pairs of case study farms.



certain areas), adjustments were made toward more normal conditions. Questionnaires were first mailed to case farmers. Follow-up personal interviews were then focused on (1) reviewing and clarifying completed parts of questionnaires and (2) raising for response those questions not yet completed by farmers.

Since differences in beef cattle production technologies followed by matching pairs of near-organic and mainstream case farms tended to be relatively limited, the near-organic versus mainstream distinction is dropped in this report. Each pair of farms is labeled simply Farm 1 and Farm 2.

The case farm selection procedure precludes the eight farms from being viewed in any way to formally represent the complete population of cow-calf operations in South Dakota. However, the farms studied are scattered rather widely throughout the state and in several respects are rather similar to other farms in the counties in which they are located. In the "case farms selected" section, descriptive data on the case farms are compared with average data for (1) all farms in the respective counties in which the case farms are located and (2) the state.

Matching on-farm livestock manure production and utilization

In examining livestock manure production and utilization, (1) amounts of nitrogen (N) and phosphorus (P) available to crops and grass in the manure produced by livestock on the respective case farms at the time of application to cropland and rangeland were estimated and then compared with (2) estimated amounts of N and P required to meet the fertility needs of the crops and rangeland grasses produced on the respective case farms.

Livestock manure N and P production. The eight case farmers apply their manure in a solid raw form (rather than as liquid or slurry). Estimating amounts of livestock manure N and P produced, available for use by crops on cropland and grass on rangeland, involved taking into joint account the following:

* Amounts of solid manure ("spreader dry matter") available for application to farmland, from different categories and weights of cattle and hogs, during periods of time within a year that animals are present in farmers' herds;

* Proportions of total manure available for application to farmland assumed to be scraped, collected, and spread on cropland versus dropped on rangeland;

* N and P nutrient content of manure produced by cattle and hogs; and

* Percentages of total N and P present in manure assumed to be available for plant use.

Estimated values for these four parameters were based on various findings reported in the literature as follows.

1. Estimated rates of beef cattle and hog manure voided were obtained from Conservation Technology Information Center (1992), Ensminger (1987), Killorn (1985), Midwest Plan Service (1985), Nelson and Shapiro (1989), Sutton et al. (1985), Van Dyne and Gilbertson (1978), and Watts (1991). The dry matter content of beef cattle and hog manure at the time of application to farmland was estimated to be 30% and 18%, respectively (Ensminger, 1987; Killorn, 1985; Midwest Plan Service, 1985; Nelson and Shapiro, 1989; Sutton et al., 1985; and Watts, 1991).[2] Assumed manure storage and handling losses were based on Van Dyne and Gilbertson (1978, p 5) who indicate such losses to result in 89% of the manure initially voided being available for application to farmland. Thus, in this study, amounts of "manure produced at the time of application to farmland" should be interpreted as estimated amounts of manure voided, adjusted down by 70% (beef manure) and 82% (hog manure) for moisture losses and an additional 11% for storage and handling losses.

Taking into account results of the literature review, we concluded that beef cattle produce--for application to farmland--5.535 lb of manure per day per 100 lb (cwt) of body weight. To determine average daily rates of manure production per head, this coefficient was multiplied by the cwt reported by each producer for each category of mature breeding animal, the average reported cwt between weaning and calving for replacement heifers, and the average

[2]In practical terms, these amounts of "manure dry matter" can be interpreted as amounts of dry matter in manure in spreaders ready for application to cropland. While manure that drops on grazing land does not have the same amount of moisture as manure in a spreader, at a certain point in its natural decomposition, water will evaporate from the manure to the same extent that water evaporates prior to its being place in a spreader. Thus, to simplify procedures in determining amounts of N and P contained per ton of manure, common N and P percentages were applied against manure with a given dry matter content, regardless of whether the manure was assumed to be spread on cropland or dropped on grazing land.

reported cwt for market cattle between their being placed on and taken off feed. Brood sows and market hogs were assumed to produce 11 lb of manure per day for application to farmland. These daily rates were multiplied by reported days in the herd per production period for the various categories of cattle and hogs.

Determination of estimated per-head manure production is illustrated as follows:

* A 1,300 lb mature beef cow: 13 cwt * 5.535 lb/day * 365 days = 26,264 lb/yr = 13.1 tons/yr; and

* A backgrounded steer that enters the feedlot at 555 lb and leaves the feedlot 90 days later at 735 lb: 6.45 cwt * 5.535 lb/day * 90 days = 3,213 lb = 1.61 tons/production period.

By multiplying per-head tonnages of manure produced by numbers of various categories of beef cattle and hogs on the respective farms, total whole-farm manure production was determined.

2. In the baseline analysis, it was assumed that manure dropped in dry lot would be scraped, collected, and spread only on cropland. The following percentages of total manure available for application to farmland were assumed to (a) be spread on cropland versus (b) dropped on rangeland (percentage decisions made taking into account Office of Technology Assessment, 1990, p 136):

* Brood cows, service bulls, stockers, and backgrounded cattle: 20%-80%;
* Replacement heifers: 40%-60%; and
* Brood sows and market hogs: 100%-0.

Thus, for example, of a mature beef cow's annual manure production of 13.1 tons, 2.62 tons (13.1 * 0.20) were assumed to be spread on cropland and 10.48 tons (13.1 * 0.80) were assumed to drop on rangeland.

3. Data on estimated percentages of nitrogen (N) and phosphorus (P) in beef cattle and hog manure were obtained from Baker and Raun (1989), Cooke (1982), Ensminger (1987), Gerwing and Gelderman (1996), Killorn (1985), Midwest Plan Service (1985), McGary (1989), Nelson and Shapiro (1989), Schmitt (1988), Sutton et al. (1985), and Watts (1991). In references in which phosphorus was reported as P_2O_5, rather than P, the P_2O_5 percentage was multiplied by 0.44 (Midwest Plan Service, 1985, p 10.3). Resulting from consideration of these references was a decision to assume the following N and P percentages in manure applied to fields (N-to-P ratios are shown in parentheses):

* Beef cattle: N = 0.724% and P = 0.227% (3.19/1.00); and
* Hogs: N = 0.422% and P = 0.142% (2.97/1.00).[3]

---

[3]These are percentages of amounts of manure ready for application to farmland, not percentages of oven-dried manure. The ratios reported in text apply to total N and P in manure, not to plant-available N and P in manure. Since only 75% of total manure N is assumed to be available to plants, but 100% of total manure P is, plant-available N-to-P ratios are only 75% as great as these ratios (i.e., 2.40 and 2.23, respectively).

4. Of the total manure N and P estimated to be produced and applied annually to farmland, 75% of N and 100% of P was assumed to be available over time for plant use. This assumption was based on Lorimor et al. (1995) and research undertaken by Pennsylvania State University reported by McGary (1989, p AC-8).

By (1) multiplying the percentages of N and P in beef cattle and hog manure by the respective whole-farm amounts of beef cattle and hog manure produced and (2) taking into account the availability to plants of 75% of the total manure N and 100% of manure P applied to farmland, the estimated tons of manure N and P (i.e., manure N and P fertilizer credits) available for use by crops and grasses on each cow-calf operator's farmland were determined.

Thus, assumptions for the following items were common for all eight case farms: manure production rates per 100 lb of liveweight for beef cattle and per day for hogs, manure "dry matter," proportions of manure assumed to be spread on cropland versus dropped on rangeland (this assumption was relaxed in the post-baseline threshold analysis), manure N and P nutrient content, and percentages of total manure N and P applied assumed to be available to crops and grasses produced. Case farmers were also assumed to follow sound management practices in handling, storing, applying, and incorporating manure in their farming operations. Further, manure was assumed to be applied uniformly over all cropland receiving spread manure applications and to drop uniformly over all rangeland in the respective farming operations. While these assumptions are acknowledged to be somewhat unrealistic, research resources were inadequate to permit gathering and use of farmer-specific information on these variables. Results of the study must, therefore, be considered as indicative rather than definitive.

Crop and grass production N and P needs. Except as indicated in Footnote 6, crop and grass production N and P balances were determined with information on yields from the respective case farmers and from South Dakota's "Fertilizer Recommendations Guide" by Gerwing and Gelderman (1996, pp 2-16).

Nitrogen (N) and phosphorus (P) recommendations for various crops depend on yield goals (YGs) and residual soil test nitrogen (STN) and phosphorus (STP) levels. To illustrate, for corn grain, recommended N is determined by the following formula "1.2 YG - STN" and recommended P_2O_5 by "0.70 YG - 0.044 STP * YG" (p 5).

Base yields assumed for each row crop, small grain, and native hay[4] were those attained by the respective case farmers in 1993, modified by impacts of unusual weather (see Annex A). Because producer-specific information on (1) yield goals against which to fertilize and (2) farmland soil test nitrogen and phosphorus levels were not obtained from individual case farmers, it was decided to examine two yield goals regarding N crop fertility needs (namely, 1.0 and 1.25 times "1993" yields) and two STP levels ("medium" and "low"). The Gerwing and

[4]Native hay was included with the various crops in this phase of analysis because its manure needs were assumed to be met through spread manure rather than manure dropped by grazing cattle.

Gelderman (1996, p 2) state-wide default value for STN (40 lb/acre) was assumed for all crops.[5] Provision was made for legume N credits from alfalfa to succeeding crops, with an assumed equivalence between yield in tons/acre and "plants/sq ft" (Gerwing and Gelderman, 1996, p 3).

In regard to rangeland fertilizer recommendations, the formula for "grass" in Gerwing and Gelderman (1996, p 5) is "25 YG."[6] Very few tests of residual nitrates with rangeland are undertaken. In view of this informational gap and the possibility that manure droppings on rangeland may lead to nitrate build-up in soil underlying grassland in South Dakota, two situations involving rangeland STN were examined: one in which the rangeland grass fertilization recommendation was based on "25YG" with zero assumed STN and the other in which STN was assumed to be equal to 20 lb/acre.

The estimated per-acre N and P needs determined through the above considerations were multiplied by the respective acreages of each crop and the rangeland operated by the respective case farmers in 1993. Resulting from these calculations was determination of the estimated total whole-farm N and P needs for crop and grass production for two cropland N yield goal, two cropland STP, two rangeland STN, and two rangeland STP conditions.

"The match" between manure production and utilization. In the baseline manure balance analysis, total estimated amounts of plant-available N and P in livestock manure produced on the case farms were compared with total estimated amounts of N and P required to meet the needs of the various crops and grass produced on the respective farms under the different yield goal, STN, and STP conditions mentioned above. Under each condition, a determination was made of whether each farm's total manure N and P production was less than, approximately equal to (plus or minus 10%), or more than its total crop and grass production N and P fertility needs.

If total estimated manure production was less than total estimated crop and grass production fertility needs under particular case farm conditions, sensitivity analysis was undertaken to determine how much the farm's livestock population could be expanded until its manure production would just match its crop and grass N and P needs.

If total estimated manure production was more than total estimated crop and grass fertility needs under particular case farm conditions, we recognized that possible damage to soil and water resources might result from leaching and/or runoff of excess N and/or P. In such cases, two alternative courses of action were explored. First, sensitivity analysis was undertaken to determine how much the farm's livestock population would need to be contracted, in order that its manure production would just match its crop and grass N and P needs.

---

[5]For native hay, however, STN was assumed to be zero.

[6]Estimated rangeland yield levels of 1.0 ton/acre for the case farmers in Corson and Mellette Counties and 1.5 ton/acre for the case farmers in McPherson, Edmunds, and Beadle Counties were based on information provided by Natural Resource and Conservation Service personnel in the respective case farmers' counties of residence (February 28, 1996).

Second, in a post-baseline "threshold" analysis, possibilities were explored for current "surpluses" of manure on cropland and/or rangeland to be diverted to other on-farm uses. Other uses involved possible (1) unrestricted allocation of manure between rangeland and cropland, rather than according to the cropland-rangeland manure disposition ratios indicated above; and (2) application of manure to Conservation Reserve Program (CRP) and fallow land for which no fertilizer is recommended.

In the threshold analysis, CRP and fallow land were assumed to receive manure applications equal to the weighted average pounds per acre of N and P for existing fertilized crops on the respective case farms. In this second type of analysis, we explored whether manure produced in excess of the farm's crop and grass production fertility needs could be managed (without processing) so as not to become a possible threat to the farm's soil and water quality.[7]

Matching on-farm livestock feedstuff production and consumption

The overall objective of this phase of analysis was to estimate and reconcile the amounts of total digestible nutrients (TDN) produced on the case farms with the TDN required by the livestock on the respective farms. This objective was accomplished through a three-step procedure. First, amounts of TDN contained in the crops (including alfalfa) and grass produced in 1993 on individual case farms were estimated. Second, amounts of TDN required in annual livestock rations for the various categories of livestock on the respective case farms were estimated. Third, amounts of TDN in livestock feedstuffs produced were reconciled with amounts of TDN required by livestock. Since, in addition to TDN, protein is an especially critical nutrient need of livestock, attention was also given to the adequacy of protein in produced feedstuffs, with provision of purchased protein supplement to meet protein deficits.[8]

Crop and grass TDN production. To determine the tons of TDN produced on each case farm, acreages of crops and grass raised in 1993 on each farm were multiplied by (1) various crop and grass yields obtained by the respective farmers and (2) amounts of TDN contained per unit of production for each type of crop and grass raised. The TDN content of all feedstuffs except rangeland and grazed corn stalks was determined with data taken from National Research Council (NRC, 1984, pp 47-84). For the respective "NRC feedstuffs," pounds of TDN per unit of production were computed as the cross-product of (1) percent dry matter, (2) percent TDN, and (3) pounds per unit (Table 1).[9]

---

[7]It is recognized that, to the extent that slopes may be steep and/or aquifers are close to the soil surface, some of the N and P applied to fallow land could find its way into surface water or groundwater.

[8]In the whole-farm feedstuff balancing analysis, choosing to focus attention only on TDN (i.e., not also on protein) not only simplified the analysis but also accords with the real-world in which most beef cattle producers purchase supplemental protein to complement the protein available in their home-raised feedstuffs. In other words, self-sufficiency in protein production and consumption does not seem to have the same type of possible real-world validity that self-sufficiency in TDN does.

Readers interested in more detail than that provided herein are invited to see Annex C, "Balancing Demands by Livestock for Feedstuffs with the Supplies of Feedstuffs Produced on Case Farms," in Taylor (1995).

[9]As noted above, in balancing livestock rations, attention was given not only to TDN but also to protein. Because some feed is lost in the process of its being stored and fed, amounts of TDN and protein per unit of production available for consumption by livestock are less than amounts per unit produced. In anticipation of these issues being addressed later in the study, data covering these two phenomena are also included in Table 1.

Table 1. Total digestible nutrient (TDN) and protein content of livestock feedstuffs and cash crops.

		Pounds of nutrients per unit:			
		Produced[a]		Available for livestock consumption[b]	
Crop	Unit	TDN	Protein	TDN	Protein
Livestock feedstuffs					
Forages					
Alfalfa hay	ton	1,044	307	783	230
Alfalfa/grass hay	ton	1,008	263	756	197
Millet hay	ton	1,027	149	770	112
Native hay	ton	939	107	704	80
Oat hay	ton	1,001	169	751	127
Corn silage	ton	462	54	370	43
Sorghum sudan silage	ton	330	65	264	52
Rangeland	AUM	320	36	320	36
Grazed corn stalks	acre	320	36	320	36
Grains					
Corn	bu	44.3	4.9	42.1	4.7
Oats	bu	26.0	4.5	24.7	4.3
Sorghum	bu	40.9	4.9	38.9	4.7
Barley	bu	35.8	5.7	34.0	5.4
Soybean oil meal	ton	1,495	888	1,495	888
Cash crops					
Buckwheat	bu	29.0	5.0	n/a	n/a
Millet grain	bu	35.0	5.4	n/a	n/a
Soybeans	bu	48.0	22.4	n/a	n/a
Wheat	bu	45.0	8.1	n/a	n/a

[a]TDN and protein of all feedstuffs and cash crops except rangeland and grazed corn stalks were taken from National Research Council (1984, pp 47-84). TDN and protein content of the two grazing resources were based primarily on Lamp et al. (1989, pp 33-34), as explained in text.

[b]Quantities available for consumption are quantities produced--adjusted down for the following assumed storage, shrinkage, and feeding losses: hay 25%, silage 20%, and grain 5% (Taylor et al., 1990, p 7).

The TDN content of rangeland was determined through the following procedure. Rangeland production was initially measured by the estimated number of "animal unit months" (AUMs) that could be supported by the rangeland acreages for the respective case farms. Level of rangeland production was assumed to depend on average annual precipitation and rangeland condition (Lamp et al., 1989, p 33). Average monthly precipitation data for 1961-90 for the weather station closest to each pair of case farms were obtained, and annual precipitation totals were calculated (Table 2, Column 2).

Traditionally, the Society of Range Management has defined "animal unit months" (AUMs) as the amount of feed or forage required by a mature 1,000 lb cow for one month; this amount is 600 lb of feed/forage (Holechek et al., 1989, p 173). Based on a table of rangeland production rates in Lamp et al. (1989, p 33) and (1) taking into account annual levels of precipitation in the region of each pair of case farms and (2) assuming "fair" to "good" rangeland conditions, "traditional" AUMs per acre were determined (Column 3).

Table 2. Determination of AUMs of rangeland production, case farms.

Case farm	1961-90 average annual precipitation (in)[a]	"Traditional" AUMs per acre	"Modern" AUMs per acre	Acres of rangeland	Total AUM production
Northwest					
Farm 1	16.5	0.55	0.481	1,703	819
Farm 2	16.5	0.55	0.481	2,839	1,366
South Central					
Farm 1	18.1	0.70	0.613	1,007	617
Farm 2	18.1	0.70	0.613	2,480	1,520
North Central					
Farm 1	18.7	0.70	0.613	1,460	895
Farm 2	18.7	0.70	0.613	1,215	745
Central					
Farm 1	20.1	0.80	0.700	220	154
Farm 2	20.1	0.80	0.700	315	221

[a]Based on data provided by the Office of Climate and Weather Information, SDSU Agricultural Engineering Department.

Because beef cows over the past 2-3 decades have become generally larger-framed and heavier, "traditional" AUMs are now being redefined to represent the feed required by 1,200 lb cows (personal communication, April 14, 1995, Patricia S. Johnson, SDSU Range Management Specialist). Over the course of a year, a 1,200 lb mature producing cow requires about 12.5% more feed than a 1,000 lb cow (National Research Council, 1984, pp 84-85). To reflect the feed needs of "modern" larger cows, "traditional" AUMs/acre were down-sized by 12.5% (Column 4).

By multiplying "modern" AUMs per acre by the numbers of acres of rangeland for the respective case farmers (Column 5), total levels of AUM production from rangeland for each farmer were calculated (Column 6). To convert rangeland AUMs to TDN, we assumed that 1.0 AUM was equivalent to 0.33 ton of grass hay (Lamp et al., 1989, p 34). Taking into account the percentages of dry matter and TDN in "prairie plants, Midwest, hay, sun-cured" reported in National Research Council (1984, p 54) and judgment of concerned scientists, it was decided to assume that one AUM of rangeland provides 320 lb of TDN. Cattle were assumed to derive one AUM of feed value from grazing one acre of corn stalks (Taylor et al., 1990, p 6).

Livestock TDN and protein requirements. Annual TDN and protein requirements for various types of cattle in the herd of each case farmer were determined according to (1) weights of mature breeding cattle and average weights over respective feeding periods for growing cattle, (2) rates of gain, and (3) numbers of days on feed for each producer's mature brood cows, herd sires, replacement heifers, backgrounded animals, and finishing steers. Daily nutrient requirements for various types of cattle were extracted from National Research Council (1984, pp 77-85) as follows:

* Mature brood cows: (1) "cows nursing calves--average milking ability," from calving to weaning; (2) "dry pregnant mature cows--middle third of pregnancy," from weaning until the 274th day of the cattle production year; and (3) "dry pregnant cows--last third of pregnancy" for the final 91 days of cattle production year;

* Herd sires: "bulls, maintenance and slow rate of growth (regain body condition)," with zero lb/day gain, for 365 days;

* Replacement heifers: "medium-frame heifer calves" for all case farms except North Central Farm 1 which has "large-frame heifer calves," with three periods of feeding--(1) weaning to breeding at 15 months, (2) 183 days from breeding to completion of two-thirds of pregnancy, and (3) 91 days for "pregnant yearling heifers--last third of pregnancy;"

* Backgrounded cattle: medium- and large-frame steers and heifers as above for replacement heifers, 90 day feeding period, 2.0 lb/day rate of gain for medium-frame cattle and 2.5 lb/day for large-frame cattle; and

* Finishing cattle: "medium-frame steers," 1.46 lb/day rate of gain for 515 days (the intensity of feeding for the case farmer who finishes cattle is much less than that typically followed in South Dakota).

Feed requirements for hogs were based on the procedures and data provided by Mayrose et al. (n.d.). Average feed efficiencies, defined as the pounds of feed required per pound of gain by slaughter hogs, were assumed to be 4.1 for the entire farrow-to-finish period and 3.6 for feeder pigs until marketing.

To illustrate application of these average feed efficiencies, for one sow unit (a brood sow, her baby pigs until finished, her replacement, and that part of the boar required to serve her) of the Northwest Farm 1 hog operation, 17.5 slaughter hogs weighing 240 lb each are produced. Total feed required for one unit of the farrow-to-finish enterprise is therefore:

$$17.5 \text{ hogs} * 240 \text{ lb} * 4.1 \text{ lb feed/lb of gain} = 17{,}220 \text{ lb}.$$

Of this total, 12,600 lb are required for slaughter hogs (17.5 hogs * 200 lb gain * 3.6 lb feed/lb of gain) and the remainder of 4,620 lb for sows. Of the 12,600 lb, 65% was reported by the producer to be from oats (256 bu), 30% from barley (79 bu), and 5% from alfalfa (0.315 ton). Of the 4,620 lb, 95% is from oats (137 bu) and 5% is from alfalfa (0.116 ton). Combining the two, the total feed requirement per sow unit for the Northwest Farm 1 hog operation is 393 bu oats, 79 bu barley, and 0.43 ton alfalfa. Applying similar procedures to the Central Farm 2 hog operation resulted in determination of a feed requirement of 178 bu corn and 1.66 tons of soybean oil meal per sow unit.

"The match" between livestock feedstuff production and consumption. In determining the balance between amounts of TDN in livestock feedstuffs produced and livestock feedstuffs required on the respective farms, the following general strategy in formulating rations was pursued. Livestock TDN requirements were met first through rangeland and crop residues. Once grazing resources were exhausted, TDN needs were assumed to be met first by corn and/or sorghum sudan silage and then by various types of hays. Unless cattle protein needs were unfulfilled with native hay, millet hay, and oat hay, the supplies of these hays were used up before alfalfa hay was assumed to be used. Any protein deficits remaining after use of the above procedures were assumed to be met by soybean oil meal. Four refinements/exceptions to this general strategy were as follows.

1. Replacement heifers were assumed to be on rangeland for 180 days, during the period immediately after their being bred. Mature cows and herd sires were assumed to graze on rangeland as long as rangeland production on the respective case farmers was adequate, but for no more than the following numbers of days: 180 for Central Farm 2, 185 for North Central Farm 2, 210 for Central Farm 1, 215 for North Central Farm 1 (reported grazing periods for the respective case farms), and 289 for the Northwest and South Central farms (an assumed maximum 9.5 month grazing season). If protein needs were not met through grazed rangeland resources, those unmet needs were provided through supplemental feeding of alfalfa. If the nutrients provided by case farmers' rangeland resources were not totally used by their herds within the maximum grazing periods indicated above, farmers were assumed to rent out the "surplus" rangeland.

2. If case farmers indicated they conditioned cows with protein supplement at one or both of the following two specified times of year, the following amounts of soybean meal were provided in the ration for each cow:

* 35 lb, at time of breeding; and
* 50 lb, at time of calving.

3. Energy and protein needs of growing replacement heifers, backgrounded cattle, and finishing cattle were met with the following per-head amounts of TDN and protein supplied by home-raised grains and alfalfa and/or purchased soybean oil meal (Pflueger et al., 1991, p 6, 10, and 14; Taylor and Wagner, 1991, pp 24-25):

* Replacement heifers: 915 lb TDN and 165 lb protein;
* Backgrounded cattle: 410 lb TDN and 60 lb protein; and
* Finishing cattle: 3,240 lb TDN and 415 lb protein.

Nutrient needs over and above these were assumed to be met by alfalfa.

4. Storage, shrinkage, and feeding losses of 25% for hay, 20% for silage, and 5% for grain were assumed (Taylor et al., 1990, p 7). Thus, for example, although each ton of alfalfa hay produced contains 1,044 lb of TDN, only 783 lb of that TDN was assumed to be available for consumption by livestock (see Table 1).

Determining the on-farm balance between livestock manure production-utilization and livestock feedstuff production-consumption

In reconciling case farm livestock manure production-utilization with livestock feedstuff production-consumption, "tons of TDN per cow" required to meet total whole-farm livestock nutrient needs for each farm were first determined. We then estimated the tons of TDN that would be required for herd sizes determined to be just matched in manure production-utilization under various yield goal, STN, and STP conditions. These tonnages of TDN required to meet livestock nutrient needs were compared with tonnages of TDN in livestock feedstuffs currently produced on each of the eight farms.

Instances were identified in which the TDN in currently produced livestock feedstuffs exceeded, was approximately (within 10%) equal to, or was less than TDN livestock nutrient requirements for herd sizes just matched in manure production-utilization. Particular attention was given to determining if any case farm matched (plus or minus 10%) in both livestock manure production-utilization and livestock feedstuff production-consumption under one or more of the yield goal, STN, and STP conditions was simultaneously balanced with respect to (1) both cropland and rangeland in the baseline analysis and (2) both nitrogen and phosphorus in the threshold analysis. For a particular case farm to be judged to be "balanced ecologically," the simultaneous conditions would need to be found to apply. Failing this, findings from the study would shed doubt on the feasibility of individual real-world farms being "perfectly" integrated in crop and livestock production.

CASE FARMS SELECTED

Total acres of farmland operated by the eight case farmers range from 810 to 3,989 and average 2,248 (Table 3). This average acreage is 71% above the state-wide average of 1,316 acres (U.S. Dept. of Commerce, 1994a, p 8). Cropland acreages for the eight case farms range from 520 to 1,218 and average 787. This average cropland acreage is 21% above the state-wide average of 650 (U.S. Dept. of Commerce, 1994a, p 8).

Table 3. Overview of nature and scale of case farms.

Farm resource	Northwest		South Central		North Central		Central		Eight farm average
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	
Farmland (acres)									
Cropland									
Under production 1993	828	755	957	490	540	685	410	615	660
Summer fallow & CRP	390	395	0	120	0	0	110	0	127
Sub-total	1,218	1,150	957	610	540	685	520	615	787
Native hay	100	0	0	0	200	80	70	0	56
Rangeland	1,703	2,839	1,007	2,480	1,460	1,215	220	315	1,405
Total	3,021	3,989	1,964	3,090	2,200	1,980	810	930	2,248
Cattle (head)									
Cows and calves	129	120	39	128	201	172	51	32	109
Backgrounded cattle	14	17	4	0	76	0	0	0	14
Slaughter cattle	0	0	0	0	0	0	13	0	2
Hog-farrow finish (head)									
Sows that farrow	6	0	0	0	0	0	0	18	3
Litters fed	12	0	0	0	0	0	0	27	5

Beef cow herd sizes for the eight case farms range from 32 to 201 and average 109 head. This average herd size is 27% above the state-wide average of 86 head (U.S. Dept. of Commerce, 1994a, p 30). Relatively small supplementary livestock enterprises are found on six farms. Four farmers background cattle, with the number of head for the four farms ranging from 4 to 76 and averaging 28. One farmer finishes 13 head of cattle. Two farmers have hog farrow-finish operations involving the marketing of 12 and 27 litters per year.

A farm's land area-to-livestock population ratio is critical in impacting whether the amount of manure produced on the farm will be in balance with the amount of manure needed to meet the farm's crop and grass fertility needs. Since beef cow herds are by far the dominant livestock enterprise on the eight case farms, attention is given to the geographic concentration of beef cow herds for South Dakota relative to that for the nation's 10 major cow-calf producing states and for the case farms relative to that for the counties in which they reside and South Dakota as a whole.

South Dakota's beef cow inventory of 1.60 million cattle in 1992 ranked fifth--behind Texas (5.19), Missouri (1.88), Nebraska (1.86), and Oklahoma (1.73)--among the nation's 50 states (U.S. Dept. of Commerce, 1994b, pp 321-325). Among the nation's top 10 cow-calf producing states, South Dakota's average herd size of 86 ranks second behind that in Montana (Table 4). In terms of total farmland (cropland, rangeland, plus "other") per cow, Montana has by far the most of the 10 states (21.4 acres). South Dakota's average farmland acreage of 15.3 per cow is relatively close to the 16.5 and 15.7 in second-ranking Texas and third-ranking Kansas. The other six major cow-calf producing states, however, have a more geographically concentrated cow-calf population, with farmland acreages per cow ranging from 6.0 to 12.3.

South Dakota's average cropland acreage of 7.6 per cow is not far from the 5.9-8.6 acres per cow for seven of the states.[10] At the two extremes are Kansas with a relatively large cropland acreage per cow (11.7) and Kentucky and Tennessee with small cropland acreages per cow (4.1 and 4.4). In terms of "other farmland"--the vast majority of which is rangeland--South Dakota's 7.7 acres per cow is third to that in Montana (14.0) and Texas (10.6), but considerably more than that in the other seven states (0.5-5.3 acres per cow).

Table 4. Beef cow concentration, ten major states of production, United States, 1992.

	State averages per farm[a]				Acres per cow of:		
State	Total crop-land (acres)	Other land (acres)	Total farm-land (acres)	Beef cow inventory (head)	Crop-land	Other land	Total farmland
Montana	900	1,713	2,613	122	7.38	14.04	21.42
South Dakota	650	666	1,316	86	7.56	7.74	15.30
Nebraska	483	356	839	77	6.27	4.62	10.89
Kansas	552	186	738	47	11.74	3.96	15.70
Texas	259	466	725	44	5.89	10.59	16.48
Oklahoma	273	207	480	39	7.00	5.31	12.31
Iowa	308	17	325	36	8.56	0.47	9.03
Missouri	222	69	291	32	6.94	2.15	9.09
Kentucky	103	48	151	25	4.12	1.92	6.04
Tennessee	102	47	149	23	4.44	2.04	6.48

[a]Based on data from U.S. Dept. of Commerce (1994b, pp 215-226 and 321-325).

[10]The cropland acreages per cow are computed with respect to cropland areas for all farms in the respective states, not to cropland areas for only those farms having beef cows.

Overall, then, the acreage of rangeland per beef cow in South Dakota is definitely above-average relative to that for the nation's other nine major cow-calf producing states. The acreage of cropland per cow in South Dakota, on the other hand, is more or less intermediate among the other nine states.

Data analogous to the just presented statewide-data for each of the eight case farms and the respective counties within which the case farms are located are presented in Table 5.

Acres of total farmland per cow for the eight case farms range from 11.0 to 50.4 and average 20.6. Cropland acres per cow range from 2.7 to 24.5 and average 7.2. Rangeland acres per cow range from 5.7 to 25.8 and average 13.4. Thus, compared to the state, the average acres per cow for the eight case farms are 4% below-average for cropland, but 73% above-average for rangeland and 35% above-average for total farmland.

Relative to respective county averages, total farmland acreages per cow are greater for five of the eight case farms, ranging from 20% higher for one farm to 3.0 times higher for another. Total farmland acreages per cow for the other three case farms are 15%-24% below-average. Relative to respective county averages, cropland acreages per cow are above-average (by 34% to 4.45 times) for five case farms and below-average (by 14-69%) for the other three case farms. For rangeland, however, seven of the case farms are above-average, having 13% to 4.7 times more rangeland than the averages for the respective counties, and only one is below-average (by 33%).

Table 5. Beef cow concentration, case farms compared to county and state averages.

Beef cow concentration parameter	Case study farms: Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	State average[a]
Case farms (1993)									
Cropland (acres)	1,218	1,150	957	610	540	685	520	615	787
Other land (acres)	1,803	2,839	1,007	2,480	1,660	1,295	290	315	1,461
Farmland (acres)	3,021	3,989	1,964	3,090	2,200	1,980	810	930	2,248
Herd size (head)	129	120	39	128	201	172	51	32	109
Acres per cow									
Cropland	9.44	9.58	24.54	4.77	2.69	3.98	10.19	19.22	7.22
Other land	13.98	23.66	25.82	19.37	8.26	7.53	5.69	9.84	13.40
Total farmland	23.42	33.24	50.36	24.14	10.95	11.51	15.88	29.06	20.62
Census county averages (1992)[b]									
Cropland (acres/farm)	907		768		847	975	699		650
Other land (acres/farm)	2,875		1,879		579	324	192		666
Farmland (acres/farm)	3,782		2,647		1,426	1,299	891		1,316
Herd size (head)	137		139		99	87	92		86
Acres per cow									
Cropland	6.62		5.52		8.55	11.21	7.59		7.56
Other land	20.99		13.52		5.85	3.72	2.09		7.74
Total farmland	27.61		19.04		14.40	14.93	9.68		15.30
Case farm as a ratio to census average									
Acres per farm									
Cropland	1.34	1.27	1.25	0.79	0.64	0.70	0.74	0.88	1.21
Other land	0.63	0.99	0.54	1.32	2.87	4.00	1.51	1.64	2.20
Farmland	0.80	1.05	0.74	1.17	1.54	1.52	0.91	1.04	1.71
Cows per herd	0.94	0.88	0.28	0.92	2.03	1.98	0.55	0.35	1.27
Acres per cow									
Cropland	1.43	1.45	4.45	0.86	0.31	0.36	1.34	2.53	0.96
Other land	0.67	1.13	1.91	1.43	1.41	2.02	2.72	4.71	1.73
Total farmland	0.85	1.20	2.64	1.27	0.76	0.77	1.64	3.00	1.35

[a]The "state averages" shown in the first section below represent averages for the eight case farms. In the second section, they represent averages for all counties in the state, not just for the counties shown in the table.

[b]Based on data from U.S. Dept. of Commerce (1994a, pp 162-168 and 346-352). The farm selected to match the near-organic farm in McPherson County in the North Central Region was located in the neighboring county (Edmunds). Since both farms in each of the other regions are from the same county, county-level data are shown only once for each of these pairs of farms.

ON-FARM LIVESTOCK MANURE PRODUCTION AND UTILIZATION

Livestock manure sources and disposition

On average for the eight farms, brood cows account for 76% of the total manure produced (Table 6). Replacement heifers account for 14%, service bulls 5%, hogs 2%, and backgrounded and slaughter cattle 1% each of total manure produced. For five of the eight case farms, beef brood cows account for at least 75% of the total manure produced. The percentages for the other three farms are smaller for the following reasons: (1) South Central Farmer 1 is in the process of building up his herd, with a result that the manure produced by his replacement heifers is 10 percentage points more than that for any other farm; (2) Central Farmer 1 feeds out 13 slaughter cattle that account for 18% of his total manure produced; and (3) Central Farmer 2 has 18 sows and feeds out 27 litters of pigs which account for 30% of his total manure produced.

Table 6. Sources of manure produced, case farms.

	Percentage of total manure produced, by category of livestock						
	Beef cow herd						
Case farm	Brood cows	Replacement heifers	Service bulls	Total	Backgrounded cattle	Slaughter cattle	Hogs
Northwest							
Farm 1	75.9	14.6	3.5	94.0	1.1	0	4.9
Farm 2	77.7	15.9	4.9	98.5	1.5	0	0
South Central							
Farm 1	69.9	26.3	2.7	98.9	1.1	0	0
Farm 2	82.5	11.0	6.5	100.0	0	0	0
North Central							
Farm 1	78.4	13.0	5.0	96.4	3.6	0	0
Farm 2	77.7	15.5	6.8	100.0	0	0	0
Central							
Farm 1	65.4	12.6	4.1	82.1	0	17.9	0
Farm 2	53.0	12.2	5.2	70.4	0	0	29.6
Eight farm average	75.9	14.3	5.2	95.4	1.3	1.1	2.2

Total amounts of manure produced annually per case farm range from 676 tons (cow herd of 39 cows) to 3,625 tons (cow herd of 201 cows) and average 1,837 tons (Table 7). On average for the eight case farms, 76% of the total manure produced drops on rangeland. The remainder of manure is assumed to be scraped, collected, and spread on cropland (plus native hay). Of the total manure produced on individual farms, between 55% (the farm with 18 sows) and 79% (a farm with no supplementary livestock enterprises) is estimated to drop on rangeland.

Table 7. Disposition of manure produced, case farms.[a]

Case farm	Dropped on rangeland Tons	Dropped on rangeland Percent	Spread on cropland[b] Tons	Spread on cropland[b] Percent	Total tons
	Amount of manure produced annually per case farm assumed to be:				
Northwest					
Farm 1	1,523	73.9	538	26.1	2,061
Farm 2	1,455	77.8	415	22.2	1,870
South Central					
Farm 1	509	75.3	167	24.7	676
Farm 2	1,487	79.1	393	20.9	1,880
North Central					
Farm 1	2,842	78.4	783	21.6	3,625
Farm 2	2,275	78.3	632	21.7	2,907
Central					
Farm 1	604	64.0	341	36.0	945
Farm 2	402	54.9	330	45.1	732
Eight farm average	1,387	75.5	450	24.5	1,837

[a]The amounts of manure indicated below are estimated tons of manure available for application to farmland (30% dry matter for beef manure and 18% dry matter for hog manure).

[b]"Cropland" on which manure was spread, includes not only individual row crops, small grains, and alfalfa, but also native hay.

Estimated N and P production

Estimated whole-farm livestock manure N produced on the eight case farms available for use by plants on cropland ranges from 0.91 to 4.25 tons/farm and averages 2.35 tons/farm (Table 8). Analogous data for rangeland manure N are a range of 2.19 to 15.43 tons and an average of 7.53 tons. Thus, the average whole-farm amount of N available to meet the fertility needs of grass on rangeland is 3.2 times as much as the average whole-farm amount of N to meet the fertility needs for various crops on the farm. In total, on each farm, amounts of manure N range from 3.49 to 19.68 tons and average 9.88 tons.

Table 8. Estimated whole-farm livestock manure nitrogen and phosphorus produced available to crops, case farms.[a]

Disposition of manure produced	Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average
	Estimated tons per farm								
Manure spread on cropland[b]									
Nitrogen	2.69	2.26	0.91	2.13	4.25	3.43	1.85	1.30	2.35
Phosphorus	1.14	0.94	0.38	0.89	1.78	1.44	0.77	0.56	0.99
Manure dropped on rangeland									
Nitrogen	8.27	7.90	2.76	8.07	15.43	12.35	3.28	2.19	7.53
Phosphorus	3.46	3.30	1.15	3.37	6.45	5.16	1.37	0.91	3.15
Total manure produced on farm									
Nitrogen	10.96	10.16	3.67	10.20	19.68	15.78	5.13	3.49	9.88
Phosphorus	4.60	4.24	1.53	4.26	8.23	6.60	2.14	1.47	4.14

[a]Since plants use only 75% of manure nitrogen applied to farmland (Lorimor et al., 1995; McGary, 1989), the amounts of manure nitrogen shown in this table are 75% of the estimated total amounts of manure nitrogen produced.

[b]"Cropland," on which manure was spread, includes not only individual row crops, small grains, and alfalfa, but also native hay.

In all situations except for manure spread on cropland and on total farmland for Northwest Farm 1 and Central Farm 2 which have hog operations, 2.40 pounds of available N are contained per pound of available P in the manure produced on the case farms (hereafter abbreviated as a 2.40 "N-to-P ratio").[11] In the exceptional situations involving hog as well as beef manure, the manure N-to-P ratio is as low as 2.32.

Estimated crop and grass production N and P needs

Baseline per-acre needs. Baseline estimated weighted-average per-acre crop and grass production N and P needs are displayed in Table 9.[12] On-average for the eight case farms, per-acre **cropland** N needs for farmers with yield goals of 1.25 times their "1993" yields ("1.25 YG") are 54% greater than for farmers with yield goals just equal to "1993" yields ("1.0 YG") (33.5 versus 21.8 lb/acre). Case farmers with low STP levels on-average require 63% more **P** to meet crop fertility needs from external sources as farmers with medium STP levels. On-average for the eight case farms, whole-farm **rangeland** N needs for farmers with "STN = 0" are 3.33 times those for farmers with "STN = 20 lb/acre." Case farmers with low STP levels each require 2.17 times as much P to meet crop fertility needs as farmers with medium STP levels.

Cropland N needs range among farms and between yield goal criteria from 6.0 to 51.5 lb/acre. Cropland P needs vary among case farms and between low and medium soil test levels from 6.8 to 22.3 lb/acre.[13] Analogous ranges for rangeland are 5.0 to 37.5 lb/acre of N and 5.3 to 11.4 lb/acre of P.

Cropland N-to-P need ratios are highest under the condition of "1.25 YG" for N and a medium STP. In this case, the ratios range among farms from 1.07 to 5.84 and average 3.44. At the other extreme, cropland N-to-P need ratios are lowest under the condition of "1.0 YG" for N and a low STP (range = 0.35 to 2.43; average = 1.37). Rangeland N-to-P need ratios are highest under the condition of "STN = 0" and a medium STP (range = 4.73 to 7.10; average = 5.41) and lowest under the condition of "STN = 20 lb/acre" and a low STP (range = 0.44 to 1.53; average = 0.75).

---

[11]Because data are rounded to the nearest thousand in Table 8, the manure N-P ratios displayed in that table may not round exactly to 2.40.

[12]Individual farm averages are based on per-acre applications of N and P for each fertilized crop on each case farm weighted by the respective acreages of each fertilized crop on the farm. The eight farm average is based on the weighted per-acre average for each farm weighted by the respective fertilized acreages on each farm.

[13]See Annex A for acreages, yields, and N and P balances determined for individual fertilized crops and rangeland on each case farm. Recommended per-acre N and P levels, of course, tend to be higher for those farms which have higher crop and grass yields. This explanation underlies larger weighted per-acre N and P amounts for crops and N for rangeland on North Central and Central farms compared to Northwest and South Central farms, and for N and P for crops on Northwest Farm 1 compared to Northwest Farm 2. Further, farms with higher proportions of crops requiring above-average amounts of fertilizer tend to have larger weighted per-acre N and P levels. Cropland fertilizer levels are higher on Northwest Farm 1 than on the two South Central farms because wheat and oats--which use above-average amounts of fertilizer--are relatively more important in the crop mix on Northwest Farm 1 than on the other two farms.

Table 9. Baseline estimated average per-acre crop and grass production nitrogen and phosphorus needs, case farms.

Nature of yield goals and soil test levels	Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average
Average N and P needs for manure (lb/acre):[a]									
Spread on cropland[b]									
Nitrogen (YG=1.25)	38.83	14.93	13.52	13.34	40.32	51.47	40.80	58.83	33.47
Nitrogen (YG=1.0)	25.36	7.19	6.04	7.04	28.88	35.06	28.06	40.49	21.77
Phosphorus (STP=low)	11.32	11.43	14.12	19.92	22.20	14.83	22.27	16.68	15.90
Phosphorus (STP=med)	6.83	7.25	9.05	12.45	13.14	8.97	13.50	10.07	9.74
Dropped on rangeland									
Nitrogen (STN=0)	25.00	25.00	25.00	25.00	37.50	37.50	37.50	37.50	28.57
Nitrogen (STN=20)	5.00	5.00	5.00	5.00	17.50	17.50	17.50	17.50	8.57
Phosphorus (STP=low)	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44	11.44
Phosphorus (STP=med)	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28
N-to-P ratios in manure:									
Spread on cropland[b]									
N(YG=1.25) to STP=med	5.69	2.06	1.49	1.07	3.07	5.74	3.02	5.84	3.44
N(YG=1.0) to STP=med	3.71	0.99	0.67	0.57	2.20	3.91	2.08	4.02	2.24
N(YG=1.25) to STP=low	3.43	1.31	0.96	0.67	1.82	3.47	1.83	3.53	2.11
N(YG=1.0) to STP=low	2.24	0.63	0.43	0.35	1.30	2.36	1.26	2.43	1.37
Dropped on rangeland									
N(STN=0) to STP=med	4.73	4.73	4.73	4.73	7.10	7.10	7.10	7.10	5.41
N(STN=0) to STP=low	2.19	2.19	2.19	2.19	3.28	3.28	3.28	3.28	2.50
N(STN=20) to STP=med	0.95	0.95	0.95	0.95	3.31	3.31	3.31	3.31	1.62
N(STN=20) to STP=low	0.44	0.44	0.44	0.44	1.53	1.53	1.53	1.53	0.75

[a]Individual farm averages are based on per-acre applications of N and P for each fertilized crop on each case farm weighted by the respective acreages of each fertilized crop on the farm. The eight farm average is based on the weighted per-acre average for each farm weighted by the respective fertilized acreages on each farm.

[b]"Cropland," on which manure was spread, includes not only individual row crops, small grains, and alfalfa, but also native hay.

Thus, we see illustrated in these baseline results that crop and grass production N-to-P need ratios are highly variant, depending on individual farmers' (1) yield goals against which fertilization levels are determined; (2) soil test nitrogen and phosphorus levels; (3) fertilization needs for cropland versus for rangeland; and (4) for cropland, particular combinations of crops raised. Further, on any given farm, the probability of the N-to-P ratio needed in manure for spreading on cropland being the same as that for manure to be dropped on rangeland and/or being the same as that in the manure produced on the farm is essentially zero. These findings are consistent with Klausner (1989) and National Research Council (1993) who indicate that, under most farmland conditions--when manure is applied at a rate adequate to match the need for one of N, P, and K--the needs for the other two will not be simultaneously just met (usually, if N needs are met, P and K will be in excess).

Baseline whole-farm needs. Table 10 shows the baseline per-acre crop and grass production N and P needs displayed in Table 9 multiplied by the respective acreages of cropland and rangeland on the individual farms. Estimated baseline whole-farm levels of manure N required to meet crop fertility needs under various yield goals and soil test levels on-average for the eight farms are as follows:

* Cropland N (1.25 YG): 12.0 tons;
* Cropland N (1.0 YG): 7.80 tons;
* Cropland P (STP = low): 5.70 tons;
* Cropland P (STP = medium: 3.49 tons;
* Rangeland N (STN = 0): 20.1 tons;
* Rangeland N (STN = 20 lb/acre): 6.02 tons;
* Rangeland P (STP = low): 8.04 tons; and
* Rangeland P (STP = medium): 3.71 tons.

Table 10. Baseline estimated whole-farm crop and grass production nitrogen and phosphorus needs, case farms[a].

Nature of yield goals and soil test levels	Estimated tons per farm: Northwest, Farm 1	Northwest, Farm 2	South Central, Farm 1	South Central, Farm 2	North Central, Farm 1	North Central, Farm 2	Central, Farm 1	Central, Farm 2	Eight farm average
Manure spread on cropland[b]									
Nitrogen (YG=1.25)	18.01	5.63	6.47	3.28	14.92	19.69	9.79	18.09	11.99
Nitrogen (YG=1.0)	11.77	2.71	2.89	**1.73**	10.68	13.41	6.73	12.45	7.80
Phosphorus (STP=low)	5.25	4.32	6.76	4.88	8.21	5.67	5.34	5.13	5.70
Phosphorus (STP=med)	3.17	2.74	4.33	3.05	4.86	3.43	3.24	3.10	3.49
Manure dropped on rangeland									
Nitrogen (STN=0)	21.29	35.49	12.59	31.00	27.38	22.78	4.13	5.91	20.07
Nitrogen (STN=20)	**4.26**	**7.10**	*2.52*	**6.20**	**12.78**	**10.63**	**1.93**	2.76	6.02
Phosphorus (STP=low)	9.74	16.24	5.76	14.19	8.35	6.95	*1.26*	1.80	8.04
Phosphorus (STP=med)	4.50	7.49	2.66	6.55	**3.85**	**3.21**	**0.58**	*0.83*	3.71
Total for farm[c]									
Nitrogen									
Cropland YG = 1.25, rangeland STN = 0	39.30	41.12	19.06	34.28	42.30	42.47	13.92	24.00	32.06
Cropland YG = 1.0, rangeland STN = 0	33.06	38.20	15.48	32.73	38.06	36.19	10.86	18.36	27.87
Cropland YG = 1.25, rangeland STN = 20	22.27	12.73	8.99	9.48	27.70	30.32	11.72	20.85	18.01
Cropland YG = 1.0, rangeland STN = 20	16.03	9.81	5.41	7.93	23.46	24.04	8.66	15.21	13.82
Phosphorus									
STP = low	14.99	20.56	12.52	19.07	16.56	12.62	6.60	6.93	13.74
STP = medium	7.67	10.23	6.99	9.60	8.71	6.64	3.82	3.93	7.20

[a]Instances in which estimated amounts of plant-available N and P in manure produced exceed estimated amounts of manure N and P just adequate to match crop and grass production needs are highlighted in **bold**. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

[b]"Cropland" on which manure was spread includes not only individual row crops, small grains, and alfalfa, but also native hay.

[c]This final section of the table was calculated for later comparison with data in Table 11.

Whole-farm "threshold" levels. In the less restrictive post-baseline "threshold" analysis, estimated threshold whole-farm levels of manure N that could be accommodated on existing farmland range from an average for the eight case farms of 33.8 tons with cropland "1.25 YG" and rangeland "STN = 0" to 14.9 tons with cropland "1.0 YG" and rangeland "STN = 20 lb/acre" (Table 11). The analogous range for manure P is 14.6 tons with low STP to 7.7 tons with medium STP.

Table 11. Estimated threshold whole-farm levels of manure nitrogen and phosphorus that could be accommodated on existing farmland, case farms.[a]

Nature of yield goals and soil test levels	Estimated tons per farm: Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average
Nitrogen									
Cropland YG = 1.25, rangeland STN = 0	46.88	44.07	19.06	35.08	42.29	42.47	16.16	24.00	33.75
Cropland YG = 1.0, rangeland STN = 0	38.00	39.62	15.48	33.15	38.06	36.19	12.40	18.36	28.91
Cropland YG = 1.25, rangeland STN = 20	29.85	15.68	8.99	*10.28*	27.69	30.32	13.96	20.85	19.70
Cropland YG = 1.0, rangeland STN = 20	20.97	11.23	5.41	**8.35**	23.46	24.04	10.20	15.21	14.86
Phosphorus[b]									
STP = low	17.20	22.81	12.52	20.26	16.56	12.62	7.83	6.93	14.59
STP = medium	9.00	11.66	6.99	10.34	*8.72*	*6.64*	4.56	3.93	7.73

[a]Instances in which estimated threshold amounts of manure N and P that could be accomodated on existing farmland are less than amounts of plant-available N and P in manure produced by existing livestock populations on the case farms are highlighted in **bold**. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

[b]In this analysis, individual farms' STP levels for cropland and rangeland were assumed to be the same.

"The match" between livestock manure production and utilization

In the following, current whole-farm crop and grass production manure N and P needs are compared with available N and P in whole-farm manure currently produced. Baseline analysis results are first presented (Table 10 versus Table 8), followed by threshold analysis results (Table 11 versus Table 8).

Baseline analysis. On-average for the eight farms with **cropland** N "1.25 YG," whole-farm N needs are 5.1-fold whole-farm N production (11.99/2.35 tons). Under cropland N "1.0 YG," the manure N need-production difference is 3.3-fold. On-average for the eight farms and under a low STP cropland level, whole-farm P needs are 5.7-fold whole-farm P production. Under a medium STP cropland level, the manure P need-production difference is 3.5-fold.

On-average for the eight farms with **rangeland** "STN = 0," whole-farm N needs are 2.7-fold whole-farm N production. Under "STN = 20 lb/acre," however, the manure N need is 20% less than manure N production. On-average for the eight farms with a low STP rangeland level, whole-farm P needs are 2.6-fold whole-farm P production. Under a medium STP cropland level, the manure P need is 18% more than manure P production.

Thus, current manure N and P needs on-average for the eight farms exceed current manure N and P production, with margins of difference greater for cropland than for rangeland. Under one rangeland condition considered ("STN = 20 lb/acre"), the current manure N need for grass production is less than that for manure currently dropping on rangeland.

Instances in which estimated current amounts of manure N and P produced exceed estimated current amounts of manure N and P just adequate to meet crop and grass production needs from external sources are shown in bold type in Table 10. Instances in which current manure N and P production is approximately equal to (within 10% of each other) current crop and grass N and P needs are shown in italics. Finally, instances in which current amounts of manure N and P produced are less than estimated crop and grass N and P needs are shown in normal type.

For **cropland**, in no situation, is whole-farm plant-available N and P from livestock manure produced approximately equal to (within 10% of) whole-farm N and P fertility needs. In 31 of the 32 case farm-N and P situations considered, whole-farm manure N and P production is inadequate to meet whole-farm crop and grass production N and P fertility needs. In 1 situation (N "YG = 1.0"), the opposite situation prevails, i.e., manure production exceeds current fertility needs.

For **rangeland**, in 3 of the 32 situations, whole-farm plant-available N and P from manure is approximately equal to whole-farm N and P fertility needs. In 20 situations, N and P production is less than adequate to meet N and P needs. Finally, in 9 situations, N and P production is greater than N and P fertility needs. Six of these 9 situations are when "STN = 0," and 3 are when "STP = medium."

Thus, in the vast majority (80%) of situations examined, crop and grass production N and P fertility needs exceed amounts of plant-available N and P from livestock manure produced on the case farms. In 5% of the situations, N and P needs approximate manure N and P production. And, in 15% of the situations, livestock manure N and P exceed crop and grass needs. In 9 of the latter 10 situations, livestock manure "surpluses" are with respect to rangeland (rather than cropland). In interpreting this finding, recall that acres of rangeland per cow are greater (1) for seven of the eight case farms than on-average for farms in the respective counties in which the case farmers reside and (2) in South Dakota than in all except two of the other nine major cow-calf producing states in the U.S. (recall Table 4). Results of this study, therefore, suggest the possibility of rangeland in the seven other states being vulnerable to "excessive" amounts of manure N and P.

Numbers of cows that would allow whole-farm manure production to be matched with current whole-farm manure N and P needs under each case farm N and P situation examined are displayed in Table 12.[14] These numbers vary widely, depending on the crop and grass manure nutrient need criterion. For example, to meet his rangeland "STN = 20 lb/acre" need, Northwest Farmer 1 would need only 66 cows. But, to meet his N "1.25 YG" need, he would require 13.1 times as many (863) cows. This margin of difference is least for Northwest Farm 2. But even for it, 5.5 times as many cows are required under a rangeland low STP condition as under a rangeland "STN = 20 lb/acre" condition.

[14]In this sensitivity analysis, ratios of initial supplementary livestock enterprises to initial cow herd sizes were preserved. In other words, if herd sizes doubled in the sensitivity analysis, each supplementary livestock enterprise was also assumed to double in size.

Table 12. Estimated numbers of cows required in baseline analysis to achieve a match in livestock manure production and utilization under various yield goal and soil test assumptions, case farms.[a]

Nature of yield goals and soil test levels	Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average
Number of cows									
Manure spread on cropland[b]									
Nitrogen (YG = 1.25)	863	300	278	197	705	986	270	445	555
Nitrogen (YG = 1.0)	563	144	124	**103**	505	672	186	306	361
Phosphorus (STP=low)	596	549	695	700	929	680	352	290	629
Phosphorus (STP=med)	360	348	446	437	550	411	213	175	385
Manure dropped on rangeland									
Nitrogen (STN=0)	332	539	178	497	357	317	64	86	291
Nitrogen (STN=20)	**66**	**108**	*36*	**99**	**166**	**148**	**30**	40	87
Phosphorus (STP=low)	364	590	194	538	260	231	*47*	63	278
Phosphorus (STP=med)	168	272	90	248	**120**	**107**	**22**	*29*	128
Ratio of largest to smallest cow numbers above	13.08	5.46	19.31	7.07	7.74	9.21	16.00	15.34	7.23
Current herd size (head)	129	120	39	128	201	172	51	32	109
Number of cows required to meet crop and grass production nutrient needs as a ratio to current herd size									
Greatest number	6.69	4.92	17.82	5.47	4.62	5.73	6.90	13.91	5.77
Least number	0.51	0.90	0.92	0.77	0.60	0.62	0.43	0.91	0.80

[a] Instances in which numbers of cows required to provide manure just adequate to match crop and grass production nitrogen and phosphorus needs are less than current herd sizes are highlighted in **bold**. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

[b] "Cropland," on which manure was spread, includes not only individual row crops, small grains, and alfalfa, but also native hay.

The **greatest numbers of cows** required to meet crop and grass production N and P needs for the case farms are 4.6 to 17.8 times the current numbers of cows on the respective farms. For seven of the eight farms, the greatest number of cows required to meet crop and grass production N needs is in respect to manure spread on cropland. In four cases, greatest numbers of cows are for low STP, and in three cases for N "1.25 YG." In one case, however, the greatest number of cows to meet crop and grass production N and P involves the rangeland low STP situation.

The **least numbers of cows** required to meet grass production N and P needs are 9% to 57% fewer than those in existing herds. For the four Northwest and South Central farms, the least number of cows required to meet crop and grass nutrient needs is associated with the "STN = 20 lb/acre" rangeland criterion. For the four North Central and Central farms, however, least numbers of cows are associated with the medium STP rangeland criterion.

Thus, these herd size data convey in very practical terms the infeasibility of the plant-available N and P contained in livestock manure produced on particular case farms being matched with the crop and grass manure N and P needs on the farms.

Threshold analysis. In the less restrictive post-baseline "threshold" analysis, estimated amounts of N on-average for the eight farms are 3.7% to 9.4% more and amounts of P are 6.3% to 7.4% times greater than for corresponding conditions under the baseline analysis (eight farm averages in Table 11 are compared with analogous averages in the second half of Table 10).

In 3 of 48 instances under the threshold analysis, the amount of plant-available N and P from manure produced by existing livestock populations is approximately equal to that which can be accommodated on existing farmland. In only 1 situation (2.1%), with cropland N "YG = 1.0" and rangeland "STN = 20," is the estimated amount of manure N and P that could be accommodated on existing farmland less than the amount of plant-available N and P in manure produced by the existing livestock population. This compares to 15% (10 of 64) of total instances considered in the baseline analysis in which N and P in livestock manure exceeds N and P needed by crops.

The average estimated maximum number cows that could be accommodated on existing farmland, under assumed threshold conditions, ranges from 384 with low STP to 164 for cropland N "1.0 YG" and "STN = 20 lb/acre" (Table 13). The less restrictive manure allocation restrictions under threshold conditions lead to much less variation in the maximum numbers of cows that could be accommodated on each farm's farmland under the six different yield goal and soil test conditions examined. For example, the ratio of largest to smallest cow numbers for individual case farms under the six different threshold conditions ranges from only 1.8 to 5.7 compared to 5.5 to 19.3 under baseline conditions (recall Table 11).

Table 13. Estimated maximum numbers of cows that could be accommodated on existing farmland, threshold analysis, case farms.[a]

Nature of yield goals and soil test levels	Northwest		South Central		North Central		Central		Eight farm average
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	
Number of cows									
Nitrogen									
Cropland YG = 1.25, rangeland STN = 0	552	521	203	444	432	463	161	220	373
Cropland YG = 1.0, rangeland STN = 0	447	468	164	420	389	394	123	169	319
Cropland YG = 1.25, rangeland STN = 20	351	185	96	*130*	283	330	139	191	217
Cropland YG = 1.0, rangeland STN = 20	247	133	57	**106**	240	262	101	140	164
Phosphorus[b]									
STP = low	483	645	318	608	405	329	186	150	384
STP = medium	253	330	178	310	*213*	*173*	108	85	204
Ratio of largest to smallest cow numbers above	2.23	4.85	5.58	5.74	2.03	2.68	1.84	2.59	2.34
Current herd size (head)	129	120	39	128	201	172	51	32	109
Number of cows required to meet crop and grass production nutrient needs as a ratio to current herd size									
Greatest number	4.28	5.38	8.15	4.75	2.15	2.69	3.65	6.88	3.52
Least number	1.91	1.11	1.46	0.83	1.06	1.01	1.98	2.66	1.50

[a]Instances in which numbers of cows would provide more manure than can be accommodated on existing farmland are highlighted in **bold**. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

[b]In this analysis, individual farms' STP levels for cropland and rangeland are assumed to be the same.

ON-FARM LIVESTOCK FEEDSTUFF PRODUCTION AND CONSUMPTION

Estimated crop and grass TDN production

In determining the tons of TDN produced from crops on each case farm, acreages of crops and grass raised in 1993 were multiplied by (1) various crop and grass yields obtained by the respective farmers in 1993 (see Annex A) and (2) amounts of TDN contained per unit of production for each type of crop and grass raised (recall Table 1). Separate attention was given to produced TDN in livestock feedstuffs versus in cash crops (buckwheat, millet grain, soybeans, and wheat), since the former is directly pertinent to the whole farm assessment of balance between whole-farm production of TDN and whole-farm livestock consumption of TDN.

On average for the eight farms, 62% of total farmland (1,405 acres) is in rangeland (Table 14). Eighteen percent is represented by cropland on which livestock feedstuffs are produced (416 acre average), with 51% of such cropland being in alfalfa or alfalfa/grass and 18% in oats. Of total farmland, 11% is in cash crops (244 acre average), 4% summer fallow, 3% native hay, and 2% CRP grassland.

Table 14. Acreages of potential livestock feedstuffs and cash crops, case farms.

Crop type	Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average Acres	Eight farm average Percent
Potential livestock feedstuffs										
Cropland										
Alfalfa or alfalfa/grass hay	190	350	390	260	220	84	135	73	213	9.5
Oat grain	143	40	122	0	40	70	115	67	75	3.3
Corn or sorghum sudan silage	105	0	0	0	110	160	60	0	54	2.4
Corn grain	0	0	0	0	30	0	100	120	31	1.4
Barley	0	0	0	0	0	136	0	0	17	0.8
Sorghum grain	0	0	0	110	0	0	0	0	14	0.6
Oat or millet hay	0	70	0	30	0	0	0	0	12	0.5
Sub-total	438	460	512	400	400	450	410	260	416	18.5
Native hay	100	0	0	0	200	80	70	0	56	2.5
Rangeland[a]	1,703	2,839	1,007	2,480	1,460	1,215	220	315	1,405	62.5
Cash crops										
Spring wheat	390	295	100	0	140	235	0	230	174	7.7
Winter wheat	0	0	0	90	0	0	0	100	24	1.1
Millet grain	0	0	185	0	0	0	0	0	23	1.0
Buckwheat	0	0	160	0	0	0	0	0	20	0.9
Soybeans	0	0	0	0	0	0	0	25	3	0.1
Sub-total	390	295	445	90	140	235	0	355	244	10.8
Other										
Summer fallow	390	225	0	120	0	0	0	0	92	4.1
CRP grassland	0	170	0	0	0	0	110	0	35	1.6
Sub-total	390	395	0	120	0	0	110	0	127	5.7
TOTAL	3,021	3,989	1,964	3,090	2,200	1,980	810	930	2,248	100.0

[a]In addition to grazing on these acres of rangeland, the cow herds graze 30 acres of corn stubble for 30 days on North Central Farm 1 and 100 acres of corn stubble for 30 days on Central Farm 2.

Average estimated total TDN production for the eight farms is 832 tons per farm, 66% of which is in the form of potential livestock feedstuffs grown on cropland,[15] 19% cash crops, and 15% rangeland grass (Table 15). On individual farms, total TDN production ranges among farms from 645 tons to 1,186 tons. The importance of TDN in the form of livestock feedstuffs on cropland relative to total TDN produced ranges among farms from 51% to 96%. Cash crop TDN production ranges from zero to 39% of total TDN production. TDN production from rangeland grass varies in relative importance from 4% to 38%.

[15]Since manure was assumed to be spread not only on cropland, but also on native hay land, "cropland" in the feedstuff balance analysis also includes native hay land.

Table 15. Estimated crop and grass TDN production, case farms.

Case farm	Crops: Potential livestock feedstuffs[a] Tons	%	Cash crops[b] Tons	%	Sub-total Tons	%	Grass on rangeland Tons	%	Total Tons for farm
Northwest									
Farm 1	455	52.9	274	31.9	729	84.8	131	15.2	860
Farm 2	378	50.5	152	20.3	530	70.8	219	29.2	749
South Central									
Farm 1	482	61.9	198	25.4	680	87.3	99	12.7	779
Farm 2	334	51.8	68	10.5	402	62.3	243	37.7	645
North Central									
Farm 1	945	79.7	98	8.3	1,043	88.0	143	12.0	1,186
Farm 2	699	71.0	166	16.9	865	87.9	119	12.1	984
Central									
Farm 1	670	96.4	0	0	670	96.4	25	3.6	695
Farm 2	423	56.1	295	39.1	718	95.2	36	4.8	754
Eight farm average	548	65.9	157	18.8	705	84.7	127	15.3	832

[a]Includes TDN produced, not only from "crops," but also from native hay.

[b]"Cash crops" include buckwheat, millet grain, soybeans, and wheat.

Thus, while rangeland accounts for 62% of total farmland acreage, it accounts for only 15% of TDN produced. Further, TDN production is far more intensive on cropland used for producing livestock feedstuffs (18% of total acreage contributes 66% of total TDN produced) than on cropland for producing cash crops (11% of total acreage contributes 19% of total TDN produced).

The data in Table 16 show that on-average for the eight case farms (1) TDN production per acre on cropland used for producing potential livestock feedstuffs is 80% greater than on cropland used for cash crops and (2) TDN production per acre on cropland as-a-whole is nearly 11 times as great as that on rangeland. The more intensive TDN production on cropland for livestock feedstuffs compared to cash crops is illustrated with the following data showing a greater TDN production per acre for "moderate" yields of the main livestock feedstuffs (alfalfa, oats, and corn) compared to a "moderate" yield of the main cash crop (spring wheat): 8.0 tons of corn silage = 3,696 lb; 3 tons of alfalfa = 3,132 lb; 70 bu of corn grain = 3,101 lb; 60 bu of oats = 1,560 lb; and 30 bu of spring wheat = 1,350 lb.

Table 16. Estimated per-acre TDN production in livestock feedstuffs and cash crops produced on cropland and in grass produced on rangeland, case farms.

	Estimated TDN production (lb per acre)				
	Cropland				
Case farm	Potential livestock feedstuffs[a]	Cash crops[b]	Sub-total	Grass on rangeland	Average for whole-farm[c]
Northwest					
Farm 1	1,691	1,405	1,571	154	569
Farm 2	1,643	1,031	1,404	154	392
South Central					
Farm 1	1,883	890	1,421	196	793
Farm 2	1,670	1,511	1,641	196	417
North Central					
Farm 1	3,150	1,400	2,819	196	1,078
Farm 2	2,638	1,413	2,261	196	994
Central					
Farm 1	2,792	n/a	2,792	228	1,986
Farm 2	3,254	1,662	2,335	228	1,622
Eight farm average	2,322	1,287	1,969	181	752

[a]Includes TDN produced, not only from "crops," but also from native hay.

[b]"Cash crops" include buckwheat, millet grain, soybeans, and wheat.

[c]The acreage used in this calculation includes summer fallow, but not CRP grassland.

Estimated livestock TDN and protein requirements

Estimated whole-farm livestock TDN requirements range among farms from 131 tons to 673 tons and average 350 tons (Table 17).[16] On-average, brood cows require 71% of total TDN, replacement heifers 17%, herd sires and hogs 4% each, and backgrounded cattle and slaughter cattle 2% each.

It will be recalled that brood cows, on average for the eight farms, generate 76% of total manure produced (Table 6). Thus, their role in manure production is 5 percentage points greater than in TDN feed consumption. On the other hand, hogs produce only 2.2% of total manure, but consume 3.7% of total TDN.

Estimated whole-farm livestock protein requirements range among farms from 20 tons to 103 tons and average 53 tons. On average, brood cows require relatively more whole-farm protein than whole-farm TDN (2.8 percentage points more) and hogs slightly less (0.5 percentage points less).

[16]Tons of soybean oil meal (44% protein) to meet protein needs of livestock on the respective farms are as follows: Central Farm 2 = 30.54; North Central Farm 1 = 10.53; South Central Farm 2 = 6.84; Northwest Farm 1 = 3.55; Northwest Farm 2 = 3.30; Central Farm 1 = 2.32; and South Central Farm 1 and North Central Farm 2 = 0.

Table 17. Estimated TDN and protein requirements for livestock, case farms.

Type of livestock	Estimated tons required: Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average Tons	Eight farm average %
Total digestible nutrients										
Brood cows	279.5	265.0	86.1	280.1	497.2	406.7	112.6	69.3	249.6	71.4
Replacement heifers	67.9	64.9	40.3	44.9	109.2	109.4	27.5	20.8	60.6	17.3
Herd sires	10.2	12.8	2.6	16.7	24.9	27.2	10.7	5.3	13.8	3.9
Backgrounded cattle	6.7	10.2	2.1	n/a	41.7	n/a	n/a	n/a	7.6	2.2
Finished cattle	n/a	n/a	n/a	n/a	n/a	n/a	42.1	n/a	5.2	1.5
Sub-total	364.3	352.9	131.1	341.7	673.0	543.3	192.9	95.4	336.8	96.3
Hogs	32.0	n/a	n/a	n/a	n/a	n/a	n/a	71.0	12.9	3.7
TOTAL	396.3	352.9	131.1	341.7	673.0	543.3	192.9	166.4	349.7	100.0
Protein										
Brood cows	43.0	41.3	13.4	43.3	78.6	64.1	17.6	10.6	39.0	74.2
Replacement heifers	9.2	8.7	5.4	6.1	14.4	14.6	3.7	2.9	8.1	15.4
Herd sires	1.4	1.9	0.4	2.3	3.5	3.8	1.5	0.8	2.0	3.8
Backgrounded cattle	1.1	1.4	0.3	n/a	6.5	n/a	n/a	n/a	1.1	2.1
Finished cattle	n/a	n/a	n/a	n/a	n/a	n/a	5.3	n/a	0.7	1.3
Sub-total	54.7	53.3	19.5	51.7	103.0	82.5	28.1	14.3	50.9	96.8
Hogs	5.7	n/a	n/a	n/a	n/a	n/a	n/a	7.8	1.7	3.2
TOTAL	60.4	53.3	19.5	51.7	103.0	82.5	28.1	22.1	52.6	100.0

"The match" between livestock feedstuff production and consumption

In meeting whole-farm livestock nutrient needs, all corn and sorghum sudan silage and all oat and millet hay produced on the case farms is fed to livestock on the farms (Table 18). On two of the four farms producing native hay, all the hay produced is fed. On one of the eight farms producing alfalfa hay, all alfalfa produced is fed . One farmer feeds only 50% of his native hay and two farmers feed as little as 14% of the alfalfa they produce.

Table 18. Percentages of livestock feedstuffs produced fed to farmers' own livestock, case farms.

Livestock feedstuff	Northwest Farm 1	Northwest Farm 2	South Central Farm 1	South Central Farm 2	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2
Roughages								
Corn/sorghum sudan silage	100.0	n/a	n/a	n/a	100.0	100.0	100.0	n/a
Oat/millet hay	n/a	100.0	n/a	100.0	n/a	n/a	n/a	n/a
Native hay	82.7	n/a	n/a	n/a	100.0	100.0	50.0	n/a
Alfalfa hay	59.6	20.6	14.2	41.6	45.8	100.0	14.3	36.5
Grains								
Oat grain	40.6	58.9	7.9	n/a	58.0	36.3	13.4	7.8
Corn grain	n/a	n/a	n/a	n/a	38.3	n/a	12.2	33.4
Sorghum grain	n/a	n/a	n/a	9.3	n/a	n/a	n/a	n/a
Barley grain	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a

In general, percentages of home-raised grains produced fed to farmers' own livestock are lower than for home-raised roughages. Percentages of total oat production fed to livestock range from 8% for two farms to 58-59% for two farms. For corn grain, the range in percentages of total corn grain produced fed to livestock is 12% to 38%.

The percentage of TDN in total home-raised livestock feedstuffs produced fed to farmers' own livestock ranges among farms from 25% to 81% and averages 60% (Table 19).[17] The average percentage of feedstuffs produced that is fed to farmers' own livestock is much higher for grass (98%) than for crops (51%). For grass, the range among farms in percentages of total quantities produced fed to owned livestock is only 83% to 100%, whereas for crops the range is from 13% for one farm to 77% for another farm.

Table 19. Estimated match between TDN in livestock feedstuffs produced and TDN in feedstuffs consumed, case farms.

Case farm	Crops[a]			Grass			Total		
	Tons produced	Tons consumed	Percent consumed	Tons produced	Tons consumed	Percent consumed	Tons produced	Tons consumed	Percent consumed
Northwest									
Farm 1	455	324	71.2	131	131	100.0	586	455	77.6
Farm 2	378	171	45.2	219	219	100.0	597	390	65.3
South Central									
Farm 1	482	63	13.1	99	82	82.8	581	145	25.0
Farm 2	334	131	39.2	243	237	97.5	577	368	63.8
North Central									
Farm 1	945	669	70.8	143	143	100.0	1,088	812	74.6
Farm 2	699	541	77.4	119	119	100.0	818	660	80.7
Central									
Farm 1	670	207	30.9	25	25	100.0	695	232	33.4
Farm 2	423	144	34.0	36	36	100.0	459	180	39.2
Eight farm average	548	281	51.3	127	124	97.6	675	405	60.0

[a]Includes TDN produced, not only from "crops," but also from native hay.

ON-FARM BALANCE BETWEEN LIVESTOCK MANURE PRODUCTION-UTILIZATION AND LIVESTOCK FEEDSTUFF PRODUCTION-CONSUMPTION

As a prelude to reconciling case farm manure and feedstuff balances, recall two main interrelated points from the section in which manure balances were discussed. First, it was determined that individual case farmers' per-acre N and P needs depend on several factors: (1) yield goals against which fertilization levels are determined; (2) soil test nitrogen (STN) and phosphorus (STP) levels; (3) fertilization needs for cropland versus for rangeland; and (4) for cropland, particular combinations of crops raised.

[17]The average total amount of TDN produced that is required by livestock on the eight farms is 16% more than that average amount actually consumed by the livestock (405 tons produced as shown in Table 19 versus 350 tons required as shown in Table 17). This difference represents the average collective storage and feeding loss of all home-raised feedstuffs fed.

Second, estimated sizes of cow herd required to provide manure just adequate to meet crop and grass production N and P needs varied a great deal for each case farm, depending on which yield goal, STN, and STP condition was assumed. These estimates were made under (1) eight "baseline" situations in which (a) stipulated proportions of total livestock manure produced were assumed to be applied to cropland versus to rangeland and (b) livestock manure was assumed to be applied to only those crops for which fertilizer is normally applied and (2) six "threshold" situations in which restrictions on the allocation of manure between cropland and rangeland were removed and in which any manure not needed for fertilizing crops could be applied to CRP and fallow land up to the weighted average per-acre amount for the fertilized crops on the respective farms.

In reconciling case farm manure and feedstuff balances, "tons of TDN required per cow" to meet livestock nutrient needs on each farm were determined by dividing total estimated whole-farm livestock TDN consumption by size of cow herd. These amounts range among farms from 2.88 to 5.63 tons/cow and average 3.72 tons/cow (Table 20). The amounts differ among farms primarily because of varying natures and sizes of supplementary livestock enterprises on the different farms. Differences among farms in proportions of replacement heifers relative to mature brood cows, weaning and mature weights of animals, dates of weaning calves and selling various types of growing animals, and rates of gain of growing animals also contribute to differences in tons of TDN per cow on different farms.

Table 20. Tons of TDN required per cow to meet estimated whole-farm livestock nutrient requirements, case farms.

Case farm	Tons/cow	Case farm	Tons/cow
Northwest		North Central	
Farm 1	3.53	Farm 1	4.04
Farm 2	3.25	Farm 2	3.84
South Central		Central	
Farm 1	3.72	Farm 1	4.55
Farm 2	2.88	Farm 2	5.63
		Eight farm average	3.72

Tons of TDN required to meet the nutrient needs of herd sizes determined to be just matched in livestock manure production-utilization under each of the just-described 14 conditions under various yield goal and soil test assumptions were then computed by multiplying those herd sizes by respective tons of TDN per cow (Table 21). Average amounts of TDN for the eight farms range among the eight baseline conditions from 324 to 2,355 tons/farm and among the six threshold conditions from 609 to 1,429 tons/farm.

In 4 of the 64 (6%) situations examined, the herd size allowing for matched manure production-utilization simultaneously allows for matched (plus or minus 10%) feedstuff production-consumption. Each such instance involves rangeland. No case farm matched in

Table 21. Tons of TDN required to support the estimated numbers of cows required to achieve a match in livestock manure production-utilization under various yield goal and soil test assumptions, baseline and threshold analyses, case farms.[a]

Nature of yield goals and soil test levels	Northwest		South Central		North Central		Central		Eight farm
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Average
Baseline analysis									
Manure spread on cropland[b]									
Nitrogen (YG = 1.25)	4,321	1,484	1,034	704	2,850	3,783	1,509	2,503	2,355
Nitrogen (YG = 1.0)	2,822	714	**462**	**370**	2,041	2,577	1,037	1,723	1,521
Phosphorus (STP = low)	2,987	2,719	2,586	2,505	3,753	2,608	1,969	1,634	2,688
Phosphorus (STP = medium)	1,803	1,724	1,656	1,566	2,222	1,578	1,193	986	1,649
Manure dropped on rangeland									
Nitrogen (STN = 0)	1,171	1,752	661	1,430	1,440	1,217	**292**	*487*	1,081
Nitrogen (STN = 20)	**234**	**350**	132	**286**	**672**	**568**	**136**	**227**	324
Phosphorus (STP = low)	1,282	1,917	723	1,547	*1,051*	*888*	**213**	**355**	1,034
Phosphorus (STP = medium)	*592*	885	**334**	714	**485**	**410**	**98**	**164**	477
Threshold analysis									
Nitrogen									
Cropland YG = 1.25 rangeland STN = 0	1,945	1,692	753	1,277	1,745	1,775	*730*	1,239	1,385
Cropland YG = 1.0, rangeland STN = 0	1,577	1,521	*612*	1,206	1,570	1,513	**560**	948	1,186
Cropland YG = 1.25, rangeland STN = 20	1,239	*602*	**355**	**374**	*1,142*	1,267	*631*	1,076	808
Cropland YG = 1.0, rangeland STN = 20	870	**431**	**214**	**304**	**968**	1,005	**461**	785	609
Phosphorus									
STP = low	1,704	2,095	1,183	1,747	1,635	1,262	846	844	1,429
STP = medium	891	1,071	661	892	**860**	**664**	**493**	*478*	757
Tons of livestock feedstuffs TDN produced	586	597	581	577	1,088	818	695	459	675

[a]Instances in which the TDN produced on the farm's current acreage exceeds the TDN required to support the estimated numbers of cows in which manure production-utilization is "perfectly" balanced are highlighted in **bold**. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

[b]"Cropland," on which manure was spread, includes not only individual row crops, small grains, and alfalfa, but also native hay.

manure production-utilization and in livestock feedstuff production-consumption on rangeland, however, is simultaneously matched in a similar way on cropland, thus resulting in "perfect ecological balance." In 18 (28%) situations, the herd size that would match (1) manure N and P production with (2) crop and grass manure N and P requirements would generate a surplus of livestock feedstuffs that could be sold, or possibly stored as insurance against abnormally low feedstuff production in subsequent years. In the other 42 (66%) situations, the herd size just matched in manure production-utilization would not generate adequate livestock feedstuff TDN to meet the needs of that herd size.

In 6 of the 48 (12%) threshold analysis situations, the herd size allowing for matched manure production-utilization simultaneously allows for matched (plus or minus 10%) feedstuff production-consumption. Five of these situations involve nitrogen, and one phosphorus. However, no one farm is simultaneously matched for both nitrogen and phosphorus, thereby resulting in "perfect ecological balance." In 11 (23%) situations, the herd size that would match feedstuff TDN production and livestock feedstuff TDN utilization would generate a surplus of livestock feedstuffs for sale or storage. In the other 31 (65%) situations, the herd size just matched in manure production-utilization would not generate adequate livestock feedstuff TDN to meet the needs of that herd size.

In conclusion, results from this study of eight case farms show no situation in which a case farm is either in "perfect" (plus or minus 10%) simultaneous balance for both livestock manure production-utilization and livestock feedstuff production-consumption with its current farmland acreage and livestock population, or is it in "perfect" simultaneous balance for both livestock manure production-utilization and livestock feedstuff production-consumption for (1) both its cropland and rangeland, under the baseline analysis involving existing farmland acres but simulated contracted or expanded livestock populations, or (2) both nitrogen and phosphorus in the less restrictive threshold analysis. Thus, while the notion of crop and livestock nutrient requirements being met internally on diversified farms is desirable, it appears that full realization of the concept in particular current real-world farm situations is difficult. If current basic farming systems were altered rather dramatically, however, it is conceivable that livestock manure production-utilization and livestock feedstuff production-consumption could be brought into balance with one another.

Although these results are somewhat discouraging relative to closing of the nutrient cycle on the farms studied, they do indicate positive possibilities for meeting the goals of decreased risk of water quality degradation and decreased off-farm nutrient inputs.

In dealing with these inherently complex issues, we encourage creative use of nutrient budgets to further evaluate agroecosystems and identify areas for improvement patterned after studies such as the following. Complete nutrient budgets for Australian agroecosystems containing legumes as a major component, showed closely balanced systems and the importance of balancing nutrients on a farm basis (Loomis and Connor, 1992). In Central America, Berish and Ewel (1988) achieved the natural ecosystem function of nutrient cycling by replacing naturally occurring species with morphologically similar food crops. Approaches which mimic natural ecosystems have also been investigated in the U.S. Researchers at the Land Institute in Kansas are using the prairie as a model for agriculture in the Midwest (Soule and Piper, 1992). This includes the use of perennial grains and polycultures to couple plant and animal interactions and complete nutrient cycles. Regardless of the approach taken, the next step is to study and develop agroecosystems which tighten the nutrient cycle.

Readers are encouraged to return to the first section of the report for a summary of the major findings and conclusions from the study.

REFERENCES CITED

Altieri, M.A. 1995. Agroecology. Westview Press. Boulder, Colorado.

Baker, F.H., F.E. Busby, N.S. Raun, and J.A. Yazman. 1990. The relationships and roles of animals in sustainable agriculture and on sustainable farms. **The Professional Animal Scientist** 6(3): 36-49.

Baker, F.H. and N.S. Raun. 1989. The role and contributions of animals in alternative agricultural systems. **Amer. J. Alternative Agric.** 4(3&4):121-127.

Berish, C.W. and J.J. Ewel. 1988. Root development in simple and complex tropical successional ecosystems. **Plant and Soil** 106:73-84.

Caneff, D. 1993. Sustaining land, people, animals, and communities: The case for livestock in sustainable agriculture. Midwest Sustainable Agriculture Working Group. Washington, D.C.

Conservation Technology Information Center. 1992. Managing livestock manure to maximize its value as a fertilizer. **Conserv. Impact** (Newsletter of CTIC, West Lafayette, Indiana) 10(2):3.

Cooke, G.W. 1982. Organic manures and fertilizers. In Fertilizing for maximum yield. Granada. London. 3rd ed.

Ensminger, M.E. 1987. Beef cattle science. (Animal Agric. Series). Interstate Printers and Publishers. Danville, Illinois. 6th ed.

Gerwing, J. and R. Gelderman. 1996. Fertilizer recommendations guide. EC 750 (rev). South Dakota State Univ. Coop. Ext. Serv. Brookings.

Guan, M. 1994. Sustainable production practices adopted by beef cattle producers in South Dakota. Masters thesis. South Dakota State Univ. Brookings.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1989. Range management principles and practices. Prentice Hall. Englewood Cliffs, New Jersey.

Killorn, R. 1985. Animal manure: A source of crop nutrients. Pm-1164 (rev). Iowa State Univ. Coop. Ext. Serv. Ames.

Kincheloe, S. 1994. Tools to aid management: The use of site specific management. **J. Soil & Water Conserv.** 49:43-45.

Klausner, S.D. 1989. Managing the land application of animal manures: Agronomic considerations. In Dairy manure management: Proceedings from the dairy manure management symposium, Syracuse, N.Y. NRAES-31. Northeast Regional Agric Engineering Serv., Cornell Univ. Ithaca, New York.

Koepf, H.H. 1985. Integrating animals into a production system. In T.C. Edens, C. Fridgen, and S.L. Battenfield (eds). Sustainable agriculture and integrated farming systems: 1984 conference proceedings. Michigan State Univ Press. East Lansing.

Lamp, L., L. Madsen, C. Hoyt, R. Matz, and B. Pflueger. 1989. Management guide for planning a farm or ranch business. EC 744 (rev). South Dakota State Univ. Coop. Ext. Serv. Brookings.

Loomis, R.S. and D.J. Connor. 1992. Crop ecology. Cambridge Univ. Press, Cambridge, U.K.

Lorimor, J., R. Zhang, S.W. Melvin, and R. Killorn. 1995. Land application for effective manure nutrient management. Pm-1599. Iowa State Univ. Coop. Ext. Serv. Ames.

Mayrose, V.B., D.H. Bache, and G.W. Libal. n.d. Performance guidelines for the swine operation. PIH-100. South Dakota State Univ. Coop. Ext. Serv. Brookings.

McGary, L. 1989. Make manure pay: Your livestock "waste" can be a valuable resource for crops. Farm Journal 113(3):AC-8.

Midwest Plan Service. 1985. Livestock waste facilities handbook. MWPS-18. Iowa State Univ. Ames. 2nd ed.

National Research Council. 1984. Nutrient requirements of beef cattle. Board on Agriculture. National Academy Press. Washington, D.C. 6th ed.

National Research Council. 1993. Soil and water quality: An agenda for agriculture. Board on Agriculture. National Academy Press. Washington, D.C.

Nelson, D.W. and C.A. Shapiro. 1989. Fertilizing crops with animal manure. EC 89-117. Univ. of Nebraska Coop. Ext. Serv. Lincoln.

Office of Technology Assessment. 1990. Technologies to improve nutrient and pest management. In Beneath the bottom line: Agricultural approaches to reduce agrichemical contamination of groundwater. Rpt. OTA-F-418. U.S. Government Printing Office. Washington, D.C.

Odum, E.P. 1984. Properties of agroecosystems. In Agricultural ecosystems. Wiley Interscience. New York.

Olsen, R.J., R.F. Hensler, O.J. Attoe, S.A. Witzel, and L.A. Peterson. 1970. Fertilizer nitrogen and crop rotations in relation to movement of nitrate nitrogen through the soil profile. **Soil Sci. Soc. Am. J.** 34:448-452.

Organic Foods Production Act of 1990. In Food, Agriculture, Conservation, and Trade Act of 1990, Public Law 101-624, 101st Congress, Nov. 28.

Pflueger, B., Madsen, L., C. Hoyt, L. Lamp, and R. Matz. 1991. Planning prices and livestock budgets for farm management programs. EC 745 (rev). South Dakota State Univ. Coop. Ext. Serv. Brookings.

Power, J.F. and R.F. Follett. 1987. Monoculture. **Scientific American** 255(3):79-86.

Schertz, D.L. and D.A. Miller. 1972. Nitrate-N accumulation in the soil profile under alfalfa. **Agronomy J.** 64:660-664.

Schmitt, M.A. 1988. Manure management in Minnesota. AG-FO-3553. Univ. of Minnesota Coop. Ext. Serv. St. Paul.

Shuyler, L.R. 1994. Why nutrient management? **J. Soil & Water Conserv.** 49:3-5.

Soule, J.D. and J.K. Piper. 1992. Farming in nature's image. Island Press. Washington, D.C.

Sutton, A.L., D.W. Nelson, and D.D. Jones. 1985. Utilization of animal manure as fertilizer. AG-FO-2613. Univ. of Minnesota Coop. Ext. Serv. St. Paul.

Taylor, D.C. 1995. "Near-organic" and "mainstream" crop-livestock production: South Dakota case study. Economics Research Report 95-5. Economics Dept., South Dakota State Univ. Brookings.

Taylor, D.C. and D.M. Feuz. 1992. South Dakota beef cow-calf producer management practices. Economics Research Report 92-7. Economics Dept., South Dakota State Univ. Brookings.

Taylor, D.C., D.M. Feuz, and M. Guan. 1996. Comparison of organic and sustainable fed cattle production: A South Dakota case study. **Amer. J. Alternative Agric.** 11(1):30-38.

Taylor, D.C., C. Mends, and T.L. Dobbs. 1990. Livestock budgets and whole-farm economic analysis: South Dakota sustainable agriculture case farms. Economics Research Report 90-7. Economics Dept., South Dakota State Univ. Brookings.

Taylor, D.C. and J. Wagner. 1991. South Dakota feedlot management. B 709. South Dakota State Univ. Agric. Exper. Sta. Brookings.

U.S. Dept. of Commerce. 1994a. 1992 Census of agriculture; Vol. 1, Geographic area series; Part 41, South Dakota and county data. U.S. Bureau of Census. Washington, D.C.

U.S. Dept. of Commerce. 1994b. 1992 Census of agriculture; Vol. 1, Geographic area series; Part 51 United States, summary and state data. AC92-A-51. U.S. Bureau of the Census. Washington, D.C.

Van Dyne, D.L. and C.B. Gilbertson. 1978. Estimating U.S. livestock and poultry manure production. Rpt. ESCS-12. Econ. Res. Serv., U.S. Dept. of Agric. Washington, D.C.

Watts, P. 1991. Feedlot waste management series: Manure production data. F37. Queensland Dept. of Primary Industries. Brisbane, Australia.

ANNEX A

CASE FARM CROP AND GRASS PRODUCTION NITROGEN AND PHOSPHORUS BALANCES

Note: The fertilizer recommendation data in this annex are based on Gerwing and Gelderman (1996) as follows: nitrogen recommendation equations, p 5; phosphorus recommendation tables, pp 6-16; and legume nitrogen credit table, p 3 (yields, expressed as tons per acre, were assumed equivalent to "plants/sq ft").

In the following table, N and P deficit-balances are denoted with minus (-) signs and N and P surplus-balances with plus (+) signs. Except for South Central Farmer 2 and Central Farmer 1 who direct seed alfalfa, the other farmers establish new fields of alfalfa with small grain nurse crops. Legume credits are assigned to such acreages of small grain underseeded with alfalfa. Since alfalfa is a nitrogen-scavenger (Olsen et al., 1970;Schertz and Miller, 1972), legume nitrogen credits that exceed nitrogen requirements for particular small grains are disregarded.

Acreages, yields, and nitrogen (N) and phosphorus (P) balances, by crop and case farm.[a]

			Pounds per acre			
			Nitrogen (N)		Phosphorus (P) soil test level	
Farm and crop	Acres	Yield per acre	YG=1.25	YG=1.0	Low	Medium
Northwest Farm 1						
Spring wheat	390	30 bu	- 53.75	- 35.00	- 9.24	- 5.72
Alfalfa	152	1.5 t	0	0	- 17.50	- 11.00
Oat grain	105	60 bu	- 57.50	- 38.00	- 11.00	- 6.60
Corn silage	105	6.5 t	- 44.50	- 27.60	- 10.51	- 6.64
Native hay	100	1.0 t	- 31.25	- 25.00	- 11.44	- 5.28
Oat gr (alf estab)	38	60 bu	- 32.50	- 13.00	- 11.00	- 6.60
Alfalfa (break-up)	38	1.0 t	0	0	- 11.00	- 7.00
Total/weighted avg	928	n/a	- 38.83	- 25.36	- 11.32	- 6.83
Northwest Farm 2						
Spring wheat	295	22 bu	- 28.75	- 15.00	- 6.60	- 4.40
Alfalfa	280	1.5 t	0	0	- 17.50	- 11.00
Oat hay (alf estab)[b]	70	3.0 t	- 16.25	0	- 9.24	- 5.50
Alfalfa (break-up)	70	1.0 t	0	0	- 11.00	- 7.00
Oat grain	40	50 bu	- 41.25	- 25.00	- 9.24	- 5.50
Total/weighted avg	755	n/a	- 14.93	- 7.19	- 11.43	- 7.25
South Central Farm 1						
Alfalfa	312	2.0 t	0	0	- 24.00	- 15.00
Millet grain	185	10 cwt	- 3.75	+ 5.00	- 4.84	- 4.40
Buckwheat	160	24.4 bu	- 27.10	- 13.68	- 9.39	- 5.81
Spring wheat	100	30 bu	- 53.75	- 35.00	- 9.24	- 5.72
Oat gr (alf estab)	78	60 bu	- 32.50	- 13.00	- 11.00	- 6.60
Alfalfa (break-up)	78	1.5 t	0	0	- 17.50	- 11.00
Oat grain	44	60 bu	- 57.50	- 38.00	- 11.00	- 6.60
Total/weighted avg	957	n/a	- 13.52	- 6.04	- 14.12	- 9.05

Farm and crop	Acres	Yield per acre	Pounds per acre: Nitrogen (N) YG=1.25	Nitrogen (N) YG=1.0	Phosphorus (P) soil test level: Low	Medium
South Central Farm 2						
Alfalfa	193	3.0 t	0	0	- 37.00	- 23.00
Sorghum grain	110	36 bu	- 9.50	0	- 6.34	- 3.87
Winter wheat	90	32 bu	- 60.00	- 40.00	- 9.86	- 6.10
Alfalfa (break-up)	37	2.0 t	0	0	- 24.00	- 15.00
Alfalfa estab (direct)	30	0	0	0	0	0
Millet hay[c]	30	2.0 t	- 3.75	+ 5.00	- 4.84	- 4.40
Total/weighted avg	490	n/a	- 13.38	- 7.04	- 19.92	- 12.45
North Central Farm 1						
Native hay	200	2.0 t	- 62.50	- 50.00	- 11.44	- 5.28
Alfalfa	176	4.0 t	0	0	- 49.00	- 30.00
Spring wheat	140	30 bu	- 53.75	- 35.00	- 9.24	- 5.72
Corn silage	110	9.5 t	- 83.50	- 58.80	- 16.01	- 9.63
Alfalfa (break-up)	44	3.0 t	0	0	- 37.00	- 23.00
Oat gr (alf estab)	40	65 bu	- 15.63	0	- 11.88	- 7.26
Corn grain	30	60 bu	- 50.00	- 32.00	- 11.88	- 7.48
Total/weighted avg	740	n/a	- 40.32	- 28.88	- 22.20	- 13.14
North Central Farm 2						
Spring wheat	235	30 bu	- 53.75	- 35.00	- 9.24	- 5.72
Corn silage	160	7.5 t	- 57.50	- 38.00	- 12.16	- 7.65
Barley	120	50 bu	- 66.25	- 45.00	- 11.44	- 7.04
Native hay	80	2.0 t	- 62.50	- 50.00	- 11.44	- 5.28
Oat grain	70	65 bu	- 65.63	- 44.50	- 11.88	- 7.26
Alfalfa	68	4.0 t	0	0	- 49.00	- 30.00
Barley (alf estab)	16	50 bu	- 16.25	0	- 11.44	- 7.04
Alfalfa (break-up)	16	3.0 t	0	0	- 37.00	- 23.00
Total/weighted avg	765	n/a	- 51.47	- 35.06	- 14.83	- 8.97
Central Farm 1						
Oat grain	115	55 bu	- 49.38	- 31.50	- 10.12	- 6.05
Alfalfa	113	4.5 t	0	0	- 55.00	- 34.00
Corn grain	100	60 bu	- 50.00	- 32.00	- 11.88	- 7.48
Native hay	70	2.0 t	- 62.50	- 50.00	- 11.44	- 5.28
Sorghum silage[d]	35	10.0 t	- 79.13	- 55.30	- 16.28	- 10.12
Corn silage	25	8.5 t	- 70.50	- 48.40	- 13.81	- 8.64
Alfalfa estab (direct)	11	0	0	0	0	0
Alfalfa (break-up)	11	3.0 t	0	0	- 37.00	- 23.00
Total/weighted avg	480	n/a	- 40.80	- 28.06	- 22.27	- 13.50
Central Farm 2						
Spring wheat	230	32 bu	- 60.00	- 40.00	- 9.86	- 6.12
Corn grain	120	80 bu	- 80.00	- 56.00	- 16.28	- 10.12
Winter wheat	100	45 bu	-100.63	- 72.50	- 13.86	- 8.58
Alfalfa	61	4.0 t	0	0	- 49.00	- 30.00
Oat grain	55	55 bu	- 49.38	- 31.50	- 10.12	- 6.05
Soybeans	25	28 bu	0	0	- 21.60	- 8.00
Oat grain (alf estab)	12	55 bu	0	0	- 10.12	- 6.05
Alfalfa (break-up)	12	3.0 t	0	0	- 37.00	- 23.00
Total/weighted avg	615	n/a	- 58.83	- 40.49	- 16.68	- 10.07

[a]Nitrogen (N) deficits for rangeland yielding 1 ton/acre (Northwest and South Central farms) and 1.5 tons/acre (North Central and Central farms) under STN = 0 are 25.0 and 37.5 lb/acre, respectively. Under STN = 20 lb/acre, the deficits are 5.0 and 17.5 acre. Phosphorus (P) deficits are the same for both yields: 11.44 lb/acre with STP = low and 5.28 lb/acre with STP = medium.

[b]Since oat hay is not covered in Gerwing and Gelderman (1996), the same N and P balances--before attention to the legume N credit--were assumed for oat hay (3.0 tons/acre) as for oat grain (50 bu/acre).

[c]Since millet hay is not covered in Gerwing and Gelderman (1996), the same N and P balances were assumed for millet hay (2.0 tons/acre) for South Central Farm 2 as for millet grain (10 cwt/acre) for South Central Farm 1.

[d]Since sorghum silage is not covered in Gerwing and Gelderman (1996), the N and P balances for sorghum silage were based on the sorghum grain formula, with a "10.4/1.2" adjustment. This adjustment factor represents the yield goal coefficient for corn silage as a ratio to the yield goal coefficient for corn grain. Since phosphorus needs for sorghum grain are very similar to those for corn grain, the corn silage phosphorus formula was used for determining the P recommendation for sorghum silage.