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Ecological Balance on Individual Crop-Livestock Farms: An Idealistic Notion or Also Practically Feasible?

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ECOLOGICAL BALANCE ON INDIVIDUAL CROP-LIVESTOCK FARMS: AN IDEALISTIC NOTION OR ALSO PRACTICALLY FEASIBLE?"[1]

by

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ECOLOGICAL BALANCE ON INDIVIDUAL CROP-LIVESTOCK FARMS: AN IDEALISTIC NOTION OR ALSO PRACTICALLY FEASIBLE?[a]

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[a]For a more extended version of this manuscript in English (rather than metric) units of measurement, please request a copy of "Econ Res Rpt 96-1" from the Librarian, Economics Department, SDSU, Box 504A, Brookings, S.D. 57007-0895.

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Abstract

The following research question is examined in this article: Can one or more of eight case study integrated crop and cow-calf farms/ranches in South Dakota 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?

The livestock manure production-utilization component of the study involves estimation and comparison of amounts of nitrogen (N) and phosphorus (P) (1) available to crops and grass in the manure produced by livestock on the respective case farms and (2) required to meet the fertility needs of the crops and rangeland grasses produced under 64 crop yield and soil test conditions on the respective case farms. The livestock feedstuff production-consumption component of the study involves estimation and comparison of amounts of (1) total digestible nutrients (TDN) produced on the case farms with (2) the TDN required by the livestock on the respective farms.

Results from the study 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 either (1) its current farmland hectarage and livestock population, or (2) simulated contracted or expanded livestock populations and current farmland hectarages in which livestock manure production-utilization is 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 might be brought into balance with one another.

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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; Caneff, 1993; Koepf, 1985; 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 article 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. [While beef cattle are produced on each case farm studied, the production units are heretofore described simply as "farms," rather than as "farms/ranches."]

Materials and Methods

Cow-calf operations studied

The research project underlying this article was originally designed to explore possibilities for "organic" beef production in South Dakota (Taylor et al., 1996). In the component of the study underlying results reported in this article, 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. 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 paper. Each pair of farms is labeled simply Farm 1 and Farm 2.

Total hectares of farmland operated by the eight case farmers range from 328 to 1,614 and average 910 (Table 1). This average area is 71% above the state-wide average of 533 ha (U.S. Dept. of Commerce, 1994). Cropland hectarages for the farms range from 211 to 493 and average 318. This average is 21% above the average of 263 ha for the state (U.S. Dept. of Commerce, 1994).

Table 1. Overview of nature and scale of case farms.

	Northwest		South Central		North Central		Central		Eight farm
Farm resource	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	average
Farmland (ha)									
Cropland	493	465	387	247	218	277	211	249	318
Native hay[a]	41	0	0	0	81	32	28	0	23
Rangeland	689	1,149	408	1,004	591	492	89	127	569
Total	1,223	1,614	795	1,251	890	801	328	376	910
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

[a]In this study, manure is assumed to be spread, rather than to be dropped by grazing cattle, on native hay. In the livestock feedstuff production-consumption part of the study, therefore, the TDN in native hay is considered as TDN produced on cropland.

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, 1994). 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.

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.

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

1. Data on 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). Based on data reported by Ensminger (1987), Killorn (1985), Midwest Plan Service (1985), Nelson and Shapiro (1989), Sutton et al. (1985), and Watts (1991), the dry matter content of beef cattle and hog manure at the time of application to farmland was assumed to be 30% and 18%, respectively. Assumed manure storage and handling losses were based on Van Dyne and Gilbertson (1978) 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 estimated that beef cattle produce--for application to farmland--5.54 kg of manure per day per 100 kg of body weight. To determine average daily rates of manure production per head, this coefficient was applied to the weight reported by each producer for each category of mature breeding animal, the average reported weight between weaning and calving for replacement heifers, and the average reported weight for market cattle between their being placed on and taken off feed. Brood sows and market hogs were assumed to produce 5.00 kg 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. By multiplying per-head amounts 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. Manure dropped in dry lot was assumed to 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):

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

3. Data on estimated percentages of N and 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). Based on consideration of these references, the following N and P percentages in manure applied to fields were assumed:

* Beef cattle: N = 0.724% and P = 0.227%; and
* Hogs: N = 0.422% and P = 0.142%.

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).

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 metric 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: (1) manure production rates per 100 kg of liveweight for beef cattle and per day for hogs, (2) manure "dry matter," (3) proportions of manure assumed to be spread on cropland versus dropped on rangeland, (4) manure N and P nutrient content, and (5) 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. Crop production N and P balances were determined with information on crop yields from respective case farmers, rangeland yields from local Natural Resource and Conservation Service personnel, and fertilizer yield recommendations from Gerwing and Gelderman (1996). N and P recommendations for various crops depend on yield goals (YGs) and residual soil test nitrogen (STN) and phosphorus (STP) levels.

Because producer-specific information on (1) yield goals against which to fertilize and (2) farmland STN and STP levels were not obtained from individual case farmers, it was decided to examine two yield goals regarding N crop fertility needs (1.0 and 1.25 times 1993 yields, adjusted for abnormal weather conditions that year), two STP levels for cropland and grass ("medium" and "low"), and two STN levels for rangeland (STN = 0 and STN = 22.4 kg/ha). The Gerwing and Gelderman state-wide STN default value of 44.8 kg/ha of cropland was assumed. Provision was made for legume N credits from alfalfa to succeeding crops.

The estimated per-hectare N and P needs determined through the above considerations were multiplied by the respective hectarages 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 livestock manure production and utilization. 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 each yield goal and soil test condition considered. 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 needs.

If total estimated manure production was less (more) 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 (would need to be contracted) until its manure production would just match its crop and grass N and P needs. In this analysis, ratios of initial supplementary livestock enterprises to initial cow herd sizes were preserved, i.e., if herd sizes doubled in the sensitivity analysis, each supplementary livestock enterprise was also assumed to double in size.

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.

Crop and grass TDN production. To determine the tons of TDN produced on each case farm, acreages of crops (including alfalfa) 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 (1984). The TDN content of grazing resources was based primarily on Lamp et al. (1989). Separate attention was given to TDN represented in livestock feedstuffs and in cash crops.

Livestock TDN requirements. Annual TDN 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). Feed requirements for hogs were based on the procedures and data provided by Mayrose et al. (n.d.).

"The match" between livestock feedstuff production and consumption. In determining the match 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. Mature cows and herd sires were assumed to graze on rangeland as long as rangeland production on the respective case farms was adequate, but for no more than the maximum grazing periods indicated by individual farmers. If protein needs were not met through grazed rangeland resources, those unmet needs were provided through supplemental feeding of alfalfa.

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 oil meal were provided in the ration for each cow:

* 15.9 kg, at time of breeding; and
* 22.7 kg, 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; Taylor and Wagner, 1991):

* Replacement heifers: 415 kg TDN and 75 kg protein;
* Backgrounded cattle: 186 kg TDN and 27 kg protein; and
* Finishing cattle: 1,470 kg TDN and 188 kg 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).

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. Tons of TDN required for herd sizes determined to be just matched in manure production-utilization under various yield goal, STN, and STP conditions were then estimated. 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 both cropland and rangeland. For a particular case farm to be judged to be "balanced ecologically," the simultaneous conditions would need to be found to apply.

Results and Discussion

On-farm livestock manure production and utilization

Livestock manure sources and disposition. Total amounts of manure produced annually per case farm range from 613 mt (cow herd of 39 cows) to 3,288 mt (201 cows) and average 1,666 mt (Table 2). On average for the eight case farms, 76% of the total manure produced drops on rangeland. Of the total manure produced on individual farms, between 55% (farm with 18 sows) and 79% (farm with no supplementary livestock enterprises) is estimated to drop on rangeland. The remainder of manure was assumed to be scraped, collected, and spread on cropland.

Table 2. Disposition of manure produced, case farms.

Case farm	Amount of manure produced annually per case farm assumed to be: Dropped on rangeland — Metric tons	Dropped on rangeland — Percent	Spread on cropland — Metric tons	Spread on cropland — Percent	Total metric tons
Northwest					
Farm 1	1,382	73.9	488	26.1	1,870
Farm 2	1,320	77.8	376	22.2	1,696
South Central					
Farm 1	462	75.4	151	24.6	613
Farm 2	1,349	79.1	357	20.9	1,706
North Central					
Farm 1	2,578	78.4	710	21.6	3,288
Farm 2	2,064	78.3	573	21.7	2,637
Central					
Farm 1	548	63.9	309	36.1	857
Farm 2	365	55.0	299	45.0	664
Eight farm average	1,258	75.5	408	24.5	1,666

On average for the eight farms, brood cows account for 76% of total manure produced. Replacement heifers account for 15%, service bulls 5%, hogs 2%, and backgrounded and slaughter cattle 1% each of total manure produced.

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 0.83 to 3.86 mt/farm and averages 2.13 mt/farm (Table 3). Analogous data for rangeland manure N are a range of 1.99 to 14.0 mt and an average of 6.83 mt. 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 3.17 to 17.9 mt and average 8.97 mt.

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 kg of available N are contained per kg of available P in the manure produced on the case farms (hereafter abbreviated as a 2.40 "N-to-P ratio"). In the exceptional situations involving hog as well as beef manure, the manure N-to-P ratio is as low as 2.31.

Table 3. Estimated whole-farm livestock manure nitrogen and phosphorus produced available to crops, case farms.[a]

Disposition of manure produced	Estimated metric tons per farm								
	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	
Manure spread on cropland									
Nitrogen	2.44	2.05	0.83	1.93	3.86	3.11	1.68	1.18	2.13
Phosphorus	1.03	0.85	0.34	0.81	1.61	1.31	0.70	0.51	0.90
Manure dropped on rangeland									
Nitrogen	7.50	7.17	2.50	7.32	14.00	11.20	2.98	1.99	6.83
Phosphorus	3.14	2.99	1.04	3.06	5.85	4.68	1.24	0.83	2.85
Total manure produced on farm									
Nitrogen	9.94	9.22	3.33	9.25	17.85	14.32	4.65	3.17	8.97
Phosphorus	4.17	3.85	1.39	3.86	7.47	5.99	1.94	1.33	3.75

[a]Due to rounding errors, N-to-P ratios for manure reported in the table on farms with only beef cattle do not necessarily equal exactly 2.40.

Estimated crop and grass production N and P needs. Estimated weighted-average per-hectare and whole-farm crop and grass production N and P needs are displayed in Tables 4 and 5. On-average for the eight case farms, per-hectare 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") (37.5 versus 24.4 kg/ha). 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 for the eight case farms, whole-farm rangeland N needs for farmers with "STN = 0" are 3.33 times those for farmers with "STN = 22.4 kg/ha." 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 6.77 to 66.0 kg/ha. Cropland P needs vary among case farms and between low and medium soil test levels from 7.66 to 25.0 kg/ha. Analogous ranges for rangeland are 5.61 to 42.0 kg/ha of N and 5.92 to 12.8 kg/ha 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 = 22.4 kg/ha" and a low STP (range = 0.44 to 1.53; average = 0.75).

Table 4. Estimated average per-hectare 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 1	North Central Farm 1	North Central Farm 2	Central Farm 1	Central Farm 2	Eight farm average
Average N and P needs for manure (kg/ha):[a]									
Spread on cropland									
Nitrogen (YG-1.25)	43.53	16.74	15.16	14.96	45.20	57.70	45.74	65.95	37.52
Nitrogen (YG-1.0)	28.43	8.06	6.77	7.89	32.38	39.30	31.46	45.39	24.41
Phosphorus (STP-low)	12.69	12.81	15.83	22.33	24.89	16.63	24.97	18.70	17.83
Phosphorus (STP-med)	7.66	8.13	10.15	13.96	14.73	10.06	15.13	11.29	10.92
Dropped on rangeland									
Nitrogen (STN-0)	28.03	28.03	28.03	28.03	42.04	42.04	42.04	42.04	32.03
Nitrogen (STN-20)	5.61	5.61	5.61	5.61	19.62	19.62	19.62	19.62	9.61
Phosphorus (STP-low)	12.83	12.83	12.83	12.83	12.83	12.83	12.83	12.83	12.83
Phosphorus (STP-med)	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
N-to-P ratios in manure:									
Spread on cropland									
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-22.4) to STP-med	0.95	0.95	0.95	0.95	3.31	3.31	3.31	3.31	1.62
N(STN-22.4) 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-hectare applications of N and P for each fertilized crop on each case farm weighted by the respective hectarages of each fertilized crop on the farm. The eight farm average is based on the weighted per-hectare average for each farm weighted by the respective fertilized hectarages on each farm.

Table 5. Estimated whole-farm crop and grass production nitrogen and phosphorus needs, case farms.[a]

Nature of yield goals and soil test levels	Estimated metric 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									
Nitrogen (YG-1.25)	16.34	5.11	5.87	2.98	13.54	17.86	8.88	16.41	10.87
Nitrogen (YG-1.0)	10.68	2.46	2.62	1.57	9.69	12.17	6.11	11.29	7.07
Phosphorus (STP-low)	4.76	3.92	6.13	4.43	7.45	5.14	4.84	4.65	5.17
Phosphorus (STP-med)	2.88	2.49	3.93	2.77	4.41	3.11	2.94	2.81	3.17
Manure dropped on rangeland									
Nitrogen (STN-0)	19.31	32.20	11.42	28.12	24.84	20.67	3.75	5.36	18.21
Nitrogen (STN-22.4)	**3.86**	**6.44**	*2.29*	**5.62**	**11.59**	**9.64**	1.75	2.50	5.46
Phosphorus (STP-low)	8.84	14.73	5.23	12.87	7.57	6.30	*1.14*	1.63	7.29
Phosphorus (STP-med)	4.08	6.79	2.41	5.94	**3.49**	2.91	**0.53**	*0.75*	3.36

[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 needs are highlighted in bold. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

Thus, we see illustrated in these 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).

"The match" between livestock manure production and utilization. Current average whole-farm crop and grass production manure N and P needs with **cropland** N "1.25 YG" are 5.1-fold current whole-farm manure N production (10.9 mt from Table 5 divided by 2.13 mt from Table 3). Under cropland N "1.0 YG," the manure N need-production difference is 3.3-fold. On-average for the eight farms 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 = 22.4 kg/ha," 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.

For **cropland**, whole-farm plant-available N and P from livestock manure produced approximates (plus or minus 10%) whole-farm N and P needs for none of the 32 yield goal and soil test situations examined (Table 5). In 31 situations, whole-farm manure N and P production is inadequate to meet current whole-farm crop and grass N and P fertility needs and, in 1 situation, manure production exceeds current fertility needs.

For **rangeland**, whole-farm plant-available N and P from manure is approximately equal to whole-farm N and P fertility needs in 3 of 32 situations. In 20 situations, N and P production is less than adequate to meet N and P needs and, in 9 situations, N and P production exceeds N and P fertility needs.

Thus, in the vast majority (80%) of the 64 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).

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 6. These numbers vary widely, depending on the crop and grass manure nutrient need criterion. For example, to meet his rangeland "STN = 22.4 kg/ha" 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 = 22.4 kg/ha" condition.

Table 6. Estimated numbers of cows that would allow whole-farm manure production to be matched with current whole-farm manure N and P needs 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
Manure spread on cropland									
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=22.4)	**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

[a]Instances in which numbers of cows required to provide manure just adequate to match crop and grass 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*.

On-farm livestock feedstuff production and consumption

Estimated crop and grass TDN production. Estimated total metric tons of TDN produced on the respective case farms are as follows:

* Northwest Farms 1 and 2: 780 and 679;
* South Central Farms 1 and 2: 707 and 585;
* North Central Farms 1 and 2: 1,076 and 893; and
* Central Farms 1 and 2: 630 and 684.

These amounts average 754 mt/farm, 66% of which is in the form of potential livestock feedstuffs grown on cropland, 19% cash crops, and 15% rangeland grass. 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%.

Estimated livestock TDN requirements. Estimated total metric tons of TDN required by livestock on the respective farms are as follows:

* Northwest Farms 1 and 2: 360 and 320;
* South Central Farms 1 and 2: 119 and 310;
* North Central Farms 1 and 2: 611 and 493; and
* Central Farms 1 and 2: 175 and 151.

These amounts average 317 mt/farm. 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. 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 7). The average percentage of feedstuffs produced that is fed to farmers' own livestock is much higher for grass (97%) than for crops (51%). For grass, the range among farms in percentages of total quantities produced fed to owned livestock is only 82% to 100%, whereas for crops the range is from 13% for one farm to 77% for another farm.

Table 7. Estimated balance between TDN in livestock feedstuffs produced and in feedstuffs consumed, case farms.[a]

	Crops			Grass			Total		
Case farm	Metric tons produced	Metric tons consumed	Percent consumed	Metric tons produced	Metric tons consumed	Percent consumed	Metric tons produced	Metric tons consumed[b]	Percent consumed
Northwest									
Farm 1	413	294	71.2	119	119	100.0	532	413	77.6
Farm 2	343	155	45.2	199	199	100.0	542	354	65.3
South Central									
Farm 1	437	57	13.0	90	74	82.2	527	131	24.9
Farm 2	303	119	39.3	220	215	97.7	523	334	63.9
North Central									
Farm 1	857	607	70.8	130	130	100.0	987	737	74.7
Farm 2	634	491	77.4	108	108	100.0	742	599	80.7
Central									
Farm 1	608	188	30.9	23	23	100.0	631	211	33.4
Farm 2	384	130	33.9	33	33	100.0	417	163	39.1
Eight farm average	497	255	51.3	115	112	97.4	612	367	60.0

[a]Due to storage and feeding losses, the total tons of feedstuffs "consumed" are greater (on-average for the eight farms, by 16%) than the total tons of TDN "required" nutritionally by the livestock.

[b]In addition to the protein contained in the home-raised feedstuffs consumed, the following amounts of purchased soybean oil meal (44% protein) were required to meet the total protein needs of the respective case farmers' own livestock: Central Farm 2 - 27.7 mt; North Central Farm 1 - 9.55 mt; South Central Farm 2 - 6.21 mt; Northwest Farm 1 - 3.22 mt; Northwest Farm 2 - 2.99 mt; Central Farm 1 - 2.10 mt; and South Central Farm 1 and North Central Farm 2 - 0.

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

Tons of TDN required to meet the nutrient needs of herd sizes just matched in livestock manure production-utilization under various yield goal and soil test assumptions are displayed in Table 8. Average amounts of N for the eight farms range from 294 mt/farm for rangeland with "STN = 22.4 kg/ha" to 2,439 mt/farm for cropland with a low STP level.

Table 8. Tons of TDN required to meet the nutrient needs of herd sizes determined to be just matched in livestock manure production-utilization under various yield goal and soil test assumptions, case farms.[a]

Nature of yield goals	Northwest		South Central		North Central		Central		Eight farm
and soil test levels	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	average
Metric tons livestock feedstuff TDN required									
Manure spread on cropland									
Nitrogen (YG=1.25)	3,920	1,346	938	639	2,585	3,432	1,369	2,271	2,136
Nitrogen (YG=1.0)	2,560	648	**419**	**336**	1,852	2,338	941	1,563	1,380
Phosphorus (STP=low)	2,710	2,467	2,346	2,272	3,405	2,366	1,786	1,482	2,439
Phosphorus (STP=med)	1,636	1,564	1,502	1,421	2,016	1,432	1,082	894	1,496
Manure dropped on rangeland									
Nitrogen (STN=0)	1,062	1,589	600	1,297	1,306	1,104	265	*442*	981
Nitrogen (STN=22.4)	212	**318**	**120**	**259**	**610**	**515**	**123**	**206**	294
Phosphorus (STP=low)	1,163	1,739	656	1,403	*953*	*806*	**193**	**322**	938
Phosphorus (STP=med)	*537*	803	**303**	**648**	**440**	**372**	**89**	**149**	433
Metric tons livestock feedstuff TDN currently produced	532	542	527	523	987	742	630	416	612

[a]Instances in which the TDN produced on the farm's current hectarage exceeds the TDN required to support the herd sizes determined to be just matched in livestock manure production-utilization are highlighted in bold. Instances in which the two amounts are approximately equal (within 10% of each other) are shown in *italics*.

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. [This situation is similar to pre-plow or natural ecosystem conditions on the prairie.] No case farm matched in manure production-utilization and in livestock feedstuff production-consumption on rangeland, however, is simultaneously matched in a similar way on cropland, thus resulting in "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.

Conclusion

Results from this study of eight case farms show no situation in which a case farm is balanced (plus or minus 10%) for both livestock manure production-utilization on cropland and rangeland and livestock feedstuff production-consumption with either (1) its current farmland hectarage and livestock population, or (2) simulated contracted or expanded livestock populations and current farmland hectarages in which livestock manure production-utilization is 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 (primarily by adding more forage legumes to rotations), 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.

The results also show estimated crop and grass fertilization needs to vary greatly, depending on assumed yield goals and STN and STP levels. For example, cropland N needs for farmers with yield goals 1.25 times 1993 yield levels are 54% more than with yield goals 1.0 times 1993 yield levels. Similarly, rangeland N needs with "STN = 0" are 3.3 times those with "STN = 22.4 kg/ha." Analogous data for P needs are 63% more P on cropland and 2.2 times more P on rangeland with low STP compared to medium STP. These findings highlight the importance of (1) researchers further refining procedures to accurately determine STN and STP and (2) producers to regularly test their soils for N and P and consider carefully yield goals against which to fertilize.

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.

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