5-1956

Most Profitable Rotations for the Corn Belt of Southeastern South Dakota

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CIRCULAR 129 MAY 1956

MOST PROFITABLE ROTATIONS

for the Corn Belt of Southeastern South Dakota

AGRICULTURAL ECONOMICS DEPARTMENT

AGRICULTURAL EXPERIMENT STATION

SOUTH DAKOTA STATE COLLEGE, BROOKINGS

Contents

Figures

Most Profitable Rotations

FOR THE CORN BELT AREA OF SOUTHEASTERN SOUTH DAKOTA

RUSSELL L. BERRY[1]

Choosing the Most Profitable Rotation

What is the most profitable combination of grain and forage for the Corn Belt? This question is of considerable importance to farmers in southeastern South Dakota who are in the western edge of the area where a corn-oat combination has long enjoyed a comparative advantage over other crops.[2]

Each year these farmers must make decisions regarding their crop rotations. Each must decide whether he should continue his present cropping system or change to more legumes. He needs information on the effects of legumes on yields and soil erosion and total farm production. With this knowledge he can more easily decide how much forage pays best on his farm.

The public also needs to know something of the effectiveness of various amounts of legumes and grasses in increasing production and as erosion control measures. This information is needed so that national production adjustment and conservation programs may more nearly achieve their objectives at lowest cost.

Objective and Procedure Used in This Study

The objective of this study was to determine the relative net returns from crop rotations containing different amounts of legumes in the Corn Belt under the price and production relationships likely to exist in the next few years.

The procedure used was to examine the history of corn, oat, and hay production in the South Dakota part of the Corn Belt for any trends in production which might suggest that farmers were finding an increase in legumes at the expense of other crops more profitable than in the past. The relative yields of corn, oats, and hay were then examined to determine whether or not im-

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[2]For the purpose of this study the Corn Belt is defined as that area of the Midwest where corn is the first ranking crop in percentage of cropland harvested (see figure 1) and where a legume catch crop is at least 40 percent as effective as harvested legumes in increasing grain yields. Normally this will be that portion of South Dakota where average precipitation was 22 inches or more for 1921-50.

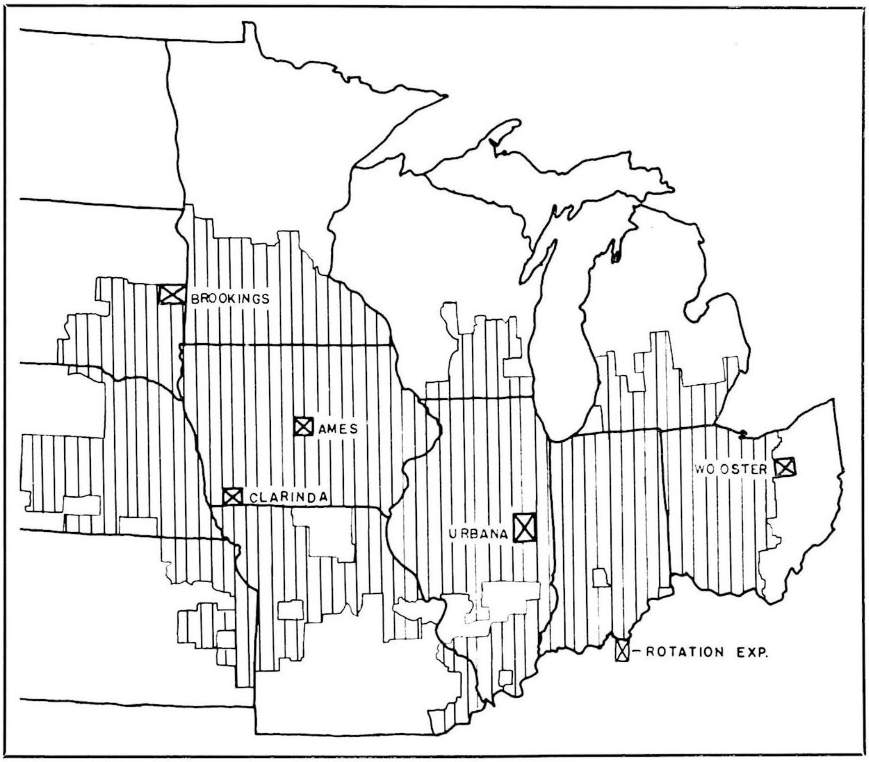

Figure 1. Location of the rotation experiments in area where corn is the first ranking crop as a percentage of harvested cropland (after J. S. Weaver, "Changing Patterns of Cropland Use in the Middle West," *Economic Geography,* vol. 30, no. 1, 1954).

proved practices were giving farmers more total digestible nutrients (TDN) per acre from hay.

The relative costs of corn and hay production were also examined. The prices of corn, oats, and alfalfa were compared to see if new feeding practices have increased the price of hay relative to grain.

To establish the relative production possibilities of grain and hay under different rotations, the results of several Corn Belt rotation experiments have been carefully reviewed and the interpretation of the data checked with soil and crop specialists familiar with the experiments. Using expected price relationships, the most profitable rotations were then determined.

In addition the yield estimates prepared for Ida-Monona soils in western Iowa and for Moody soils in northeastern Nebraska were carefully studied. As the best estimates of soil and crop specialists, they were useful in interpreting the results of past experiments.

Finally, with the help of the soil and crop specialists of the South Dakota Experiment Station, yield estimates were prepared for Moody soils in southeastern South Dakota.[3] Economic analyses of these estimates were also made using expected price-cost relationships.

A summary of the results of these procedures is presented in the remainder of this circular. In presenting these results it is hoped that they will prove useful to farmers and others in analyzing particular situations with complete farm budgets or plans.

Trends in Production, Costs, and Prices

It is no accident that corn is the first ranking crop in most of the Middle West (see figure 1). Corn has enjoyed a comparative advantage over other crops in this area because of relative yields or production possibilities, relative prices, and relative costs of production, all of which add up to relatively more profits for corn production.[4] The purpose here is to examine these relationships to see if there are significant changes which might make it more profitable in the near future to grow more legumes in the Corn Belt area of southeastern South Dakota.

That corn and oats have been relatively more profitable than other crops in southeastern South Dakota is suggested by the acreage of corn and oats shown in table 1. These two crops have occupied 70 percent of the cropland as an average in this area since 1924. A corn-oat rotation in which legumes play a minor role is suggested by these figures.

In 1949 only 5 percent of the cropland was in tame hay. By 1954 this had increased to 9 percent (see table 1). Why has this change come about? How much more should it increase?

Perhaps this change may have occurred because more farmers realize that some legumes will not only increase per acre yields but will also increase the total production of grain on the farm or per 100 acres of cropland in the rotation. Since the cost of growing legumes is usually less than the cost of growing corn, total costs are usually reduced. Obviously then, the farmer can increase the amount of legumes as long as they increase total grain production, *even if no use is made of the hay*.

When legumes increase the total production of grain in this manner, the legumes are said to be *complementary* to grain production. Legumes seeded in small grain and plowed under the following spring are almost always complementary to grain production since they in-

[3]Those assisting with the estimates at one stage or another were: B. Brage, G. Buntley, L. O. Fine, L. Puhr, F. Schubeck, F. C. Westin.

[4]For an excellent discussion of these logical relationships with special reference to grain and forage see E. O. Heady and H. R. Jensen, *The Economics of Crop Rotations and Land Use*, Iowa Agr. Exp. Sta., Research Bulletin 383, 1951, or *Economics of Cropping Systems in the Cornbelt* (North Central Regional Pub. 57), Neb. Agr. Exp. Sta. Bul. 429, 1955.

Table 1. Crops Grown in Southeastern South Dakota as Percentage of Total Cropland, 1924-54

Crop	1924 (%)	1929 (%)	1934 (%)	1939 (%)	1944 (%)	1949 (%)	1954 (%)	Average (%)
Corn	44	43	38	35	47	46	44	42
Sorghum	*	*	3	4	*	*	*	1
Soybeans	*	*	*	*	*	1	5	1
Wheat	2	2	1	3	2	3	1	2
Oats	30	24	21	20	31	35	36	28
Barley	1	10	13	13	4	2	*	6
Rye	*	*	*	3	1	*	*	1
Flax	1	1	*	1	2	2	1	1
Grain total	80	80	76	79	88	90	86	82
Alfalfa	4	4	4	3	5	4	8	5
Other tame hay	4	1	8	2	1	1	1	3
Rotation pasture	12	13	10	13	5	5	5	9
All other uses	*	2	2	3	1	*	*	1

Source: U. S. Census reports and S. D. Crop and Livestock Reporting Service reports for Census Economic Area 4b including Clay, Lake, Lincoln, Minnehaha, Moody, Turner, Union, and Yankton Counties.

*Less than 1 percent.

crease corn and oat yields without taking land out of grain.

Beyond the complementary range, however, legumes become *competitive* with grain production. This means that an increase in the amount of legumes per 100 acres will cause a decrease in the total production of grain. This decrease occurs because the grain lost by substituting legumes for grain crops per 100 acres is not offset by the increase in per acre yields.

In the competitive range, an increase in legumes can only be justified when the *net value* of the hay gained is greater than the grain lost if highest profits are the objective.

Another possible explanation of the increase in tame hay is that

Table 2. Corn, Oats, and Alfalfa Hay Production in Southeastern South Dakota by Periods, 1926-55

	Yields per Acre of:			Total Digestible Nutrients (TDN) per Acre:						
Priced	Corn (bu.)	Oats (bu.)	Alfalfa (tons)	Alfalfa (lbs.)	Corn (lbs.)	Difference* (lbs.)	Oats (lbs.)	Difference† (lbs.)	CCO‡ (lbs.)	Difference§ (lbs).
1926-30	31	32	1.6	1600	1389	211	737	863	1171	429
1931-35	20	21	1.2	1200	896	304	484	716	759	441
1936-40	22	25	1.3	1300	986	314	576	724	849	451
1941-45	39	35	1.9	1900	1747	153	806	1094	1433	467
1946-50	36	34	1.9	1900	1613	287	783	1117	1336	564
1951-55	39	31	2.2	2200	1747	453	714	1486	1403	797
Av. 1926-50	29	31	1.6	1600	1299	301	714	886	1104	496
1943-50	38	35	2.0	2000	1702	298	806	1194	1403	597

Source: S. D. Crop and Livestock Reporting Service. The counties included are: Moody, Minnehaha, Lincoln, Union, Turner, and Clay.

*Difference=Alfalfa nutrients less corn nutrients.

†Difference=Alfalfa nutrients less oat nutrients.

‡Corn-Corn-Oat rotation average yield of nutrients per acre.

§Difference=Alfalfa nutrients less CCO nutrients.

yields of hay have increased relatively more than yields of corn in recent years. Alfalfa hay yields have been higher during the past 5 years than at any other time in the period 1926-55 (see table 2). On the other hand, corn and oat yields remained about the same as for the previous 10 years.

Farmers using a corn-corn-oat rotation produce about 500 pounds less TDN per acre than they would if they were growing alfalfa as an average for the years 1926-55. These figures make no allowance for the effect of legumes on the corn and hence are high. Because of the relatively higher hay yields in recent years, farmers with a corn-corn-oat rotation were producing about 800 pounds less nutrients per acre during the past 5 years. Perhaps this increase in nutrients and the efforts of educational and action agencies are the reasons for an increase in alfalfa hay production in the area.

More hay production would be justified if the efficiency of hay production increased relative to grain. Index numbers of man hours per acre for corn, oats, and hay for the United States follow[5]:

These numbers indicate there has been relatively more improvement in corn and oat production per acre than there has been in haying. However, in South Dakota the hours of man labor per acre were nearly the same for corn and hay production in 1950 at the 1950 yields. Of course, the haying costs per acre would rise directly with the tons per acre. A 50 percent increase in yield from 1.4 tons to 2.1 tons would increase the labor required to about 9.6 hours. On the other hand, a 50 percent increase in yields of corn and oats would only increase production costs by the extra labor and fuel required to harvest and haul the additional grain and would have little or no effect on the growing costs which are relatively more important with these crops.

Prices are another factor which may help explain the increase in legumes. If the price of hay has increased more rapidly than that of grain during the past few years, then, other things being equal, more

[5]Ruben W. Hetcht and Keith R. Vice, "*Labor Used for Field Crops*," USDA, ARS, Statistical Bul. 144, 1954, Table 2.

PERIOD	ALL CORN	OATS	HAY
1910-14 (base)	100	100	100
1915-19	97	96	109
1920-24	92	84	105
1925-29	86	76	101
1930-34	80	68	87
1935-39	79	64	95
1940-44	73	59	90
1945-49	55	48	71
1950-53	37	39	55
1950 (S. D. labor)	6.5 hrs.	3.2 hrs.	6.4 hrs.
1950 (S. D. yields)	28 bu.	26 bu.	1.4 tons

Table 3. Prices Received by Farmers for Corn, Oats, and Hay in South Dakota, by Periods, 1910-54 and Expected Long-Term Price Relationships

Period	Corn Prices			Oats Prices			All Hay (Loose)		Tons Hay to Equal Value
	per bu.	per ton	per lb. TDN*	per bu.	per ton	per lb. TDN*	per ton	per lb. TDN*	of Ton Corn
1910-14	$ .51	$18.36	$.011	$.35	$21.70	$.015	$ 7.14	$.007	2.6
1915-19	1.07	38.52	.024	.52	32.24	.023	9.58	.010	4.0
1920-24	.57	20.52	.013	.33	20.46	.014	7.16	.007	2.9
1925-29	.65	23.40	.015	.35	21.70	.015	8.66	.009	2.7
1930-34	.47	16.92	.010	.27	16.72	.012	8.14	.008	2.1
1935-39	.59	21.24	.013	.25	15.50	.011	5.78	.006	3.7
1940-44	.76	27.36	.017	.44	27.28	.019	5.67	.006	4.8
1945-49	1.39	50.04	.031	.70	43.40	.030	11.90†	.012	4.2
1950-54	1.35	48.60	.030	.70	43.40	.030	12.40†	.012	3.9
Av. 1910-54	.82	29.52	.018	.43	26.66	.019	8.49	.008	3.5
Expected relationship‡	1.20	43.20	.027	.65	40.30	.028	13.50	.014	3.2

Source: Compiled from Local Market Price Movements in South Dakota, S. D. Crop & Livestock Reporting Service.
*TDN=Total digestible nutrients.
†Baled hay prices less $4 per ton for baling.
‡From: "Base Prices for Long-Term Farm Budgets," S. D. Agricultural Experiment Station, Agriculture Economics Pamphlet 51, 1954.

hay would be profitable. The prices of corn and hay presented in table 3 for 5-year periods do not indicate that the price relationships are unusually favorable to an increase in hay production, although they have been improving since the low period 1940-44 when 4.8 tons of hay were required to equal the value of 1 ton of corn.

There is little difference in the price of corn and oats per ton. However, when corn is compared with hay it can be seen that 3.5 tons of hay have been required to equal the current market value of 1 ton of corn (see last column of table 3). At expected future price relationships, 3.2 tons of hay will be necessary to equal the value of 1 ton of grain. This price relationship is more favorable than it has been at any time since 1930-34.

The expected price relationships for the years ahead are indicated by corn at $1.20 per bushel; oats $.65 per bushel and loose alfalfa hay at $13.50 per ton. They represent the expected price relationships and are not an attempt to predict prices.[6]

While relative yields, costs, and prices determine the relative profit made from different crops, the selection of the most profitable crop rotation for Corn Belt conditions cannot be determined by merely a review of these relationships. Most farmers will readily agree that corn is the most profitable crop in the Corn Belt. What they need to know is how much legumes can profitably add to this "king" crop in view of the complementary and competitive relationships of legumes to corn and oat production. One of the purposes

[6] "Base Prices for Long-Term Farm Budgets," South Dakota Agr. Exp. Sta., Agricultural Economics Pamphlet 51, 1954. These prices are based upon those prepared by the Bureau of Agricultural Economics, U. S. Department of Agriculture, as requested in Memorandum 1275, Supplement 1, September 28, 1951 by the Secretary of Agriculture.

of several crop rotation experiments in the Midwest was to answer this question. These rotation experiments will now be analyzed.

Most Profitable Rotations Under Experimental Conditions

The rotation experiments selected for analysis consist of those located at Brookings, South Dakota; Clarinda and Ames, Iowa; Urbana, Illinois; and Wooster, Ohio. The location of these experimental plots can be seen in figure 1. A comparison of some soil and climatic factors is presented in table 4.

With the exception of the Brookings experiment, which is 60 miles north of Sioux Falls, all the other experiments are 80 to 200 miles south and 150 to 680 miles east of Sioux Falls. This results in growing seasons which are 9 to 30 days longer, 4 to 12 inches more precipitation annually, and average July temperatures 1 to 2 degrees higher than at Sioux Falls.

Not only are the climatic factors different, but the soils of these experiments, with the exception of Marshall silt loam at Clarinda, and Flanagan silt loam of Urbana, are all developed from glacial till. The Marshall silt loam is derived from loess as are the Trent, Moody, and Crofton soils of southeastern South Dakota. The Flanagan silt loam developed on 3-5 feet of loess over glacial till of loam texture.

Even though the soil and climatic conditions vary from experiment to experiment, it was hoped that a pattern could be found which could be used as a guide in areas without experimental results, such as southeastern South Dakota.

Vienna Loam, Brookings, S. Dak.

Crop rotation experiments were started at Brookings in 1942. They are located on Vienna loam, which

Table 4. Some Factors Affecting Crop Rotation Experiments in the Midwest

Soil and Location	Distance From Sioux Falls, S. D. South (mi.)	East (mi.)	Growing Season (Days)	Precipitation Av. per Year (In.)	Temperature Av. July (F.)
Vienna loam					
Brookings, S. D. (study area)	(—60)	0	136	20	72
Sioux Falls, S. D.	0	0	150	26	74
Nicollet silt loam					
Ames, Iowa	80	150	159	30	75
Marshall silt loam					
Clarinda, Iowa	160	50	163	33	76
Flanagan silt loam					
Urbana, Ill.	200	400	180	36	76
Wooster-Canfield silt loam					
Wooster, Ohio	160	680	152	38	72

Source: "Climate and Man," USDA *Yearbook of Agriculture*, 1941.

is a well drained upland soil that developed over a loam or a clay loam glacial till. These plots were in a high state of fertility at the start, and consequently, the long-run effects of the various cropping systems have not had time to make their appearance. The annual average nitrogen and organic matter losses per acre of surface soil for 1942-50 are presented in table 5. It should be recognized that yields in the longer-run may be quite different for rotations having no legumes.

The average yields per acre and total production per 100 acres on Vienna loam for 1947-52 are presented in table 6. No fertilizer was used on these rotations. These yields show that sweet clover plowed under in August as a green manure crop in Rotation 3 is quite competitive with grain production. While legumes greatly increase the per acre yield of both corn and wheat, the total production per 100 acres falls due to the fact that forage has replaced grain on one-third of the land. Since no hay was secured, the loss is not offset by hay production. The long-run yields from these rotations may prove to be more favorable to legumes.

These rotations give no answer to the problem of how 10 to 25 percent sweet clover or alfalfa in the rotation would affect crop production.

Table 5. Changes in Nitrogen and Organic Matter as Influenced by Crop Rotations, Vienna Loam, Brookings, 1942-50

Rotation	Nitrogen Lost (lbs.)	Organic Matter Lost (lbs.)
Continuous corn	110	1892
Corn, oats, wheat	68	1075
Corn, wheat, and sweet clover plowed under August 1	38	367

Source: South Dakota Agricultural Experiment Station Bulletin 427, 1953, Table 22.

Marshall Silt Loam, Clarinda, Iowa

These experiments are located on gently sloping Marshall silt loam near Clarinda in Page County, Iowa. They are interesting because Marshall silt loam is a loess derived soil located only 200 miles almost south of the loess areas of South Dakota. The plots have been limed and receive 100 pounds of 20 percent superphosphate or equivalent per year.

These crop rotation experiments have been analyzed for two periods, 1943-48 and 1949-53. The yields, total production per 100 acres, and rates of substitution as compared with the highest grain producing rotation for each period are pre-

Table 6. Effects of Crop Rotation on Average Yields per Acre and Total Production per 100 Acres, Vienna Loam, Brookings, 1947-52

Crop Rotations*	Acres per 100 Acres in				Yields (Bu.) per Acre of			Total Production per 100 Acres
	Hay	Corn	Oats	Wheat	Corn	Oats	Wheat	(Tons)
1. C	----	100	—	—	45	—	—	126
2. C O W	----	33	33	33	46	44	18	84
3. C W S	33	33	—	33	53	—	29	78

Source: South Dakota Agricultural Experiment Station Bulletin 427, 1953, Table 20.
*C=corn; O=oats; W=wheat; S=sweet clover. No fertilizer was used on these rotations.

Table 7. Effects of Different Rotations on Crop Production per 100 Acres on Marshall Silt Loam, Clarinda, Iowa, 1943-48 and 1949-53

	Acres per 100 Acres in			Yields per Acre of			Total Production per 100 Acres of		Hay Gained per Ton of Grain Lost as Compared to High Rotation	
Rotation*	Legumes (A.)	Corn (A.)	Oats (A.)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value†
1943-48 yields‡										
1. C (Started 1932)	0	100	0	22	—	—	62	—	—	—
2. CO (1948-49)	0	50	50	67	29	—	117	—	—	—
3. CCOs	0	67	33	73	38	—	157	—	(High Rotation)	
4. COs	0	50	50	82	38	—	145	—	—	—
5. CCOM	25	50	25	73	39	1.7	118	42	1.1	$14.85
6. CCOM§	25	50	25	82	40	1.5	131	38	1.5	20.25
7. COM	33	33	33	83	40	1.3	98	43	0.7	9.45
8. CCOMM	40	40	20	75	37	2.4	96	96	1.6	21.60
9. COMM	50	25	25	80	40	1.9	72	95	1.1	14.85
1949-53 yields‖										
1. C (Started 1932)	0	100	0	18	—	—	50	—	—	—
2. CO	0	50	50	61	31	—	111	—	—	—
3. CCOs	0	67	33	79	32	—	165	—	(High Rotation)	
4. COs	0	50	50	88	30	—	147	—	—	—
5. CCOM	25	50	25	100	37	3.5	155	88	8.8	$118.80
6. CCOM§	25	50	25	104	42	3.4	162	85	28.3	382.05
7. COM	33	33	33	109	39	3.0	121	99	2.2	29.70
8. CCOMM	40	40	20	104	36	3.1	128	124	3.4	45.90
9. COMM	50	25	25	108	37	3.5	90	175	2.3	31.05

*C=Corn; O=Oats; s=sweet clover catch crop; M=alfalfa, or red clover, or brome mixture.
†Hay price used is $13.50 per ton loose.
‡Source: Iowa Agricultural Experiment Station, FSR 5, 1949, tables 2, 4, 6, and 7 and FSR 4, tables 4, 6, and 7.
§Manure applied at the rate of 8 tons per acre on the second-year corn crop.
‖Source: Iowa Agricultural Experiment Station, FSR 98, 1954, tables 2 and 5.

sented immediately above in table 7.

The yields for the first period, 1943-48, show that Rotation 3, corn-corn-oats with sweet clover catch crop produced 157 tons of grain. This is the highest for any rotation for this period. It is considerably higher than either continuous corn or a corn-oat rotation.

That the substitution of stand-over legumes for the sweet clover was not particularly profitable under these conditions is clearly apparent in the last column of table 7. Only .7 to 1.6 tons of hay were received for each ton of grain which would be sacrificed by changing from Rotation 3 to Rotations 5-9. Since the TDN of corn is 80 percent, oats 72 percent, and hay of all kinds approximately 50 percent, it is clear that a ton of grain contains about 1,500 pounds and a ton of hay 1,000 pounds of TDN.[7]

Because 1 ton of hay contains 1,000 pounds of TDN, the tons of hay gained per ton of grain sacrificed can also be read as thousands of pounds of nutrients. Thus for a sacrifice of 1,500 pounds of grain nutrients caused by shifting from Rotation 2 to Rotations 5-9, it is apparent that only .7 to 1.6 *thousand*

[7]For simplicity these figures will be used whenever nutrients are discussed. While the proportion of corn and oats varies in different rotations, the assumption that the grain mixture contains 75 percent TDN is conservative since the proportion of corn to oats in these rotations is never less than 1:1 and is sometimes 2:1.

pounds of nutrients are gained. Or, stated in pounds, 700 to 1,600 pounds of hay nutrients are gained per 1,500 pounds of grain nutrients lost. Because hay may have as much as 6 percent more protein than corn and oats this must also be taken into consideration.

Since market prices tend to reflect the relative feed values of grain and hay, it is helpful to analyze these rotations in terms of the relative prices expected for grain and hay over the next few years. At the expected price relationships when corn is $1.20 per bushel and oats $.65 per bushel, alfalfa-brome hay is expected to be worth $13.50 per ton loose or $17.50 per ton baled.[8]

It is important to keep in mind that these are not predictions of price levels but of price relationships. Thus, if corn prices fall 10 percent, hay prices are also expected to fall by 10 percent.

At these prices grain is worth about 2 cents per pound and a ton of grain is worth $40. Thus the last column of table 7 shows that for each $40 of grain lost, $9.45 to $21.60 worth of hay is gained. This suggests that the farmer on Marshall silt loam should use Rotation 3, corn-corn-oats with sweet clover catch crop, sell grain and buy hay as needed when these prices prevail. Exceptions might be farmers with small farms, intensive livestock programs or both, which call for considerable legume pasture. Both hay and grain might be purchased by such a farmer. Other exceptions may be the producer of certified seeds and purebred livestock.

The yields for 1949-53 suggest that the 1943-48 yields do not approximate the true yield response which can be expected on Marshall silt loam. The differences in the corn yields between the two periods are clearly apparent in figure 2. Even more important is the difference in hay yields. They were 87 percent higher as an average for 1949-53 as can be seen in table 7. Insect damage to the hay crop on the small plots in the first period 1943-48 reduced the hay yields and may have affected grain yields.

Favorable weather and insect control as well as the beneficial legumes appear to have been important factors affecting yields in 1949-53. Whatever the combination of causes, the important factor is the remarkable increase in hay yields relative to corn and oat yields. It is this change in the relative yields which makes legumes appear so much more profitable in 1949-53 than in 1943-48.[9]

Yield estimates prepared for Monona silt loam of western Iowa, another loessial soil that corresponds closely to the Moody soil of South Dakota, throw some light on what soil scientists believe can

[8]"Base Prices for Long-Term Farm Budgets in South Dakota," South Dakota Agr. Exp. Sta., Agricultural Economics Pamphlet 51, 1954.

[9]Annual Summary of Studies at the Soil Conservation Experimental Farm, Page County, Iowa for 1943-48, Iowa Agr. Exp. Sta. FSR 5, p. 7, and Annual Progress Report Soil Conservation Experiment Farm, Iowa Agr. Exp. Sta., FSR 98, March 1954, p. 10.

[10]R. V. Baumann, E. O. Heady, and A. R. Aandahl, *Costs and Returns for Soil Conserving Systems of Farming on Ida-Monona Soils in Iowa*, Iowa Agr. Exp. Sta. Res. Bul. 429, 1955, Appendix Table B-1.

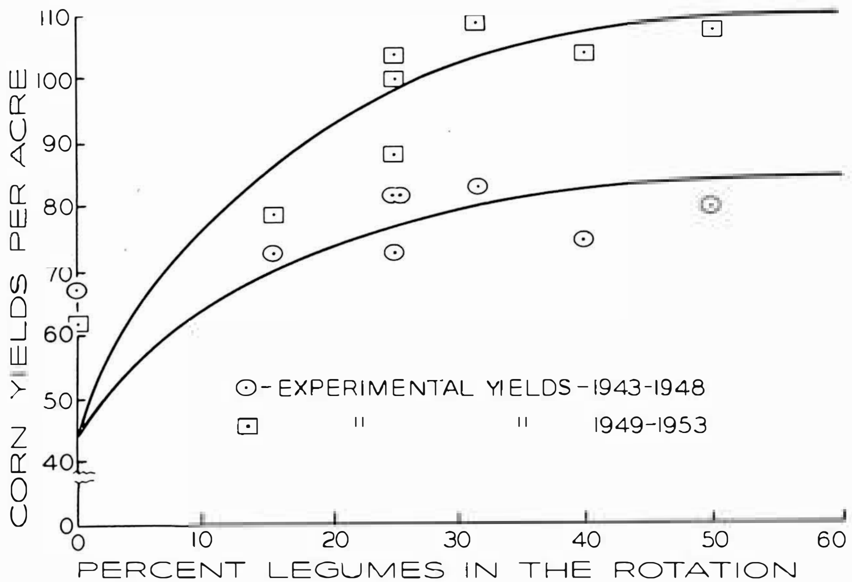

Figure 2. Possible yield response curves for corn based on the crop rotations experiments at Clarinda, Iowa.

be expected in the area under average management conditions for cash crop farms when no fertilizer is used.[10] These yield estimates are presented in table 8. The total estimated yield response to legumes is expected to be 16 bushels for both corn and oats. This is 3 bushels more for corn and 5 bushels more for oats than on Marshall silt loam for 1943-48 (see tables 7 and 8). Also the hay yield estimate of 2.4 tons is considerably higher than the insect damaged 1943-48 experimental yields.

When the economic consequences of the Monona silt loam estimates are analyzed in the last column, the results are more favorable to standover legumes than the 1943-48 yields on Marshall silt loam. Rotation 5, CCOMM, appears to be slightly more profitable than Rotation 2, CCOs, at the costs of production used in this circular when the hay is buckstacked. Since buckstacking is one of the most efficient ways of making hay, the catch crop would be more profitable if other more expensive methods of haymaking were used.

Estimates have also been prepared for situations when the crops are fed to livestock.[11] The corn yield estimates for livestock farms run about 5 bushels per acre higher than those reported in table 8 with about the same response to legumes. The oats start 6 bushels higher and show 4 bushels less response to leg-

[11]Ibid. Appendix Table B-2.

umes. The legume yields remain the same. As a result the sweet clover catch crop rotations appear even more profitable than in table 8.

These conclusions for loess soils of western Iowa are valid only if the yield estimates are the true response which can be expected in the area. The yields for 1949-53 on Marshall silt loam at Clarinda suggest that the yields of hay can be increased in comparison with corn yields until the hay gained is of greater market value than the corn lost. Hence, it would then pay to shift from corn to hay. But this situation has not existed under farm conditions in the past nor is it expected in the near future if the yield estimates on Monona silt loam may be used as a reliable guide.

Nicollet Silt Loam, Ames, Iowa

Crop rotation experiments at Ames, Iowa contain rotations with both 25 and 33 percent legumes and therefore provide another opportunity to study the effects of two

Table 8. Estimated Yields and Total Production per 100 Acres for Rotations With Different Proportions of Legumes, Farm Conditions, Monona Silt Loam, 2-8 Percent Slopes, Western Iowa

	Acres per 100 Acres in			Yield per Acre of			Total Production per 100 Acres of		Hay Gained per Ton of Grain Lost as Compared to Rotation 2†	
Rotation*	Legumes† (A.)	Corn (A.)	Oats (A.)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value‡
1. CCO	----	67	33	35	22	—	77	—	—	—
2. CCOs	—	67	33	45	28	—	99	—	—	—
3. COs	—	50	50	50	34	—	97	—	—	—
4. COsCOMM	33	33	33	55	38	2.4	71	79	2.8	37.80
5. CCOMM	40	40	20	51	34	2.4	68	96	3.1	41.85
6. COMM	50	25	25	55	38	2.4	54	120	2.7	36.45
7. COMMM	60	20	20	53	38	2.4	42	144	2.5	33.75
8. COMMMM	67	16	16	51	38	2.2	35	145	2.3	31.05

Source of yield data: Iowa Agricutlural Experiment Station, Research Bulletin 429, 1955, Table B-2. Estimates by A. R. Aandahl, F. Riecken, and W. H. Allaway.
*C=corn; O=oats; M=alfalfa brome meadow; s=sweet clover catch crop.
†Catch crop legumes are plowed under.
‡Price per ton of loose hay $13.50.

Table 9. The Effects of Legumes on Crop, Yields and Production, Nicollet Silt Loam, Ames, Iowa, 1942-51

Crop Rotation*	Acres per 100 Acres in: Hay (A.)	Corn (A.)	Oats (A.)	Per Acre Yields of: Corn (bu.)	Oats (bu.)	Hay (tons)	Production per 100 Acres in: Grain (tons)	Hay (tons)
No treatment								
1. C O	0	50	50	49	30	—	93	—
2. C C O M	25	50	25	65	53	2.3	112	58
3. C O M	33	33	33	68	55	2.3	92	76
Lime and Manure†								
4. C O	0	50	50	70	41	—	131	—
5. C C O M	25	50	25	80	60	3.0	136	75
6. C O M	33	33	33	84	62	3.0	110	99

Source: Iowa Agricultural Experiment Station, Agronomy 302, March 1954.
*C=corn; O=oats; M=legumes and grass meadow.
†The manure was added at the rate of 2 tons per acre per year—all applied before the corn crop.

quantities of legumes on the yields of corn and oats. Furthermore, these experiments were started in 1915 and thus there has been more time for the long-run effects to become apparent. These experiments are located about 200 miles southeast of the loess soil area in South Dakota. The average yields for the 1942-51 period on Nicollet silt loam are presented in table 9. Since the Nicollet is a till soil, it may not indicate the results which can be secured on the loess soils of South Dakota. Nevertheless, the results are presented here for whatever light they may shed on the problem of crop response to legumes.

A comparison of Rotations 1 and 2, table 9, shows that 25 percent legumes in the rotation are clearly profitable as compared to a corn-oat rotation. Twenty-five percent legumes in the rotation not only increased grain production by 19 tons per 100 acres but also produced 58 tons of legumes for harvest. Thus legumes were complementary to grain production since the production per 100 acres was increased, even though 25 percent of the land was taken out of grain.

Would smaller amounts of legumes, 10, 15, or 20 percent, have given still greater increases? Since there were no rotations with these small amounts this question cannot be answered.

It is clear, however, that 33 percent legumes are competitive with grain production. This can be seen by comparing Rotations 2 and 3. Here grain production fell 20 tons while hay production increased only 18 tons. This is an unprofitable trade. The same situation can be seen when Rotations 5 and 6 are compared. Grain production fell 26 tons while hay production increased only 24 tons per 100 acres.

As might be expected, manure proves to be a good means of increasing production. This can be seen by comparing Rotations 1 and 4. However, 25 percent legumes are still more productive even when manure is used. This can be seen by comparing Rotations 4 and 5. A gain of 5 tons of grain and 75 tons of hay is secured by the use of 25 percent legumes in the rotation.

Flanagan Silt Loam, Urbana, Ill.

The Morrow Plots crop rotation experiments were started in 1876 on Flanagan silt loam which developed in 3-5 feet of loess over till. Of the 10 original plots 3 remain; Plot 3 with continuous corn; Plot 4 with corn and oats in rotation, and Plot 5 with a corn-oat-red clover rotation. Starting in 1904 the northern halves of these plots were continued without change but the southern halves were treated with manure ("chiefly in proportion to the quantity of crops removed"), limestone, and phosphate as needed. All the grain, straw, stover, and hay crops were removed.[12]

The average results for both the untreated and treated halves of these plots are presented in table 10. Of the three rotations with no treatment the corn-oat-red clover rotation appears to be the more

[12]F. C. Bauer and C. H. Farnham, "The Morrow Plots, America's Oldest Experiment Field Established in 1876," Illinois Agr. Exp. Sta. Mimeograph Pamphlet, 1948.

profitable. However, the manure applied in proportion to the crops removed and phosphate and lime added as needed, continuous corn on Plot 3s gives 52 tons more of grain as compared to Plot 5n and loses only 40 tons of hay. Plot 4s with corn-oat (sweet clover catch crop) rotation is even more profitable, giving 64 tons more grain than Plot 5n with a sacrifice of only 40 tons of hay.

To carry the analysis one step further, changing from Plot 4s rotation of COs to Plot 5s rotation of CO Cl reduces total grain production by 35 tons while increasing hay 89 tons. Thus for every ton of grain lost, 2.5 tons of hay are gained. Whether or not this will be profitable will depend upon the prices of grain and hay, efficiency of cattle or sheep enterprises, and soil erosion problems. On a cash basis with grain at 2 cents per pound or $40 per ton and loose hay at $13.50 per ton, the change would not be profitable since growing and harvesting costs per acre are higher for hay than for grain.

Even when the long run effects are considered a similar conclusion is reached. This is shown in table 11 which presents yields for 1940-51 that should show the long-run effects of these rotations. A change from COs to CO Cl reduces grain production by 46 tons and increases hay production 119 tons. Thus, for each ton of grain sacrificed, only 2.5 tons of hay are gained. These data suggest that sweet clover plowed under as a catch crop, return of crop residues and the use of lime and phosphate is a more practical program for farmers having conditions similar to those in Illinois. Such hay as is needed could be produced in a minor rotation on land where erosion is a serious problem. Again a rotation with 15 to 25 percent legumes might be more profitable than 33 percent legumes, but data is lacking on this point.

Since the Urbana experiments are located about 200 miles south and

Table 10. Effects of Legumes on Crop Yields and Total Production for Flanagan Silt Loam, Urbana, Illinois, 1904-44

Plot and Crop Rotation*	Acres per 100 Acres in: R. Clover	Corn	Oats	Yield per Acre in: Corn (bu.)	Oats (bu.)	Clover (tons)	Total Production per 100 A. in Tons: Grain	Hay	Tons Hay Gained per Ton of Grain Sacrificed
No Treatment With All Forage Removed									
3n. C	0	100	0	24	—	—	67	—	—
4n. C O	0	50	50	34	34	—	75	—	comp.
5n. C O Cl	33	33	33	48	50	1.2	71	40	10
Manure, Lime, and Phosphate With All Forage Removed									
3s. C	0	100	0	44	—	—	123	—	—
4s. C Os	0	50	50	62	60	—	135	—	comp.
5s. C O Cl	33	33	33	69	68	2.7	100	89	2.5

Source: F. C. Bauer and C. H. Farnham, "The Morrow Plots, America's Oldest Experiment Field," Illinois Agricultural Experiment Station, mimeographed pamphlet, 1948, tables 1 and 2.
*C=corn; O=oats; Os=sweet clover seeded in oats and plowed under as a catch-crop; Cl=red clover.
†Manure was applied chiefly in proportion to the crops removed. An exception was the sweet clover catch crop on Plot 4s.

400 miles east of the loess soil areas of South Dakota, these results must be interpreted with considerable caution by South Dakota farmers. Because of a shorter growing season and less moisture, sweet clover catch crops are not likely to be as effective in increasing yields as they are in Illinois.

Wooster and Canfield Silt Loam Wooster, Ohio

The crop rotations at Wooster, Ohio are located about 160 miles south and 680 miles east of Sioux Falls, South Dakota. While the growing season is only 2 days longer, there are 12 inches more precipitation. The average July temperature at Wooster is 2 degrees lower than at Sioux Falls (see table 4).

These experiments were started in 1916 on Wooster and Canfield silt loams derived from glacial till. In 1937 the fertilizer treatment was changed from 200 pounds of 0-16-0 per acre per year to 150 pounds of 0-14-7 per acre per year. Liming was continued as needed. Certain rotations were replicated. One series continued to receive manure at the previous average rate of 2 tons per acre per year. A second series had all crop residues consisting of corn stalks, oat and wheat straw returned. A third series had neither manure nor residues returned.

The average results secured for 13 years, 1937-49, from some of these rotations are presented in table 12. Rotation 2, consisting of corn-oats with a sweet clover catch crop, appears to be one of the most profitable. At $40 per ton for grain and $13.50 for loose hay, Rotation 2 is clearly more profitable than Rotations 1, 3, 4, or 5 when we take into consideration the higher production costs of hay and make allowance for weather risks.

Rotations 6, 7, and 8 may be more profitable than Rotation 2 where large quantities of rotation pasture

Table 11. Effect of Legumes on Crop Yields and Total Production for Flanagan Silt Loam, Urbana, Illinois, 1940-51

Plot and Crop Rotation*	Acres per 100 Acres in			Yield per Acre of			Total Grain production per 100 A.		Tons of Hay Gained per Ton of Grain Sacrificed
	Legumes	Corn	Oats	Corn (bu.)	Oats (bu.)	Clover (tons)	Grain (tons)	Hay (tons)	
No Treatment With All Forage Removed									
3n. C	0	100	0	20	—	—	56	—	—
4n. C O	0	50	50	32	34	—	72	—	comp.
5n. C O Cl	33	33	33	62	49	.9	83	30	comp.
Manure, Lime, and Phosphate Applied With All Forage Removed†									
3s. C	0	100	0	61	—	—	171	—	—
4s. C Os	0	50	50	94	68	—	170	—	—
5s. C O Cl	33	33	33	97	65	3.6	124	119	2.5

Source: F. C. Bauer and C. H. Farnham, "The Morrow Plots, America's Oldest Experiment Field," Illinois Agricultural Experiment Station, mimeographed pamphlet, 1948, tables 1 and 2.
*C=corn; O=oats; Os=sweet clover seeded in oats and plowed under as a catch crop; Cl=red clover.
†Manure was applied chiefly in proportion to the crops removed. The sweet clover catch crop on Plot 4s was plowed down.

and hay can be utilized to good advantage with livestock. Budgetary analysis appears to be necessary for a precise answer. An important element of such an analysis will be the assumptions or estimates of the rates of substitution of forage for grain, the general productivity of the livestock enterprises, and the price expectations.

Table 12. Effects of Legumes on Crop Yields and Production per 100 Acres, Wooster and Canfield Silt Loam, Wooster, Ohio, 1937-49

	Acres per 100 Acres in				Yield per Acre of				Production per 100 Acres of		Tons of Hay Gained per Ton of Grain Lost as
Crop Rotation§	Hay (A.)	Corn (A.)	Oats (A.)	Wheat (A.)	Corn (bu.)	Oats (bu.)	Wheat (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Compared to Rot. 2
1. C O	0	50	50	0	47	41	—	—	99	—	—
2. C Os*	0	50	50	0	67	55	—	—	138	—	—
3. C C C W A	20	60	0	20	55	—	26	3.3	108	66	2.2
4. C O W Cl	25	25	25	25	59	55	38	2.1	92	53	1.6
5. C O A†	33	33	33	0	68	58	—	3.3	93	109	2.4
6. C C W A A	40	40	0	20	65	—	32	3.5	92	140	3.0
7. C W A A*	50	25	0	25	70	—	40	3.6	79	180	3.0
8. C W A A A*	60	20	0	20	72	—	43	3.9	66	234	3.2

Source: *Handbook of Ohio Experiments in Agronomy*, Ohio Agricultural Experiment Station, Book Series B-1, November 1951, table 179.
*Residues turned under.
†Stover disked in.
§C=corn; O=oats; W=wheat; A=alfalfa, and Cl=red clover.

Interpreting the Results of Crop Rotation Experiments

In order to help farmers choose most profitable amounts of legumes for their Corn Belt crop rotations, answers to the following questions are needed: (1) How much legumes are necessary to secure the maximum yield? (2) What is the total crop yield increase which can be secured by the use of legumes? (3) What is the extra or additional yield secured by each addition of legumes? (4) What are the effects on grain yields of a green manure catch crop as compared to standover or harvested legumes?

An analysis of the crop rotation experiments reviewed gives some tentative answers to these questions.

Amount of Legumes Necessary to Secure Maximum Yields

Of the five rotation experiments reviewed, only the Clarinda, Iowa and the Wooster, Ohio experiments have rotations with more than 33 percent legumes. In both of these experiments 33 percent legumes appears to give the maximum corn yield increase.

At Clarinda, Iowa, the highest yields of both corn and oats for all rotations were obtained by use of a corn-oat-alfalfa and brome meadow rotation for both the 1943-48 period and the 1949-53 period, if the rotation receiving manure is not considered (see table 7).

At Wooster, Ohio the corn yield of the corn-oat-alfalfa rotation was only 2 bushels less than a rotation with 50 percent legumes and 4 bushels less than a rotation with 60 percent legumes (see table 12).

These differences are not enough to justify increasing legumes beyond 33 percent in themselves. Thus this evidence suggests that at 33 percent legumes the maximum yield of corn is reached for all practical purposes. Estimates by Aandahl, Riecken, and Allaway indicate that the maximum corn and oat yields are reached with slightly more than 33 percent legumes (COsCOMM rotation) under a wide variety of conditions (see table 8).[13]

Total Increase in Corn and Oats Yields by Use of Legumes

The maximum corn yield increase appears to be secured by the use of 33 percent legumes in the rotation. This makes it possible to use more of the rotation experiments in an attempt to determine the total additional increase which can be expected by the use of legumes in the Corn Belt.

In table 13 corn-small grain-legume rotations are compared with the corn-small grain rotations. The range in corn yield response is quite wide, varying from 7 bushels at Brookings to 48 bushels at Clarinda. Leaving aside these extremes, the remaining yield increases range from 14 to 30 bushels per acre. Under farm conditions where lime, phosphate, and potash is available or supplied as needed and no manure is used, is seems reasonable that 15-20 bushels additional corn might be secured by the use of legumes in the crop rotation, depend-

Table 13. Effect on Corn Yields of Changing from a Corn-Oat Rotation to a Corn-Oat-Legume Rotation With 33 Percent Legumes for Rotation Experiments in the North Central States

Crop Rotation	Percent Legumes	Vienna Loam Brookings, S. D. 1947-52 (bu.)	Marshall Silt Loam Clarinda, Ia. 1943-48 None (bu.)	Marshall Silt Loam Clarinda, Ia. 1949-53 None (bu.)	Nicollet Silt Loam, Ames, Ia. 1942-51 None (bu.)	Nicollet Silt Loam, Ames, Ia. 1942-51 ML* (bu.)	Flanagan Silt Loam Urbana, Illinois 1904-44 None† (bu.)	Flanagan Silt Loam Urbana, Illinois 1940-51 None† (bu.)	Wooster & Canfield Silt Loams Wooster, Ohio 1937-49 LPK‡ (bu.)
Corn Yield Increases									
Corn, small grain, legumes	33	53§	83	109	68	84	48	62	68
Corn, small grain	0	46	67	61	49	70	34	32	47
Difference	33	7	16	48	19	14	14	30	21
Oat Yield Increases									
COM	33	—	40	39	55	62	50	49	58
CO	0	—	29	31	30	41	34	34	41
Difference	33	—	11	8	25	21	16	15	17

Source: See previous tables.
*Two tons of manure per acre per year applied. Lime applied as needed.
†No treatment. All stover and straw removed.
‡Lime as needed, 150 pounds 0-14-7 per year, no residues turned under on corn-oat rotation but stover disked in on the corn-small grain-legume rotation.
§Sweet clover plowed under as a summer fallow-green manure crop.

[13] R. V. Baumann, E. O. Heady, and A. R. Aandahl, *Costs and Returns for Soil-conserving Systems of Farming on Ida-Monona Soils of Iowa,* Iowa Agr. Exp. Sta. Res. Bul. 429, 1955. Appendix Tables B-1 and B-2.

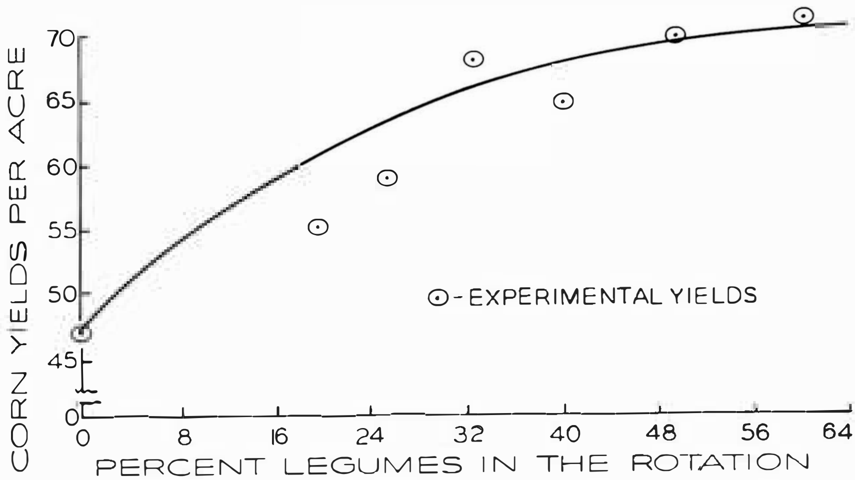

Figure 3. Possible yield response curve for corn from the crop rotation experiments at Wooster, Ohio,

ing upon the moisture available and the length of growing season.

The additional oat yields per acre secured by changing from a corn-oat rotation to a corn-oat-legume rotation is also presented in table 13. The increase in total oat yields ranged from 8-25 bushels per acre or about 5 bushels less than for corn. The estimates of Aandahl, Riecken, and Allaway previously referred to indicate that 13-15 bushels per acre increase in oats could be secured by adding 33-40 percent legumes to the rotation on Ida-Monona soils of western Iowa.[14]

Additional Yields From Additional Legumes

In order to determine the most profitable amount of legumes for Corn Belt rotations, the effects of 15, 20, 25, 33, 40, and 50 percent and more legumes on grain yields need to be known. However, since yields do not appear to increase significantly beyond the point where 33 percent legumes are added, there is little practical importance to larger amounts of legumes unless they cause yields to decrease. Evidence as to the effects of less than 33 percent legumes on crop yields is scanty, but a comparison of the increase in yields secured by 25 and 33 percent legumes is presented in table 14.

At Ames, increasing meadow from 25 to 33 percent in the rotation gave only a 3-4 bushel increase in corn yields. This small increase may be due to a deficiency of phosphate and potash in these legume rotations.[15] On the other hand, if little or no response can be expected beyond 33 percent legumes, it seems reasonable that a 3-4 bushel increase between 25 and 33 percent

[14]Ibid. Appendix Tables B-1 and B-2.

[15]F. W. Schaller and W. D. Shrader, personal letter and notes December 16, 1955.

Table 14. Effects on Corn Yields per Acre of Increasing Standover Legumes from 25 Percent to 33 Percent in the Rotation in Three Midwestern Experiments

Years in Rotation and % Legumes	Marshall Silt Loam, Clarinda, Ia.		Nicollet Silt Loam, Ames, Ia.		Wooster and Canfield Silt Loams, Wooster, O.
	1943-48	1949-53	1942-51		1937-49
	None (bu.)	None (bu.)	None (bu.)	ML (bu.)	None (bu.)
Three years, 33	83	109	68	84	68
Four years, 25	73	100	65	80	59
Difference, 8	10	9	3	4	9

Source: See Tables 7, 9 and 12.

legumes might be all that can be expected.

In contrast, the Wooster experiments show a 9-bushel increase as legumes are increased from 25 to 33 percent in the rotation. Similar results were secured at Clarinda. Changing from CCOM with 25 percent legumes to a COM rotation with 33 percent legumes, increased corn yields by 9-10 bushels (see table 14). A possible explanation is that corn follows corn in the CCOM rotation while it does not in the COM rotation. But the object here is to establish a yield response curve when only legumes is the variable. Hence the effects of corn following corn will be discussed later.

If the principle of diminishing returns is accepted as a guide, then curves which are diminishing at an increasing rate throughout may be fitted to these yields as is done in figure 2.[16]

The failure of the yields to form a smooth curve may be due to factors which are not controlled. If these factors were controlled the yields themselves should form a smooth curve when connected by lines. However, since the uncontrolled factors may be found under farm conditions, it is worth while to see what the effects of a 9-10 bushel increase per acre between a CCOM rotation and COM rotation are on total production per 100 acres.

At Clarinda for the most favorable period, 1949-53, corn yields increased from 100 bushels to 109 bushels as legumes were increased from 25 to 33 percent in the rotation (see table 7). Despite this 9-bushel increase per acre, total grain production per 100 acres fell by 34 tons while hay production increased by only 11 tons. Even if the hay yields had not fallen from 3.5 to 3.0 tons per acre, the increased hay production would be only 17 tons more, or a total of 28 tons. Thus, only 28 tons of hay would be secured for the 34 tons of grain sacrificed.

For the earlier period, 1943-48, total grain production fell 20 tons while only a 1-ton increase in hay was obtained. If the hay yields were 3.5 tons per acre in both rotations, only 28 tons of hay would have been secured for the 20 tons of grain lost.

The experiments at Ames show

[16]These are Spillman exponential curves, $y = A(1-R^x)$, in which y=yield increment, A=maximum yield increase obtainable, R=a constant ratio of one yield increase to the next and x=inputs of legumes.

that increasing legumes from 25 to 33 percent reduces grain production 20-26 tons per 100 acres, while hay production is increased by only 18-24 tons (see table 9). This of course would be an unprofitable trade.

At Wooster, changing from the COWCl rotation to COA causes total grain production to increase from 92 to 93 tons (see table 12). This increase is due largely to the increase in corn acreage at the expense of wheat in the COA rotation. Also the 56-ton increase in hay is due largely to the increase in yield secured changing from red clover yielding 2.1 tons to alfalfa yielding 3.3 tons per acre.

Changing from CCCWA with 20 percent legumes to COA results in a loss of 15 tons of grain and a gain of 43 tons of hay. For each ton of grain lost, 2.9 tons of hay are gained. This is not enough to make the trade profitable at $13.50 per ton for loose hay and $40 per ton for grain.

These results make it quite clear that it is unprofitable to increase legumes from 25 to 33 percent even if the increased yield is 10 bushels of corn per acre.

Comparative Yield Effects of Catch Crop and Standover Legumes

Because legumes seeded in oats and plowed down the following spring as a green manure catch crop is one of the alternatives which farmers should consider in deciding how much legumes to grow, the relative ability of such a catch crop to increase grain yields needs to be determined. A comparison of the yields secured with a catch crop (COs) and with 33 percent standover legumes (COM) is presented in table 15. The standover legumes give larger yields of corn per acre, but except for the Clarinda results, the differences are 1-7 bushels.

Hence as a conservative estimate it seems that a rotation such as COs, which has a legume catch crop on half of the land, should be equal in value to standover legumes on 25 percent of the land as found in a CCOM rotation. If this is correct it means that the catch crop is 50 percent as effective as standover legumes in the central Corn Belt.

On the western and northwestern edges of the Corn Belt the effectiveness of the legume catch crop diminishes because of less moisture and shorter growing season. At

Table 15. Comparison of the Effects of Standover and Catch Crop Legumes on Corn Yields per Acre in Midwestern Experiments

Rotations*	Marshall Silt Loam Clarinda, Iowa 1943-48 None (bu.)	Marshall Silt Loam Clarinda, Iowa 1949-53 None (bu.)	Flanagan Silt Loam Urbana, Ill. 1904-44 MLP (bu.)	Flanagan Silt Loam Urbana, Ill. 1940-51 MLP (bu.)	Wooster and Canfield Silt Loams, Wooster, Ohio 1937-49 LPK (bu.)
1. C O M	83	109	69	97	68
2. C Os	82	88	62	94	67
3. Difference	1	21	7	3	1

Source: See footnotes to previous tables.
*C=corn; O=oats; M= legume meadow and s=sweet clover catch crop.

Brookings, for example, a sweet clover catch crop does not usually make enough fall growth to appreciably increase grain yields the following spring. Hence it is not recommended for this county although it makes adequate growth in the southeastern part of the state, but less than in Ohio, Illinois, and Iowa.

To summarize, these rotation experiments indicate that legumes will increase corn yields 15-20 bushels per acre and oat yields 10-25 bushels, depending upon the part of the Corn Belt being considered. Little additional increase in yields can be expected from rotations containing more than 33 percent legumes. By increasing legumes from 25-33 percent, 3-10 bushels of additional corn can be expected. Finally, catch crop legumes appear to be at least 50 percent as effective as legumes which stand over and are harvested for hay in the central part of the Corn Belt.

In general the data from Clarinda, Iowa; Urbana, Illinois; and Wooster, Ohio all indicate that for the cash-grain farmer in the Corn Belt, a legume catch crop is more profitable under the expected price relationships than standover legumes. For farmers with serious erosion problems or large dairy enterprises, purebred beef cattle, or purebred sheep, standover legumes may be more profitable. But these exceptions to the general rule would require more careful evaluation of the particular circumstances of the individual farm and farmer than can be given here. There is, of course, some danger that such cropping systems will seriously deplete the soil. However, a recent study of the Wooster, Ohio rotation experiments concluded that:

> If one is willing to accept corn yield trends and total soil nitrogen as a criteria for the detection of soil productivity trends, these data indicate that, provided soil erosion is not involved, almost any of the corn belt cropping systems aside from continuous corn will maintain the crop producing capacity of the soil at a rather constant level. True, this level, as determined by corn yield criteria may be 8 to 10 percent higher for rotations with a generous percentage of meadow crops than those in which meadow or green manure crops appear less frequently. However, these data would suggest that economic factors rather than changes in the producing capacity of the soil, should be the basis for selection of cropping systems where erosion can be controlled.[17]

A similar conclusion seems to be indicated by the results secured when a heavy application of fertilizer was made to the Morrow Plots at Urbana, Illinois. Russell reports that the yield differences on the Morrow Plots, which resulted from rotations of continuous corn, corn-oats, and corn-oats-clover since 1876 were largely eliminated by the application of commercial fertilizer in 1955.[18]

Studies by agronomists at the Iowa Agricultural Experiment Station have led to the conclusion that:

> . . . Nitrogen and organic matter from meadow crops are produced more rapidly during the first one or two years of meadow than thereafter. The greatest

[17]J. L. Haynes and L. E. Thatcher, "Crop Rotations and Soil Nitrogen," *Soil Science,* Vol. 19, No. 3, July 1955, p. 327.

[18]M. B. Russell, "All the Way Back in One Year?" *Plant Food Review,* Vol. 2, No. 1, Spring, 1956, p. 18-19.

nitrogen fixation occurs in legume meadow when the nitrogen already is low. When meadows become established and soil nitrogen becomes adequate for plant growth, the meadow-legume crop simply uses mostly the supply available in the soil. Little fixation occurs then.

Indeed the nitrogen production by legume crops is much like honey in a beehive. Part of it must be removed regularly to stimulate production.[19]

It is stressed in all these articles that legumes play an important role in preventing soil erosion.

The results secured from the rotation experiments in Iowa, Illinois, and Ohio must be applied with considerable caution to southeastern South Dakota conditions. The remainder of this publication will present yield estimates for several crop rotations on Moody soil for southeastern South Dakota conditions drawing upon the experiments which have been reviewed and the knowledge of agronomists of the South Dakota Experiment Station. The general purpose is to provide farmers with the best estimates possible of the most profitable use of legumes in this area.

Estimating the Yield Response Curve of Corn and Oats as Affected by Legumes

The task of estimating the probable response of corn and oats to legumes in the rotation for soils derived from thick loess in southeastern South Dakota can be broken down into four steps. These steps are: (1) the formulation of some general assumptions about the conditions under which these estimates were prepared; (2) estimating the present yields of corn and oats under present cropping systems in the area; (3) estimating the maximum increase in yields which can be secured by use of legumes in the rotation; and (4) estimating how much of the total response should be attributed to each addition of legumes when other factors are constant. This last step will give a response curve connecting present yield with the highest yields which can be obtained with the use of legumes alone. Each of these steps will now be discussed.

Assumptions Concerning Yield Estimates

Obviously it is not practical to prepare yield estimates for every conceivable situation, therefore certain assumptions have been made which should be kept clearly in mind in using these estimates. These are that:

(1) The yield estimates will be those obtained after the legumes have been rotated on all fields in which grain is grown. Thus for a rotation of corn-oats with sweet clover as a catch crop this requirement will be met at the end of the first year since all the corn will have the bene-

[19]W. D. Shrader, W. V. Bartholomew and A. J. Englehorn, "Can Your Soil Store Meadow? *Iowa Farm Science*, Vol. 10, No. 8, February 1956, p. 8.

[20]J. L. Haynes and L.E. Thatcher ("Crop Rotations and Soil Nitrogen," *Soil Science*, July 1955, p. 324-27) indicate that the major yield effects are achieved as soon as the legumes are rotated about the field.

fit of the sweet clover for the second year. For longer rotations more time will be needed.[20]

(2) Average weather conditions will prevail. These are assumed to be similar to the years 1943-50 for southeastern South Dakota. With variations in such things as precipitation and length of growing season, different yields from these estimates must be expected. When moisture is lacking, the favorable effect of legume on nitrogen supply may be offset by the loss of soil moisture caused by the legumes.

(3) Nitrogen and moisture are the limiting factors in crop production under the rotations used rather than other plant nutrients. It is assumed that phosphorus will be added as needed. At present, potassium and lime are not needed on these soils, but it is assumed that they will be applied if needed.

(4) Some of these rotations will not provide adequate erosion control and such control is not assumed.

(5) The small differences in yields between rotations is the result of the use of a curve to indicate the general response to legumes and is not an indication of the degree of accuracy of these estimates.

Estimated Present Yields

Several sources of information were used in estimating present average yields for Moody soil in southeastern South Dakota. The crop yield information available consisted of U. S. Census and Crop and Livestock Reporting Service county yield data and information from a few farmers in the area. Since the yield estimates were to be made for the 1943-50 weather conditions, the most useful data is that provided by the Crop and Livestock Reporting service as presented in table 2. Obviously such average area yields have serious limitations. They represent the yields of all soils under a wide range of conditions as to the kind of rotations and cultural practices used.

These average area yields, however, do provide a general level of yields for the area being studied. Using this information, soil and crop scientists of the Experiment Station prepared yield estimates for corn, oats, and legumes for southeastern South Dakota. These are presented in table 16. Corn yield estimates range from 8 bushels for Crofton to 44 bushels for Trent. These yield estimates appear reasonable when compared with the 25-year average yield of 29 bushels and the 1943-50 average yield of 38 bushels per acre (see table 2). The corn yields for Trent and Moody (4-8 percent slope) are the same as those estimated earlier for average management in Clay County.[21]

Estimating the Maximum Effects of Legumes on Corn and Oat Yields

An estimate of maximum increase in corn and oat yields which could be secured by the use of legumes on the loess soils of southeastern South Dakota was necessary because experimental rotation studies in the area have not been made. This does not mean, of course, that there was

[21]G. J. Buntley, W. C. Bourne and F. C. Westin, *Soils of Clay County, South Dakota*, South Dakota Agr. Exp. Sta. Bulletin 430, May 1953, Table 3.

Table 16. Estimated Yields of Corn, Oats, and Alfalfa-Brome for Five Soils in Southeastern South Dakota

Soil*, Slope, and Degree of Erosion	Per Acre Yields of Corn (bu.)	Oats (bu.)	Alfalfa-Brome Hay (tons)
Trent soils 0-3 percent slope little or no erosion	44	42	2.4
Moody soils 4-8 percent slope slight erosion	40	38	2.2
Moody soils 9-12 percent slope moderate erosion	34	32	1.8
Moody soils 9-12 percent slope severe erosion	26	24	1.4
Crofton soils 12-15 percent slope severe erosion	8	6	.5

Source: Estimates by soil and crop scientists of the Experiment Station.
*These soil series names are used tentatively until the county soil surveys have been published.

no information available. The rotation experiments at Brookings, Clarinda and Ames, Iowa, Urbana, Illinois, and Wooster, Ohio provide ample evidence that legumes increase grain yields remarkably when soil moisture is available.

Farmers' experience in the loess area of southeastern South Dakota indicates that somewhat similar response can be expected from legumes in this area. Trials with different rates of nitrogen indicate in a general way the response which might be secured from legumes. This is true because legumes increase yields **primarily** because of the nitrogen supplied. However, the nitrogen supplied by legumes may be offset by their effect on soil moisture in dry years.

With such information and their general experience in the area, soil and crop specialists appear to be quite confident that, under the conditions assumed, legumes can be expected to increase corn yields on Moody soils by 15 bushels and oat yields by 24 bushels per acre. These precise figures are, of course, estimates which can be expected to be achieved only under the assumptions and average conditions as stated above. They are necessary, however, if farmers are to be given any help in choosing their crop rotations.

Estimated Yield Response of Corn and Oats to Increasing Amounts of Legumes

The remaining task was to estimate how much of this total estimated maximum corn and oat yield increase—corn 15 bushels, oats 24—could be secured by the use of several rotations containing increasing amounts of legumes as shown in table 17.

Since these rotations do not provide equal increments of legumes, it is easier to estimate yield response

Table 17. Corn and Oat Yield Estimates Used to Determine the Most Profitable Crop Rotations for Moody Soil

Rotations*	Percent Legumes†	Estimated Corn Yields per Acre A (bu.)	B (bu.)	C (bu.)	D (bu.)	Oat Yields Used With Corn Estimates B, C, D (bu.)	A (bu.)	Alfalfa Yields per Acre (tons)
1. C O	0	40	40	40	40	38	38	....
2. C C Os	(13)	38	39.6	41	45	46	39	....
3. C Os	(20)	45	47.2	49	52	56	46	....
4. C O C O M	20	42	44.2	46	49	52	44	2.0
5. C C O M	25	41	43.6	46	48	54	45	2.0
6. C O C O M M	33	46	48.2	51	52	56	47	2.2
7. COs C O M M	(39)	50	51.8	54	55	61	53	2.2
8. C O M M	50	52.5	53.4	55	55	62	58	2.2
9. C O M M M	60	55	54.7	55	55	62	62	2.2

*C=corn; O=oats; M=alfalfa-brome meadow; s=sweet clover green manure catch crop.
†In rotations 2, 3, and 7 the sweet clover catch crop was estimated to be 40 percent as effective as alfalfa-brome meadow.

curves such as shown in figures 2 and 3 and then read the yields from the curves for the different rotations. Several possible yield response curves for corn on Moody soil in southeastern South Dakota are presented in figure 4. Each of these curves was used to determine the specific yields for each of the crop rotations presented in table 17. In other words, yield estimates A were read from curve A, B from curve B, and so on.[22]

Because corn follows corn in rotations CCOs and CCOM, the corn yields for the second corn crop were estimated to be 10 bushels less than the corn which follows legumes or 5 bushels lower than the yield response curves of figure 4. This is a conservative drop. At Ames the average drop in corn yields was 12.5 bushels between the first and second corn crop in a CCOs rotation and 20.4 bushels for a CCOM rotation as an average for the years 1950-53.[23] At Clarinda the corn yield drop for CCOs was 14.8 bushels; for CCOM 15.7 bushels; and for C C O M M 10.4 bushels per acre.[24] At Wooster a drop in corn yields from first to second year of 3-10 bushels occurred under different rotations.[25]

No experimental data were found to indicate the comparative yields of first and second year corn in COCOM rotation but it seemed reasonable to expect at least a 6-bushel decrease or an average yield 3 bushels below the curve. For COCOMM it was estimated that a 4-bushel drop would occur on the

[22]Curves B, D and E were prepared using the Spillman exponential function $y=A(1-R^x)$ in which A is the maximum yield increase obtainable and R is the ratio of one increment of yield to the next. The maximum yield increase was set at 16 bushels. While this maximum is approached, it is never achieved with this formula. In the case of curve B the maximum was set at 20 bushels in order to fit the curve between A and C. The R values are: A=1.0; B=.8; C=(varies); D=.5; E=.4.

[23]Iowa Agr. Exp. Sta. and Extension Service mimeograph, Agron. 302, March 1954.

[24]Iowa Agr. Exp. Sta. and Extension Service FSR-98, March 1954, p. 11.

[25]*Handbook of Ohio Experiments in Agronomy*, Book Series B-1, Nov. 1951, Section 7, Crop Rotations.

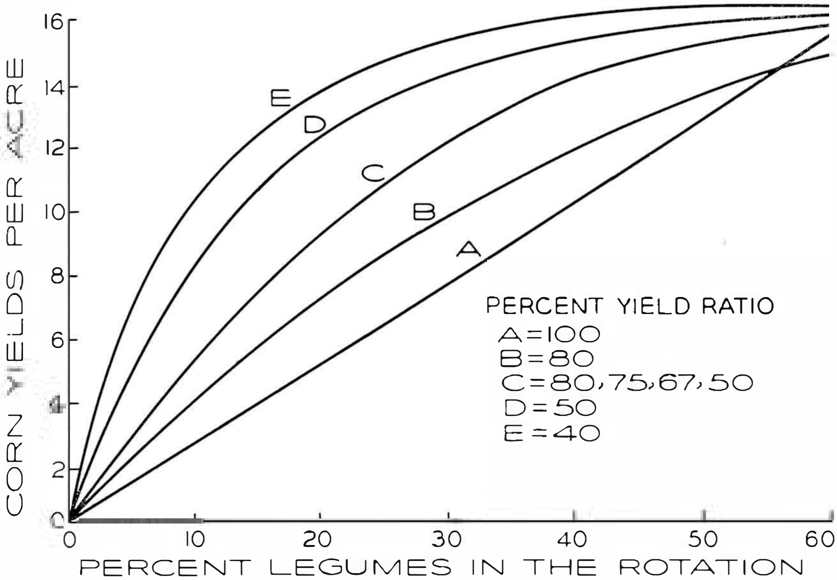

Figure 4. Possible yield response curves for corn on Moody soil in southeastern South Dakota.

second corn crop or an average of 2 bushels below the curve.

Similar curves to those used with corn were prepared as an aid in estimating the oat yields for the rotations. When oats followed two corn crops without an intervening legume, the yields were also reduced by 4 bushels as an average. The oat yield estimates used with corn yield estimates B, C, and D are the same. When corn yields from curve A were analyzed, the oat yields were read from a straight line curve like A. Where legumes stand only 1 year, they were estimated to yield 2 tons per acre. Yields were held constant at 2.2 tons per acre in all rotations in which the legumes stand 2 years or more. This yield increase in hay means that the second year would produce .4 ton more hay than the first year or .2 ton as an average for both crops. This increase seems to be fully justified. The differences in first and second alfalfa hay crops at Wooster for six rotations were 1 ton more for the second crop or .5 ton as an average for the two crops, 1937-49.[26] At Clarinda, Iowa for two rotations the difference in alfalfa-red clover-brome for first and second years was on an average .6 ton more for the second crop or .3 ton more as an average for the two crops 1943-53.[27]

The object of the analysis which follows is to demonstrate that sever-

[26]Ibid., Table 179.
[27]*Annual Progress Report,* Soil Conservation Experimental Farm, Iowa Agr. Exp. Sta. FSR 98, 1954 and FSR 5, 1949.

al bushels variation in corn yields per acre for a given rotation as indicated by curves A, B, C, D, and E in figure 4 do not affect relative ranking of the rotations as to gross returns.

Which of these corn yields response curves is most likely to represent the true response of corn to legumes? While experimental yields on Moody soil in this area are not available, simple logic, the evidence from the rotation experiments reviewed, and fertilizer trials in the area can be used to select a set of estimates most likely to represent the true response curve.

Curve A (straight line) is quite unlikely to indicate the true response of corn to legumes. The principle of eventually diminishing returns is too well established by both logic and experimental evidence to expect such a response from corn to the addition of more and more legumes.

A curve which turns upward (not shown) also seems unrealistic. With enough nitrogen available in the soil to produce 40 bushels of corn per acre it seems quite likely that the area of increasing returns at an increasing rate already has been passed on these soils in southeastera South Dakota. Hence, curves B, C, D, and E all turn downward —increasing at a diminishing rate throughout their length.

In order that these curves may be increasing at a diminishing rate, the initial 10 percent of legumes must give greater additional returns than any other 10 percent. This can be seen in table 17 and in the curves themselves. If all of the additional increases are the same size, a straight line like A results.

The curves in figure 4 indicate that the further the yield response curve lies from line A the less additional legumes beyond 25 percent increase corn yields. This is true because the farther the curves lie above A the larger the first increments of yields must be. This leaves less for the succeeding increments because 15 bushels is the maximum which can be expected. Since the last few increments in yield become smaller as the curve becomes higher, they will be less profitable than for lower curves. In other words, an optimist about the value of legumes in the rotation might choose line A while a pessimist might choose curve E.

Using the B yield estimates, the production possibilities per 100 acres of cropland were calculated. These are presented in table 18. Rotation 3, COs produces 112 tons of grain per 100 acres. The total production per 100 acres indicates that the yield curve is already far enough above the straight line to make a sweet clover catch crop (sown in the oats and plowed down for corn the next spring) produce more tons of grain than standover legumes in rotations 4-9.

However, this is not the complete story since rotations 4-9 also produce hay. Do they produce enough to overcome the loss of grain as compared to rotation 3? The last column shows that 1.4 to 2.3 tons of hay are gained per ton of grain lost by changing from rotation 3 to rotations 4-9. The value of the hay gained varies from $18.90 to $31.05

at $13.50 per ton for loose hay. At $17.50 for baled hay the value varies from $24.50 to $33.25. If corn is worth $1.20 per bushel and oats $.65 per bushel, then grain is worth over 2 cents per pound or $40 per ton. At these prices, rotations 4-9 do not appear to be especially profitable.

Does the hay provide enough nutrients to offset the nutrients lost in the corn? Corn and oats contain about 75 percent TDN. This would be 1,500 pounds TDN per ton. Alfalfa-brome hay contains about 50 percent TDN. Hence, a ton of hay contains 1,000 pounds of nutrients. Anyone electing to use rotations 4-9 in preference to rotation 3 would gain 1,400 to 2,300 pounds of hay nutrients for each 1,500 pounds of grain nutrients lost.

However, two things need to be kept in mind. First, the gain in nutrients may be offset in part at least by the higher costs of hay production and perhaps by larger weather risks. Secondly, if alfalfa-brome hay can be secured for $13.50 per ton loose or $17.50 per ton baled, it would seem the wiser course to produce grain, sell it, and buy hay because more nutrients could be secured at lower cost.

Dairy farmers and purebred producers may, however, find it desirable to raise their own legumes for hay and pasture and buy grain from others. This may be true because it is easier to move grain to cattle than it is to move cattle to distant pastures. Cattle can harvest legumes as pasture. This may reduce costs sufficiently to permit standover legumes to be used in the crop rotation.

The production possibilities for estimates C have also been calculated. These are presented in table 19. These estimates also make rotation 3, COs, appear to be most profitable per 100 acres of cropland. When the total production per 100

Table 18. Total Production Possibilities per 100 Acres Using Corn Yield Estimes B for Moody Soil

	Acres per 100 Acres in			Yield per Acre of			Total Production per 100 Acres		Hay Gained per Ton of Grain Lost as Compared to Rotation 3	
Rotation*	Legumes† (A)	Corn (A)	Oats (A)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value‡
1. C O§	0	50	50	40	38	—	86	—	—	—
2. C C Os	(13)	67	33	39.6	46	—	98	—	—	—
3. C Os	(20)	50	50	47.2	56	—	112	—	—	—
4. C O C O M	20	40	40	44.2	52	2.0	83	40	1.4	$18.90
5. C C O M	25	50	25	43.6	54	2.0	83	50	1.7	22.95
6. C O C O M M	33	33	33	48.2	56	2.2	75	73	2.0	27.00
7. C Os C O M M	(39)	33	33	51.8	61	2.2	80	73	2.3	31.05
8. C O M M	50	25	25	53.4	62	2.2	62	110	2.2	29.70
9. C O M M M	60	20	20	54.7	62	2.2	50	132	2.1	28.35

*Crop in the rotations are indicated as follows: C=corn; O=oats; Os=oats with sweet clover catch crop; M =alfalfa-brome meadow.

†The sweet clover catch crop in Rotations 2, 3, and 7 is estimated to be 40 percent as effective as standover legumes. Thus in Rotation 7 only 33 acres of legumes are harvested—the remaining 6 percent of legumes comes from the sweet clover catch crop.

‡The prices used are long-term estimates prepared for such analysis and consist of corn $1.20; oats $.65; and loose alfalfa-brome hay $13.50 per ton.

§These yields are only slightly above the 1943-50 average for six counties in the area—see table 3.

Table 19. Probable Effects of Several Rotations on Corn and Oat Production on Moody Soil in Southeastern South Dakota (Curve C Yield Estimates)

Rotation*	Acres per 100 Acres in			Yield per Acre of			Total Production per 100 Acres		Hay Gained per Ton of Grain Lost as Compared to Rotation 3	
	Legumes† (A)	Corn (A)	Oats (A)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value‡
1. C O§	0	50	50	40	38	—	86	—	—	—
2. C C Os	(13)	67	33	41	46	—	101	—	—	—
3. C Os	(20)	50	50	49	56	—	113	—	—	—
4. C O C O M	20	40	40	46	52	2.0	85	40	1.4	$18.90
5. C C O M	25	50	25	46	54	2.0	86	50	1.8	24.30
6. C O C O M M	33	33	33	51	56	2.2	77	73	1.6	21.60
7. C Os C O M M	(39)	33	33	54	61	2.2	82	73	2.4	32.40
8. C O M M	50	25	25	55	62	2.2	63	110	2.2	29.70
9. C O M M M	60	20	20	55	62	2.2	51	132	2.1	28.35

*Crop in the rotations are indicated as follows: C=corn; O=oats; Os=oats with sweet clover catch crop; M =alfalfa-brome meadow.

†The sweet clover catch crop in Rotations 2, 3, and 7 is estimated to be 40 percent as effective as standover legumes. Thus in Rotation 7 only 33 acres of legumes are harvested—the remaining 6 percent of legumes comes from the sweet clover catch crop.

‡The prices used are long-term estimates prepared for such analysis and consist of corn $1.20; oats $.65; and loose alfalfa-brome hay $13.50 per ton.

§These yields are only slightly above the 1943-50 average for six counties in the area—see table 3.

acres for estimates C are compared with those of B in table 18 it is apparent that the C yield estimates are less favorable to standover legumes than are the B estimates. However, the general picture is about the same. A sweet clover catch crop seeded in oats increases grain production rather remarkably from 86 tons to 113 tons—a gain of 27 tons per 100 acres. This is clearly profitable (compare rotations 1, 2, and 3). But changing from rotation 3 to rotations with standover legumes appears to be unprofitable except for unusual situations. For each ton of grain lost worth $40, only 1.4 to 2.4 tons of hay are gained, worth only $18.90 to $32.40.

The production possibilities of estimates D were also calculated. The production of grain and hay per 100 acres of cropland is presented in table 20. Since curve D rises more rapidly than curves B or C, it follows that CCOs and COs are credited with a larger share of the 15-bushel increase estimated to be possible under the assumptions of 1943-50 weather and average management. As a result, rotations 4-9 appear to be even less profitable than they do in tables 18 and 19.

Since the higher the curve the more profitable a sweet clover catch crop appears to be, there is little point in analyzing still higher curves such as E in figure 4. Such curves are believed to be above the area where the true yields might reasonably be expected to fall.

Yield curves B, C, D, and E all indicate that a corn-oat or a corn-corn-oat rotation with a legume catch crop is the most profitable for farm production. But is it possible that the true response curve might lie between curves A and B? If so would such a curve be more favorable to standover legumes?

To answer these questions the production possibilities were calculated for curve A, a straight line response. As mentioned before, such response is quite unlikely to be the true response for corn to legumes. However, it was used to test the possibility that a curve between A and B would be more favorable to standover legumes. The results are presented in table 21.

Surprisingly enough even the use of a straight line response curve A shows that a sweet clover catch crop is more productive per 100 acres than standover legumes. The

Table 20. Probable Effects of Several Rotations on Corn and Oat Production on Moody Soil in Southeastern South Dakota (Curve D Yield Estimates)

	Acres per 100 Acres in			Yield per Acre of			Total Production per 100 Acres		Hay Gained per Ton of Grain Lost as Compared to Rotation 3	
Rotation*	Legumes† (A)	Corn (A)	Oats (A)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value‡
1. C O§	0	50	50	40	38	—	86	—	—	—
2. C C Os	(13)	67	33	45	46	—	109	—	—	—
3. C Os	(20)	50	50	52	56	—	118	—	—	—
4. C O C O M	20	40	40	49	52	2.0	88	40	1.3	$17.55
5. C C O M	25	50	25	48	54	2.0	89	50	1.7	22.95
6. C O C O M M	33	33	33	52	56	2.2	78	73	1.8	24.30
7. C Os C O M M	(39)	33	33	55	61	2.2	83	73	2.0	27.00
8. C O M M	50	25	25	55	62	2.2	63	110	1.9	25.65
9. C O M M M	60	20	20	55	62	2.2	51	132	1.9	25.65

*Crop in the rotations are indicated as follows: C=corn; O=oats; Os=oats with sweet clover catch crop; M =alfalfa-brome meadow.
†The sweet clover catch crop in Rotations 2, 3, and 7 is estimated to be 40 percent as effective as standover legumes. Thus in Rotation 7 only 33 acres of legumes are harvested—the remaining 6 percent of legumes comes from the sweet clover catch crop.
‡The prices used are long-term estimates prepared for such analysis and consist of corn $1.20; oats $.65; and loose alfalfa-brome hay $13.50 per ton.
§These yields are only slightly above the 1943-50 average for six counties in the area—see table 3.

Table 21. Total Production Possibilities per 100 Acres Using Straight Line Response Curves for Corn and Oats (Curve A)

	Acres per 100 Acres in			Yield per Acre of			Total Production per 100 Acres		Hay Gained per Ton of Grain Lost as Compared to Rotation 3	
Rotation*	Legumes† (A)	Corn (A)	Oats (A)	Corn (bu.)	Oats (bu.)	Hay (tons)	Grain (tons)	Hay (tons)	Tons	Value‡
1. C O§	0	50	50	40	38	—	86	—	—	—
2. C C Os	(13)	67	33	38	39	—	92	—	—	—
3. C Os	(20)	50	50	45	46	—	100	—	—	—
4. C O C O M	20	40	40	42	44	2.0	75	40	1.6	$21.60
5. C C O M	25	50	25	41	45	2.0	75	50	2.0	27.00
6. C O C O M M	33	33	33	46	47	2.2	68	73	2.3	31.05
7. C Os C O M M	(39)	33	33	50	53	2.2	73	73	1.9	25.24
8. C O M M	50	25	25	52.5	58	2.2	60	110	2.1	28.62
9. C O M M M	60	20	20	55	62	2.2	51	132	2.2	29.16

*Crop in the rotations are indicated as follows: C=corn; O=oats; Os=oats with sweet clover catch crop; M =alfalfa-brome meadow.
†The sweet clover catch crop in Rotations 2, 3, and 7 is estimated to be 40 percent as effective as standover legumes. Thus in Rotation 7 only 33 acres of legumes are harvested—the remaining 6 percent of legumes comes from the sweet clover catch crop.
‡The prices used are long-term estimates prepared for such analysis and consist of corn $1.20; oats $.65; and loose alfalfa-brome hay $13.50 per ton.
§These yields are only slightly above the 1943-50 average for six counties in the area—see table 3.

reason for this is clear if rotations 3 and 4 are compared in table 21. Both these rotations contain the same amount of legumes, assuming that the catch crop is 40 percent as effective as standover legumes in increased yields. Rotation 3, COs produces 100 tons of grain per 100 acres or 1 ton per acre. Rotation 4 grain production was cut 20 tons by the fact that standover legumes occupy 20 acres of land capable of producing 1 ton per acre. Another 5 tons were lost since corn yields fall 6 bushels on the second corn crop or an average of 3 bushels for both corn crops. Oats also fall 4 bushels for the second crop or 2 bushels as an average for both crops. Grain yields would have to increase remarkably to overcome this loss of 20 tons of grain caused by growing 20 acres of hay.

Each acre of meadow produces 2 tons of hay or 40 tons total. Thus for each ton of the 25 tons of grain sacrificed, as compared to rotation 3, 1.6 tons of hay are gained. If hay yields were 3.5 tons or more per acre as an average then the shift from grain to hay would be profitable. In other words, one or more of three changes must occur if standover legumes are to replace grain in the Corn Belt. Hay yields must increase relative to grain yields. Hay prices must increase relative to grain prices. Or, hay production costs must fall relative to grain production costs. Of course not all of these changes need to occur, providing the net result is more favorable to hay production than it has been in the past, or is expected to be in the immediate future.

Thus far the analysis has been made in terms of gross returns per 100 acres assuming that grain production costs were less than hay production costs. This assumption will be analyzed in some detail in the remainder of this circular where changes in out-of-pocket costs and investment are considered.

Yield Estimates for Cost and Benefit Studies

Which of the several yield response curves presented in figure 4 is likely to approximate the true yield response to legumes in southeastern South Dakota? An answer to this question is needed if the costs and benefits of alternative farming plans are to be assessed.

Farmers interested in using legumes for conservation purposes need specific yield figures to determine the comparative cost of different rotations. Likewise farmers who are considering intensive livestock and crop production possibilities need specific yield estimates for the various crop rotations being considered. Public agencies charged with evaluating soil conservation costs and benefits require specific figures with which to work.

While there are hazards in choosing a specific curve as most likely to represent the true response to legumes, it is clearly a risk that must be taken either by the farmer or by the specialists in the various agencies concerned. It seems logical that such a choice should be based upon rotation experiments and the judgement of soil and crop specialists of the Experiment Station.

As noted earlier, only the Clarinda and Wooster rotation experiments contain more than 33 percent legumes. Both experiments indicate that little or no yield response is secured beyond the 33 percent level. This can be clearly seen in figure 2 where the Clarinda yields actually decrease after 33 percent legumes. It can also be seen in figure 3 where only 2 to 4 additional bushels of corn are secured when legumes are increased from 33 to 50-60 percent. However, corn yield increases of 2-6 bushels per acre were secured when legumes in the rotation were increased from 33 to 50 percent on Brookston soil, Holgate, Ohio, 1943-49.[28]

On the other hand, yield estimates for Ida-Monona soils by Aandahl, Riecken, and Allaway show a maximum yield increase for COsCOMM—a rotation containing slightly more than 33 percent legumes—under several soil conditions.[29]

Furthermore, the shorter growing season and lower precipitation in southeastern South Dakota suggests that the corn yield response to more than 33 percent legumes might very well be less than for Clarinda and Wooster.

By comparing figure 4 with figures 2 and 3, it can be seen that curves D and E most nearly approximate the experimental results at Clarinda and Wooster beyond 33 percent legumes. For less than 33 percent legumes, curves D and E are less satisfactory since 9 to 10 bushel corn increases were obtained between 25 and 33 percent legumes on these two rotations. Of the two curves, D is the steeper between 25 and 33 percent legumes. Hence it is more likely to represent the true yield response curve.

The net cash returns from corn yields which fall along curve D are presented in table 22. It is assumed that carrying the hay by a buckstacker to the place where it is fed is practical and that the distance from the center of the hay field to the place where stacked is one-half mile. For greater distances the cost of hay production would be greater. This also assumes that the hay can be used in feeding livestock in such a way that it is worth at least $13.50 per ton or that it is sold out of the stack at this price.

Thus, considering only cash-out-of-pocket- expenses, rotation 3, COs, shows the highest net return when the hay in rotations 4-9 is buckstacked or stored at the place fed and the price of the hay is $13.50 per ton. Rotation 2, CCOs, is $289 less profitable but also requires 31 hours more labor per 100 acres.

The third most profitable is rotation 5, CCOM with 25 percent legumes. The net profit is $436 less than COs per 100 acres or $4.36 less per acre. Also 57 hours of additional labor are used per 100 acres. Apparently the 10 acre increase in corn acres as compared to rotation 4 makes rotation 5 the more

[28]*Handbook of Ohio Experiments in Agronomy*, Ohio Agr. Exp. Sta. Book Series B-1, 1951, Table 173.

[29]Iowa Agr. Exp. Sta. Res. Bul. 429, 1955, Appendix Tables B-1 and B-2.

profitable of the two rotations. All of the remaining rotations show large losses as compared to COs, The costs used in this analysis will now be discussed.

Only the cash costs of seed, sweet clover weevil spraying, gasoline, and oil used in growing and harvesting these crops were included in table 23. Land charges and similar costs which would be the same regardless of the crops grown are not included. Labor was not included because it may not be a cash

Table 22. Net Cash Returns and Labor Requirements per 100 Acres When Hay Is Buckstacked for Several Crop Rotations on Moody Soil, Southeastern South Dakota, Using Yield Estimates D

Rotations*	Legumes Percent	Gross Returns†	Cash Costs‡	Net Cash Returns	Cost (Losses) per 100 Acres as Compared to Rotation 3: Net Cash Returns	Hours Man Labor	Total Man Hours of Labor
1. C O	0	$3635	$288	$3347	$1183	—7	213
2. C C Os	(13)	4604	363	4241	289	31	251
3. C Os	(20)	4940	410	4530			220
4. C O C O M	20	4244	431	3813	717	15	245
5. C C O M	25	4432	338	4094	436	57	277
6. C O C O M M	33	4246	294	3952	578	43	263
7. C Os C O M M	(39)	4472	475	3997	533	36	256
8. C O M M	40	4142	301	3841	689	58	278
9. C O M M M	60	3908	229	3679	851	55	275

*C=corn, O=oats, M=alfalfa-brome, s=sweet clover catch crop for green manure.
†Prices used are corn $1.20 bu.; oats $.65; loose alfalfa-brome hay $13.50
‡See table 23 and footnotes.

Table 23. Estimated Labor Costs and Cash Costs of Producing Crops in South Dakota*

Crop	Hours Man Labor per A.	Fuel Cost per Acre at $.18 per Gal.	Oil Costs per A. at $.10 per Hr.	Seed Costs per A.†	Chlordane and Twine Costs per A.‡	Total Cash Cost per A. per Year
Corn (spring plowing)	3.1	$1.05	$0.28	$1.38	$ ----	$2.71
Oats (not plowed)	1.1	.44	.11	2.50		3.05
Sweet clover	0.3	.06	.01	1.33	1.10	2.50
Oats and sweet clover	1.4	.50	.12	3.83	1.10	5.55
Alfalfa-brome buckstacked (2.2 tons per acre)						
1-year stand	3.7	.68	.25	4.62		5.55
2-year stand	3.4	.61	.22	2.31		3.14
3-year stand	3.2	.54	.20	1.54		2.28
4-year stand	2.9	.46	.17	1.13		1.76
Alfalfa-brome baled (2.2 tons per acre) Automatic-tie, power-take-off						
1-year stand	6.2	1.30	.44	4.62	.66	7.02
2-year stand	5.9	1.22	.41	2.31	.66	4.60
3-year stand	5.5	1.15	.39	1.54	.66	3.74
4-year stand	5.3	1.04	.36	1.13	.66	3.19

Source: *Farm Labor, Power and Machinery Performance in East Central South Dakota*, S. D. Agr. Exp. Sta., Circular 131, 1956, and "Base Prices for Long-Term Farm Budgets," S. D. Agr. Exp. Sta. Agr. Econ. Pamphlet 51, 1954. 23-27 DBHP tractor.

*Land charges and similar costs which would be the same regardless of the crop grown are not included. While the labor required is shown, it is not included in the total costs because it may not be a cash cost in many instances. It is assumed that haying equipment is available and that repairs on haying equipment are offset by decreased costs of repairs on grain machinery.

†Seed rates and prices used are: corn 7 acres per bu. at $9.50 per bu.; oats 2½ bushels at $1.00 per bushel; sweet clover 7 lbs. per acre at $.19 per lb.; alfalfa 6 lbs. per acre at $.46 per lb.; and brome 6 lbs. per acre at $.31 per acre.

‡Chlordane costing $1.10 per acre was applied to control sweet clover weevil and twine for baler cost $.66 per acre.

cost in many instances. However, the labor needed is shown so that this cost can be considered. It was assumed that haying equipment, including a buckstacker, was available and that increased repair on haying equipment was offset by decreased cost of repairs on grain machinery.

When the hay is baled, an additional investment of about $1,200 would have to be made in an automatic one-man square baler (power-take-off). The average annual fixed costs are estimated to be $100 depreciation, $42 interest on average inventory, and $30 for repairs totaling $172.

Since farms in southeastern South Dakota averaged 174 acres cropland in 1954, a charge of $99 per 100 acres of cropland was used when the hay was baled. This cost was added to the gas, oil, and seed costs in evaluating the production of legumes in tables 24 and 27. This charge is offset by the fact that baled hay at the projected prices used is $17.50 per ton instead of $13.50. Since the buckstacker can be used for handling manure, straw, and bales no deduction was made because it would not be used for hay harvesting.

The effect of baling the hay on net returns is presented in table 24. Since no hay is produced in rotations 1-3, these figures are the same as in table 22. Rotation 3 remains the most profitable rotation by a smaller margin than is true when the hay is buckstacked.

Rotations 4-9 show losses per acre ranging from $195 to $509 per 100 acres, depending on the amount of hay produced. Rotation 5, CCOM with 25 percent legumes, is the most profitable of the rotations containing a hay crop, but compared with COs it reduces returns by $195 and increases labor by 120 man hours per 100 acres. This analysis indicates that standover legumes are not a profitable alternative if curve D approximates the true response of corn to legumes.

Table 24. Net Cash Returns and Labor Requirements per 100 Acres When Hay Is Baled for Several Crop Rotations on Moody Soil Southeastern South Dakota, Using Yield Estimates D

					Cost (Losses) per 100 Acres as Compared to Rotation 3		
Rotations*	Legumes Percent	Gross Returns†	Costs‡	Net Returns	Net Returns	Hours Man Labor	Total Man Hours of Labor
1. C O	0	$3635	$288	$3347	$1183	—7	213
2. C C Os	(13)	4604	363	4241	289	31	251
3. C Os	(20)	4940	410	4530			220
4. C O C O M	20	4404	383	4021	509	75	295
5. C C O M	25	4632	297	4335	195	120	340
6. C O C O M M	33	4538	342	4196	334	126	346
7. C Os C O M M	(39)	4764	450	4314	216	119	339
8. C O M M	50	4582	301	4281	249	184	404
9. C O M M M	60	4436	266	4170	360	196	416

*C=corn, O=oats, M=alfalfa-brome, s=sweet clover catch crop for green manure.
†Prices used are corn $1.20 bu.; oats $.65; baled alfalfa-brome hay $17.50.
‡See table 23 and footnotes. To these costs were added $99 of fixed costs incurred when a one-man automatic baler is added to the line of machinery.

But perhaps curve D rises too rapidly at first—perhaps this portion of the curve should be more nearly a straight line between 0 and 33 percent legumes. The fact that 9 to 10 bushels of corn were obtained on the Clarinda and Wooster experiments when legumes were increased from 25 to 33 percent supports this idea. To test this idea, the following yields for the first six rotations have been estimated for a straight line between 0 and 33 percent legumes:

ROTATION	CORN, BU.	OATS, BU.	HAY, TONS
1. CO	40	38	—
2. CCOs	41	45	—
3. COs	49	53	—
4. COCOM	46	49	2.0
5. CCOM	47	56	2.0
6. COCOMM	53	60	2.2

Rotations 7-9 would give no yield increases over rotation 6. The relative returns per 100 acres from these yield estimates are presented in table 25. Even with an unrealistic straight line response, COs is still the most profitable rotation although the cost of shifting to CCOM has fallen to $185 and 57 man hours of labor per 100 acres.

Another possibility is that in southeastern South Dakota there will be some increase in legumes beyond the 33 percent level. Both the Clarinda and Wooster data suggest that this is unlikely, but it should be kept in mind that these two rotation experiments are a considerable distance from southeastern South Dakota and conditions are also different. Hence it is possible, if improbable, that there will be a significant response beyond the 33 percent level. In other words curve C may be nearer the true response curve than curve D. Also there is the possibility that the true curve may fall between C and D.

Because of these possibilities, corn yield estimates which fall along curve C are analyzed in table 26. Rotation 3, COs was the most profitable and requires less labor than any other rotation except CO.

Rotation 5, CCOM with 25 percent legumes, is the second most

Table 25. Net Cash Returns and Labor Requirements per 100 Acres When Hay Is Buckstacked for Several Crop Rotations on Moody Soil, Southeastern South Dakota, Using a Straight Line Yield Response Between 0 and 33 Percent Legumes

Rotations*	Legumes Percent	Gross Returns Buckstacked†	Cash Costs‡	Net Cash Returns	Cost (Losses) as Compared to Rotation 3: Net Returns	Cost (Losses) as Compared to Rotation 3: Hours Man Labor	Total Man Hours of Labor‡
1. C O	0	$3635	$288	$3347	$965	—7	213
2. C C Os	(13)	4175	363	3812	440	31	251
3. C Os	(20)	4662	410	4252	—	—	220
4. C O C O M	20	4022	431	3591	661	15	245
5. C C O M	25	4405	338	4067	185	57	277
6. C O C O M M	33	4372	294	4078	174	43	263
7. C Os C O M M	(39)	4536	475	4061	251	36	256
8. C O M M	50	4175	301	3874	438	58	278
9. C O M M M	60	3934	229	3705	607	55	275

*C=corn, O=oats, M=alfalfa-brome, s=sweet clover catch crop for green manure.
†Prices used are corn $1.20 bu.; oats $.65; buckstacked alfalfa hay $13.50.
‡The cash and labor costs are the same as those for table 22. See also table 23 for sources.

profitable. It costs $376 and 57 hours more labor than rotation 3. The cost (losses) of the remaining rotations are smaller than when yield response curve D is used, but are still large enough to discourage their use (compare with table 22).

When the hay is baled, the returns and labor requirements of CCOs and COs do not change, since no hay is involved (see table 27). Hence, COs remains the most profitable rotation although the difference is smaller than for the other estimates presented in tables 22, 24, and 26. However, it should be kept in mind that the available evidence suggests that curve D is more likely to be the response to legumes which can be expected in southeastern South Dakota under the moisture and other growing conditions as they existed during the 8-year period, 1943-50.

Table 26. Net Cash Returns and Labor Requirements per 100 Acres When Hay Is Buckstacked for Several Crop Rotations on Moody Soil, Southeastern South Dakota, Using Yield Estimates C

					Cost (Losses) per 100 Acres as Compared to Rotation 3 in		Total
Rotations*	Legumes Percent	Gross Returnst	Cash Costs‡	Net Cash Returns	Net Cash Returns	Hours Man Labor	Man Hours of Labor
1. C O	0	$3635	$288	$3347	$1003	—7	213
2. C C Os	(13)	4282	363	3919	431	31	251
3. C Os	(20)	4760	410	4350			220
4. C O C O M	20	4100	431	3669	681	15	245
5. C C O M	25	4312	338	3974	376	57	277
6. C O C O M M	33	4205	294	3911	439	43	263
7. C Os C O M M	(39)	4432	475	3957	393	36	256
8. C O M M	50	4142	301	3841	509	58	278
9. C O M M M	60	3908	229	3679	671	55	275

*C=corn, O=oats, M=alfalfa-brome, s=sweet clover catch crop for green manure.
†Prices used are corn $1.20 bu.; oats $.65; loose alfalfa-brome hay $13.50
‡These costs are the same as those in table 22. See also table 23 for source.

Table 27. Net Cash Returns and Labor Requirements per 100 Acres When Hay Is Baled for Several Crop Rotations on Moody Soil, Southeastern South Dakota, Using Yield Estimates C

		Gross			Cost (Losses) as Compared to Rotation 3		Total
Rotations*	Legumes Percent	Returns Baled†	Costs‡	Net Returns	Net Returns	Hours Man Labor	Man Hours of Labor
1. C O	0	$3635	$288	$3347	$1003	—7	213
2. C C Os	(13)	4282	363	3919	431	31	251
3. C Os	(20)	4760	410	4350	—	—	220
4. C O C O M	20	4260	383	3717	633	75	295
5. C C O M	25	4512	297	4215	135	120	340
6. C O C O M M	33	4497	342	4155	195	126	346
7. C Os C O M M	(39)	4724	450	4274	76	119	339
8. C O M M	50	4582	301	4281	69	184	404
9. C O M M M	60	4436	266	4170	180	196	416

*C=corn, O=oats, M=alfalfa-brome, s=sweet clover catch crop for green manure.
†Prices used are corn $1.20 bu.; oats $.65; baled alfalfa-brome hay $17.50.
‡These costs are the same as for table 24. See table 23 for source. To these costs were added $99 of fixed costs incurred with the addition of a one man baler to• the line of equipmen.t

Summary and Conclusions

What is the most profitable crop rotation for the Corn Belt or for that area of southeastern South Dakota which is generally considered to be in the Corn Belt? The purpose of this study was to answer this question.

The procedure consisted of analyzing trends in production, costs, and price relationships between grain and forage. Then the yield data of crop rotation experiments being carried on at Brookings, South Dakota; Clarinda and Ames, Iowa; Urbana, Illinois; and Wooster, Ohio were analyzed to determine the most profitable crops under experimental conditions. Finally yield estimates were prepared and analyzed for Moody soil in southeastern South Dakota.

Would it be profitable for farmers in the Corn Belt area to grow more legumes? An analysis of several Corn Belt rotation experiments indicates rather clearly that a green manure catch crop of legumes seeded in small grain and plowed down the following spring for corn is more profitable than standover legumes used for hay at usual growing and harvesting costs.

Changing from a corn-oat legume catch crop rotation at Urbana reduced total grain production 56 tons per 100 acres of cropland and gave only 119 tons of hay in return. In other words a sacrifice of a ton of grain was offset by only 2.5 tons of hay. At expected price relationships for corn at $1.20 per bushel, oats at 65 cents per bushel, and loose hay at $13.50, this is trading $40 worth of grain for $34 of hay.

Some rotations at Wooster gave 3 tons of alfalfa hay for each ton of grain sacrificed. This is a return of $40.50 for each $40 worth of grain lost. Since per acre costs of growing and harvesting hay are usually higher than for corn, this does not pay except in specialized livestock producing situations where the hay nutrients can be effectively utilized.

While the yield data for the Marshall silt loam rotation experiments, 1949-53, are highly favorable to hay production as compared to a sweet clover catch crop, usually favorable conditions appear to have prevailed. Estimates of expected yields for Monona silt loam in western Iowa for farm conditions are more conservative. The maximum hay gained per ton of grain sacrificed is 3.1 tons worth $41.85 at expected prices. Considering the higher cash and labor costs this is not an attractive alternative to a corn-oat-legume catch crop rotation.

Can the results of Ohio, Illinois, and Iowa be applied to the conditions found in the Corn Belt area of southeastern South Dakota? Estimates were prepared by the soil and crop specialists of the Experiment Station for Moody soil having 4-8 percent slopes with slight erosion. These estimates were made assuming 1943-50 weather conditions, average management, and phosphate supplied but no barnyard manure or commercial nitrogen being provided. The average yields of corn and oats were 38 and 35 bushels, respectively, for 1943-50 in the six counties—Union, Clay, Lincoln, Turner, Minnehaha, and Moody. The average alfalfa yield was 2 tons per acre for the same period in the same counties.

The estimated yields for a corn-oat rotation (CO) without legumes on Moody soil were corn 40 bushels, oats 38 bushels, and alfalfa 2.0 to 2.2 tons. It was further estimated that legumes would increase corn yields on this soil about 15 bushels per acre.

Several possible corn yield response curves were prepared to indicate the possible rate of response of corn to increasing amounts of legumes. Using each of these curves to prepare yield estimates, the calculations showed that sweet clover seeded in oats as a green manure catch crop increased grain production rather remarkably (14-32 tons per 100 acres) as compared to a corn-oat rotation without legumes.

The calculations also showed that changing from a sweet clover catch crop to standover alfalfa-brome was not an especially attractive alternative under the assumptions made. Using four sets of yield estimates, total grain production dropped 25 to 30 tons per 100 acres when a 5-year rotation, COCOM, having 20 percent alfalfa-brome replaced a corn-oat rotation with a sweet clover catch crop (COs). While 40 tons of alfalfa-brome hay were secured, this was only 1.3 to 2.4 tons of hay for each ton of grain sacrificed. In terms of nutrients for livestock this represented a loss of 200 pounds of nutrients at one extreme and a gain of 900 pounds total digestible nutrients at the other, depending upon the corn yield estimates used. Against this gain one must subtract higher costs per acre for haying and possibly increased weather risk.

At expected long-term price relationships indicated by corn at $1.20 per bushel; oats at 65 cents per bushel; and loose alfalfa-brome hay at $13.50 per ton, a ton of grain is worth over $40. To break even on a gross value basis 3.1 tons of hay has to be produced for each ton of grain lost. Considering all four sets of yield estimates for all rotations, no rotation came closer than 2.4 tons of hay per ton of grain lost.

Experimental evidence from the Clarinda, Iowa, rotation experiments and the Wooster, Ohio, experiments suggest little corn or oats response to legumes can be expected beyond the 33 percent level.

Generally, it appears that there is little advantage to standover legumes unless soil erosion is a serious problem or livestock is the major enterprise. Most farmers on Moody soil would do well to grow a green manure catch crop and, if necessary, sell grain and buy hay when the expected price relationships prevail.

If the legume can be economically used as pasture then costs of the legume crop might be low enough to justify standover legumes in the rotation. Livestock or seed specialists or farmers with severe erosion problems may find legumes for hay or pasture profitable for other reasons than their effect on the other crops in the rotation.