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MAIZE-SOYBEAN ROTATIONS AND CONTINUOUS CROPPING IN NORTHERN UNITED STATES

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INTRODUCTION

My informant tells me that you would like me to discuss current American attitudes on maize-soybean rotations and to review our findings regarding continuous cropping. But, the U.S.A. is a large and diverse country, and maize is grown in every state. Cropping patterns, needs and customs vary, as I'm sure they do in New Zealand.

From knowing the variability within your own country, you can visualize the magnitude of the climatic topographic, and soil differences that exist in the U.S.A. Even at this relatively safe distance of 8,000 miles from home, I won't pretend to convey on American attitude, if in fact one even exists. More accurately, this talk will reflect my observations on maize and soybean culture in northern U.S.A. over the last several years.

The "Corn Belt" contains 16 million hectares of soybeans, about 61% of our 1978 crop. It also contains 25 million hectares of maize or almost 80% of our crop.

While I am not closely attuned to fertilizer use, the fact is, virtually all management practices interact with some facet of fertilizer use; the amount, the time of application, the placement or the source. Any management factor that improves yield will almost necessarily increase the need for plant nutrients.

We have had a dramatic increase in the use of fertilizer in the United States in the last 15-20 years, but we have not had a commensurate increase in crop production per hectare. It is understandable that farmers will increase the level of any input which brings a marked increase in production. Fertilizer is such an input. It is my contention that other farm management practices have not kept pace with the increased rate of fertilizer applied, and I cannot resist an opportunity to comment on this subject.

For a long time, we have removed more nutrients from the soil than have been returned in fertilizer. Only recently have we observed that in an entire state, the nutrients applied exceeded those removed. Good yields and profit require an adequate level of fertility, and soil buildup applications of fertilizer are often made.

However, individual farmer applications often fail to reflect farm management. Trierweiler of Ohio State University has estimated that 2/3 of Ohio's soils were either over fertilized or under fertilized.

Planting date

The interaction of planting date and nitrogen fertilizer use is one example of the need to keep our management practices in balance. Late planted maize cannot effectively use much nitrogen as that planted on time. Illinois advisors recommended that the N rate be reduced by 20 units per hectare for each week's delay in planting after the optimum date. With late planting, grain yield drops faster than dry matter production. In one test, a 3½ week delay in planting reduced maize yields 28%, but dry matter production (and presumably nutrient uptake) was reduced only 9% (Erdmann and Hildebrand, 1977). Thus, almost as much plant food was required to produce the smaller crop.

Population

It takes a high plant population to capitalize on high rates of fertilizer and produce high yields. Data from Illinois show that high rates of nitrogen fertilizer are poorly used at low plant populations (Mulvaney *et al.*, 1972). The same is true of phosphorus and potassium. In one Kentucky study, the yield increase from added phosphorus was 10 times greater, and that from potassium was twice as large as at the low population.

MAIZE-SOYBEAN ROTATIONS

Let's move now to the maize-soybean situation. In Midwestern U.S.A., farmers *prefer* to grow maize. A 1976 survey in the State of Iowa showed that 36% of the fields had been in maize 10 or more years and 3.6% had been in maize over 20 years (Anon. 1977b).

A typical Midwest farmer has some land in continuous maize and some land in a maize-soybean rotation. The ratios depend on whether he is primarily a cash grain farmer or a livestock feeder.

This year there is one hectare of soybeans for each 1.6 ha of maize in our "corn belt".

Many farmers grow both maize and soybeans in order to spread the workload. Maize is planted first as soybean yield is less affected by later planting. Soybeans are harvested first to minimize losses from shattering.

The commitment to the corn-soybean rotation is not strong, and farmers readily switch their planting plans as economics and weather dictate. It is easy for a farmer to change his plans right up to the moment of planting. He uses essentially the same soil preparation methods and the same planting equipment for both crops. (This year, for example, we anticipate over 2 million more hectares of soybeans and 1.6 million less hectares of maize than in 1977.)

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A late planting season occasioned by cold or wet weather, such as we had the past spring, favours a switch to soybeans. To make the switch, the farmer need consider only two agronomic factors:

1. the presence of herbicide residues detrimental to soybeans; and
2. previous fertilizer applications.

Herbicide selection

Herbicide selection is less of a factor in the maize-soybean rotation than it once was. Atrazine is a favourite herbicide for use on maize. At one time, it was applied alone at a rate of 3-4 kg of active ingredient per hectare. Residue carryover prevented planting soybeans as the following crop.

Now, atrazine is applied at 1.5-2 kg per hectare in combination with other herbicides. Atrazine carryover does not prevent planting soybeans after maize except under unusual circumstances such as a dry fall or spring when herbicides are not decomposed or, in cases of faulty application.

Fertilization

Virtually all maize is fertilized directly. When farmers plan to follow maize with soybeans, they usually apply all of the fertilizer for both crops prior to or at the time of planting maize.

In Illinois, a major corn and soybean state, the average rate of phosphorus and potassium applied to maize is adequate to replace the nutrients removed in the grain of the average maize plus the average soybean crop (calculated from U.S.D.A., reports).

In northern U.S.A., there is a tendency to apply nitrogen for maize during the fall before planting. But a farmer who applies nitrogen in the fall or early spring in anticipation of planting maize is unlikely to switch to soybeans at planting time.

On the subject of nitrogen, it is a popular guideline to reduce the nitrogen applied to maize by 1 kg for each 60 kg ha^{-1} of soybeans produced the preceding year. This gives credit for nitrogen in soybean residues that is available to maize.

Relatively little fertilizer is applied directly to soybeans. In 1976, less than 3% of U.S.A. fertilizer was applied to soybeans, while 42% was applied to maize (Anon. 1977a). In Iowa, our second leading soybean state, only 14% of the soybeans received fertilizer directly in 1977.

Soybeans have the reputation of being a strong feeder for, maybe even having a preference for, fertilizer left over from a previous crop. Nevertheless, soybeans do respond to high levels of soil fertility. Furthermore, they respond to direct fertilization on soils testing low in P and K. Direct fertilization is preferred if micronutrients are to be applied, and direct fertilization is essential if soybeans follow soybeans.

At least a partial explanation for soybeans mediocre response to direct fertilization is the fact that they are planted later than maize. This places them in a warmer soil, where their physiological activity is higher, and they are better able to capitalize on nutrients released by microbial activity or by weathering during the previous winter.

Recent research in Ohio confirms that early planted soybeans are more responsive to fertilizer. This is consistent with research with small grain which demonstrated that at lower temperatures, fertilizer P is proportionately more available than is soil P (Wallingford, 1978).

Perhaps it is worth noting that although soybean is a leguminous crop, it makes a net removal of nitrogen from the soil at a rate estimated to be 25 kg of N per tonne (Welch, 1977). In the Northern and Western part of the "corn belt", agronomists recommend that a small amount of nitrogen be applied to soybeans at planting.

Research results

The Morrow plots on the campus at the University of Illinois provide research data on continuous maize and maize-soybean rotations. In 1967, plots which had been in a maize-oats rotation since 1876 were converted to a maize-soybean rotation. Yields were compared to those from a plot which had been in continuous maize since 1876 (Welch, 1977, Pers. comm.)

Since 1969, there have been five years when maize was grown on both plots at the same time. Maize following soybeans outyielded maize following maize in every instance, and averaged 1.5 tonnes ha^{-1} higher.

This is a significant difference and we need to learn why it exists. This may enable us to duplicate or even magnify the favourable effects of rotation by some other means. Several possible explanations have been suggested.

Fertility

Much of the benefit of crop rotations has been attributed to the nitrogen of forage legumes being made available to non-legumes. If this is the case, then fertilizer nitrogen should fully compensate for the effect of the rotation.

The effect of nitrogen on continuous maize and maize following soybeans was examined in a four-yearly study at Elwood, Illinois. Maize following soybeans consistently gave higher yields. Differences in the amount of nitrogen available may be a partial explanation for increased yield of maize following soybeans at 0 and low rates of nitrogen. However, any difference in yields due to nitrogen would be expected to disappear at high rates of added nitrogen. Since this did not occur, differences in yield were apparently due to something other than nitrogen.

Soil Physical Properties

Soil is more loose and friable following soybeans than following maize. While more friable soil following soybeans could result in a better stand of maize on farmer fields if a good seedbed is not prepared, that was not a factor in these tests. Differences in yield were not explained by differences in stand.

On sloping land, the more friable nature of soil after soybeans could be a disadvantage if water erosion were a problem. Soybeans provide less residue than maize; this also would favour more erosion following soybean. However, these research plots were located on soil with less than 2% slope. Differences in the amount of erosion were not a factor. Furthermore, rainfall simulation studies in New York indicated that soil under continuous maize with manure and stalks returned, was no more subject to erosion than was soil that had been in a four-year rotation of maize-oats-alfalfa-alfalfa (Zinerman, 1970).

Moisture

Water use by soybeans is probably less than by maize. Soybean roots do not go as deep into the soil. In Illinois, the soil is fully charged with water prior to spring planting. Therefore, any differences in water use between these two crops would not likely affect the following crop.

Water infiltration is another factor which may differ following maize and soybeans, particularly on sloping fields in low rainfall areas. This factor was judged unimportant on this nearly level land.

Toxic Substances

Research has revealed that some products of residue decomposition may be detrimental to the growth of certain plants, especially during the germination and seedling stages. At this time, it has not been determined whether maize residues produce substances that inhibit growth of maize plants or whether soybean residues produce substances that enhance maize growth.

Pests

Growing the same crop year after year often results in a buildup of diseases and insects. This buildup is less severe if crops are rotated. Certain species of weeds also buildup with various crops because of different chemicals or cultural practices. No differences attributed to diseases, insects or weeds were observed in this study.

Other factors

Welch (pers. comm.) of the University of Illinois, has observed that in every instance where comparisons have been made, maize after soybeans has outyielded continuous maize. This may be due to some growth factor we have not discussed, but the yield difference is of such magnitude that it merits additional thought and research.

CONTINUOUS CROPPING

I will turn now to some American observations on the effects of continuous cropping.

From the beginning, researchers in several states had long-term field trials to compare the value of different crop rotations and different fertilizer programmes. However, sponsors of such trials eventually lost interest because of the expense and low return in new information. Now only two locations have trials that have existed for over ninety years; these are the Morrow plots at the University of Illinois and Sanborn Field at the University of Missouri.

The Morrow plots

The oldest of these is the Morrow plots. In 1976, on the occasion of the 100th anniversary of their establishment, Welch and co-workers summarized the lessons learned from the Morrow plots (Welch *et al.*, 1976). The work on the plots was divided into three periods.

The first period – 1876 to 1903: the cropping patterns were essentially as follows:

a. continuous maize
b. maize-oats rotation and a six year rotation of
c. maize-maize-oats-meadow-meadow-meadow which becomes maize-oats-clover in 1901.

Two lessons were learned during the first 28 years.

1. The highly fertile prairie soil could be depleted by cropping, and
2. Depletion could be postponed by use of crop rotations.

The second period – 1904 to 1955: no soil treatment was applied to the plots until they were 29 years old. Beginning in 1904, manure, lime, and phosphorus (MLP) were added to the South half of each plot. Manure was applied to each plot at a rate equivalent to that which would have been produced had the crop from the plot been fed to livestock.

During this period we learned that:

3. Use of manure, lime and phosphorus (MLP) increased crop yields.
4. Fertilisation did not completely replace the effect of rotation. Highest yields were obtained with fertilizer (MLP) on the rotation plots.

The third period – 1955 to 1975: the early phosphorous rates were low by today's standards, so in 1955 medium levels of limestone, nitrogen, phosphorous and potassium (LNPK) were added to part of each previously untreated plot and also to part of each fertilizer (MLP) plot. And, in 1967, high levels of fertilizer (LNPK) were added to certain subplots.

During the period 1955 to 1975, we learned:

5. If the topsoil remains, fertilizer can quickly restore productively to an unproductive soil. Plots that first received soil treatment in 1955 yielded 91% as much during 1955-1975 as plots that began receiving low rates of fertilizer (MLP) in 1904 and medium rates of fertilizer (LNPK) in 1955 (Table 1).

TABLE 1. Maize yields from the Morrow Plots as affected by cropping system and soil treatment.

Soil Treatment	Maize Yield Tonnes ha^{-1}*		
	Continuous Maize	Maize-Oats, Maize-Soybeans†	Maize Oats, Clover
None	2.6	3.3	4.8
MLP since 1904	5.6	7.8	8.5
Medium LNPK since 1955	7.1	7.9	8.5
MLP since 1904, medium LNPK since 1955	7.8	8.2	8.4

* All plots were planted to maize once every 6 years. Yields are average for 1955, 1961, 1967 and 1973.
† Maize oats 1876-1967; Maize-soybeans since 1968.

6. Even with high fertility, yields of continuous maize have been less than those of maize following soybeans.
7. The relative yield of soybeans is affected less by soil treatment than is maize yield (Table 2).

Corn Yields on the Morrow Plots: In the 1904-1919 period, yield from continuous maize

TABLE 2. Maize and soybean yields from the Morrow Plots, with different soil treatments in the maize-soybean system*

Soil Treatment	Maize t ha^{-1}	%	Soybeans t ha^{-1}	%
None	5.0	47	2.6	76
MLP since 1904	8.2	77	3.5	104
Medium LNPK since 1955	9.4	87	3.3	98
MLP since 1904 medium LNPK since 1967	9.2	86	3.4	102
MLP since 1904 high LNPK since 1967	10.7	100	3.3	100

* Soybean yields mean for 1968, 1970, 1972, 1974; Maize yields mean for 1969, 1971, 1973, 1975.

systems were markedly lower than yields from rotation systems. Fertilizer (MLP) treatment increased yields about 50 percent over untreated plots. From 1920 to 1937, yields declined slightly on most plots (Guernsey *et al.*, 1969).

Introduction of hybrid corn varieties in 1937 substantially increased yields on all fertilized plots, however, greatest increases occurred on the rotation plots. Fertility in the untreated maize-oats and untreated continuous maize plots was apparently so low that the soils were unable to respond to the high yield potential of hybrids.

The 4.2 tonnes ha^{-1} increase from the application of fertilizer (LNPK) to previously untreated continuous maize plots indicated that the soil had retained its productive potential through nearly 80 years of inadequate soil treatment.

Soil Nitrogen Status: As you suspect, yield differences reflect soil differences. One of the main differences is soil nitrogen content (Welch, *et al.*, 1976).

From 1904 to 1973, the nitrogen content of untreated plots decreased by about 1,350 kg ha^{-1} with all rotations. The loss was less on plots receiving fertilizer since 1904.

With continuous maize and no soil treatment, soil nitrogen was only 68 percent as great in 1973 as in 1904. However, on the maize-oats-clover plot which had received fertilizer since 1904, there was 92 percent as much nitrogen in 1973 as in 1904. Thus, it appears that well fertilized maize will maintain soil organic matter as measured by soil nitrogen content.

Rooting Zone: In 1964, after over 80 years of cultivation, maize rooting pattern was determined and certain soil physical and chemical properties were measured on selected plots (Guernsey *et al.*, 1969).

Root penetration under continuous maize was limited to 150 cm but there was little penetration below 120 cm except on the fertilized (MLP) plot. On the rotation (C-O-Cl) plots, roots penetrated entirely through the 180 cm cores studied.

Root distribution differed in three ways. The rotation plus fertilizer (C-O-Cl plus LNPK) plot had:

1. more roots in the plow layer
2. a lower density of roots in the B horizons, and
3. deeper root penetration.

There was also higher total root weight under the rotation plot. Continuous maize without fertilization increased bulk density, reduced porosity, lowered organic matter content, and lowered aggregate stability in the plow layer.

The depleting effect of continuous maize without fertilization was expressed through lower levels of exchangeable Ca, Mg and K throughout the 120 cm of the profile which was examined.

Sanborn Field

The Sanborn Field, established in 1888, is located in the Southern part of the corn belt. Incidentally, it was from this field that the fungus which produces aureomycin was isolated in 1945. The fungus was found in a plot which had been in continuous timothy since 1888 without soil treatment.

TABLE 3. Maize yields 1950-77, Sanborn Field

Cropping system	Soil Treatment *	years in system	yield t ha^{-1}	O.M., %†
Continuous corn	none	88	0.6	1.5
	full treatment	28	5.5	2.4
Corn-wheat (sweet clover under)	full treatment plus high Mg and micronutrients	17	6.0	2.6
Corn-oats-wheat (red clover under)	full treatment	28	5.9	2.6
Corn-wheat-red clover	full treatment	28	5.7	2.4
Corn-oats-wheat-red clover	full treatment	28	5.5	2.2

* Full treatment: Lime, P & K based on soil test 112 kg 6-24-24 ha^{-1} as starter. 112 kg N ha^{-1} plowed down. 37 kg N ha^{-1} side dressed.

† Spring 1978

Maize Yields: During the last 28 years, continuous maize with full treatment of lime, N, P and K tended to yield less than maize in rotation but also with full treatment (Upchurch, pers. comm.) (Table 3).

• *Soil Nitrogen:* Soil organic matter content of these plots was determined last spring. While these data obviously reflect not only the most recent 28 year period but also prior treatment, they indicated that only the soil under continuous maize had a markedly lower organic matter content.

Soil Nitrogen (Continuous Cropping): The pattern of nitrogen depletion of the top 18 cm of soil during the first 50 years was reported in 1942 (Smith, 1942). Nitrogen content of treated plots was compared to that of a field maintained in permanent bluegrass.

Continuous maize without treatment was the most exhaustive crop as evidenced by nitrogen depletion; followed in order by wheat, oats and timothy. The heavily manured, continuous timothy plot has a nitrogen content somewhat above that of the virgin soil.

The continuous maize plot receiving 15 tonnes ha^{-1} of manure annually had a lower nitrogen content than the continuous timothy plot with no treatment. Continuous oats with manure just about maintained the original nitrogen level, while continuous wheat (when manured) lost over 12 percent of the original soil nitrogen. The removal of nitrogen by the crops was much less than the amount of nitrogen supplied by the manure.

Soil Nitrogen (Crop Rotations): Rotations have been less exhaustive of soil nitrogen than the continuous production of any crop, excepting timothy. This would be the expected result since the rotations contain legumes which add nitrogen.

Although the six-year rotation with manure maintained soil nitrogen near that of virgin soil, it is interesting that the 780 tonnes ha^{-1} of manure applied over a 50-year period added at least 6,750 kg of nitrogen, yet did not quite maintain the original nitrogen level of the soil.

Other Studies:

Numerous other studies have been made on the effects of continuous cropping. Jenny, (1941), concluded that under average farming conditions in the corn belt, 25% of the native nitrogen was lost the first 20 years, about 10% the second 20 years, and 7% the third 20 years. Bartholomew and Kirkham also concluded that steady state conditions were attained in 50 to 100 years (Stevenson, 1965).

A survey made by Haas *et al.*, in the Great Plains showed that over a 30-43 year period, from 24-60% of the original soil nitrogen was lost through cropping, and in 70 years of cultivation the blackland soils of Texas lost about 50% of their surface organic matter.

In the East, studies at the Jordon Plots in Pennsylvania (now discontinued) showed that after 72 years of cropping to a 4-year rotation (maize-oats-wheat-mixed hay), untreated plots had lost 40% of the native N compared to adjacent grassland, but a heavily manured plot had lost only 10%.

A decline in the N content of land under cultivation results from reduced quantities of plant residues of humus synthesis plus increased microbial activity. A temporary increase in respiration rate occurs each time an air-dried soil is wetted, and since soil is subjected to repeated wetting and drying through cultivation, loss of nitrogen by this process could be appreciable.

In summary, loss of nitrogen through cropping is greatest with intertilled crops, intermediate with cereal crops and smallest with legume and sod crops.

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