EFFECTS OF RESIDUE MANAGEMENT ON FERTILIZER USE EFFICIENCY ON CORN IN THE WESTERN CORN BELT[1]

Gary W. Hergert
University of Nebraska-WCREC
North Platte, NE 69101

INTRODUCTION

Interest in residue management began in parts of the Great Plains following the "dirty thirties" when the government responded to wind and water erosion problems by creating the Soil Conservation Service. Stubble mulch in winter wheat production areas evolved into no-till as herbicides became available. Interest in limited or no till systems in the Corn Belt began in the 1950's.

Higher residue levels are required to reduce erosion while maintaining soil productivity but an additional reason is the need to maintain acceptable residue cover on highly erodible land (HEL) to remain eligible for government programs. Conservation tillage (CT) evolved as a means of maintaining residue and it has been defined as any tillage system that left at least 30% residue cover after planting. After 1983 federal legislation required farmers with HEL to maintain enough crop residue to adequately protect the soil from erosion throughout the year. The amount of residue cover required depends upon the soil type, slope, crop rotation, current crop, and climatic factors. Although the emphasis has been on preventing soil erosion, water quality has become an overriding concern in many cropping systems. Because of confusion about the definition of CT, the term crop residue management (CRM) was adopted by the Soil Conservation Service to be a system of year-around residue management to reduce soil erosion.

The maintenance of higher amounts of surface residue combined with less soil disturbance from limited tillage affects all the biochemical and chemical reactions in the soil-plant system. The factors affected include:

1. Crop sequence and maturity.
2. Harvesting and residue distribution.
3. Fertilizer application method, source, rate, and timing.
4. Crop response to applied nutrients.
5. Soil response including residual fertility, nutrient and pH stratification, compaction or changes in bulk density.
6. Water quality including both surface and subsurface waters due to a changing distribution of water to infiltration, runoff, evaporation and transpiration.
7. Pests--weeds, disease and insects.
8. Wildlife considerations.

Numerous reviews and symposia on the subject have been written (D'Itri, 1988; Logan et al., 1987; Power, 1987; SCSA, 1983; Sprague and Triplett, 1986; Unger and McCalla, 1980; Unger et al., 1988; Wiese, 1985.). The discussion for this paper will focus on a

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summary of the effects of CRM or CT on crop response and soil response on corn in the western Corn Belt. A number of principles will be discussed that modify soil and plant responses under minimum or no-till compared to conventional low residue systems. Understanding the plant-soil concepts of nutrient availability as they are influenced by increased levels of residue and limited tillage can provide a basis for predicting how different fertilizer management systems may affect nutrient use efficiency.

DEFINING MINIMUM TILLAGE SYSTEMS

Tillage is the mechanical manipulation of soil. A "tillage system" is the normal farming operations used during the year to produce a crop and to maintain a given residue level. An excellent summary of minimum tillage systems was published last year by a group of agricultural engineers and agronomists from the north central region (MidWest Planning Service, 1992). It provides a complete overview of the management required to make conservation tillage profitable. This paper summarizes much of the fertilizer management information presented in that publication.

Tillage systems can be defined by the objective or by the equipment used. Conservation tillage can include ridge till, mulch till, strip till, minimum tillage, or reduced tillage. Other terms such as no-till, zero-till, or slot planting have been used to identify systems which retain higher amounts of crop residue. Although these systems may differ, the primary objective is to provide profitable crop production while minimizing wind and/or water erosion of soil.

For this paper, the western Corn Belt includes Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota. Acreage in minimum tillage has increased steadily in this area since the 1960's. The current acreage estimates of crop residue management systems is shown in Table 1.

Table 1. Conservation tillage acreage in the western corn belt in 1992 (CTIC, 1992).

State	Cropland Million Acres	>30% residue or 1000 lb SGE[1] No-Till[2]	Ridge-till[3]	Mulch-till[4]	Total Acres	% in CT
IA	22.11	2.76	2.81	6.68	9.71	44
KS	19.69	0.69	0.20	4.46	5.35	27
MN	18.30	0.53	0.57	2.97	4.08	22
MO	10.50	1.91	0.05	2.64	4.60	44
NE	15.43	1.58	1.33	4.65	7.57	49
ND	18.99	0.66	0.05	4.33	5.04	27
SD	13.15	0.99	0.17	3.10	4.25	32

[1]SGE = Small grain equivalent residue.
[2]Soil left undisturbed from harvest to planting except for nutrient injection. Planting in a slot or narrow seedbed created by coulters, row-cleaners, disk openers, in-row chisels or rototillers. Weed control primarily with herbicides.
[3]Soil left undisturbed from harvest to planting except for nutrient injection. Planting on ridges using sweeps, disk openers, coulters or row cleaners. Residue left on surface between ridges. Weed control with herbicides and cultivation. Ridges rebuilt during cultivaton.
[4]Soil disturbed prior to planting. Chisels, field cultivators, disk, sweeps, and blades used. Weed control with herbicides and cultivation.

RESIDUE EFFECTS ON FERTILIZER USE EFFICIENCY

System Principles

To determine the effects of residue management on fertilizer response or fertilizer use efficiency the tillage system must be accurately defined. An overview of minimum tillage is too general, so to simplify the presentation this paper will concentrate on no-till systems (any high residue, limited soil disturbance system), ridge till (ridge shaving by any means leaving some bare soil in the row) compared to convention tillage (plow, tandem disk, or chisel plow).

What makes a limited tillage system different than conventional tillage? The primary changes are in *bulk density* which influences *porosity, infiltration, water holding capacity,* and *air-filled pore space.* The changes in soil structure (macropores/micropores) vary depending on soil texture and alter water and solute movement on and in the soil. The additional residue changes the *soil temperature regime* and *evaporation* compared to clean-tilled soil. Soils in no-till systems are usually cooler and wetter in the spring than bare soil systems, but are likely to be wetter and warmer in the fall. The interaction of these soil physical changes influence the *chemical and biochemical processes* of the soil including fertilizer chemistry. These principles have been known since the beginning of CT but have not always been used to modify management (Baeumer and Bakermans, 1973).

Because of the marked difference in annual precipitation (Fig 1.) and temperature (Fig 2.) across the western Corn Belt the influence of residue management can have a marked effect on fertilizer needs and crop response. Another aspect of the concerns for adequate fertility in conservation tillage systems is *time.* Because a minimum tillage systems changes many of the chemical/biochemical reactions in soil, there may be short term effects (N immobilization, P or K fixation) that do not persist once the system has come to a new "equilibrium." Some of the responses are predictable based on past research. The idea of rotation may also need to be applied to tillage so tillage is "rotated" among fields over time to mix the top 8 inches. Mixing may be needed for a specific residue/disease problem, nutrient stratification, and liming.

Immobile Nutrients

Nutrient stratification of immobile nutrients should be expected in no-till systems if broadcasting is used. This may or may not be a problem, but in the lower rainfall conditions of the western Corn Belt, positional unavailability will be a greater risk than in the humid east. Banding immobile nutrients at planting away from the seed or preplant banding (4-6 inch depth) with coulters ahead of the knives can overcome positional unavailability problems, provide improved fertilizer use efficiency, and maintain acceptable residue levels.

Nitrogen

Research during the last 20 years has shown that crop response to fertilizer N or nitrogen use efficiency (NUE) between conventional tillage and CRM systems can be divided into six categories (Fig. 3) (Fox and Bandel, 1986). In the first category yield is the same for both tillage systems, therefore NUE would be the same if N uptake were similar. In the

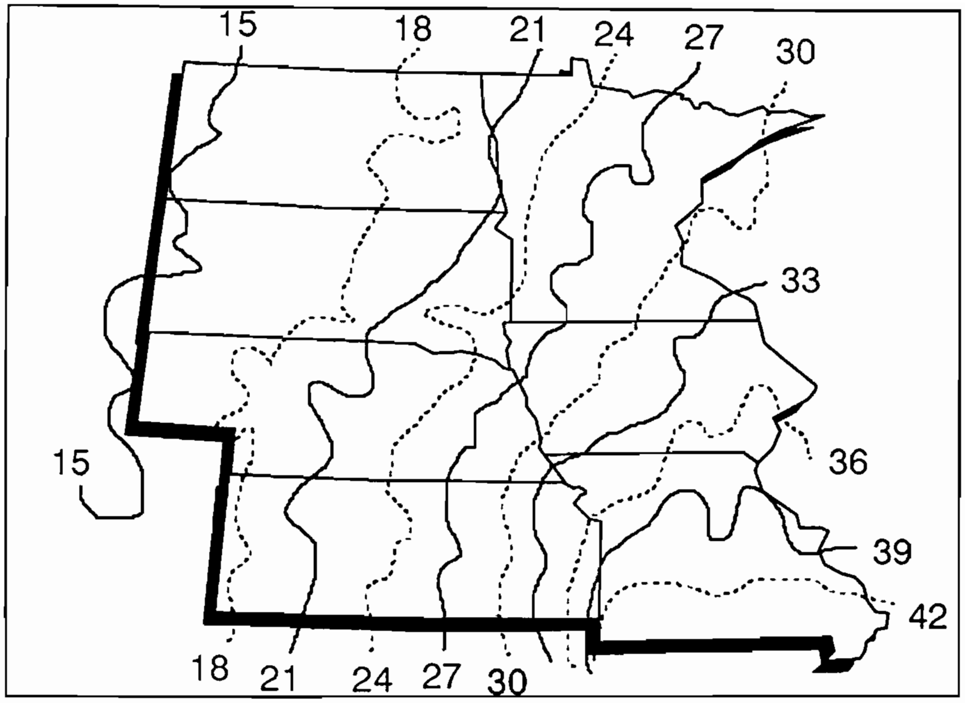

Figure 1. Average annual precipitation across the western Corn Belt.

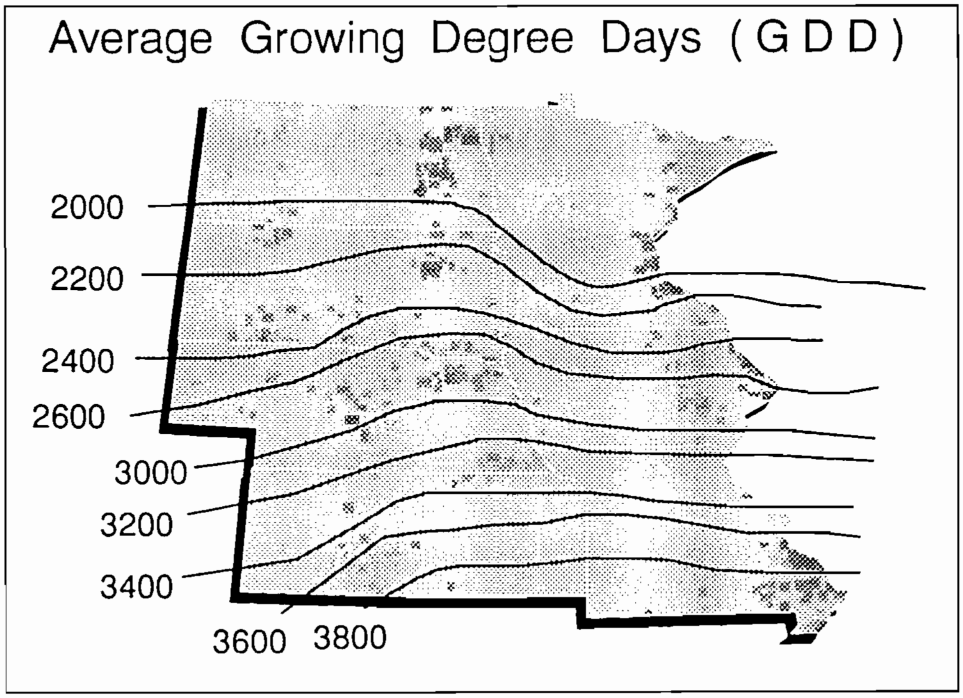

Figure 2. Average annual 50°F-base growing degree days.

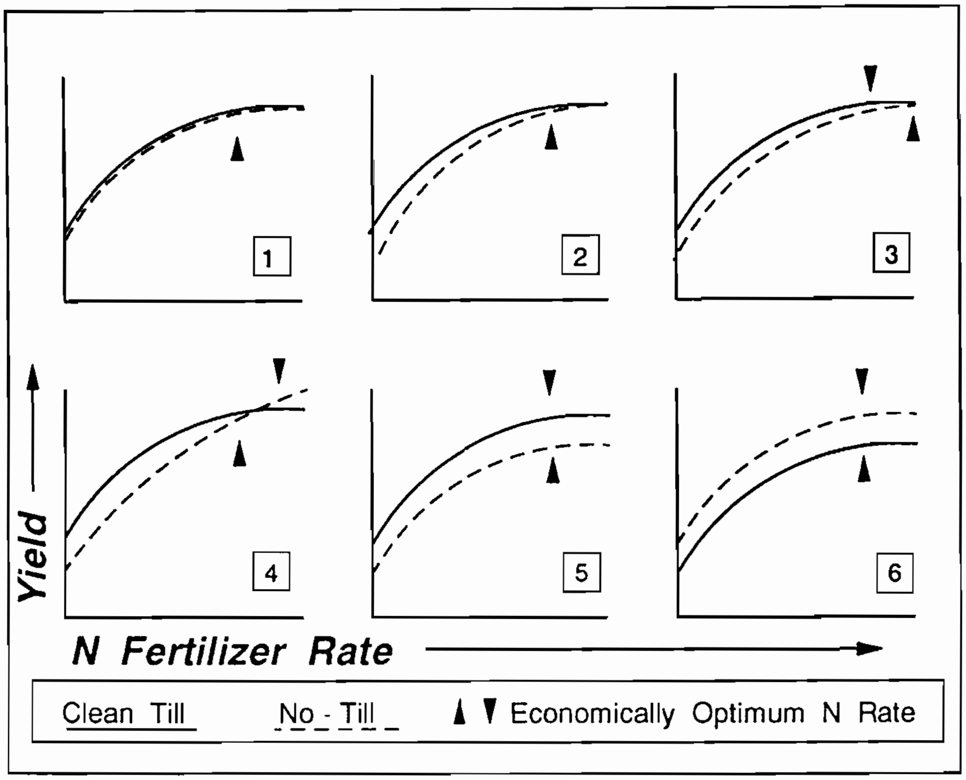

Figure 3. Possible nitrogen response patterns in no-till versus conventional tillage.

second category yield is lower at low N rates for CRM but the same N rate maximized yield in both systems. This would produce lower NUE at low N but the same NUE at maximum yield. Yield is lower for the CRM system in situation 3 and more N was required for CRM maximum yield than conventional tillage resulting in an overall lower NUE for the CRM system. In the fourth category yield is lower in CRM than conventional at low N rates but CRM yielded more than conventional. The NUE would be less in CRM at low N rates and either lower or similar at higher N rates. In the fifth situation yields are lower with CRM than conventional giving a lower NUE for CRM at all N rates. The sixth situation is just a reverse of the fifth where CRM out yielded conventional at all N rates. In situations 5 and 6 something other than N limited yield in the lower producing tillage system.

FERTILIZER MANAGEMENT

Soil Testing

The starting point of a good fertilizer management plan is with a soil test, however, minimum tillage complicates the soil testing process. In conventional tillage the upper 6 to 8 inches is thoroughly mixed. Depending upon the degree of tillage and the method of fertilizer application used in a CRM system non-mobile nutrients (P,K, Zn) may concentrate in the upper 2 to 3 inches of soil and the surface may become very acidic (Blevins et al., 1983; Kruse et al., 1983). This change in nutrient and pH distribution may have a significant effect on soil test level, nutrient availability and crop yield. An intensive soil sampling study by Robbins and Voss (1991) investigated P and K stratification in long-term conservation tillage plots. In ridge till systems P and K were concentrated in the interrow area from broadcast P and K applications due to the ridging operation and to erosion of the ridge during the winter and early spring.

If we know that stratification exists, how should soil samples be taken? Most researchers in the higher rainfall areas of the eastern Corn Belt have found no decrease in nutrient availability due to nutrient stratification under normal growing conditions (MidWest Planning Service, 1992). The explanation is that surface stratified nutrients combined with the increase in root activity due to high soil moisture under the residue provide adequate nutrition. Problems come during drier periods. The currently recommended soil sampling procedure is to split the normal 6 to 8 inch surface sampling depth into 2 sub-samples representing 0 to 3-4 inch and 3-4 to 6-8 inch depths. Fertilizer recommendations are still made on the normal 0 to 6-8 inch sample. If the soil test results from the deeper sample are very low, then deeper fertilizer placement techniques or tillage to mix nutrients in the root zone are recommended to "weather proof" the crop.

Banding (whether row applied or deep banding) of P and K also complicates soil sampling. In some CRM systems bands remain undisturbed by tillage year after year, but in some ridge till systems planting and rebuilding the ridge mixes the previous year's row applied fertilizer. In ridge till systems where mixing of row applied P and K bands occurs, taking a sample on the shoulder of the ridge one third of the way between the row and the furrow approximates the "average" soil test level in the normally assumed 0-8 inch depth (Ferguson, et al., 1990; Randall, 1983).

A recent study by Kitchen et al. (1990) suggested two strategies for P sampling depending on whether or not the band location was known. If the band location was known the number of cores required to determine the "true mean" depended on the band spacing. For a 30 inch band spacing the ratio of 1:20 in-the-band:away-from-band was required; for a 24 inch band spacing the ratio of 1:16 in-the-band:away-from-band was required; and for a 12 inch band spacing the ratio of 1:8 in-the-band:away-from-band was required. If the location of the P band was unknown, complete random sampling was the only alternative. For soils with moderate to high P fixing capacity about 15 to 20 cores per sample were required. For soils with low P fixation 25 to 30 cores per sample was recommended.

Another deviation from the normal 6 to 8 inch soil sampling depth may result from the need to monitor surface pH where N is broadcast. Soil sampling the top 2 inches on a regular basis can detect pH changes. Lime can then be applied to prevent low pH from affecting plant growth and herbicide activity.

In many parts of the western Corn Belt deep sampling (2 to 4 feet) for residual nitrate-N is routinely recommended (Penas, et al., 1991). This management practice can fine tune N recommendations and improve profitability.

With the advent of variable rate technology, information to assess spatial variability can be used to modify fertilizer management. The two basic approaches currently used include systematic grid sampling on a regularly spaced interval or the use of detailed soil survey maps to define sampling areas. Both systems should lead to improved fertilizer use efficiency.

Managing P, K, and lime

As a general rule P and K deficiencies or lime needs should be corrected before the adoption of CRM but all is not lost if this is not done. Row application or deep banding of P and K can be used to correct P and K deficiencies. Many of the soils in the western Corn Belt are calcareous and banding is the preferred method of application to overcome P fixation. Banding P and K between 4 to 8 inches deep reduces surface nutrient stratification and will improve positional availability in dry years. Starter placement to the side of the seed also works well. Most studies show similar responses to P and K whether row applied or deep banded.

In the western corn belt soil acidity and liming is usually not a problem because most of the soils are calcareous. Correcting soil acidity problems before beginning a CRM system simplifies the process. Ag lime recommendations are usually based on the 0 to 6-8" soil sample and assume a uniform incorporation of ag-lime. Producers may need to plan "tillage rotation" in areas that require liming for best results.

Low surface pH caused by continued broadcasting of N can be corrected by surface liming. The amount of soil influenced is much less than in normal liming, so lime rates must be lowered accordingly to prevent over-liming which can induce micronutrient deficiency such as zinc in corn or manganese and iron in soybeans.

Research from the northern portion of the western Corn Belt shows yield responses to banded starter fertilizers even on soils that test high in P and K (Rehm, 1992; MWPS, 1992). Cooler soil temperatures and higher soil moisture in CRM systems in northern latitudes increase the probability of yield responses to starter fertilizer. The main unanswered question is the minimum rate of N, P, and K required to provide maximum early growth and yield response.

In the southern portion of the western Corn Belt (NE, IA, KS, MO) there is generally very little yield response to starter fertilizer unless there is a nutrient deficiency. Potassium needs in ND, SD, NE, and KS are low because most soils high native K levels (300 to 500 ppm K).

Managing Nitrogen

Nitrogen management can be improved in CRM systems if N can be injected into the soil 4 to 6 inches below the surface residue (Gordon, et al., 1992; Hergert, 1985; Vitosh et al., 1985). This application method limits the possibility for N volatilization and immobilization and allows the use of anhydrous ammonia which can provide cost savings compared to liquid or dry N forms. The primary disadvantage of injection is disturbing residue cover and higher power requirements, although currently manufactured coulter and knife combinations can apply at this depth and not reduce residue levels. Spoke injection works well but has not been widely adopted. Other alternatives include surface dribble banding or the use of the urease inhibitor NBPT. Any surface application does have the risk of some volatilization, however.

Time of N application in CRM systems can affect N use efficiency. In the more humid eastern Corn Belt, increased infiltration and reduced evaporation in CRM can increase leaching and denitrification so delayed N applications until corn is 6-12 inches tall is often recommended. In most of the western Corn Belt there may be some advantage in some years to delayed application, but preplant N often is equal or superior to sidedress N (Killorn and Voss, 1992). Sidedressed N can result in positional unavailability in dry years (Randall, 1983), but provides improved NUE in wet years like 1991 and 1992 if N can be applied.

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Research and Education Center
P.O. Box 469
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