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Field-Level Measurement of Land Productivity and Program Slippage

A condition of a farmer's participation in U.S. commodity programs is the diversion of crop acreage from production. One purpose of this requirement is to decrease aggregate supply and thereby increase the commodities' market prices. Practical experience shows that program participation and land diversions are positively correlated with increased per-acre yields and that a commodity's total supply is reduced proportionately less than the program-induced reduction in the number of acres devoted to the crop (e.g., Gardner, p. 61; Eriksen; Love and Foster). This phenomenon is well known in the agricultural economics profession as slippage. Broadly speaking, slippage arises because of an increase in the use of inputs and the diversion of relatively less productive land.

Understanding slippage is important to policy makers and analysts concerned with the efficacy and consequences of commodity programs. To the policy maker, greater knowledge of the determinants of slippage would aid in formulating program designs that mitigate the deleterious effects of slippage on policy objectives, such as increasing commodity prices. To the policy analyst, a better appreciation of the influence of program incentives on slippage at the regional and national levels would allow improved evaluation of supply responses to market and policy changes.

In this paper we report on a research effort to measure the significance of heterogeneous land quality in determining the slippage effect for corn. Our field-level analysis (the first of its kind to our knowledge) isolates the influence of land productivity from other factors in order to gauge the importance of land allocation decisions for slippage. Our analysis is related to an earlier (1966) work of Weisgerber using county-level productivity indices.

The contributions of this paper are methodological and numerical. First, we describe the gathering of an extensive data set on North Carolina field productivity and planting decisions in the presence of commodity programs. Second, we describe a method of measuring slippage under the corn program, attributed to the diversion of heterogeneous land, using both data from the Agricultural Stabilization and Conservation Service (ASCS) and data on soil productivity from soil maps prepared by the Soil Conservation Service (SCS). Finally, we assess North Carolina slippage rates for corn calculated from observed land allocation decisions. We find that, while slippage does occur, the program-participating farmer does not always divert the lowest productive land. We also contrast observed slippage rates with hypothetical rates calculated as if the participant did indeed divert the least productive land first.

In addition to measuring the effects of heterogeneous land quality on slippage, the results of this research will contribute to other positive and normative analyses. Data on land productivity and allocation will aid in determining the effects of land characteristics on the program participation decision and on cropping patterns. Elements of this data collection effort have already proven useful in laying the foundation for appraising recommended farming practices given differing incentives of conservation and commodity programs (Hoag and Holloway; Hoag and Jack).

Land Quality Slippage

There are three basic causes of slippage. First, farmers participating in commodity programs may achieve productivity gains on non-diverted land because of the allocation of fixed resources (e.g., management time) over a reduced number of acres. Second, the package of incentives to join land-diversion programs may induce farmers to intensify use of all productive resources on cultivated land. Although presently "decoupled" from production, target payments in the recent past have been based on farmer's historical yields and proven yields. As a result, a farmer may use the potential of future government payments when making marginal production decisions. In addition, the existence of programs may alter the probability distribution of market prices that would in turn affect the behavior of both participants and non-participants.

The third cause of slippage, which we address herein, is land quality slippage (LQS). LQS results from participating farmers diverting their least productive land. This is a widely accepted belief regarding farmer behavior, supported both by theoretical work (e.g., Rausser, Zilberman, and Just) and by data on acreage diverted (e.g., Weisgerber). The average productivity of cultivated land rises as land with below average yields are diverted for program compliance. Thus, as farmers find commodity programs more attractive, average land quality rises and aggregate per-acre yield increases.

Conventional research holds that all forms of slippage for major field crops range from 25 to 58 percent (eg., Gardner, p. 61; Tweeten p. 315; Love and Foster). Because of their reliance on aggregate data, these estimates do not disentangle the effects of diverting low-quality land from the effects of input use. Weisgerber estimated for feed grains, wheat, and cotton that diverted acres would yield 80 to 90 percent of non-diverted acres in 1966. A comparison of recent aggregate research (Love and Foster) with Weisgerber's earlier county-level study implies that input adjustments may be more important for slippage than the diversion of low-quality land. For example, using a 45% slippage rate (in the range of the Love and Foster estimates) and assuming that all slippage is due to the diversion of low-quality land, implies that on a per-acre basis divertedacres yield only 40 percent as much as would be produced on non-diverted acres. Compare this with Weisgerber's estimates of relative productivity of diverted acres indicating a 80 to 90 percent as great a yield on diverted acres. This implies a maximum slippage rate of 8% to 16% with diversion requirements of 10% and 20%.

Further lessening the contribution of heterogeneous land quality to total slippage rates is the ambiguous relationship between an acre's productivity (as measured by per-acre yields) and profitability. Given that a farmer participates in a land-diversion program, the farmer will divert land with the lowest opportunity cost. If an acre's opportunity cost is monotonically increasing in productivity, then the farmer's optimal land diversion decision is that which maximizes the difference between yields on nondiverted acres and the potential yields on diverted acres.

There may be several reasons, however, why the opportunity cost of diversion does not increase with productivity, thus weakening the connection between heterogeneous land quality and slippage rates. The per-acre production costs of a field may be influenced by the shape of the field, the distance from adjoining fields and the farm headquarters, the variability of land quality within the field, and other characteristics. Furthermore, the opportunity cost of diversion also includes costs and benefits associated with crop rotation and fallowing.

In light of these other factors affecting opportunity costs, it appears unwarranted immediately to conclude that slippage is primarily due to the diversion of the least productive land first. Using field-level productivity data, if LQS slippage is indeed significant, then this would confirm models of farmer choice suggesting that the worst-land-out-first behavior is a major contribution to aggregate slippage rates. If, on the other hand, LQS is small relative to a farm's potential slippage, then observed increases in per-acre yields at the aggregate level is more consistent with other sources of slippage such as increased per-acre use of non-land inputs. As we discuss in the following sections, in the case of North Carolina corn production, we in fact observe low LQS relative to the farm's potential LQS slippage.

Land Quality Slippage in North Carolina

To estimate land quality slippage, we use data of field-level soil classification and cropping decisions. We derive a measure of field productivity from agronomic estimates of corn yields for various soil types under average management practices. LQS is defined as the percentage gain in estimated average corn yields on non-diverted acreage relative to estimated yields that would result if diverted and non-diverted cropland was under production:

$$LQS = \frac{Y_C - Y_F}{Y_F} \quad . \tag{1}$$

The variable Y_C is the average yield on land remaining in production under a land diversion program (non-diverted acres) and Y_F is the average yield assuming all cropland (non-diverted and that which would have been diverted if the farmer had participated in commodity programs) is in production. Previous efforts to measure slippage rates have utilized aggregate yield data, confounding the sources of slippage. The land productivity data used in this study assumes a constant application of material inputs and management time. Thus, any the slippage estimates are due solely to heterogeneous land quality.

We collected data for this analysis from actual farms producing corn in North Carolina. Soils in North Carolina are divided into three primary regions, the Mountains, the Piedmont, and the Coastal Plain. The geology, geomorphology, and climate are similar within each region. Soil types can be further classified and subclassified within each region to the most precise description, known as a soil mapping unit (SMU), based on topography, parent material, organic matter, wetness, erosion, and other factors.

High elevation, steep and rocky soils and climate combine to make much of the Mountain region relatively inhospitable to row and field crops. Piedmont soils are very clayey and are found on rolling hills which make them susceptible to drought. By contrast, Coastal Plain soils are flat sandy or sandy loams that occupy about 45 percent of the state. The Coastal Plain produces the greatest proportion of the agricultural commodities in the state.

The complete data set was constructed by selecting counties from which individual farms would be sampled. Selected counties were chosen by a conditional random drawing: only counties with available soil maps and cooperative Agricultural Stabilization and Conservation Service (ASCS) offices were included in the draw pool. Each county in the pool was weighted by its relative corn production. Two Piedmont counties, Yadkin and Stanly, and four Coastal Plain counties, Brunswick, Cumberland, Edgecombe and Jones, were chosen. The Mountain region was excluded because of its limited production of program crops. Farms were randomly drawn from each county from four crop acreage strata to increase variability, less than 50 acres, 50 to 100 acres, 101 to 250 acres, and more than 250 acres. Farms were chosen at random from a pool of ASCS farms that had corn base acreage. Many farmers in North Carolina have multiple ASCS farms, but each is treated as a single operating unit for purposes of program participation.

For each sample farm, aerial photos of fields were compared to soil maps prepared by the Soil Conservation Service (SCS) to determine the proportion of each soil type present in the fields on the selected farms. The SCS maps consist of soil-contour lines superimposed on reproductions of aerial photographs. Comparing the two allows an estimation of the proportion of each soil type present in the fields on the selected farms. The productivity of these soil types has been estimated for use-value taxation purposes by the North Carolina Use Value Advisory Committee. Productivity for each SMU is measured as the corn yield that would result under average management techniques. A field's yield is estimated as a weighted sum of yields of the soil types within the field, where the weights are the proportions of the field in the soil types. An example of matching aerial field photos with SCS soil maps is shown in Figure 1 for a farm in Cumberland county.

The cropping history for each field was collected from ASCS. The histories indicate the percentage of the fields planted to crops, diverted into Acreage Conservation Reserve (ACR) or placed into other, non-profitable uses. The time period of this study was characterized by relatively low grain prices and declining grain acreage in North Carolina. Consequently, the amount of land left idle by many farms was substantial. The cropping data were collected for each year from 1985 to 1988 with the exception of 1988 for Stanly and Edgecombe Counties.Information was not available to determine sub-field allocations when the whole field was not utilized for a single purpose.

The soil productivity data and the proportion of each soil in the sample fields allows the mean soil quality at both the field and farm level to be calculated. Mean soil quality for field j, μ_j, is calculated by:

(2) $$\mu_j = \sum_s \alpha_{js} Y_s \ ,$$

where α_{js} is the percentage of field j in soil type s, and Y_s is the per-acre yield index of soil type s. The mean soil quality for farm i, μ_i is calculated as:

(3) $$\mu_i^F = \frac{\sum_j \mu_j A_j}{\sum_j A_j} \ ,$$

where A_j is the size of field j and μ_j is mean productivity of field j. The denominator of this equation is the farm size.

Average farm yield on land planted to corn for farm i, Y_{iC}, is calculated as:

(4) $$Y_{iC} = \frac{\sum_j Y_j A_j \alpha_{jc}}{\sum_j A_j \alpha_{jc}} \ ,$$

where α_{jc} is the fraction of field j planted to corn. The subscript i on the right-hand-side variables is suppressed for clarity. The average yield of farm i, assuming that all crop acreage (non-diverted and diverted) was planted, Y_{iF}, is given by:

(5) $$Y_{iF} = \frac{\sum_j \mu_j A_j(\alpha_{jc}+\alpha_{ja})}{\sum_j A_j(\alpha_{jc}+\alpha_{ja})} \quad ,$$

where α_{ja} is the fraction of field j placed into ACR. County measures of average land qualities for land planted to corn, Y_C, and land planted and diverted, Y_F, can be obtained from (4) and (5):

(6) $$Y_C = \frac{\sum_i Y_{iC}L_{ic}}{\sum_i L_{iC}} \quad ,$$

and

(7) $$Y_F = \frac{\sum_i Y_{iF}(L_{iC}+L_{ia})}{\sum_i (L_{iC}+L_{ia})} \quad .$$

where L_{ic} and L_{ia}, are the amounts of land planted to corn and placed into ACR on the ith farm.

Results and Analysis

Table 1 presents yearly county-level estimates of Y_C and Y_F for each of the six counties from the observed data. The percent of corn or land placed into ACR and the resulting slippage rates are also presented. The productivity measures used to calculate slippage are based on the average productivity of fields. Therefore, the influence of subfield allocations is not measured in Table 1. For example, Jones County had an observed yield index of 83.08 in 1985. The weighted average productivity of fields that contained some corn acreage in 1985 was 83.08. The weights are given by acres planted to corn. The weighted average productivity of fields that contained either ACR or corn acreage in 1985 was 82.52. The largest positive difference between the productivity of corn acreage and corn plus ACR acreage was in Cumberland County in 1987, with a slippage rate of 2.28%.

With the exception of Yadkin County in 1986 and 1987, slippage was positive in all counties for all years. Extension personnel familiar with Yadkin County attribute the anomalous result of negative slippage in Yadkin County to farmers devoting their management time to enterprises other than corn. Corn is often planted in Yadkin County as a rotation crop or as wildlife habitat. Given these facts, a negative slippage rate for two years may not be too surprising.

It appears that, on average, farmers in North Carolina diverted less productive land than they planted. The average yield of diverted acreage, Y_a, can be derived using the definition that:

$$Y_F = (1-d)Y_c + dY_a \tag{8}$$

where d is the percentage of land diverted acreage. For example, Y_a = 83.73 for Cumberland County in 1987, which is approximately 5.1% below the average yield of planted acreage for that year. The first column of Table 2 presents the ratio of the productivity of diverted acreage to planted acreage for all counties and years.

Most of the observations indicate that diverted acreage is over 95% as productive as non-diverted acreage. Regressions were run to determine if these ratios are statistically different from unity. The left-hand-side variable in the regressions was the ratio of the productivity of diverted acreage to the productivity of planted acreage on participating farms. First, this ratio was regressed against a single constant term. The estimated constant was 0.98. The null hypothesis that the constant was equal to one was rejected at the 99% confidence level. Second, the ratio was regressed against county-specific constants. The null hypothesis that the ratio was equal to one was rejected for Cumberland, Jones, Stanly, Edgecombe, and Yadkin Counties, with Yadkin County having an estimated constant greater than one. The estimated constant for Brunswick County was less than one, although not statistically significant.

Thus, the data indicate that, with the exception of Yadkin County, farmers in North Carolina divert lower-yielding lands than they plant. What may be surprising is not that farmers do this, but rather that the magnitude of the yield differences are small. One reason for these small yield differences may be homogeneous average land qualities between fields. Potential yield differences between corn acreage and ACR acreage are also presented in Tables 1 and 2 along with the resulting potential slippage rates to determine the extent to which land quality homogeneity exists.

Potential slippage was calculated by having farmers plant their most productive fields and diverting their least productive fields. These estimates were obtained by first ranking the sample farms' fields by their mean productivity and holding the amount of diverted land and planted land constant at the observed levels for each farm. For each farm, planted land was first placed in the most productive fields, followed by the next highest productive fields until the number of acres planted was fully assigned. The same was done for the diverted land, except the least productive land was diverted first. The range of potential slippage was from 0% (no land was diverted in Yadkin County in 1985) to 16.35% in Yadkin County in 1987, and the average slippage rate was 5.44%. The range of potential ratios of ACR acreage to planted acreage is 0.69 in Brunswick County in 1986 and 1987, to 0.91 in Jones County in 1986. These potential yield numbers place an upper bound on slippage that can be attained solely from differences in the average soil qualities of fields.

The North Carolina estimates reveal that farmers achieved only a small portion of potential slippage. The potential slippage forgone or not used, LSQ_F, is calculated as:

$$LQS_F = \frac{LQS_P - LQS_A}{LQS_P} \quad , \tag{9}$$

where LQS_A and LSQ_P denote actual and potential slippage. Forgone slippage rates range from 36% to 134%. The farmers, for the most part, did not take advantage of over half the slippage they could have.

It appears that in North Carolina the average productivity of fields is not the sole determinant of the acreage diversion decision. Other factors that influence the opportunity cost of land diversions, such as field size, shape, and location, and rotation considerations may play significant roles. Additional factors that may influence diversion decisions include higher-order moments of the distribution of soil qualities on fields. The estimates of actual and potential slippage in Table 1 are based on average field-level productivity. If significant allocation decisions are based on sub-field considerations, then the results in Tables 1 and 2 provide lower-bound estimates of actual and potential slippage. Because sub-field locations of planted and diverted acreage were not available when an entire field was not planted or diverted, no estimates of actual yield index differences between planted and diverted fields could be obtained. If one is willing to make the assumption that the least productive portions of those fields that contained only a fraction of diverted land were diverted, then one would obtain lower estimates of the yield of diverted land. If one is further willing to make the additional assumption that the planted portions of partially planted fields were located in the most productive portions of the fields, then one would obtain a higher estimate of the yields of planted land. No attempt was made to determine the magnitude of changes that such assumptions would make. However, some idea of the potential for the effects of sub-field allocation can be obtained by examining the extent to which partial land diversion and planting was done. Over the entire sample of 4155 fields, 41% of diverted land and 53% of land planted to corn were located on fields with no sub-field allocations.

Concluding Comments

Previous efforts at measuring the effects of land diversions on the supply of commodities have concluded that significant average yield increases arise when land is taken out of production to meet commodity program requirements. The yield increases are attributed to the reallocation of fixed inputs and the greater application of variable inputs on planted land, and/or the diversion of less productive land than that which remains in production. No disentanglement of the contribution from each source is possible because of the use of aggregate data.

The findings of this study indicate that for North Carolina, yield increases from the diversion of low-quality land contributes relatively little to possible yield increases from diversion requirements. The analysis here lays the groundwork for further study of the influence of heterogeneous land quality in other regions. Weisgerber's national study of county-level productivity, the only other published land-quality analysis, indicated that less than 16% of slippage was attributable to land quality. The North Carolina data indicate that potential slippage is approximately the same, but that actual slippage is much less. This suggests that in North Carolina field characteristics other than average productivity such as field size and accessibility may also be important factors influencing diversion decisions. In addition, higher-order moments of the distribution of soil qualities may also influence diversion decisions. Future research will investigate the role of the distribution of a farm's land quality in the program participation decision and cropping patterns.

NOTES

1. Some soils were classified as not capable of supporting a crop. Upon investigation, we realized that this was a subjective opinion about the suitability of these soils for crop production rather than a statement about their inherent productivity. After discussions with the appropriate soil scientists, we reclassified all such soils as 50 bushel-per-acre soils. This rating corresponds to the lowest rating given any soil.

2. The 1988 cropping data for Stanly and Edgecombe counties were unavailable in the local ASCS offices at the time of the data collection effortfor this study.

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Table 1. Slippage rates for observed and potential yields by county and by year.

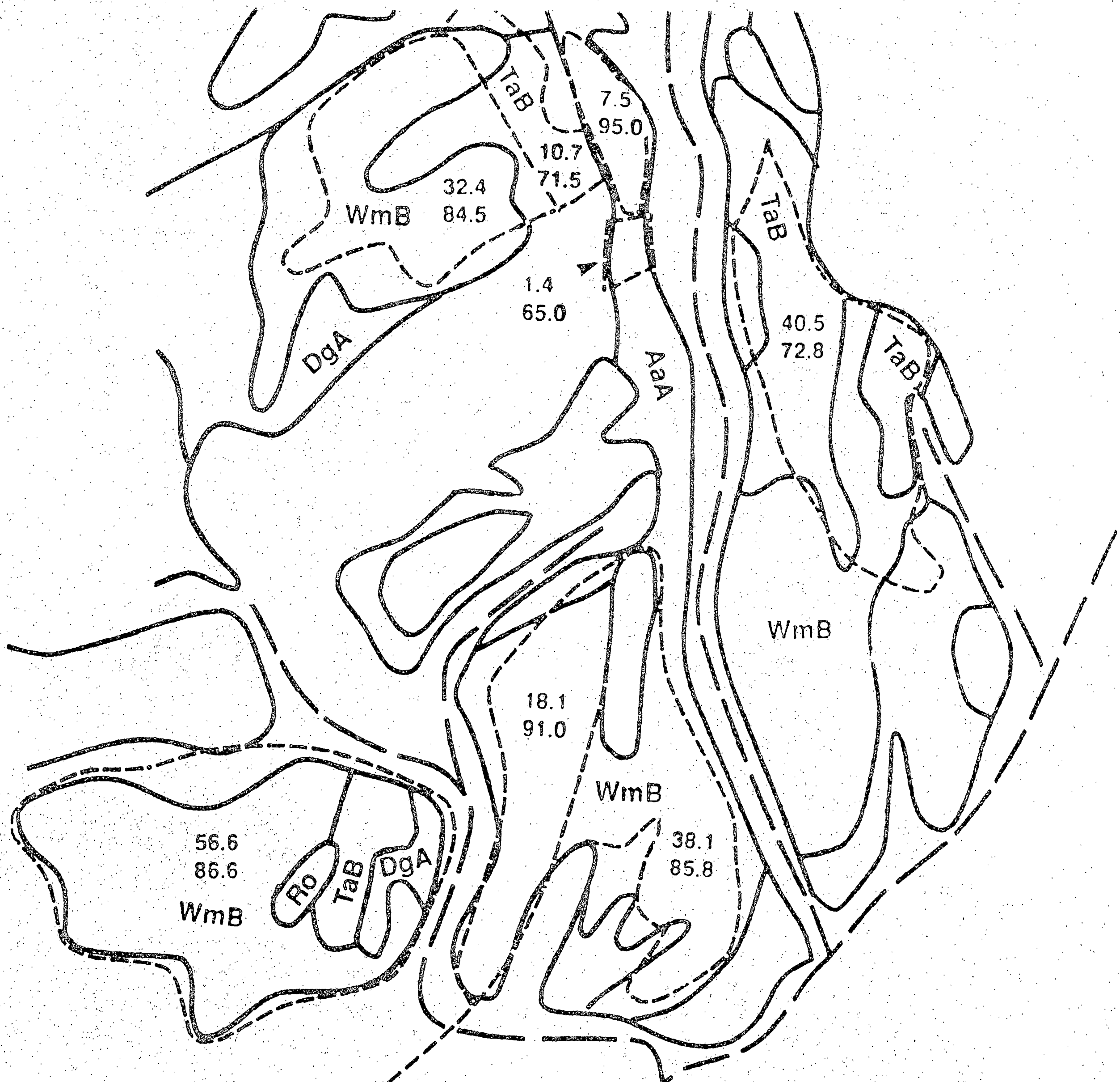
		Observed Yields[a]			Potential Yields		
County	Set-aside (%)	Y_F (bu.)	Y_C (bu.)	Slippage (%)	Y_F (bu.)	Y_C (bu.)	Slippage (%)
Stanly							
1985	1.90	84.96	85.07	0.13	87.86	88.16	0.34
1986	16.4	82.46	82.69	0.28	84.22	86.21	2.31
1987	41.2	85.30	86.14	0.98	82.85	88.91	7.31
1988				not available			
Yadkin							
1985	0.0	74.17	74.17	0.0	83.35	83.35	0.00
1986	19.0	75.26	74.03	-1.63	78.18	81.90	4.76
1987	50.3	76.83	73.61	-4.19	72.34	84.17	16.35
1988	37.7	76.37	76.81	0.58	74.41	83.68	12.46
Jones							
1985	12.8	82.52	83.08	0.68	85.42	86.57	1.33
1986	13.6	82.97	83.14	0.20	85.40	86.50	1.29
1987	34.4	81.92	83.32	1.71	83.49	87.43	4.51
1988	30.8	82.19	82.87	0.82	82.96	86.06	3.60
Cumberland							
1985	8.80	87.89	88.13	0.27	89.33	90.98	1.85
1986	24.1	87.87	88.26	0.44	88.04	91.12	3.50
1987	43.6	86.28	88.25	2.28	85.87	92.47	7.69
1988	36.4	84.21	85.15	1.12	82.95	88.19	6.32
Edgecombe							
1985	23.3	86.34	86.45	0.12	88.94	92.43	3.92
1986	31.7	85.62	86.21	0.69	87.57	92.71	5.87
1987	47.3	84.49	85.53	1.23	84.74	92.83	9.55
1988				not available			
Brunswick							
1985	4.00	87.58	88.26	0.78	91.81	92.93	1.22
1986	2.80	87.89	87.99	0.11	91.97	92.77	8.70
1987	22.4	86.14	87.00	1.00	85.02	91.28	7.37
1988	29.2	78.73	79.93	1.52	83.79	91.65	9.38

a) Y_F is the average yield on all acres, Y_C is the average yield on cropped acres

Table 2. Relative Productivity of Diverted Fields and Forgone Slippage.

County	Observed[a] Y_a/Y_c	Potential[b] Y_a/Y_c	Forgone Slippage[c]
Stanly			
1985	0.93	0.82	62
1986	0.98	0.86	88
1987	0.98	0.83	87
1988		not available	
Yadkin			
1985	0.0	0.0	undefined
1986	1.09	0.76	134
1987	1.09	0.72	126
1988	0.98	0.71	95
Jones			
1985	0.95	0.90	49
1986	0.99	0.91	84
1987	0.95	0.87	62
1988	0.97	0.89	77
Cumberland			
1985	0.97	0.80	85
1986	0.98	0.86	87
1987	0.95	0.84	70
1988	0.97	0.84	82
Edgecombe			
1985	0.99	0.84	97
1986	0.98	0.83	88
1987	0.97	0.82	87
1988		not available	
Brunswick			
1985	0.81	0.70	36
1986	0.96	0.69	87
1987	0.96	0.69	86
1988	0.95	0.71	84

a) Yield of actual land diverted/Yield of actual land cropped.
b) Yield if worst land is diverted/Yield if best land is cropped.
c) Forgone slippage is the percentage difference between potential and actual slippage measures from Table 1.



Key

Field Boundaries
Soil Mapping Unit Boundaries
Stream Beds

Figure 1. Cumberland County field and soil map overlay with field size (top number) and weighted average corn yield (bottom number).

Note: TaB type soil yields 65 bu/ac, WmB 91 bu/ac, AaA 95 bu/ac, Ro 91 bu/ac, and Dga 95 bu/ac.