TILLAGE AND N-FERTILIZER SOURCE EFFECTS ON YIELD AND WATER QUALITY IN A CORN-RYE CROPPING SYSTEM

Dinku M. Endale[1]*, Harry H. Schomberg[1], Michael B. Jenkins[1], Miguel L.Cabrera[2], David R. Radcliffe[2], Peter G. Hartel[2] and Nancy W. Shappell[3]

[1]USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville, GA 30677
[2]Crop and Soil Sciences Dept., University of Georgia, Athens, GA 30602
[3]USDA-ARS, Red River Valley Agricultural Research Center, Fargo, ND 58105

*Corresponding author's email: dendale@uga.edu

ABSTRACT

Tillage and nutrient source choices have important agronomic and environmental consequences in cropping system management, which need to be quantified in the Southeast. In three years of research at the USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville-GA, we compared agronomic benefits and water quality impacts of no-till and poultry litter versus conventional-till and conventional fertilizer in a corn-rye cropping system. No-till and poultry litter each enhanced corn yield by 15 to 23% over three years. When combined, they enhanced yield by 27%. Off-site effects in terms of nitrate-nitrogen and ammonium-nitrogen losses through runoff or drainage were similar among treatments. Concentrations were dependant on N application rates. Below a 3 ton acre^{-1} application rate of poultry litter (90 lbs N acre^{-1}), nitrate levels are expected to be below 10 ppm, especially if the first precipitation or irrigation event is delayed after N application. Application of poultry litter increased loss of ortho-phosphate in runoff by 5 to 6 times compared to conventional fertilizer. The sex hormones estradiol and testosterone coming off poultry litter plots were not above levels observed for conventional fertilizer plots. Managing corn with no-till and/or poultry litter at normal N application rates has agronomic advantages, and does not appear to present large additional risks of nitrate or hormone contamination of water resources. However, offsite effect of ortho-phosphate is a concern.

INTRODUCTION

Tillage and nutrient source choices are important management variables that have agronomic and environmental consequences. Many soils in the Southeast have low water holding capacity and/or root restrictive layers. Crusting is a problem in soils with low organic matter, which encourages runoff from fields. Conventional-till methods, such as disking and harrowing, encourage development of these adverse soil conditions. No-till systems reduce runoff and soil loss, and increase infiltration as compared to conventional-till (Bradley, 1995; Endale et al., 2002; Fawcett et al., 1994; Golabi et al., 1995; Radcliffe et al., 1988). No-till systems increase soil water availability, which can offset water stress arising due to frequent summer droughts.

Poultry production is a significant source of income for many row crop and cattle producers. In 2002, 8.6 billion broilers were raised in the U.S. with a value of $13.3 billion (NAAS, 2003). Four southeastern states (AL, AR, GA and NC) produced 50% of these broilers. In the process, almost 14 million tons (2000 lb units) of poultry litter was produced. Poultry litter can be a valuable resource, which provides a wide range of nutrients and organic matter (Moore et al., 1995). It is often an economical alternative to inorganic fertilizer.

Repeated application of poultry litter can lead to potential negative environmental impacts. In particular, the water quality ramifications of repeated application of poultry litter in cropping systems are of interest to many citizens. Poultry litter can be a source of nitrate and phosphate, but the hormones estradiol and testosterone (shown to affect reproductive development in animals) are also present in it, which is a concern. Research is required that would address agronomic and environmental impacts of combinations of tillage and nutrient sources specific to the environmental conditions of the Southeast. The objective of this research was to quantify the agronomic benefits and water quality impacts of no-till and poultry litter in a corn-rye cropping system in comparison to conventional-till and conventional fertilizer.

MATERIALS AND METHODS

The research was conducted from fall 2000 to fall 2003 at the USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, GA (83°24' W and 33°54' N) on 12 large (30 x 100 ft) plots instrumented for automatic monitoring and sampling of runoff and drainage for water quality assessment. The site is located on nearly level (<2% slope) Cecil sandy loam (fine, kaolinitic thermic Typic Kanhapludult). Cecil and closely related soil occupy over half the area of the Southern Piedmont (Langdale et al., 1992). These soils are deep, well drained and moderately permeable. The pH decreases with depth. According to Bruce et al. (1983), the soil at the research site has about 8 inches thick Ap-horizon of brown sandy loam, underlain by 2 to 4 inches thick BA-horizon of red sandy clay loam to clay loam texture. The Bt-horizon consists of red clay about 40 inches thick followed by about 12 inches thick red loam to clay loam BC-horizon. The C-horizon is a loamy saprolite. Total available water in the top 40 inches of soil is approximately 4 inches, not taking changes due to long-term tillage manipulations into account. Long-term average daily air temperature in summer ranges from 75 to 80 °F at the site. Frost-free days in the growing season average 200 to 250. Mean annual rainfall is 48.8 inches. Mean monthly rainfall varies from 3.8 in May to 5.4 inches in March during fall, and from 3.8 in August to 4.8 inches in July during summer. Short-term summer droughts are frequent with serious consequences on crop yield.

The experiment was laid out as a randomized complete block split plot design with three replications. Conventional-till (CT) and no-till (NT) were main plots. Fertilizer subplots consisted of ammonium sulfate as, conventional fertilizer (CF), or poultry litter (PL). The CT consisted of a 12 inches deep chisel plowing followed by one to two diskings to a depth 8 inches and a subsequent disking to 3 inches to smooth the seed bed. The only soil disturbance in NT was a coulter disk for planting. NT treatments have continued on the same plots since the fall of 1991.

The cropping system consisted of cereal rye (*Secale cereale* L., cv. Hy-Gainer) grown in the late-fall to early spring followed by corn (*Zea Mays*, cv. Pioneer 3223) from mid-spring to mid fall. Nitrogen fertilization for corn for the first two years was at a rate of 150 lbs N acre^{-1}. This meant an application of 5 tons acre^{-1} (30% moisture) for PL. The PL source was from local growers, who usually generate three flocks per cleaning on concrete floors covered with sawdust and shavings. Each flock takes 6-8 weeks to mature. Mineralization of N in PL was assumed to be 50% (Vest et al., 1994) during the corn season. Conventional fertilizer was put out in split applications, one-third a day or two before planting, and two-thirds about 33 days later. The N application rate was doubled to 300 lbs N acre^{-1} in the third year in order to increase potential levels of the hormones estradiol and testosterone, which remained at background levels at the application rates of the first two years. The rye cover crop was fertilized with ammonium nitrate at 100 to120 lbs N acre^{-1}. Soil analysis was used to determine P and K needs. All N, P and K fertilizers were applied to the surface of plots one to two days before planting, and incorporated in CT plots only. In addition, a mix of atrazine (1.5

qts acre-1), and dual (1 qt acre-1) was applied before planting and incorporated into soil in CT but not NT plots.

Corn yield was determined by hand harvesting and weighing all whole corn ears from each plot. Twenty to thirty ears were randomly picked from each plot to determine shelled corn weight. The kernel yield was determined in proportion to the whole ear yield of each plot and expressed at 15% moisture equivalent. Statistical analysis was carried out using the MIXED procedure of SAS (Littell et al., 1996; SAS Inst. 1990) including analysis as repeated measures for years. Unless otherwise indicated, all significant differences are given at $P \leq 0.05$.

RESULTS AND DISCUSSION

Annual Corn Kernel Yield

There were substantial differences in yield between years (Fig. 1; $P < 0.0001$ for year). Average kernel yield in 2001 varied from 6265 with CTCF to 8352 lbs acre^{-1} with NTPL. Yield plummeted across all treatments due to severe drought in 2002, and varied from 1586 with CTPL to 2083 lbs acre^{-1} with NTPL. Yield increased somewhat in 2003 and varied from 4103 with NTCF to 5958 lbs acre^{-1} of kernel with CTPL. The average yield over three years varied from 4195 with CTCF to 5253 lbs acre^{-1} of kernel with NTPL.

Several reasons contributed to the yield differential among years, besides treatments, the most prominent of which was reduced precipitation in 2002. Figure 2 shows the amount and distribution of precipitation during the 3 years of corn growth period. During the two weeks prior to planting, natural precipitation was 1.2, 0.7 and 3.6 inches in 2001, 2002 and 2003, respectively. Conditions for seed germination were unfavorable in 2002. The plots had to be irrigated. Since we also needed to induce runoff to measure hormone levels, we applied 2.2 and 2.6 inches of irrigation on days 13 and 14, respectively, after planting. Total natural precipitation between planting and start of flowering, approximately 42 days into the corn season, was 9.3, 3.6, and 12.3 inches in 2001, 2002 and 2003, respectively. But, because of the 4.8 inches of irrigation, the 2002 corn crop had received 8.4 inches of water supply by the start of flowering. During flowering, between days 42 and 70 after planting approximately, total natural precipitation amounted to 7.3, 2.0 and 6.9 inches in 2001, 2002 and 2003, respectively. The corn crop was, therefore, severely stressed in 2002 at a time of its most critical period of water need. Average daily temperature was 2 ^{o}F higher in 2002, during the flowering period, compared to 2001 and 2003 (78 ^{o}F) also, which would have increased potential evapotranspiartion during this period further exacerbating the water stress.

Precipitation was not an issue for the 2003 crop (Fig. 2) and yet corn kernel yield was 74, 81, 50 and 64 percent of the 2001 kernel yield for CTCF, CTPL, NTCF and NTPL, respectively. Four of the six NT plots had severe damage to the young shoots in several rows soon after germination, possibly by corn rootworm attack. Replanting became necessary in these rows, some of which did not recover as expected. In addition, growth in the downstream third of one NT plot in the 2nd replication and both NT plots in the 3rd replication was visibly less vigorous than in the remaining part of these plots, which resulted in reduced yield. The reasons are not clear, but there was an infestation of corn borer early in 2003 and we had to spray all the plots with sevin (carbaryl).

Soil water measurements in 2003 showed that precipitation events (Fig. 2) during the flowering period quickly replenished soil water and soil water levels remained steady, and averaged about 21 to 25%, but three CT plots averaged less than 20% and one NT plot averaged above 25%. In contrast, in 2002, soil water steadily decreased from about 20 to 25% at the start of flowering to about 10 to 15% at the end of flowering with the exception of a 5 to 8% replenishment in response to the 2 inches of precipitation a week and half into the flowering period. Average soil water content was 15 to 19% in half the CT plots, less than 10% in the remaining half, and 15 to 17% in the 5 of 6 NT plots, with the last NT plot averaging 22%. We do not have soil water measurement data during flowering in 2001. We can surmise from Fig. 1, however, that there would have been steady withdrawal of soil water during the first two weeks of flowering, followed by a full saturation of the soil profile in the third week in response to a 6.7 inches of precipitation which occurred in one day and replenished water for crop growth.

Tillage Effect on Corn Yield

Tillage had significant effect on yield but this varied from year to year (P = 0.005 for tillage; P = 0.0001 for tillage*year; Fig. 1). In 2001, corn yield from NT plots exceeded that from CT plots by 29% in plots receiving CF and 14% in plots receiving PL. Although corn yield was 30 to 40% greater in 2002 in NT compared to CT plots, the differences were not statistically significant because of high variance. Then in 2003 CT plots, in a reversal, produced about 13% greater corn yield than NT plots but the differences were again not statistically significant. In 2003 NT plots experienced proportionately more insect damage to plants. Over the three years, average corn yield in NT plots exceeded that in CT plots by 23% in plots receiving CF and 18% in plots receiving PL. Generally, no-till had greater yield enhancing influence in plots receiving conventional fertilizer than those receiving poultry litter.

Fertilizer Effect on Corn Yield

The fertilizer effect on corn yield was also variable from year to year (P = 0.001 for fertilizer; P = 0.005 for fertilizer*year; Fig. 1). In 2001, in plots under CT, those receiving PL produced 16.7% significantly greater corn yield than those receiving CF (i.e. CTPL > CTCF). Also in 2001, NTPL plots had 3% greater yield than NTCF plots but the difference was not statistically significant. In 2002 plots under CF treatment did better by producing 4 to 12% greater yield than those under PL treatment but the differences were not statistically significant. Poultry litter showed strong positive influence on corn yield in 2003 when PL plots produced 28 and 30% greater yield in plots under CT and NT treatment, respectively, than the equivalent CF treatment plots. Over the three years, in poultry litter plots, corn yield was greater by 13% with CT and 8% with NT. However, only the PL effect in CT plots was statistically significant. Generally, poultry litter had greater yield enhancing influence in conventional-till than no-till plots.

Combined Tillage and Fertilizer Effect on Corn Yield

The combined no-till and poultry litter treatment effect enhanced corn yield by 33% in 2001, 26% in 2002 and 14% in 2003, compared to the combined conventional-till and conventional fertilizer treatment effect. The effect, however, was statistically significant only in 2001. Over three years average corn yield was significantly greater in NTPL than CTCF by 27%.

Water Quality - Nutrients

Distribution of nutrient concentrations [nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) and ortho-phosphorus (PO_4-P)] in runoff and drainage based on 14 samplings between 6/1/2001 and 7/1/2003 are presented in Figures 3 to 5.

NO_3-N

Nitrate-nitrogen in runoff was generally below 4 ppm (mg L^{-1}) with half in the range 0.5 to 2 ppm (Fig. 3). Overall means and medians for CTCF, CTPL, NTCF and NTPL were, respectively: 1.74 & 0.96, 0.90 & 0.79, 1.54 & 1.33, and 0.97 & 0.70 ppm. On the other hand, the cropping systems had impact on NO3-N released through drainage. The over all means were similar between treatments:

13.81, 18.84, 15.5 and 17.49 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. The medians (10.11, 13.46, 11.42, and 12.62 ppm, respectively) were similarly all above the maximum EPA standard of 10 ppm for safe human consumption (Fig. 3). But since the N application rates were variable over time, NO_3-N concentrations in drainage were also highly variable. The highest concentrations occurred after the 300 lbs N acre^{-1} application (10 tons acre^{-1} for PL) on 5/27/03. Overall mean NO_3-N concentrations for events prior to this high rate of application were in 9.61, 10.82, 11.95, and 12.05 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. Concentrations were lowest following the lowest application of 100 lbs N acre^{-1}, with the means below 10 ppm and similar among treatments.

NH_4-N

Mean NH_4-N concentrations varied between 3 and 4 ppm for all treatments in runoff (Fig.4). Mean concentrations were much less in drainage: 1.12, 0.31, 0.43, and 0.18 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. The higher concentrations again occurred following the 300 lbs N acre^{-1} application in 2003.

PO_4-P

Mean concentrations for PO_4-P in drainage were 0.13, 0.32, 0.05, and 0.23 ppm for CTCF, CTPL, NTCF, and NTPL, respectively (Fig.5). Similarly median concentrations were 0.04, 0.11, 0.04, and 0.09 ppm, respectively. Treatment effects were clearly apparent in PO4-P concentrations in runoff. Overall means were 0.64, 1.48, 3.97, and 6.83 ppm for CTCF, CTPL, NTCF, and NTPL, respectively. Poultry litter application, therefore, had great impact on soluble phosphorus loss through runoff. This was influenced greatly again by the 300 lb N acre^{-1} application (without it equivalent overall means were 0.63, 2.70, 1.02, 3.60 ppm). In CF treatments about 71% of samples had PO_4-P concentration less than 1 ppm, whereas in PL treatments 78% were above 1 ppm.

Hormones

Application of poultry litter to field plots did not increase the amount of estradiol and testosterone in runoff or drainage. Typical values from irrigation and rainfall events are presented in Table 1. No statistical differences emerged due to treatment effects from these values. Background levels of estradiol and testosterone were present in the conventional fertilizer plots. We hypothesized that these hormone levels occurred naturally due to the local bird populations that included Canadian geese. Both estradiol and testosterone were also found attached to soil but again no treatment effects were observed.

CONCLUSIONS

The following conclusions can be made based on results from three years of research to quantify the agronomic benefits and water quality impacts of no-till and poultry litter in a corn-rye cropping system in a Cecil soil, in comparison to conventional-till and conventional fertilizer.

1. Environmental and management factors can lead to substantial yield variability from year to year across all treatments.
2. No-till enhances corn yield by as much as 25% over several years. Generally, no-till has greater yield enhancing influence in plots receiving conventional fertilizer than those receiving poultry litter.
3. Poultry litter enhances corn yield by as much as 15% over several years. Generally, poultry litter had greater yield enhancing influence in conventional-till than no-till plots.
4. The combined yield enhancing effect of no-till and poultry litter is greater than that of no-till or poultry litter individually.

5. Water stress and pest pressure can eliminate these yield enhancing advantages of no-till and poultry litter
6. Concentrations of NO3-N in runoff appear to be low (<2 ppm) in all treatments. Loss of NO3-N in drainage depended on application rate of N fertilizer; the higher the N rate, the higher the NO3-N concentration. Overall differences among treatments were small. For poultry litter application of less than 3 tons acre^{-1} (90 lbs N acre^{-1}), concentration of NO3-N in drainage appears to be less than 10 ppm, the EPA safe limit for human consumption. Higher rates leach through the soil if precipitation occurs soon after application.
7. Off-site effects could be of concern in cropping systems using no-till and poultry litter in terms of high PO4-P concentration in runoff. But because runoff is usually less in no-till compared to conventional-till, the off-site effect in term of loads could be similar among treatments. This needs further investigation.
8. Application of poultry litter to cropland even at 2 to 3 times the normal rate does not appear to increase hormones levels above those found naturally in the environment. Movement of hormones from poultry litter is similar in conservation tillage and conventional-till systems.

ACKNOWLEDGMENTS

This research was supported in part by a grant from NRICGP, USDA-CSREES. We thank Stephen Norris, Stephanie Steed, and Shaheen Humayouns for their expert assistance. We appreciate assistance of Dwight Seman with statistical analysis.

REFERENCES

Bradley, J.F. 1995. Success with no-till cotton. p. 31-38. *In* M.R. McClelland, T.D. Valco, and F.E. Frans (ed.) Conservation-tillage systems for cotton: A review of research and demonstration results from across the cotton belt. Arkansas Agric. Exp. Stn., Fayetteville, AR.

Bruce, R.R., J.H. Dane, V.L. Quisenberry, N.L. Powell, and A.W. Thomas. 1983. Physical characterization of soils in the southern region: Cecil. Southern Coop. Series Bull. No. 267. University of Georgia, Athens, GA.

Endale, D.M., D.E. Radcliffe, J.L. Steiner, and M.L. Cabrera. 2002. Drainage characteristics of a Southern Piedmont soil following six years of conventionally tilled or no-till cropping systems. Transactions of the ASAE: 45(5): 1423-1432.

Fawcett, R.S., B.R. Christensen, and D.P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: A review and analysis. J. Soil and Water Cons. 49(2):126-135.

Golabi, M.H., D.E. Radcliffe, W.L. Hargrove, and E.W.Tollner. 1995. Macropore effects in conventional-tilland no-tillage soils. J. Soil and Water Cons. 50 (2):205-210.

Langdale, G.W., L.T. West, R.R. Bruce, W.P. Miller, and A.W. Thomas. 1992. Restoration of eroded soil with conservation tillage. Soil Technology. 5(1): 81-90.

Littell, R. C., G.A. Milliken, W.W. Stroup, and W.R. Wolfinger. 1996. SAS Systems for Mixed Models. SAS Inst., Inc. Cary, NC.

Moore Jr., P.A., T.C. Daniel, A.N. Sharpley, and C.W. Wood. 1995. Poultry manure management: Environmentally sound options. J. Soil and Water Cons. 50(3): 321-327.

NASS. 2003. Poultry – Production and Value 2002 Summary. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture.

Radcliffe, D.E., E.W. Tollner, W.L. Hargrove, R.L. Clark, and M.H. Golabi. 1988. Effect of tillage practices on infiltration and soil strength of a Typic Hapludult soil after ten years. Soil Sci. Soc. Am. J. 52 (3):798-804.

SAS Institute, Inc. 1990. SAS/STAT User's Guide, Ver. 6. 4th ed. SAS Institute Inc. Cary, NC:

Vest, L., B. Merka, and W.I. Segars. 1994. Poultry waste: Georgia's 50 million dollar forgotten crop. Leaflet 206/July, 1994. Georgia Cooperative Extension Service, College of Agricultural and Environmental Sciences, University of Georgia. Athens, GA. At http://www.ces.uga.edu/pubcd/L206-w.html. Verified 27 Dec. 2003.

Table 1. Typical mean values of flow-weighted concentration of estradiol and testosterone in drainage and runoff from an irrigation and a rainfall event.

	Drainage		Runoff	
Treatment	Estradiol	Testosterone	Estradiol	Testosterone
	------------------------------ ppb (ng/l)--------------------------------------			
Irrigation event				
CTCF	23.3	6.7	27.8	7.6
CTPL	36.6	7.9	26.9	8.4
NTCF	5.7	4.7	35.2	7.4
NTPL	9.7	8.6	20.5	5.6
Rainfall event				
CTCF	25.2	5.7	8.7	16.8
CTPL	10.0	32.2	24.2	17.6
NTCF	10.7	15.9	16.5	13.6
NTPL	8.2	99.5	43.7	18.9

Figure 1. Corn kernel yield from 2001 to 2003. Within each year, corn yields between any two treatments sharing similar letters above the error bars are not significantly different from each other at P = 0.05.

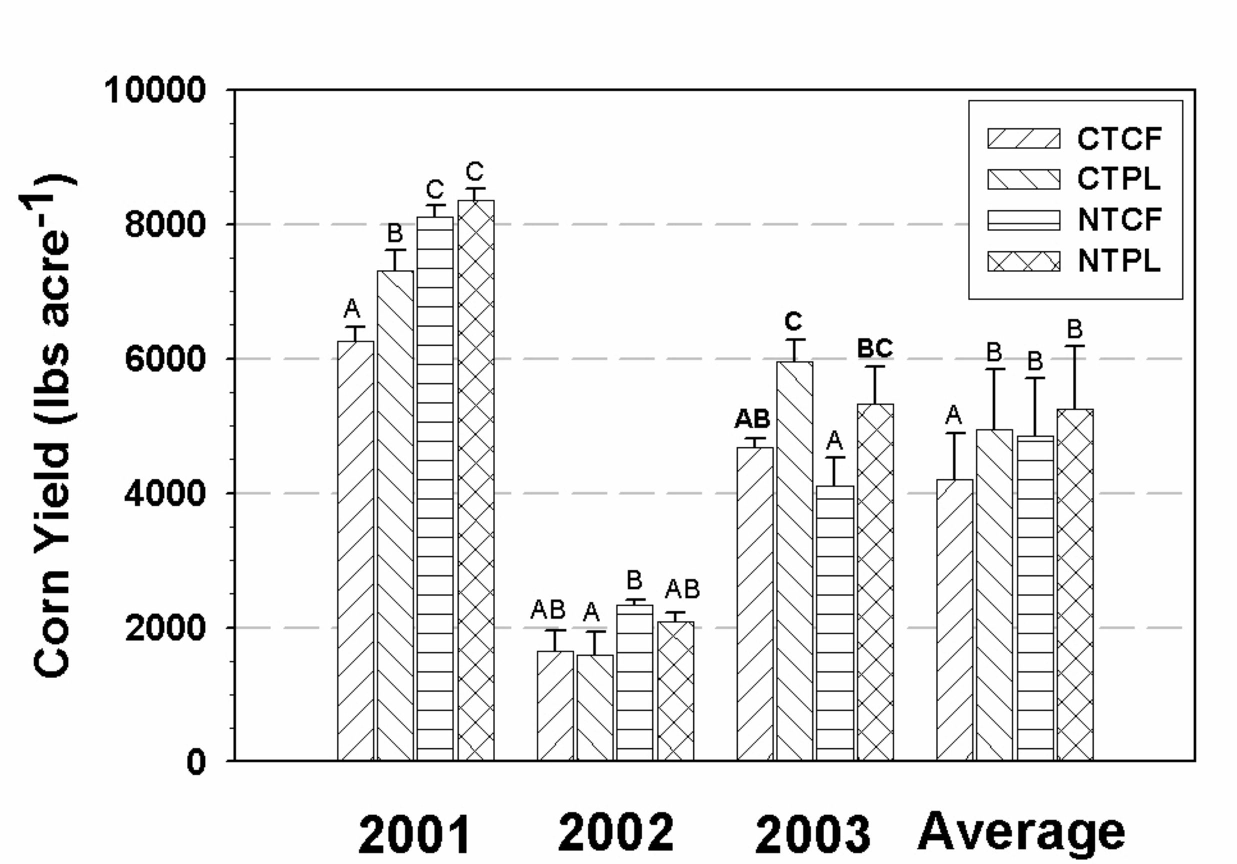

Figure 2. Cumulative precipitation during the 2001-2003 corn season.

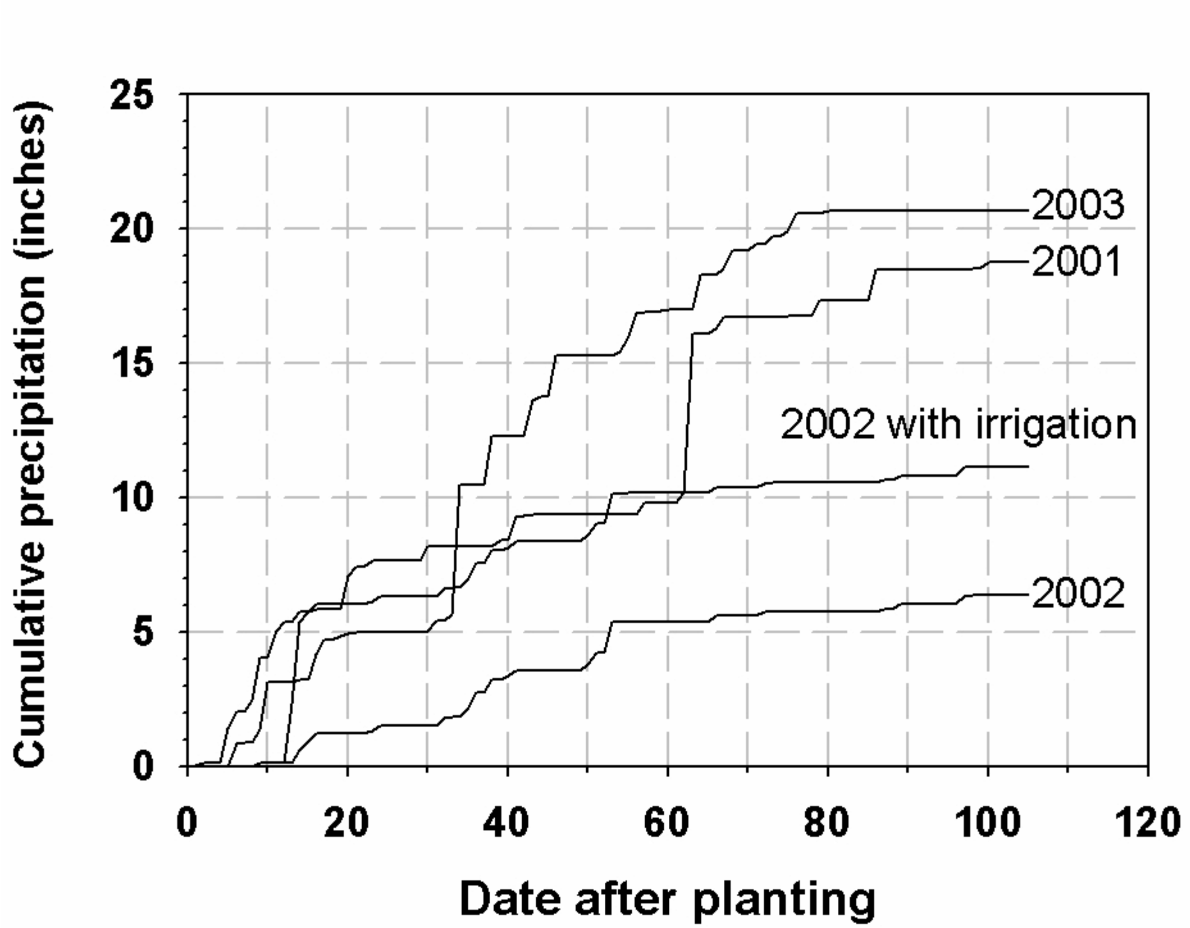

Figure 3. Box plots showing distribution of NO_3-N concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

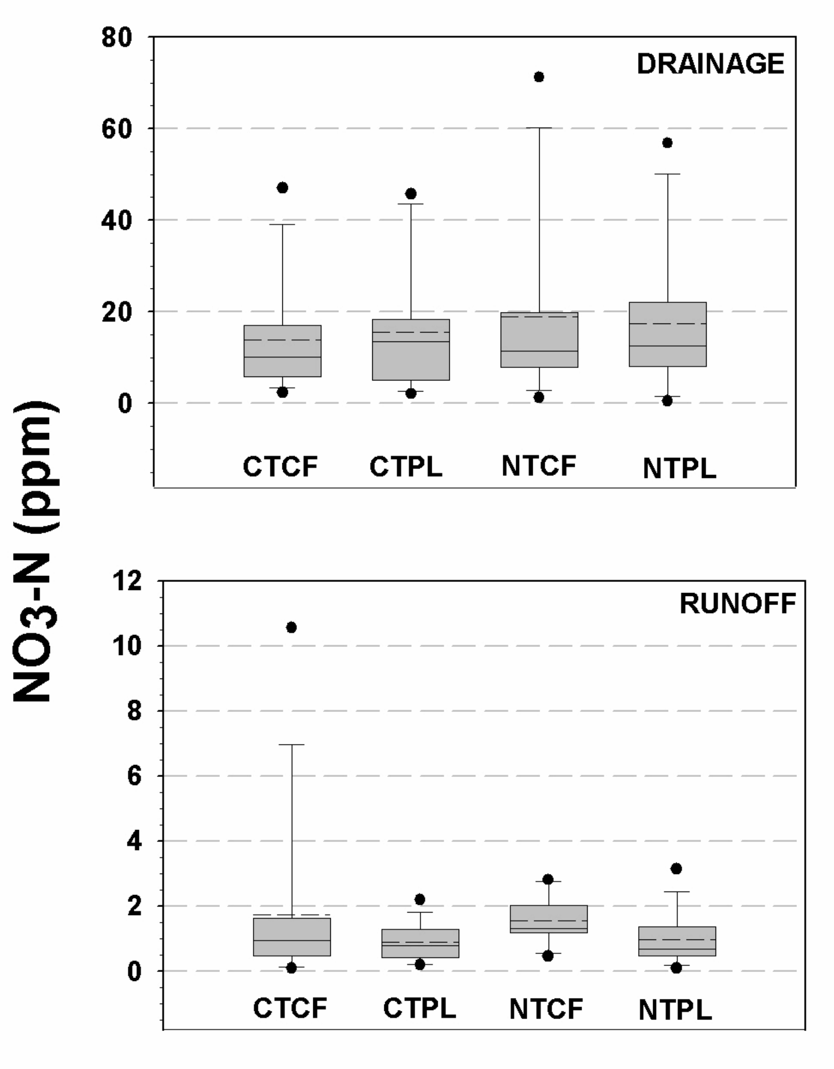

Figure 4. Box plots showing distribution of NH_4-N concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.

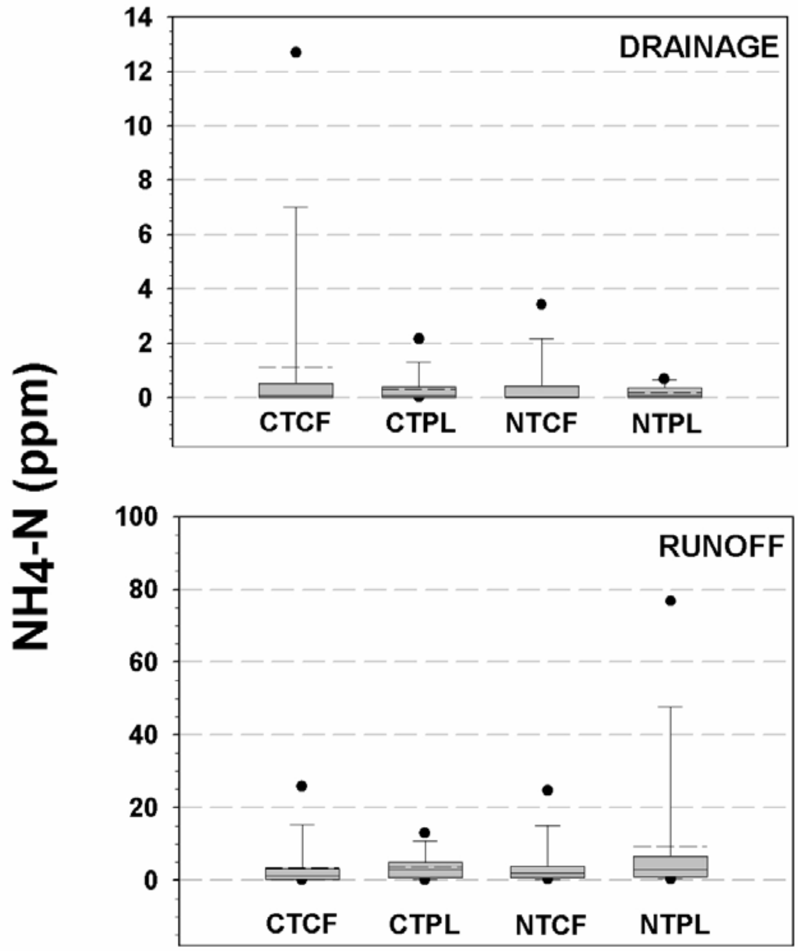

Figure 5. Box plots showing distribution of PO_4-P concentration in runoff and drainage based on 14 samplings between 06/01/2001 and 07/01/2003. Each box shows the 25th percentile, median, and 75th percentile. Means are shown as dotted lines inside boxes. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots.