THE EFFECT OF ROTATION, TILLAGE, AND FERTILITY ON RICE GRAIN YIELDS AND NUTRIENT FLOWS

Merle M Anders[1]*, Dan Olk[2], Travis Harper[3], Tommy Daniel[3], and Jared Holzhauer[1]

[1]Rice Research and Extension Center, 2900 Hwy. 130E, Stuttgart, AR. 72160
[2]Dan Olk: National Soil Tilth Laboratory, Ames, Iowa
[3]University of Arkansas, Fayetteville, AR 72703

*Corresponding author's e-mail address: rrec_manders@futura.net.

ABSTRACT

Rice is one of the most intensively cultivated row crops in America. In order to move away from current tillage practices it will be necessary to maintain current yield levels. A key to successful no-till rice production will be to maintain plant fertilizer efficiency in a system that is flooded much of the growing season and not increase nutrient runoff. A study was established in 2000 that compares fertility, variety, and conventional-and no-till rice rotations. Rice grain yields, across all treatments, were between 140 and 195 bu a^{-1}. Yields were most affected by rotation and tillage. Continuous rice grain yields averaged 34 bu a^{-1} lower than a rice-soybean rotation. Plant P and K uptake varied significantly between rotation treatments but not between tillage, fertility, or variety treatments. Phosphorus concentrations in run off liquid were significantly higher in the no-till plots. Total P in runoff was lower in the no-till plots because of reduced P being carried in solids. Total nitrogen uptake was lower in the continuous rice rotation compared to the rice-soybean rotation with soil N uptake higher for the no-till compared to conventional-till in both rotations.

MATERIALS AND METHODS

Field #8 at the University of Arkansas Rice Research and Extension Center was selected for this study and cut to a 0.15% slope in February, 1999. This site had not been previously used for rice research because irrigation water was not available. Soil at the site is referred to as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludolf. Initial soil samples showed a pH range of 5.6 to 6.2 with carbon content averaging 0.84% and nitrogen 0.08%. Plots measuring 250' x 40' were laid out in a north-south direction. These plots were then divided in half east-west with each side randomized as conventional or no-till treatments. Each tillage treatment was then split into a standard and high fertility treatment. For rice, 'standard' fertility consisted of a single pre-flood N application of 100 lbs urea a^{-1} plus 40 lbs a^{-1} P_2O_5, and 60 lbs a^{-1} K_2O applied prior to planting. Rates increased to 150 lbs a^{-1} N, 60 lbs a^{-1} P_2O_5, and 90 lbs a^{-1} K_2O for the 'enhanced' treatment with application times remaining the same. Two varieties of each crop species were planted in a continuous strip across the conventional-and no-till treatments. In March, soil samples were collected for fertility evaluations. Soil samples were ground and dried. Phosphorus and potassium determinations were made using a Melich III extraction at a 1:10 extraction ratio. Plant samples were collected following physiological maturity but before leaf senescence for nutrient determinations in 1999, 2000, and 2001. Plants were divided into grain, leaf, and stem portions for analysis. Plant analysis was completed using a HNO_3 digest and read with a ICP (Spectro Model D). The following rotations were started in 1999: 1) continuous rice, 2) rice-soybean, 3) soybean-rice, 4) rice-corn, 5) corn-rice, 6) rice (wheat) rice (wheat), 7) rice (wheat)-soybeans (wheat), 8) soybeans (wheat)-rice (wheat), 9) rice-corn-soybeans, 10) rice-corn (wheat)-soybeans. Yield data and nutrient uptake will be presented for the continuous rice and rice-soybean rotations.

Rice was sown into 7.5 in rows using an Almaco no-till drill. The seeding rate was 90 lbs a^{-1} with Icon used as a seed treatment. P and K were applied prior to sowing with a single pre-flood nitrogen application made prior to flooding. P and K were incorporated in the conventional till treatment and not in the no-till treatment. An ANOVA analysis for each year was completed using SAS PROC MIXED (Littell et al., 1996) and a Duncan means test used to group treatments. Comparisons were made using all rotations with data presented only for the three rotations included in nutrient uptake measurements.

Runoff data were collected in May, 2003 after the rice had been sown but had not emerged. A rainfall simulator representing a plot size of 5’ x 7’ was used. Rainfall was applied at a rate of 2in/hr for 30min. Runoff was collected and analyzed for turbidity, total solids, and phosphorus content.

Nitrogen uptake comparisons were made using ^{15}N enriched urea (5 atomic percent ^{15}N) fertilizer in ‘enhanced’ fertility plots planted into the variety Wells in the continuous rice and rice-soybean rotations. Four metal rings 2' in diameter were inserted into the appropriate larger plots. When the rice plants had reached the 4-5 leaf growth stage, labeled N was applied inside each ring at a rate of 150 lbs N a^{-1} (same rate that was used in the larger plots) at the same time the larger plots were fertilized. Each ring was flooded to a depth of 2-3 inches and water maintained at this depth for a period of two weeks. At that time, rubber stoppers were removed from the ring and water from the larger plot allowed to maintain water depth inside the ring. No additional fertilizer was applied to the larger plots after they were flooded. Plant and soil samples for ^{15}N determination were collected from rings at 2 weeks following N application, green ring, flowering, and harvest times during plant growth. Soil bulk density samples were collected at the two weeks and flowering sample times. The ^{15}N atomic enrichment of the soil was determined by continuous flow isotope ratio mass spectrometry, using a Fisons NA 1500 NC elemental analyzer coupled to a Finnigan Delta S mass spectrometer. Rainfall runoff was measured in 2003 on plots that had been planted into rice and before the rice had emerged.

RESULTS AND DISCUSSION

Mean rice grain yields were highest (195 bu a^{-1}) the first year of the study and declined the next two years (Table 1). In the years 2002 and 2003 grain yields reflected seasonal trends. Grain yields for three of four years tillage comparisons were made were higher in the conventional-till treatments when compared to the no-till treatments. This difference ranged between 11 and 18 bu a^{-1} with yields similar in 2003. This difference will represent a significant impediment to adopting conservation tillage in rice production. Government payments are closely tied to grain yield while farmers are not responsive to small changes in production costs. Obtaining equal grain yields in conservation-tilled fields, as was the case in 2003, will enhance adoption. Grain yield differences were most evident in the rotation comparisons with the continuous rice rotation grain yields significantly lower than the rice-soybean rotation (Table 1). For the continuous rice rotation, grain yields declined 27 bu a^{-1} from 2000 to 2002 and recovered only 6 bu a^{-1} in 2003. Trends of lower yields in continuous rice rotations when compared to rice-soybean rotations have been known for a number of years and there are fertilizer recommendations that compensate for this difference by adding additional N (Slaton, 2000). Significant differences in fertility comparisons were present only in 1999 when the ‘standard’ fertility treatment grain yield was 7 bu a^{-1} higher than the ‘enhanced’ treatment. This same trend continued until 2003 when the ‘enhanced’ fertility treatment resulted in higher, non-significant, grain yields. Lack of a clear response to higher fertility (N, P, K) levels supports current fertilizer recommendations. There were no significant differences between varieties for any year comparison.

Potassium fertilizer was applied pre-plant to the soil surface in the no-till plots while it was incorporated into the top 4in of soil in conventional-till plots. Plant K uptake and soil K levels were measured to determine if the two fertilizer application methods resulted in similar K uptake and soil K values. There were no treatment differences in the percent of total above-ground dry matter contained in grain, leaf, and stem for any given variety over the three years data were collected. For the variety Wells, percentages of 45% grain, 21% leaf, and 34% stem were used to determine nutrient uptake. Differences in K concentration in grain, leaf, or stem were present only in the rotation treatment comparison and not in tillage or fertility comparisons. Leaf K concentration increased from 1.10% in the continuous-rice rotation to 1.21% in the rice-soybean rotation. Plant stem K concentration increased from 2.08 to 257% for the same comparison while grain remained constant at 0.30% K. Annual total K uptake for tillage treatments averaged over 4 years was 189 lbs a^{-1} for the no-till treatments as compared to 195 lbs a^{-1} for conventional-till.

Phosphorus plant uptake trends closely followed those for potassium. Average yearly P uptake for Wells in the continuous rice rotation was 26 lbs a^{-1} as compared to 37 lbs a^{-1} for the rice-soybean rotation. This result came as a result of P concentration increases in all plant parts measured. P uptake for tillage treatments measured over the same time period averaged 32 lbs a^{-1}. Increasing P fertilizer levels resulted in an average increase in P uptake of 2 lbs a^{-1} annually.

Restricting the amount of P moving off agricultural fields is a focus of current environmental legislation. If applying P to the soil surface as it was in our no-till treatment results in increased P loss from the field a different approach to applying P fertilizer will be necessary. Rice soils are characterized as 'high runoff' (Figure 1). Runoff consists of liquid and solid material that is carried in the water. P concentrations in runoff water from no-till plots were significantly higher than in runoff form conventional till plots (Figure 2). These results illustrate problems encountered when P is added to the soil surface. When P contained in the solid runoff is included in total P lost in runoff no-till resulted in less P loss (Figure 3). These results indicate there is an expected reduction in P lost in runoff when no-till is compared to conventional-till but there needs to be concern on the high P concentrations found in water moving off no-till fields.

Nitrogen is the most important element in rice growth (Norman et al. 2003). Nitrogen concentration for the variety Wells averaged 1.34%, 1.80%, and 0.49% N in the grain, leaves, and stem respectively. Mean annual plant N uptake ranged between 120 and 151 lbs a^{-1} from 1999 to 2003. As with K and P uptake, there were no differences in tillage or variety treatments. Fertilizer N uptake measured using ^{15}N indicated a significant reduction in uptake by the continual rice rotation when compared to the rice-soybean rotation (Figure 3). These results follow yield trends. There was an additional significant reduction in N uptake by the no-till treatment when compared to the conventional-till treatment in the continuous rice rotation. This was not the case for the rice-soybean rotation where there was no difference in fertilizer N uptake between tillage treatments. Plant soil N uptake results indicate a benefit from no-till when compared to conventional-till regardless of rotation (Figure 5). There was a significant reduction in soil N uptake in the conventional-till treatment when compared to the no-till treatment in the continuous rice rotation; a trend that was not significant in the rice-soybean rotation. Total plant N uptake reflected both rotation and tillage effects (Figure 6). There were no tillage differences within each rotation but a significant reduction in total plant N uptake in the continuous rice rotation when compared to the rice soybean rotation. These results are similar to those found in California studies where it was reported that no-till continuous rice had approximately 10 lbs a^{-1} more plant N uptake when compared to a conventional-till treatment (Eagle et al. 2000). There was a clear advantage in N uptake in no-till when compared to conventional-till but no clear answer as to why we had lower uptake and grain yields from the continuous rice rotation.

CONCLUSIONS

Changing from conventional-till to no-till is not expected to result in significant reductions in rice grain yields for producers using a rice-soybean rotation. Producers who grow continuous rice should anticipate lower grain yields than they would get from a rice-soybean rotation. Applying potassium and phosphorus to the soil surface in no-till systems did not result in decreased plant K and P uptake. Phosphorus concentrations in runoff water increased significantly in no-till management; a result attributed to P being applied to the soil surface. Total P (liquid + solids) concentration in runoff was lower in the no-till managed field because of reduced soil (solids) loss. No-till reduces P loss via erosion but does not eliminate the loss of P that is dissolved in runoff water. No-till resulted in reduced fertilizer uptake in continuous rice while it had no effect on rice in a rice-soybean rotation. Soil N uptake was increased with no-till in both continuous rice and rice-soybean rotations. Total N uptake increased with no-till indicating a possibility of maintaining grain yields at slightly lower N fertilizer rates.

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Table 1: Summary of rice mean grain yield (bu a^{-1}) for treatment main effects in 1999, 2000, 2001, 2002, and 2003 in the long-term cropping systems study at the University of Arkansas Rice Research and Extension Center, Stuttgart, Arkansas.

Effect	Treatment	Year 1999	2000	2001	2002	2003
All	All	195	140	137	159	166
Tillage	Conventional	NA	149 a[z]	143 a	168 a	153 a
	No-till	NA	131 b	131 b	151 b	153 a
Rotation	Continuous rice	NA	159 b	145 b	132 c	138 b
	Rice-soybeans	NA	198 a	164 a	174 a	173 a
Fertility	Standard	198 a	138 a	135 a	156 a	159 a
	Enhanced	191 b	142 a	138 a	163 a	147 a
Variety	Wells	198 a	187 a	159 a	168 a	153 a
	LaGrue	191 a	178 a	157 a	164 a	157 a

[z] Means within a column followed by different letters are significantly different at the P=0.05 level of confidence.

Figure 1: Percent of total water collected as runoff following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

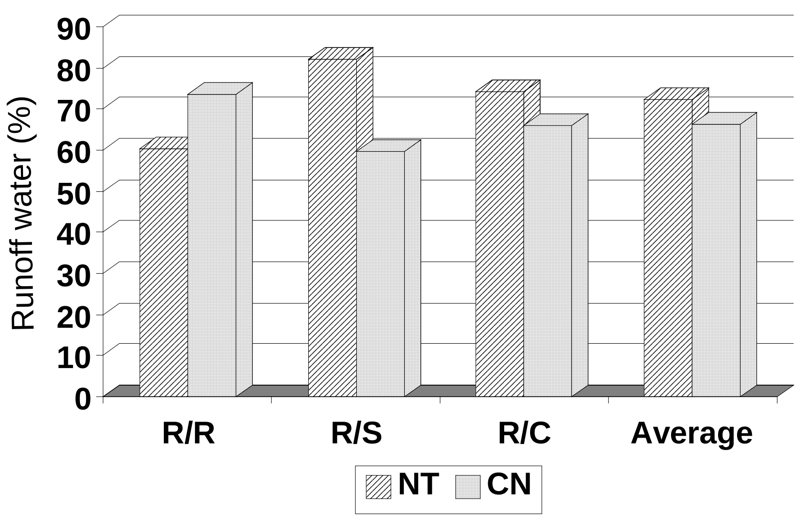

Figure 2: Phosphorus (P) concentration (mg/L) in runoff water following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

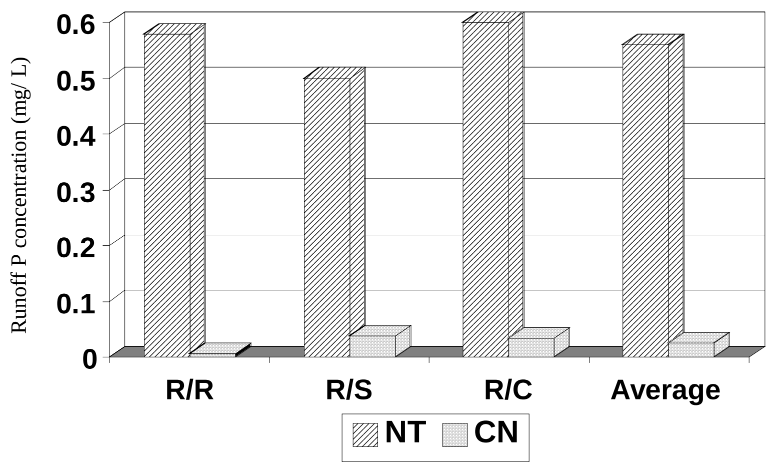

Figure 3: Total phosphorus (P) concentration in runoff (water+solids) following a single simulated rainfall event from continuous rice (RR), rice-soybean (R/S), and rice-corn (R/C) rotations that were either conventional-till (CT) or no-till (NT) from 2000 to 2003 when the samples were taken.

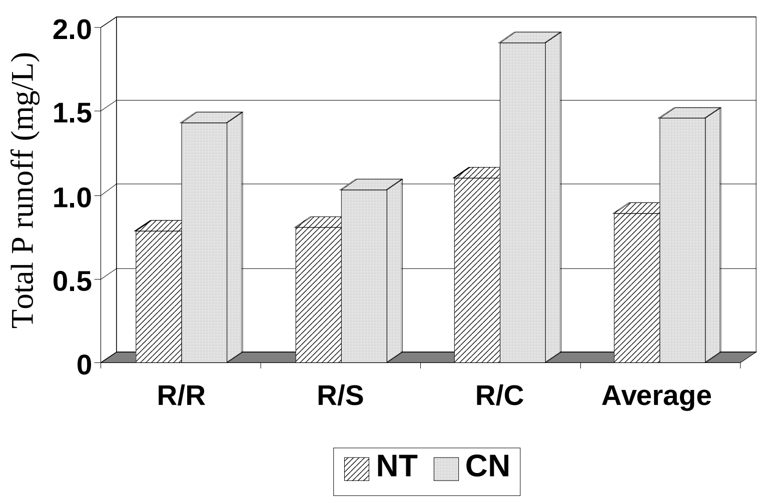

Figure 4: Plant fertilizer nitrogen (N) uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).

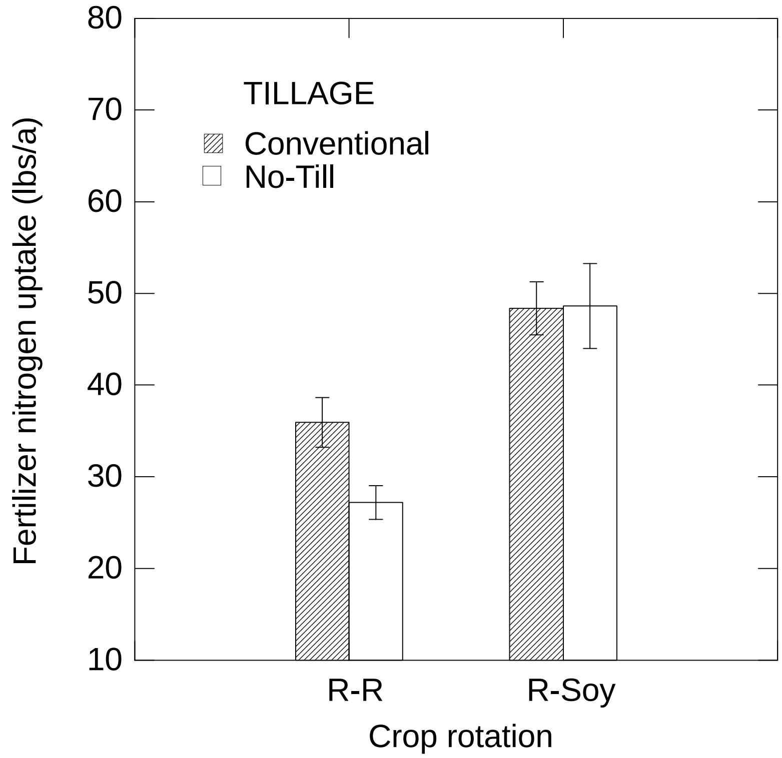

Figure 5: Plant soil nitrogen uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).

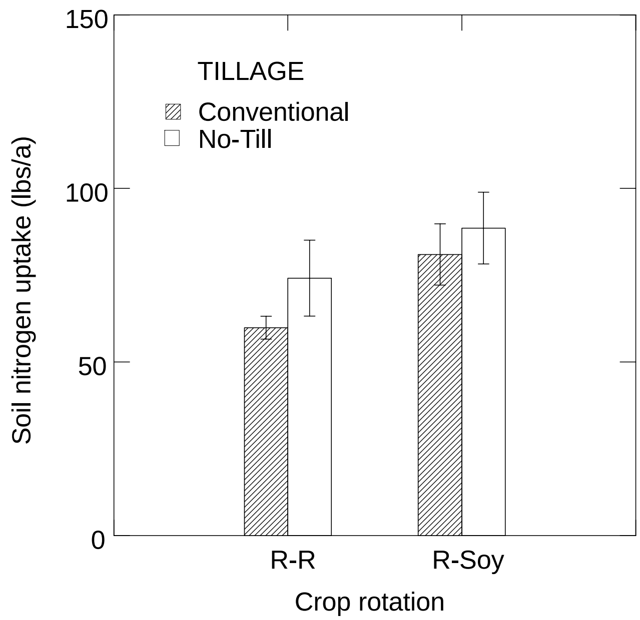

Figure 6: Total plant nitrogen (N) uptake measured using ^{15}N for conventional-and no-till rice grown in a continuous rice (RR) or rice-soybean (R-Soy) rotation at the University of Arkansas Rice Research and Extension Center in 2002 (bars indicate standard error).