Accepted for publication 4 October 2006. Published 19 January 2007.

Soil Chemical Properties and Rice Yield Response to Nitrogen Rate and Timing After Precision Leveling

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Walker, T. W., Kingery, W. L., Street, J. E., Cox, M. S., Gerard, P. D., and Oldham, J. L. 2007. Soil chemical properties and rice yield response to nitrogen rate and timing after precision leveling. Online. Crop Management doi:10.1094/CM-2007-0119-02-RS.

Abstract

Precision-leveling agricultural fields provides benefits in soil and water conservation, crop production, and management; therefore, the practice has been widely adopted in the midsouthern USA crop-production area. Plant health and crop yields can be compromised where the topsoil is removed (cut) compared to undisturbed and fill areas. Experiments were conducted to evaluate the change in Lancaster extractable P, K, Ca, Mg, Na, Zn, as well as soil pH and total N on Sharkey soils (very-fine, smectitic, thermic Chromic Epiaquert). Furthermore, N rate and application timing studies were conducted in the cut areas of these soils for two rice cultivars. Concentrations of total N and Lancaster P declined with soil profile depth on Sharkey clay and Sharkey silty clay soil. Soil pH significantly decreased at one of two locations. Sodium and Mg tended to increase with increasing profile depth, whereas only minor changes were detected for Ca and Zn. Rice grain yields decreased as the percentage of preflood (PF) N increased for 'Lemont.' Optimum yields for 'Priscilla' were obtained at 151 to 202 kg of N per ha. These data suggest that the cut areas of newly precision-leveled clay soils can be fertilized with N rates that are similar to what is recommended for non-disturbed clay soils.

Introduction

Precision land-leveling has been widely adopted by producers throughout the midsouthern USA crop producing area because this practice provides producers more efficient methods to manage irrigation water. Precision land-leveling reduces water inputs (8), and because of this, the 2002 Farm Bill included substantial financial assistance to growers who were willing to adopt precision land leveling and other water-saving practices (4,28). Precision land-leveling offers benefits other than water savings. Decreased tillage and increased harvest efficiency can be achieved because precision land leveling reduces the area consumed by levees (12,13). Some aerial agricultural chemical applications can be replaced with ground applications, which are less expensive (32). Furthermore, because flooding in precision-leveled fields is more uniform and more timely, improved nutrient uptake and weed management result in increased yields (27).

Though the benefits of precision land leveling are numerous, problems often arise after land-leveling is conducted. Walker et al. (29) reported that extractable concentrations of P, K, and Zn, as well as total N were less in cut areas compared to fill areas across a wide range of soils cropped to rice in Mississippi. In addition, rice yield in the cut areas, i.e., areas where the topsoil has been removed, was typically less than in fill areas (17,29). Precision land-leveling also increased near-surface spatial variability among soil chemical, physical, and biological properties in Arkansas (3,4,5,6).

In midsouthern USA rice production, the amount of N and the incidence of application are greater than any other nutrient (21). Unlike nutrients such as P, K, and Zn, no suitable soil test method has been established and implemented for determining the N-supplying capacity for soils used to produce rice (11). Instead, numerous N rate and application timing studies are conducted on experiment stations and farms to determine N recommendations for the various cultivars that are grown in the rice-producing states. Furthermore, fertilizer-N is not the only N source for obtaining maximum grain yields. Rather, it has been shown that fertilized rice plants can obtain up to 50 to 80% of their N requirement from native soil nitrogen (10,19,24). Organic residues can be mineralized by microbial processes that convert organic forms of N into NH_4^+ or NO_3^-, which are both utilized by the rice plant (15,19).

In the midsouthern USA, optimum N-fertilizer use efficiency has been achieved by applying at least 50% of the total N immediately prior to permanent flood (PF) establishment, and the remaining N applied within a 2- to 3-week window centered around internode elongation (IE) (2,16,30,31). However, rice yield of some new cultivars with a single preflood (SPF) N application is comparable to, and sometimes greater than a 2- or 3-way split of the total applied N (20). Rate and timing of N are critical for optimum rice grain yield. Nitrogen increases rice plant height, panicle number, leaf size, spikelet number, and number of filled spikelets (11), ultimately determining the yield potential. Panicle number is influenced by the number of tillers that develop during the vegetative stage, while spikelet number and number of filled spikelets are determined in the reproductive stage (10).

Our hypothesis was that N recommendations that are derived from soils that have not been recently disturbed by precision land leveling may not be sufficient for rice grown the first year after precision land leveling because the total N pool, as well as the equilibrium among soil chemical, physical, and biological properties is altered in the process. Land-leveling is a costly investment for the producer; therefore it is imperative to manage those fields in a manner that provides maximum production as soon as possible after land-leveling.

The objectives of this research were to: (i) quantify the change in soil fertility parameters after precision land leveling; and (ii) determine the optimum N rate and application timing for 'Lemont' and 'Priscilla' on recently-leveled clay soils.

Four Sampling Depths

The study was conducted at Shelby, Choctaw, and Leland, MS in 1999, 2000, and 2001, respectively. Each of the locations had a history of rice and soybean [*Glycine max* (L.) Merr.] prior to land-leveling. The Shelby and Leland sites were precision leveled to achieve zero slope, and the Choctaw site was leveled to achieve 0.15% slope. Sharkey soils (very-fine, smectitic, thermic Chromic Epiaquert) were present at all sites; however, the surface texture at Shelby was silty clay as opposed to clay at the Choctaw and Leland sites. Precision land-leveling occurred in the spring prior to planting at Shelby and in the fall prior to the following spring planting at Choctaw and Leland. Approximately 46, 55, and 18 cm of topsoil were removed in the plot area at Shelby, Choctaw, and Leland, respectively.

Soil cores that measured 5.7 cm in diameter were collected in 15-cm increments at soil depths of 0 to 60 cm on 15 March 1999, and 7 July 1999, at Shelby and Choctaw, respectively (Table 1). The 60-cm depth was chosen to compensate for the depth of cut that would be made in the experimental plot area. These samples were collected as a preliminary approach to determine the effect of precision leveling on nutrient concentrations. Following precision leveling, soil samples were randomly collected throughout the experimental plot area immediately before planting at all locations in order to determine the nutrient levels prior to plot establishment (Table 2). Soil samples were analyzed for pH (1:1 H_2O), Lancaster extractable nutrients (9,23) (Ca, K, Mg, Na, P, and Zn) measured by inductively-coupled argon plasma spectroscopy (Perkin Elmer Optima 4300DV OES, Norwalk, CT), and total N (Carlo Erba N/C 1500 dry combustion analyzer, Milan, Italy). Deep soil cores were not collected prior to leveling at the Leland site. This experiment was analyzed as a randomized complete block (RCB) design in which the sampling points were replicates and sample depths were treatments. A general linear model procedure (25) was used to test the variation in soil chemical properties. Means for observations at each depth were separated using Fisher's LSD at the 5% significance level. Locations were analyzed separately.

Table 1. Mean pH, Ca, K, Mg, Na, P, Zn, and N concentrations for soil samples collected at four depths prior to leveling at Shelby and Choctaw.

Location	Depth (cm)	pH	Lancaster-extractable (Mg/kg) Ca	K	Mg	Na	P	Zn	Total N
Shelby	0-15	6.5a	4365a	296a	1038a	50a	94a	5.8a	1329a
	15-30	6.2b	4521a	272a	1059a	68b	55b	6.0a	972b
	30-45	5.9c	4598a	273a	1099a	77b	49bc	5.5a	877b
	45-60	5.7c	4360a	272a	1106a	76b	41c	4.4a	781b
Choctaw	0-15	6.2	5877a	349a	1534a	126a	90a	10.4a	1852a
	15-30	6.7	5579b	306a	1575ab	226ab	52b	7.1a	1508b
	30-45	6.4	5321c	261b	1609b	338bc	37b	7.5a	1029c
	45-60	6.0	5216c	318a	1722c	440c	38b	8.9a	790d

Means within the same column and location followed by different letters are different at the 0.05 significance level.

Table 2. Soil series and mean soil pH, Ca, K, Mg, Na, P, Zn and N concentrations for N rate and application timing experiment areas for Shelby, Choctaw, and Leland sites collected at the time of planting.

Location	Soil series	pH	Ca (mg/kg)	K	Mg	Na	P	Zn	N
Shelby	Sharkey silty clay	5.7	4189	233	1046	90	39	5	781
Choctaw	Sharkey clay	6.3	5418	261	1581	270	93	10	1088
Leland	Sharkey clay	6.5	4623	266	1077	74	64	3	972

Two Cultivars, Four N Rates, Three Application Timings, Three Locations

On 15 May 1999 and 28 April 2000, 'Lemont' and 'Priscilla' rice were drill seeded at a rate of 100 kg/ha with commercial drills equipped with openers spaced 18 cm apart. After emergence, plots (experimental units) were created with dimensions of 2.5 m wide by 6 m long, and 1-m alleys separated replicates. On 25 April 2001, 'Lemont' and 'Priscilla' were drill seeded at a rate of 100 kg/ha using a 1.8-m plot drill. The plot dimensions were 1.8 m wide by 7.5 m long with 1-m alleys separating each replication. At each site, and for both cultivars, a factorial combination of four N rates (101, 151, 202, and 270 kg of N per ha) as urea, and three application timings (50, 67, and 100% PF) were arranged in an RCB design and replicated four times. When rice reached the 5- to 6-leaf stage, PF N treatments were broadcast onto dry soil by hand, and a permanent flood was established within 3 days after PF N application. The experiments remained flooded until 10 to 14 days prior to harvest. For the treatment combinations that included 50% and 67% of the N applied PF, the remaining N was broadcast by hand into the flood water in two equal applications at 1.3-cm IE and 7 days after. At Shelby and Choctaw, herbicide and insecticide treatments were applied as needed by the producer. For the Leland site, herbicide and insecticide applications were applied with a 3-m boom using a CO_2^- pressurized backpack sprayer. As a means of alleviating any potential S deficiency due to the removal of the topsoil, 27 kg of S per ha in the form of $(NH_4)_2SO_4$ was commercially applied to rice at the 2-leaf stage and incorporated by a flush irrigation.

Plots were harvested on 6 October 1999, 13 September 2000, and 19 September 2001, at Shelby, Choctaw, and Leland, respectively. The center three rows were harvested using a small plot combine. Grain yields were weighed and adjusted to 12% moisture for reporting.

Rice yield data were combined over locations for analysis of variance (ANOVA) and tested for main effects and interactions using a mixed model approach (25). Nitrogen rate and application timing were considered fixed effects. Year, replication, and any interactions between these factors were considered random effects as suggested by Carmer et al. (7) and were included in the ANOVA so that broader inferences could be made concerning treatment effects. Separate analyses were conducted for 'Lemont' and 'Priscilla.' Means were separated using Fisher's LSD at a significance level of $\alpha = 0.05$.

Sampling Depth and Soil Chemical Properties

At Shelby, soil pH, Lancaster-P, and total N were greatest in the top 15-cm sampling depth, but Na concentration was the least of all depths (Table 1). Soil pH and Lancaster-P concentrations decreased with increasing sampling depth. Soil pH was 0.8 units lower at the 45- to 60-cm depth compared to the upper 15-cm depth. When measured at the 45- to 60-cm depth, P concentration was approximately 44% of the 0- to 15-cm depth. Total N at the deepest sampling depth was approximately 60% of the surface 15-cm concentration (Table 1).

Lancaster extractable-Ca, K, Mg, Na, P, and total N differed among sampling depths at Choctaw (Table 1). Calcium concentrations decreased with increasing depth until the 30- to 45-cm depth. A relatively large decrease in P was observed when comparing 15- to 30-cm depth to the 0- to 15-cm depth; however, the deepest three sampling increments did not differ. Total N decreased with increasing sampling depth. Total N at the 45- to 60-cm depth was about 43% of the total N at the top 15 cm. The K concentration in the 30- to 45-cm depth was less than all other sampling depths. Magnesium and Na concentrations increased with increasing sampling depth (Table 1).

Measured changes in concentrations with respect to soil profile depth were greatest for Lancaster-P and total N. Phosphorus concentrations at the deepest sampling depth were 42% and 44% of the uppermost sampling depth at Shelby and Choctaw, respectively. Though P was reduced, the resulting concentrations were still greater than the critical level for Lancaster-P for optimal rice production. Furthermore, typical P deficiency symptoms, such as stunting and decreased tillering were not observed at any location. For total N, an approximate 2- and 3-fold reduction at lower depths was observed at the Shelby and Choctaw locations, respectively. The assumption was made that the organic N was reduced more than the inorganic-N fraction, and thus rice plants may require more fertilizer-N than is recommended for soils where no disturbance has occurred. Except for Na at the Choctaw location, other soil nutrients and soil pH were minimally affected with respect to sample depth, and remained at levels sufficient for high rice yield.

Rice Grain Yield

Analysis of variance indicated that no interaction was observed among application timing and N rate for 'Lemont' or 'Priscilla' grain yield. 'Lemont' was affected by application timing ($P = 0.0134$), whereas grain yield for 'Priscilla' was affected by N rate ($P = 0.0026$). When yield was averaged across N rates for 'Lemont,' yield decreased as the percentage of N applied PF increased (Table 3). For 'Priscilla,' when yield was averaged across application timings, rice grain yield was greatest for N rates above 101 kg of N per ha. Although both cultivars are stiff-strawed, semi-dwarf cultivars, there are phenotypic and genotypic differences that may explain why 'Lemont' was more responsive to application timing than ‘Priscilla.’ ‘Lemont’ is slightly shorter in height compared to Priscilla; however, the canopy of ‘Lemont’ is more dense and leafy compared to ‘Priscilla.’ This can cause excessive shading, especially when high N rates are applied during the vegetative growth stage (21). Furthermore, ‘Lemont’ is rated very susceptible to sheath blight (*Rhizoctonia* solani) (1), whereas ‘Priscilla’ is rated moderately susceptible (14). Sheath blight was observed more frequently over the 3-year period in ‘Lemont’ when compared to ‘Priscilla’ (*data not shown*). Slaton et al. (26) reported that the incidence of sheath blight increased earlier in the season as the PF N rate increased on the sheath blight susceptible cultivar ‘Cocodrie.’ However, Slaton et al. (26) also reported that yield potential increased with increasing PF N rate.

Table 3. Mean rice grain yield pooled across N rate and application timing for ‘Lemont’ and ‘Priscilla.’

N rate (kg/ha)	**Yield** (kg/ha)	
	‘Lemont’	‘Priscilla’
101	7553a	7986a
151	8249a	8644b
202	8388a	9052b
270	8171a	9042b
Timing[x]		
50/50	8681a	8556a
67/33	8007ab	8747a
100	7584b	8740a

Means in the same column within followed by a different letter are significantly different at the 0.05 significance level.

[x] Represents percentage of N applied PF and percentage applied in equal applications at 1.3-cm IE and 1.3-cm IE + 7 days.

Based on these yield data, N rate recommendations that are derived from studies where clay soils have not been recently disturbed are sufficient for the cut areas of soils that have been recently leveled; therefore, the hypothesis that additional N is needed in the cut areas because of decreased total N was not supported. Though there were relatively large reductions in total N when comparing pre-leveling values to planting values, N response for both varieties was similar to what has been observed on non-disturbed soils (18).

Concentrations of total N and Lancaster-P declined with soil profile depth on Sharkey clay and silty clay soils. Though Lancaster-P concentrations decreased, they were well above the published critical level for rice. Soil pH significantly decreased at one location, but remained at a level that would promote near optimum nutrient availability in a flooded soil environment (22). Sodium and Mg tended to increase with increasing profile depth, whereas only minor changes were detected for Ca and Zn. Rice grain yields decreased as the percentage of PF N increased for ‘Lemont’; however, timing did not affect grain yields for ‘Priscilla.’ Optimum yields for ‘Priscilla’ were obtained at the N rate of 151 to 202 kg of N per ha, which is very similar to what is recommended in Mississippi on non-disturbed clay soils.

These data suggest that the cut areas of newly precision-leveled clay soils can be fertilized with N rates that are similar to what is recommended for non-disturbed clay soils. For Priscilla, applying 100% of the N PF is an alternative for growers who can practice efficient water management, i.e., fertilize and establish a permanent flood within 5 days after N application. For cultivars that are susceptible to sheath blight, growers must make their N management decision realizing that a fungicide application may be required for susceptible cultivars when higher PF N rates are applied.

Acknowledgments

The authors thank Mr. Grady Jackson for the technical support in data collection and processing. The Mississippi Rice Promotion Board provided partial funding for this research. Published with the approval of the Director of the Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, manuscript number J-10978.

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