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Rice Yield and Soil Chemical Properties as Affected by Precision Land Leveling in Alluvial Soils

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ABSTRACT

In 1998 and 1999, two soil series representative of a large percentage of rice (*Oryza sativa* L.) growing hectarage in the Mississippi Delta were sampled in increments to a depth of 120 cm. Measurements were made to determine how extractable levels of Ca, K, Mg, Na, P, and Zn as well as the total N content and soil pH varied with respect to soil profile depth. Total N, extractable P, Zn, Ca, and pH all tended to decrease with depth while Na tended to increase. Only small differences were seen in Mg and K concentrations. An on-farm study was conducted in 2000 and 2001 to further investigate the effects of precision land leveling on pH and concentrations of organic matter and extractable nutrients. This study was conducted on seven farms, all of which possessed yield monitor–equipped combines. Field elevation sheets and GPS/GIS technologies were utilized to investigate soil nutrient and yield data for areas of *cut* and *fill* at each location. Yields were lower in the cut areas than the fill areas on five of the seven fields. Results from the soil nutrient data were similar to those findings in 1998 and 1999. A nutrient deficiency was apparent in only one of the five fields where yields were reduced. However, the percentage yield loss in the cut areas compared with the fill areas was directly proportional to the volume of soil moved per hectare during the precision land-leveling process (r^2 = 0.78). This research indicates that yields can be reduced after precision land leveling in many soil types, but the reduction may or may not be nutrient related.

In recent years, the market price for rice has decreased, but the cost for producing the crop has not. Hence, it is critical to increase rice yields and decrease production inputs to offset the decrease in value. A cultural practice that many producers in Mississippi have adopted as a result is precision land leveling. Approximately 40 to 50% of the total rice produced in Mississippi in 2001 was produced on fields precision-leveled to a slope of 0 to 0.2% (J.E. Street, personal communication, 2001). Precision land leveling involves altering the field in such a way as to create a constant slope of 0 to 0.2%. This practice makes use of large horsepower tractors and soil movers that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved by either cutting or filling to create the desired slope. Once the slope is created, levees can be constructed so that a flood depth of between 10 and 20 cm can be maintained.

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Soils that have been precision land-leveled have more desirable flooding and drainage characteristics. Optimizing the flood depth increases nutrient availability and weed control. Good drainage characteristics aid in harvest efficiency as well as create a larger window for practices that need to be done in the spring (Street and Bollich, 2002).

Some production costs can be reduced when fields are precision land-leveled. On average, water usage is less for precision land-leveled fields than contour-leveed fields (Cooke et al., 1996). Levees are constructed straight and perpendicular to the slope of the land. This practice reduces the amount of hectarage required for levees, decreases tillage, and increases harvest efficiency (Ellis, 1982; Johnston and Miller, 1973). Precision land leveling also gives producers the option of applying some pesticides and nutrients with ground equipment as opposed to aerial application. Labor cost savings are an additional benefit. Precision land-leveled rice production requires about half the labor required for contour-leveed rice (Laughlin, 2000). All of the above factors contribute to average projected returns of \$199.30 ha^{-1} for precision land-leveled rice compared with \$67.16 ha^{-1} for contour-leveed rice, using 2001 commodity and production prices (Laughlin, 2000).

Although precision land-leveled rice fields produce higher yields on average, some yield depressions can be seen in the cut areas, especially the first year after precision land leveling. Topsoil is rich in both organic matter and available nutrients, such as P and K, that are less mobile in the soil (Dobermann et al., 1997). Upon removal of the topsoil and subsequent exposure of subsoil, rice roots will be in contact with a much different chemical, physical, and microbiological environment. Total N and Lancaster-extractable P levels decrease with increasing depth into the soil profile (Walker et al., 2001). Studies in Arkansas in the 1980s revealed that yield was decreased, and variability of available nutrients increased as a result of precision land leveling (Miller, 1990).

Rice production in Mississippi occurs on various soil types that range in texture from clay to sandy loam. Growers throughout the alluvial region known as the Delta have had conflicting opinions about yield reduction on newly precision land-leveled rice fields. Some producers have stated that yields were reduced on fine-textured clay soils while others have stated that their yields were only reduced on the coarser-textured soils such as silt and sandy loams. The lack of available information on the effects of precision land-leveling alluvial soils justifies the conflicting information that was available before this study.

The objective of this study was to determine the effects that precision land leveling has on yield and soil chemical properties, including pH, extractable nutrients, and organic matter content across various alluvial soils on which rice is produced in the Mississippi Delta.

MATERIALS AND METHODS

Soil Profile Descriptions

The soils selected for study in 1998 and 1999 were located in Bolivar and Coahoma counties and represented two soil series and two soil textures on which much of the rice hectarage in Mississippi is produced. The soil series, their respective surface textures, and the locations from which the samples were collected are as follows: Alligator clay, near Clarksdale; Alligator silty clay, Shelby; and Sharkey silty clay, Shelby. Soil series descriptions are given in Table 1.

Before precision land leveling, four soil cores at each study site were collected with a 6-cm-diam. bucket auger at randomly selected points that would be located within a cut area on precision land leveling. The first two sampling depths were taken in 15-cm increments, and the remaining three were taken in 30-cm increments to the depth of 120 cm for a total of five sample depths. The soils were air-dried and ground to pass a 2-mm sieve, and pH (1:1 H_2O), Lancaster (Raspberry and Lancaster, 1977; Cox, 2001)-extractable nutrients (Ca, K, Mg, Na, P, and Zn) [measured by inductively coupled argon plasma spectroscopy (ICAP)] (Perkin Elmer Optima 4300DV OES, Perkin Elmer, Norwalk, CT), and total N and C (Carlo Erba N/C 1500 dry combustion analyzer, Carlo Erba Instruments, Milan, Italy) were determined.

This experiment was analyzed as a randomized complete block design in which sampling points were blocks and sampling depths were treatments. A general linear models procedure (SAS Inst., 1999) was used to test the variation in soil chemical properties. Means for observations made at each soil depth were separated using Fisher's protected LSD at the 5% significance level. Each location was analyzed separately.

Soil Chemical Properties and Precision Land Leveling

In 2000 and 2001, seven newly precision land-leveled fields, which are described in Tables 1 and 2, were soil-sampled before planting, with the exception of the site labeled as Dean-E, which was sampled one month after harvest. The various-sized fields were divided into 0.8-ha quadrants with the use of Farm GPS software (Red Hen Syst., 1997) aided by a Trimble AgGPS-132 DGPS receiver (Trimble Navigation Limited, Sunnyvale, CA). Farm GPS was then used to navigate to the central point of the 0.8-ha grid, which served as the center of eight soil-sampling points that were randomly selected within a 10-m radius of the central point. The soil samples were taken to a depth of 15 cm and composited. Soils were air-dried and sieved (2 mm) before performing the same measurements described above.

Table 1. Official descriptions of the soils sampled in 1998–2001.

Soil type	Description
Alligator	very-fine, smectitic, thermic Chromic Dystraquerts
Dowling	very-fine, smectitic, nonacid, thermic Vertic Endoaquepts
Dundee	fine-silty, mixed,active, thermic Typic Endoaqualfs
Forestdale	fine, smectitic, thermic Typic Endoaqualfs
Sharkey	very-fine, smectitic, thermic Chromic Eqiaquerts
Tunica	clayey over loamy, smectitic over mixed, superactive, thermic Vertic Epiaquepts

Yield

The cooperating producers harvested the fields of interest with GPS yield monitor–equipped combines. After harvest, the yield monitor data were entered into ArcView (ESRI, 1999), a geographical information system (GIS), to accompany the soils data. Elevation sheets, which delineated the areas of cut and fill based on 30-m^2 grid spacings, were obtained from the cooperating producers. These data were not digitally available; hence, the hard copies of the cut sheets were manually overlain onto properly scaled field maps that contained the sample points. This allowed each sample point to be labeled with a cut or fill classification that was used in the statistical analyses. Using ArcView, means of rice yields were obtained from selected 30-m^2 areas centered on each sampling point.

This experiment was analyzed as a completely randomized design. A general linear models procedure (SAS Inst., 1999) was used to test the differences in elevation after precision land leveling, i.e., cut or fill, on yield, extractable Ca, K, Mg, Na, P, Zn, total N, total C, and pH. Means for the effect of precision land leveling were separated using Fisher's protected LSD at the 5% significance level.

RESULTS AND DISCUSSION

Soil Profile Descriptions

Analysis of variance revealed that differences in nutrient concentrations occur with a change in sampling depth. Total N, P, Zn, pH, and Ca levels decreased with increasing soil profile depth for each of the soils that were investigated (Tables 3–5). The decrease in total N is most probably a result of decreased organic matter in the subsurface horizons (Kundu and Ladha, 1997). Because P and Zn are considered immobile nutrients, their decrease with soil depth is justified (Dobermann and Fairhurst, 2000). A decrease in Bray (II) P was also

Table 2. Year, location, soil type, and rice cultivar for leveled fields sampled in 2000 and 2001.

Year	Site	Location	ha	m^3 ha^{-1}†	Soil type(s)	Cultivar
2000	Rich-1	near Leland	30	610	Sharkey c	Lemont
2000	Rich-2	near Leland	37	630	Sharkey c	Lemont
2000	Steed-C	Shelby	18	1880	Alligator c, Dowling c, Tunica sic	Cocodrie
2000	Steed-P	Shelby	7	2210	Dundee sicl, Dowling c	Priscilla
2001	Dean-E	Boyle	14	570	Forestdale sicl, Forestdale sil	Cocodrie
2001	Jack-E	near Tchula	24	760	Forestdale sil	Priscilla
2001	RSE	Leland	27	680	Sharkey c	Lemont

† Indicates the average soil volume cut per hectare.

Table 3. Soil chemical properties measured at depths of 0 to 120 cm for an Alligator clay soil, before leveling.

Depth	Ca	K	Mg	Na	P	Zn	N	pH
cm	mg kg^{-1}							
0–15	5780a†	344	1570d	68e	77a	6.3a	2120a	6.6ab
15–30	5820a	378	1640d	135d	61a	6.0a	1730b	6.8a
30–60	5220a	360	1760c	266c	37b	5.6a	1200c	6.3b
60–90	4590b	356	1960b	429b	27bc	4.3b	890d	5.7c
90–120	4220b	372	2110a	538a	16c	3.7b	800d	5.6c
LSD	268	NS‡	79	39	19	1.3	260	0.3

† Means in the same column followed by the same letter are not significantly different ($\alpha = 0.05$).
‡ NS, not significant at the 0.05 level of probability.

reported by Schumacher et al. (1988) for both Sharkey and Alligator soils in Louisiana.

It was reasonable to expect that the cropping history of these soils has greatly effected the soil pH in the uppermost 30 cm. Underlying aquifers used for irrigation of rice and soybean [*Glycine max* (L.) Merr.] can contain dissolved Ca, Mg, and Na carbonates and bicarbonates (Thomas, 2001). Because a rice rotation has been in place in the Alligator silty clay field, the elevated pH and the higher concentration of Ca levels in the top 30 cm seems justified (Table 4). Although the extractants are different, these Ca data were similar to the NH_4OAc-extractable Ca for four Alligator clay soils in Louisiana, which averaged 4030 mg kg^{-1} in the Ap horizons and 4610 mg kg^{-1} in the Bg3 horizons (Schumacher et al., 1988), and the Lancaster-extractable Ca in a pecan (*Carya illinoinensis*) orchard on an Alligator clay in Mississippi, which ranged from 3888 mg kg^{-1} at the surface to 5600 mg kg^{-1} at a depth of 100 cm (Green et al., 1998).

Potassium and Mg concentrations remained unchanged for two of the three soils. Average K and Mg levels practically remained stable for the Alligator silty clay (Table 4). Magnesium levels were also stable for the Sharkey silty clay (Table 5) while K levels were stable for the Alligator clay (Table 3); however, average Mg concentrations increased with increasing profile depth for the Alligator clay (Table 3) while K concentrations decreased with increasing soil depth for the Sharkey silty clay (Table 5). Both Mg and K concentrations for each of the three soils are very similar to those reported by Green et al. (1998) for Alligator and Sharkey soils.

Sodium levels were similar for the 0- to 15-cm depths for each of the three soils; however, for the Alligator clay, Na increased from 68 mg kg^{-1} in the surface 15 cm to 538 mg kg^{-1} at the deepest depth (Table 3), which was approximately 4.5 times greater than the Alligator silty clay (Table 4) and 7.5 times greater than the Sharkey silty clay (Table 5). The Na values for the Alligator clay, though large compared with the other soils listed, were similar to those reported by Pettry and Wood (1996) on an Alligator clay in Quitman County, MS, where Na levels ranged from 53 mg kg^{-1} in the top 25 cm to 794 mg kg^{-1} at the 60- to 130-cm depth. A Sharkey clay soil in Louisiana was reported by Schumacher et al. (1988) with NH_4OAc-extractable Na levels that ranged from 69 mg kg^{-1} in the surface 15 cm to 184 mg kg^{-1} at the 60- to 90-cm depth.

After investigating the nutrient concentrations at different soil depths, it was determined that except for N, a yield response to added fertilizer would not have been expected for any other nutrient on any of the soils, except for P for the Alligator clay at the lowest sampling depth. The Mississippi Soil Testing Laboratory separates Lancaster P levels into the following categories to determine the fertilizer recommendation: 0 to 4.5 mg kg^{-1} (VL), 4.51 to 9.0 (L), 9.1 to 18 (M), 18.1 to 23 (H), and >23.1 (VH). The fertilizer recommendations for

Table 4. Soil chemical properties measured at depths of 0 to 120 cm for an Alligator silty clay soil, before leveling.

Depth	Ca	K	Mg	Na	P	Zn	N	pH
cm	mg kg^{-1}							
0–15	7140a†	295	1240b	60c	87a	5.6	1380a	7.7a
15–30	6110b	285	1240b	90b	62b	4.8	920b	7.7a
30–60	5470b	279	1320a	116a	53b	4.9	740bc	7.4b
60–90	4640c	281	1300ab	121a	32c	3.9	660c	6.1c
90–120	4420c	276	1340a	121a	32c	3.5	600c	5.9c
LSD	685	NS‡	72	12	12	NS	190	0.3

† Means in the same column followed by the same letter are not significantly different ($\alpha = 0.05$).
‡ NS, not significant at the 0.05 level of probability.

Table 5. Soil chemical properties measured at depths of 0 to 120 cm for a Sharkey silty clay soil, before leveling.

Depth	Ca	K	Mg	Na	P	Zn	N	pH
cm	mg kg^{-1}							
0–15	4370a†	296a	1040	50	94a	5.8a	1330a	6.5a
15–30	4520a	272a	1060	68	55b	6.0a	970b	6.1b
30–60	4460a	275a	1110	79	44b	4.7ac	830b	5.8c
60–90	3920b	246b	1040	75	42b	3.3bc	600c	5.7c
90–120	3740b	223b	1000	73	48b	3.6b	530c	5.8c
LSD	380	26	NS‡	NS	15	1.7	184	0.3

† Means in the same column followed by the same letter are not significantly different ($\alpha = 0.05$).
‡ NS, not significant at the 0.05 level of probability.

Table 6. Comparison of soil chemical properties and rice yield for cut areas and fill areas for fields sampled in 2000.

Location		pH	Ca	K	Mg	Na	P	Zn	N	C	Yield
			mg kg^{-1}								kg ha^{-1}
Rich-1	Cut	6.6	5 790	274b†	1 490	203a	58b	5.2b	1 440b	13 970b	8 100b
	Fill	6.6	5 780	310a	1 440	131b	70a	5.9a	1 780a	18 860a	8 990a
	LSD	NS‡	NS	10	NS	49	7	0.6	217	2 610	781
Rich-2	Cut	6.6	5 940	274b	1 470	169a	58b	4.2b	1 480b	14 790b	7 300
	Fill	6.6	5 910	310a	1 470	118b	67a	5.5a	1 680a	17 780a	6 620
	LSD	NS	NS	12	NS	28	7	0.8	166	1 990	NS
Steed-C	Cut	5.5a	4 030	266b	1 730	198a	58	3.0	788	5 950	4 800b
	Fill	5.2b	4 030	292a	1 670	135b	52	2.8	890	7 130	8 490a
	LSD	0.1	NS	19	NS	63	NS	NS	NS	NS	1 000
Steed-P	Cut	5.6	4 330	207	1 130	82	50	1.9	720b	5 800	5 280b
	Fill	5.5	4 220	223	1 050	55	44	1.9	911a	7 980	8 460a
	LSD	NS	NS	NS	NS	NS	NS	NS	188	NS	1 320

† Means in the same column followed by the same letter are not significantly different within location ($\alpha = 0.05$).
‡ NS, not significant at the 0.05 level of probability.

the categories of VL to VH are 40, 20, 15, 0, and 0 kg P ha^{-1}, respectively. Hence, if a minimum of 90 cm of soil would have been removed, an application of 15 kg P ha^{-1} would have been recommended.

Soil Chemical Properties and Precision Land Leveling

The data presented in Tables 6 and 7 indicate that no differences in the mean concentrations of Ca resulted from the precision land-leveling practice at any of the locations. These data also indicate that Mg concentrations were different in the cut area when compared with those in the fill area at only one location, which was Dean-E. At this location, Mg in the cut was approximately 200 mg kg^{-1} greater than in the fill area, which was just beyond the LSD of 153 mg kg^{-1} (Table 7). The values reported for the clay-textured soils correspond well to those given in the previously discussed profile descriptions.

Although no significant differences in mean K concentrations were detected at Steed-P (Table 6) and Dean-E (Table 7), the trend for all locations was that K concentrations were less in the cut areas than in the fill areas. However, these differences would not limit rice yield, according to the Mississippi Soil Testing Laboratory recommendations. Just as was described earlier for P, a predicted yield response for K would only occur if the soil test level for K was at or below 90 mg kg^{-1}.

Zinc and P levels were lower in the cut areas than the fill areas for the Sharkey soils (Table 6 and Table 7), but no differences occurred for the other soils, except for Jack-E, which contained less P in the cut areas than the fill areas (Table 7). Though there was a difference in P, no yield response from a P fertilizer application would have been recommended based on the information previously discussed. No yield response would have been predicted for a Zn application either because even the lowest reported concentrations were still greater than the 0.8 mg kg^{-1} margin of cutoff for an expected yield response.

Sodium followed the same trend in the field studies that was observed in the profile descriptions. Except for the coarse-textured soil at Jack-E, Na was greater in the cut areas than the fill areas. Sodium was actually four to eight times lower at Jack-E than other locations. Even though rice was grown on the soil at Jack-E, the soil is not typical of most rice-producing soils in Mississippi. This soil is suitable for the corn (*Zea mays* L.)–cotton (*Gossypium hirsutum* L.) rotation in which it has been for the last several years and will go back into that rotation in 2003. It has a lower cation exchange capacity and much better internal drainage than the soils with higher clay content; therefore, the Na concentration in the soil is expected to be low compared with the other soils.

Soil pH for all of the locations was in the range of 5.2 to 7.1 (Tables 6 and 7). Though some fields had different pH levels in the cut and fill areas (Tables 6 and 7), none of the differences were deemed important in terms of affecting rice growth because the flooded culture of rice aids in alleviating many nutrient disorders related to soil pH (De Datta, 1981).

The general trend for total N and total C followed the data discussed earlier for the profile descriptions

Table 7. Comparison of soil chemical properties and rice yield for cut and fill areas for fields sampled in 2001.

Location		pH	Ca	K	Mg	Na	P	Zn	N	C	Yield
			mg kg^{-1}								kg ha^{-1}
Dean-E	Cut	6.5b†	3 420	172	1 160a	122a	29	1.7	968b	13 770b	5 850b
	Fill	7.1a	3 800	177	957b	79b	36	2.6	1 250a	18 190a	7 840a
	LSD	0.5	NS‡	NS	153	20	NS	NS	200	4 350	1 390
Jack-E	Cut	5.5b	1 810	167b	244	26	68b	3.3	526b	6 350b	10 540
	Fill	6.3a	1 800	249a	220	22	84a	3.4	633a	7 920a	10 120
	LSD	0.3	NS	36	NS	NS	11	NS	71	1 150	NS
RSE	Cut	6.7	3 680	231b	947	110a	59b	4.2b	863b	11 080b	8 400b
	Fill	6.6	3 680	279a	921	87b	77a	5.0a	1 120a	14 620a	8 980a
	LSD	NS	NS	26	NS	15	12	0.5	122	1 680.0	527

† Means in the same column followed by the same letter are not significantly different within location ($\alpha = 0.05$).
‡ NS, not significant at the 0.05 level of probability.

(Tables 6 and 7). There were only two locations in which the total C concentrations were not less in the cut areas than the fill areas (Tables 6 and 7), and these same areas also were practically the same in total N content although the difference in Steed-P for total N was 191 mg kg^{-1}, which was slightly higher than the 188 mg kg^{-1} LSD.

Actually, the data indicate that the means of almost all of the measured soil parameters for the cut areas and fill areas for Steed-C and Steed-P were essentially the same (Table 6). These data can be explained by the cut-sheet information. An average of 1880 m^3 ha^{-1} soil for Steed-C and an average of 2210 m^3 ha^{-1} soil was cut for Steed-P (Table 2). The resulting surface layer in the *fills* that are performed on fields when large volumes of soil are moved actually contain a relatively deep layer of subsoil when compared with fields with smaller volumes of moved soil. Volumes of soil that were moved for each of the other fields that were studied ranged from approximately 570 at Dean-E to 760 m^3 ha^{-1} soil at Jack-E.

Yield

Analysis of variance indicated that rice yield in five of the seven fields was lower in the cut areas than in the fill areas. Rich-2 and Jack-E were the only sites in which yield did not differ from cut to fill areas (Tables 6 and 7). Of those fields in which yield was less in the cut area than the fill area, Rich-1 and RSE resulted in the least amount of yield loss (Tables 6 and 7). The cut areas in Dean-E averaged 5850 kg ha^{-1}, which was approximately 2000 kg ha^{-1} less than the 7840 kg ha^{-1} average that resulted in the fill areas (Table 7).

Part of this yield reduction can be attributed to a P deficiency that occurred in one area of the field. Lancaster P levels in this area decreased to <4.5 mg kg^{-1}. However, in an adjacent cut area, P levels were sufficient for rice growth, but the yields were still less than what was obtained in the fill area.

The largest yield reduction occurred at Steed-C and Steed-P (Table 6). Yields in the cut areas averaged 4800 kg ha^{-1} for Steed-C and 5280 kg ha^{-1} for Steed-P while the fill areas averaged 8490 kg ha^{-1} for Steed-C and 8460 kg ha^{-1} for Steed-P. As was previously mentioned, soil fertility levels were sufficient throughout the entire field; however, the yield reduction corresponds well to the volume of soil per hectare that was cut in these two fields ($r^2 = 0.78$). The fact that there were small fertility differences with concomitant large yield differences when comparing the cut and fill areas promotes the idea that something other than fertility levels was affecting yields.

Some general conclusions can be made from these data. Most soil nutrient levels remain at productive levels even at depths of 120 cm for soils with clayey textures. It should be noted, however, that P, which is very important to rice root growth and tillering (De Datta, 1981), decreased to a level that would have warranted an application when a cut greater than 90 cm was made on an Alligator clay soil. These data also indicated that some coarser-textured soils, such as at Dean-E, may contain a lower native P level, which would require a P fertilizer application, especially in the cut areas for optimum rice production. Furthermore, it is likely that yields will be reduced in the cut areas regardless of the soil texture and resulting fertility level after precision land leveling. The magnitude of yield loss seems to be more related to the quantity of soil that was moved. However, a nutrient deficiency such as P will further magnify the yield loss, as was seen at one location. Using the yield losses reported here and the 2001 market price for rice, economic losses ranged from \$85 to \$542 ha^{-1} in the cut areas of the fields. The significance of these economic losses on a whole-field basis depended on the ratio of cut hectarage to fill hectarage, i.e., the higher the percentage of cut hectarage, the greater the significance of economic losses the first cropping year after precision land leveling.

In a study conducted in conjunction with the one reported, it was determined that N fertilizer rates and application timing recommendations for contour-leveed rice are suitable for newly precision land-leveled fields. It is also recommended that at least 27 kg S ha^{-1} be applied between planting and permanent flood establishment to avoid an expected S deficiency because of the decrease in soil organic matter due to precision land leveling. However, experiments should be conducted to test whether compaction is a yield-limiting factor in precision land-leveled soils because of the many passes of heavy equipment across the cut areas of fields being leveled, in addition to the fact that bulk densities are greater in subsoil than in topsoil. Kundu et al. (1996) noted that soil compaction restricted root penetration and proliferation, which caused underutilization of the available soil nutrients below the compacted zone and thus resulted in a decrease in rice yields. Furthermore, current soil test recommendations are based on research performed in the 1970s for cultivars whose yield targets were 4500 kg ha^{-1}, and N applications seldom exceeded 120 kg ha^{-1} (Anderson, 1970). It is imperative that these recommendations be validated for the modern cultivars that have greater yield potential, require approximately 70% more fertilizer N, and have a 20- to 30-d shorter growing period.

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