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First-year soybean growth and production as affected by soil properties following land leveling

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Abstract

In severely disturbed soils, such as those that have been recently land leveled, the interactions among soil properties are accentuated because of the disruption of pre-leveling equilibrium, and manifest their controlling influence on growth and production of sensitive crops, such as soybean [*Glycine max* (L.) Merr.]. The objective of this study was to identify pre-plant soil properties that influence first-year soybean growth and production following shallow land leveling in an alluvial soil commonly used for rice and soybean production in the Mississippi Delta region in eastern Arkansas, USA. Soil physical (i.e., bulk density and particle-size fractions), chemical (i.e., organic matter, pH, electrical conductivity, and extractable soil nutrients) and biological (i.e., bacterial and fungal biomass) properties were evaluated in the top 10 cm of soil following land leveling. Soybean leaf area index at the R5-6 growth stage, plant population, above-ground dry matter, seed yield and harvest index were also measured at 50 grid points spaced evenly within a 0.36-ha study area. Post-leveling soil properties were significantly correlated with first-year soybean growth and production parameters. Variations in soil chemical properties, particularly extractable soil nutrient contents, organic matter concentrations and biological properties (i.e., microbial activities) accounted for the largest percentage of the variability in first-year soybean growth and production parameters. Results from this study indicate that factors other than those measured in this study, such prolonged soil moisture conditions and poor internal drainage, may contribute to the resulting variability of first-year soybean growth and productivity following land leveling.

Abbreviations: BD – bulk density; CV – coefficient of variation; DM – dry matter; EC – electrical conductivity; HI – harvest index; LAI – leaf area index; OM – organic matter; SE – standard error

Introduction

Land leveling is a relatively common agricultural practice in the south-central United States to facilitate more uniform distribution of irrigation water and to maintain more uniform soil moisture conditions (Cooke et al., 1996). Land leveling is routinely performed in fields where irrigated crops will be grown, such as rice (*Oryza sativa* L.) and soybean [*Glycine max* (L.) Merr.]. Many have reported a decline in soil fertility coupled with reduced crop productivity as a result of land leveling. Deficiencies in essential plant nutrients [e.g., nitrogen (N) and phosphorus (P)] can limit crop growth following land leveling (Whitney et al., 1950; Eck, 1987; Robbins et al., 1997, 1999). Exposing the subsoil can also result in major changes in surface soil pH, decreased organic carbon and exposure of sodic horizons (Miller, 1990).

In the mid-southern United States, rice is typically grown in the first year following land leveling

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because the flooded soil environment can facilitate nutrient availability and the fibrous root system of rice has a much larger surface area for nutrient uptake in the disturbed soil following land leveling. In contrast, to maintain a crop rotation, soybean may be grown immediately after land leveling. However, soybean is more sensitive to disturbed soil conditions and altered soil fertility than rice. This presents potential management difficulties with a first-year soybean crop following land leveling because significant alteration of the magnitudes and spatial distributions of soil physical, chemical, and biological properties can occur after even relatively shallow land leveling activities (Brye et al., 2003, 2004; Walker et al., 2003). A potential complication for management of a first-year soybean crop following land leveling is that soybean growth and yield have been shown to be responsive to a wide variety of stimuli that are directly related to soil physical and chemical properties. Therefore, it may be difficult to determine and address potential yield-limiting factors prior to planting.

Much is known about the importance of proper soybean nutrition and growth as well as productivity response to various macro-nutrients, such as P (Grabau et al., 1986), calcium (Ca; Kirkby and Pilbeam, 1984; Keiser and Mullen, 1993), magnesium (Mg; Univ. Ark., 2000), and micro-nutrients, such as manganese (Mn; Leidi et al., 1987; Marschner, 1995; Purcell et al., 2000; Univ. Ark., 2000), iron (Fe; Leidi et al., 1987; Mortvedt, 1991; Jolley et al., 1996; Univ. Ark., 2000), boron (B; Guertal et al., 1996; Univ. Ark., 2000) and zinc (Zn; Hazra and Mandal, 1996; Mandal et al., 2000), in non-leveled soils. However, relatively little information exists on the relationships among soil chemical properties and soybean yield following severe soil disturbance from land leveling activities.

Since soil pH affects the availability of most essential plant nutrients and is a controlling factor for many plant and microorganism processes, exposing subsoil with an acidic pH could negatively affect subsequent crop growth. If the soil pH decreases to around 5.5 or less, aluminum toxicity may result (Tisdale et al., 1993). In contrast, molybdenum, required by nodule-forming bacteria in soybean that perform N_2 fixation, may become deficient at pH < 5.8 (Univ. Ark., 2000). However, increases in soil pH have been related to increased severity of sudden death syndrome and increased quantities of inocula that cause this disease in soybean (Sanogo and Yang, 2001). Soybean root growth has also been shown to be sensitive to pH (Suthipradit and Alva, 1986). In addition to the potential effects of soil chemical properties, soil physical properties, such as sand content (Sanogo and Yang, 2001), soil compaction (Baligar et al., 1975) and soil bulk density (Baligar et al., 1980), have been shown to affect soybean growth and productivity in non-leveled soil, but less information exists for soils severely disturbed by land leveling.

Since a multitude of knowledge exists for soybean response on non-leveled soils and very little, if any, information are available for soybean response on land-leveled soils, a better understanding of possible soil factors that influence soybean growth and productivity could improve management, and ultimately yield, of first-year soybean crops following land leveling. Furthermore, little is known about the potential relationship between soil biological properties, such as microbial biomass, and soybean growth and productivity in the first year following relatively shallow land-leveling activities.

The objectives of this study were to (i) identify pre-plant soil physical, chemical, and biological properties that influence first-year soybean production; and (ii) evaluate the influence of spatial variability of soil properties on first-year soybean production following shallow-cut land leveling in an alluvial soil commonly used for irrigated rice and soybean production in the Mississippi Delta region in eastern Arkansas, USA. We hypothesized that (i) soybean growth and production are significantly related to post-leveling, pre-plant variations in extractable soil nutrients; (ii) post-leveling, pre-plant variability of soil chemical properties, particularly macro- and micro-nutrient contents, affect soybean production more than the variability of soil physical properties and; (iii) post-leveling, pre-plant variability of soil biological properties are significantly related to soybean growth and production in the first year following shallow-cut land leveling.

Methods and materials

Site description

The study site consisted of a 0.36-ha area within an approximately 25-ha field predominantly cropped to rice and located in Arkansas County, Arkansas (34°6′ N, 91°22′ W). The soil was a Stuttgart silt loam (fine, smectitic, superactive, thermic Albaqultic Hapludalf; SSD, 2002). The Stuttgart series, formed in silty and clayey alluvium, is a very deep, moderately well to somewhat poorly drained and slowly permeable soil.

Prior to land leveling, the entire field was under rice production and was gently rolling with the slope ranging from 1 to 2%. The slope within the 0.36-ha study area was more subtle, ranging from 0 to $< 1\%$.

Experimental design

Following land leveling, a 40×90-m sampling grid was established in the study area. Grid points were spaced evenly at 10-m apart in both directions, for a total of 50 grid points, to facilitate evaluation of the spatial distribution and variability of first-year soybean growth and production parameters following shallow-cut land leveling. The grid was positioned in the field so that roughly one-half of the sampling area was cut (i.e., topsoil was scrapped and removed from an area of relatively high elevation) and the other half was filled (i.e., deposition into an area of relatively low elevation of soil previously scrapped and removed from another area within the same field).

Study site manipulations

Land leveling of approximately 5 ha of the 25-ha field occurred at the site in April 2002 resulting in a uniform, approximately 0.2% slope throughout the study area. After initial cutting and filling occurred, the entire manipulated area was re-graded to eliminate minor topographic variations. During the re-grading process, some material originally removed from the cut area was pushed from the filled area back onto the cut area. Overall, the maximum depth of soil manipulation was relatively shallow, approximately 15 cm.

Within 2 weeks following land leveling and several weeks prior to soybean planting, semi-solid composted poultry litter was broadcast at approximately 2.2 Mg ha^{-1} fresh weight, as recommended by the University of Arkansas Cooperative Extension Service (Slaton, 2001), throughout the entire study area using a tractor-drawn manure spreader. The exact chemical composition and physical character of the composted poultry litter applied to the study area is not known. However, composted poultry litter from northwest Arkansas typically has a pH of 8.0 to 8.7 and contains ~ 36 g kg^{-1} N, 1.6 to 3.0 g kg^{-1} soluble-reactive P, 31 to 35 g kg^{-1} total P and ~ 21 g kg^{-1} K on a dry-weight basis (Edwards and Daniel, 1992; Govindasamy et al., 1994; DeLaune, 1999). These concentrations and contents are similar to the chemical composition of other sources of composted poultry litter in the southeastern U.S. (Tyson and Cabrera, 1993; Warren and Fonteno, 1993; Freeman and Cawthon, 1999). The addition of poultry litter was assumed to effect the entire study area equally; thus having a consistent, if any, overall effect on soybean growth.

Following poultry litter application, the soybean variety Armor 54-Z4 (conventional maturity group 5) was sown into soil with adequate moisture conditions at a row spacing of 76 cm and a seeding rate of 63 kg ha^{-1} (i.e., ~ 1 bu acre^{-1}). The soybean crop was flood irrigated on an as-needed basis approximately three times throughout the growing season.

Soil sampling and measurements

In May 2002, approximately 1 week following poultry litter application, post-leveling soil samples were collected for physical, chemical, and biological property determinations. Prior to collecting soil samples at each grid point, any poultry litter remaining of the soil surface was scrapped aside to minimize litter effects on soil properties. A single 4.8-cm diameter soil core (the soil-core sampling chamber was beveled to the outside to minimize compaction upon sampling) was collected from the 0- to 10-cm depth within a 20-cm radius surrounding each grid point, oven dried at 70 °C for 48 h, and weighed for bulk density determination. Oven-dried soil samples were subsequently crushed and sieved to pass a 2-mm mesh screen for determination of the percentages of sand, silt, and clay using the hydrometer method (Arshad et al., 1996). Ten 2-cm diameter soil cores were collected and composited from the 0- to 10-cm depth within the 20-cm radius surrounding each grid point, oven dried at 70 °C for 48 h, and crushed and sieved to pass a 2-mm mesh screen for soil chemical property determination. Dried and sieved soil was extracted with Mehlich-3 extractant solution (Tucker, 1992) in a 1:10 soil-to-extractant solution ratio and analyzed for extractable nutrients [i.e., P, K, Ca, Mg, sodium (Na), sulfur (S), Fe, Mn, Zn, copper (Cu), and B] by inductively coupled Argon-plasma spectrophotometry. Soil pH and EC were determined potentiometrically on a 1:2 soil-to-water paste. Organic matter was determined by weight-loss-on-ignition after 2 h at 360 °C (Schulte and Hopkins, 1996). A second set of ten 2-cm diameter soil cores was collected and composited from the 0- to 10-cm depth within the 20-cm radius surrounding each grid point. These samples were immediately iced in the field, then refrigerated for fungal and bacterial biomass determinations. A dilution series was prepared from fresh soil samples and aliquots removed for bacterial and fungal agar-plate counts. Total fungal (Ingham and Klein, 1984) and bacterial biomass (Babiuk and Paul, 1970) concentrations were estimated by epi-fluorescent microscopy and sample staining. The ratio of fungal to bacterial biomass content was also calculated for each sample.

Plant sampling and measurements

Soybean leaf area index (LAI) was measured at each grid point during the R5 to R6 reproductive stage (Fehr et al., 1971), approximately four weeks prior to harvest, using a LI-COR LAI-2000 plant canopy analyzer (LI-COR, Inc., Lincoln, NE 68504, USA; Wells and Norman, 1991) on a day with uniformly overcast sky conditions, which is recommended for obtaining LAI measurements. Each LAI measurement consisted of one above-canopy measurement with four below-canopy measurements taken in the row and at one-quarter, one-half, and three-quarters of the inter-row distance to the adjacent row.

On 5 October 2002, following relatively uniform maturation by visual observation, a 1-m length of row straddling each grid point was harvested by hand. The number of plants per 1-m row was recorded for plant population determination based on a 76-cm row spacing. Harvested plant samples were air dried for 10 d at approximately 24 °C, oven dried at 70 °C for 48 h, weighed for above-ground dry matter (DM) determination, and subsequently mechanically thrashed to separate seeds from the vegetative portion of the samples. The seeds were collected, weighed, and oven-dry seed weights were adjusted to 13% moisture by weight. Soybean harvest index (HI) was calculated as the ratio of seed mass to mass of total above-ground dry matter.

Data manipulation and statistical analyses

Extractable soil nutrient and microbial biomass concentrations, expressed on a mass mass^{-1} basis, were converted to extractable nutrient and microbial biomass contents, expressed on a mass area^{-1} basis, using measured bulk density values. Means ± standard errors (SE), data ranges, and coefficients of variation (CV) were calculated and reported for soil properties and soybean growth and production parameters.

Although the sampling grid was positioned such that approximately one-half of the area was cut and one-half of the area was filled, the re-grading process that occurred following initial site manipulations caused the entire study area to have some degree of fill material. Therefore, the roughly cut and filled areas were not treated as experimental treatments and were not separated during statistical analyses.

Pearson linear correlations were performed to ascertain relationships among post-leveling, pre-plant soil properties and soybean growth and production parameters (Minitab 13.31, Minitab Inc., State College, PA). In addition, all soil variables, regardless of correlation significance, were used in a multiple regression analysis to determine the contribution of post-leveling, pre-plant soil physical (i.e., BD and percentages of sand, silt and clay), chemical (i.e., pH, EC, OM and extractable soil nutrients) and biological properties (i.e., bacterial and fungal biomass and fungal-to-bacterial biomass ratio) to variations in soybean growth and production parameters. Sequential sums of squares (i.e., type I) were pooled for soil biological, physical, and chemical properties when added to the model in this order as predictors of soybean growth and production parameters. Though type I sums of squares depend on the order in which predictors are added to a model, only one order of variable addition to the model was used for all soybean growth and production parameters examined by multiple regression analyses. The ratio of the sum of squares for each of the three classes of soil properties to the regression sum of squares for the whole model was calculated to reflect their relative importance for each of the soybean growth and production parameters.

Geostatistical analyses were conducted using GS+ (version 5.1, Gamma Design Software, Plainwell, MI) to evaluate the spatial variability of first-year soybean growth and production. Only isotropic semivariograms were considered in the analyses.

Spatial distributions of first-year soybean growth and production parameters were determined by mapping using Surfer 7 (Golden Software, Inc., Golden, CO). Point kriging with no search radius was used as an unbiased, weighted-linear interpolation method that minimizes total parameter variance by incorporating semivariogram functions to create contour maps (Isaaks and Srivastava, 1989). Only the linear semivariogram function for all variables was used to facilitate mapping and comparisons among soybean growth and production parameters. If the proportion of spatial to total variability approaches zero, then the phenotypic variation is not due to spatial distributions, but rather to genetic or other underlying factors. The geostatistical approach used here to analyze spatial data has been a previously accepted methodology in a similar research context (Brye et al., 2003, 2004). In addition to the geostatistics approach, multiple regression analysis was conducted using relative x and y coordinates of the grid points as predictors of the measured response variables (i.e., soybean growth and production parameters) (SAS Version 8.1, SAS Institute, Inc., Cary, NC).

Results

First-year soybean growth and production following land leveling

Within the 0.36-ha study area, first-year soybean growth and production following land leveling were highly variable, as indicated by the standard error, range, and CV of each parameter measured (Table 1). Coefficients of variation for all first-year soybean growth and production parameters were large ranging from 20% for HI to 44% for LAI at the R5-6 growth stage. Spatial distributions of LAI, plant population, above-ground DM (Figure 1), seed yield and HI (Figure 2) also demonstrate the large degree of variability within the study area as indicated by the overall field averages. The spatial distribution pattern for LAI, plant population, above-ground DM and seed yield were similar within the study area, but differed noticeably for HI (Figures 1 and 2). Kriging soybean growth and production data identified roughly six localized areas of higher magnitude for all parameters surrounded by areas of more uniform or much smaller magnitude within the study area.

There are several possibilities that could explain the large degree of variations in soybean growth and production parameters. The variability in first-year soybean growth and production parameters may have occurred due to (i) variations associated with post-leveling soil physical, chemical, and/or biological properties; (ii) a combination of both spatial variability of first-year soybean growth and production parameters and post-leveling soil properties; or (iii) pre-leveling soil properties. However, the likelihood that first-year soybean growth and production was unaffected by the land-leveling activities and are an expression of variations associated with pre-leveling soil properties is minimal since land leveling resulted in significant alteration of many soil properties in the top 10 cm (Brye et al., 2003, 2004) and that pre-existing microdepressions affecting soil moisture availability were eliminated after re-grading the site.

Geostatistical analyses indicated that, in the context of this study, there was no spatial dependence in the variation of measured soybean growth and production parameters (Table 2). The proportion ($C/C_o + C$) of the spatial component (C) to the total variability ($C_o + C$) was 0 for all first-year soybean growth and production parameters evaluated. This result indicates one of two possible scenarios: (i) that all of the variability associated with these parameters was due to inherent, non-spatially related variability and/or to correlation with soil property variations; or (ii) that the 10-m spacing between grid-sampled points was not fine enough to identify any spatial dependence. Of the potential models available to fit semivariograms (i.e., spherical, exponential, linear, linear to sill, and Gaussian), the linear model resulted in the lowest residual sum of squares for all soybean growth and production parameters, thus justifying the use of only linear semivariogram functions to determine and depict the spatial distributions of first-year soybean growth and production parameters following land leveling in Figures 1 and 2.

Multiple regression analyses also supported the outcome from the geostatistical analyses that there was little to no spatial component responsible for the overall variability in first-year soybean growth and production parameters (data not shown). Relative x and y coordinates were not significant in multiple regression models predicting soybean growth and production parameters, except for HI. In the multiple regression model for HI, the y-coordinate parameter ($P = 0.013$) and the overall model ($P = 0.01$) were significant, but the model's predictive capability was low ($r^2 = 0.18$).

Soybean growth and production relationships with soil properties

The effects of land leveling on soil physical and biological properties (i.e., how overall means and spatial variability changed as a result of land leveling) are presented in detail in Brye et al. (2003). Similarly, the effects of land leveling on soil chemical properties are presented in Brye et al. (2004). Therefore, the relationships between post-leveling soil properties and soybean growth and production parameters will be focused on here.

Similar to the overall variability with first-year soybean growth and production parameters, a large degree of variability was associated with post-leveling soil properties (Table 3). Wide variability was observed for most of the soil properties evaluated except for BD, % silt, OM, and pH. Coefficients of variation

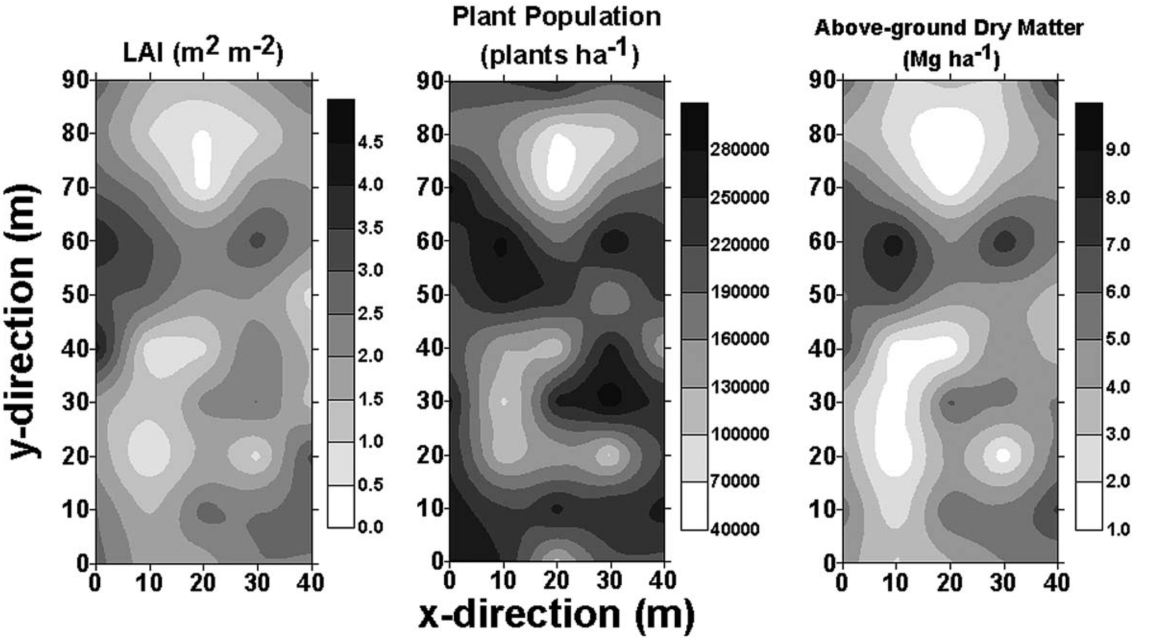

Figure 1. Spatial distributions of LAI at the R5-6 stage and plant population and above-ground dry matter at harvest of first-year soybean following shallow-cut land leveling in a 40- by 90-m sampling area. The *x*-direction is North and the *y*-direction is west on the land surface. The eastern roughly one-half of the area was cut and the western roughly one-half of the area was filled.

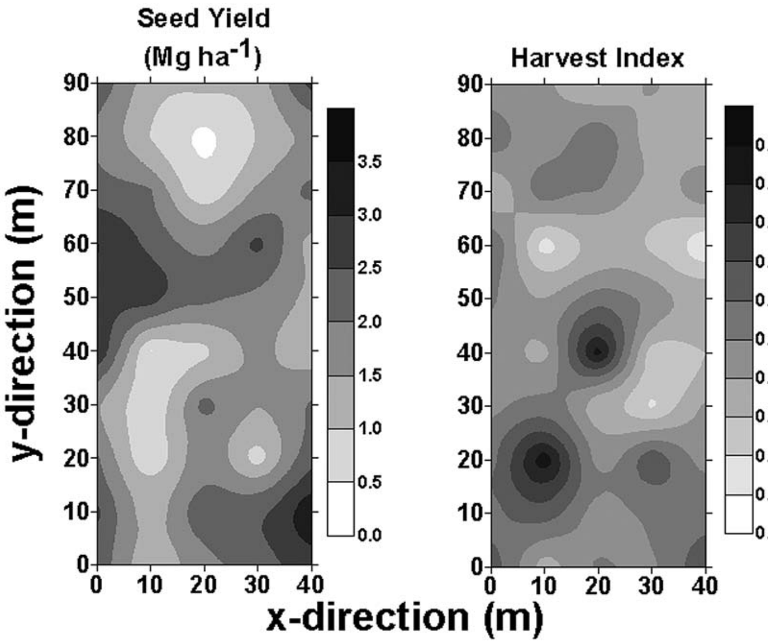

Figure 2. Spatial distributions of yield and harvest index of first-year soybean following shallow-cut land leveling in a 40- by 90-m sampling area. The *x*-direction is north and the *y*-direction is west on the land surface. The eastern roughly one-half of the area was cut and the western roughly one-half of the area was filled.

Table 1. Summary of first-year soybean growth and production parameters from a shallow-cut, land-leveled field in eastern Arkansas, USA

Soybean parameter	Mean ± standard error	Range	CV (%)
$LAI_{R5\text{-}6}$ ($m^2\ m^{-2}$)	2.02 ± 0.27	0.32–4.34	44
Plant population (plants ha^{-1})	202625 ± 9277	52 493–301 837	32
Above-ground dry matter (Mg ha^{-1})	4.38 ± 0.27	0.72–8.62	44
Seed yield (Mg ha^{-1})	1.81 ± 0.11	0.37–3.47	42
Harvest index	0.43 ± 0.01	0.25–0.69	20

Table 2. Geostatistical summary from linear models fit to semivariograms for soybean growth and production parameters from a shallow-cut, land-leveled field in eastern Arkansas, USA

Soybean parameter	Nugget (C_o)	Sill (C_o + C)	Range (m)	Proportion [C/(C_o+C)]	r^2	RSS[a]
$LAI_{R5\text{-}6}$ ($m^2\ m^{-2}$)	0.81	0.81	62.5	0.0	0.22	0.12
Plant population (plants ha^{-1})	4.27×10^8	4.27×10^8	62.5	0.0	0.69	2.14×10^{18}
Above-ground dry matter (Mg ha^{-1})	3.58	3.58	62.5	0.0	0.51	1.83
Seed yield (Mg ha^{-1})	0.56	0.56	62.5	0.0	0.16	0.05
Harvest index	7.84×10^{-3}	7.84×10^{-3}	62.5	0.0	0.03	8.93×10^{-7}

[a]RSS is the residual sum of squares from linear models fit to the semivariograms.

were < 10% for soil BD, % silt, OM concentration and pH and ranged from 12 to 26% for all other soil physical and chemical properties combined (Table 3). The largest CV range was associated with the soil biological properties, 56 to 74%. Based on visual comparison of maps produced from kriging using only the linear semivariogram function, post-leveling soil physical (Brye et al., 2003), chemical (Brye et al., 2004), and biological (Brye et al., 2003) properties varied as much as first-year soybean growth and production parameters throughout the study area. Although a spatial component accounted for none of the variability, first-year soybean growth and production parameters were related to variations in soil properties.

First-year soybean growth and production parameters within the study area were significantly correlated with numerous soil physical, chemical and biological properties in the top 10 cm of soil (Table 4). Leaf area index was significantly ($P < 0.05$) positively correlated with OM concentration, the contents of Fe, bacteria, and fungi, and fungal-to-bacterial biomass ratio ($0.32 < r < 0.45$). Soybean plant population was significantly ($P < 0.05$) positively correlated with only fungal-to-bacterial biomass ratio ($r = 0.30$). Above-ground DM was significantly ($P < 0.05$) positively correlated with OM concentration, the contents of P, Ca, Fe, Mn, Cu, Zn, bacteria, and fungi, and fungal-to-bacterial biomass ratio ($0.28 < r < 0.49$). Soybean yield was significantly ($P < 0.05$) positively correlated with OM concentration, the contents of Zn, bacteria, and fungi, and fungal-to-bacterial biomass ratio ($0.30 < r < 0.50$) although the spatial distributions of seed yield (Figure 2) and fungal and bacterial biomass contents (Brye et al., 2003) were not visually similar. Harvest index, the ratio between yield and total above-ground DM, was significantly ($P < 0.05$) positively correlated with soil BD and clay fraction ($r = 0.41$ and 0.33, respectively). However, HI was significantly negatively correlated with sand and clay fractions, soil pH, EC and the contents of P, Ca, Mg, Fe, Mn, Cu, Zn, and B ($0.33 < r < 0.40$). Silt fraction and K, Na and S contents were unrelated to soybean growth and production parameters measured in this study. These results indicate that variations in multiple soil properties account for at least part of the variations in first-year soybean growth and production.

As expected, soil chemical properties typically accounted for a large percentage of the variations (46.9% overall) in first-year soybean growth and production parameters (Table 5). In fact, soil chemical proper-

Table 3. Post-leveling, pre-plant soil physical, chemical and biological properties from the top 10 cm of a shallow-cut, land-leveled field in eastern Arkansas, USA

Soil property	Mean ± standard error	Range	CV (%)
Physical			
BD (g cm^{-3})	1.29 ± 0.01	1.15 – 1.44	5
Sand (%)	12.7 ± 0.2	8.8 – 16.7	12
Silt (%)	71.4 ± 0.5	64.2 – 82.5	5
Clay (%)	15.8 ± 0.5	3.6 – 22.9	21
Chemical			
OM (g kg^{-1})	18.5 ± 0.2	14.0 – 21.0	9
pH	7.6 ± 0.06	6.0 – 8.1	6
EC (dS m^{-1})	0.16± < 0.01	0.09 – 0.22	21
P (kg ha^{-1})	33.1 ± 1.0	15.6 – 49.0	22
K (kg ha^{-1})	180 ± 5.9	107 – 280	23
Ca (kg ha^{-1})	2704 ± 72	1 455 – 3 630	19
Mg (kg ha^{-1})	416 ± 7.2	285 – 500	12
Na (kg ha^{-1})	218 ± 4.5	142 – 320	15
S (kg ha^{-1})	41.9 ± 1.5	28.4 – 78.8	25
Fe (kg ha^{-1})	339 ± 13	127 – 511	26
Mn (kg ha^{-1})	361 ± 12	102 – 462	23
Cu (kg ha^{-1})	4.0 ± 0.1	2.4 – 5.1	16
Zn (kg ha^{-1})	8.8 ± 0.3	3.6 – 12.3	24
B (kg ha^{-1})	1.8 ± 0.3	0.8 – 2.6	23
Biological			
Bacteria (g m^{-2})	16.3 ± 0.6	1.2 – 25.7	56
Fungi (g m^{-2})	10.2 ± 0.82	10.6 – 190	57
Fungal-to-bacterial content ratio	0.68 ± 0.07	0.10 – 2.75	74

ties (i.e., OM concentration, pH, EC, and extractable nutrient contents) accounted for the largest percentage of variations in LAI at the R5-6 stage and plant population, and HI at the time of harvest. However, the combination of bacteria and fungi content and fungal-to-bacterial biomass ratio accounted for the largest percentage of variations in above-ground DM and soybean yield, and 37% overall with all properties combined. Sixty to 80% of the total amount of variation in soybean growth and production parameters induced by all soil chemical properties was attributed to extractable soil nutrient contents. Soil physical properties (i.e., BD, and particle-size fractions) accounted for the smallest percentage of variations in first-year soybean growth and production parameters (16% overall), but the percentage attributable to soil physical properties was similar to that of soil chemical and biological properties for variations in soybean HI.

Discussion

Many studies have documented the influence of soil-property variations on the spatial variability of crop yields within a given year in undisturbed soils (Bakhsh et al., 2000a). Since crop production is a result of complex interactions between soil characteristics and environmental factors such as local climatic conditions (Bakhsh et al., 2000b), it is not surprising that first-year soybean growth and production following shallow-cut land leveling are significantly related to multiple post-leveling soil properties, as demonstrated by this research.

Since soil pH affects the availability of many soil macro- and micro-nutrients, both soil pH and extractable soil nutrients were expected to be related to crop production. In this study, post-leveling soil pH was not significantly correlated with soybean growth and production parameters, except for a negative correlation with HI (Table 4). However, within the soil pH range that existed following land leveling (i.e., pH 6 to

Table 4. Pearson linear correlations (r) among post-leveling, pre-plant soil properties and first-year soybean growth and production parameters from a shallow-cut, land-leveled field in eastern Arkansas, USA

Soil property	$LAI_{R5\text{-}6}$	Plant population	Above-ground dry matter	Seed yield	Harvest index
Physical			r		
BD	0.030	−0.085	−0.033	0.129	0.411**
Sand fraction	0.008	0.082	0.119	−0.010	−0.323*
Silt fraction	0.105	0.074	0.168	0.099	−0.181
Clay fraction	−0.112	−0.114	−0.227	−0.096	0.333*
Chemical					
OM	0.445***	0.161	0.374**	0.430**	−0.084
pH	0.014	−0.128	0.107	−0.046	−0.332*
EC	0.205	0.187	0.243	0.132	−0.330*
P content	0.131	0.118	0.343*	0.265	−0.348*
K content	0.054	0.041	0.208	0.173	−0.223
Ca content	0.233	−0.052	0.302*	0.171	−0.341*
Mg content	0.119	−0.149	0.171	0.038	−0.355*
Na content	−0.214	−0.145	−0.190	−0.251	0.002
S content	−0.096	0.165	−0.141	−0.08	0.150
Fe content	0.316*	0.061	0.381**	0.258	−0.341*
Mn content	0.224	0.001	0.283*	0.157	−0.385**
Cu content	0.165	0.023	0.359**	0.216	−0.399**
Zn content	0.272	0.076	0.382**	0.299*	−0.354*
B content	0.130	−0.128	0.221	0.114	−0.326*
Biological					
Bacteria content	0.401**	0.250	0.484***	0.497***	−0.065
Fungi content	0.403**	0.256	0.490***	0.490***	−0.089
Fungal-to-bacterial content ratio	0.352*	0.304*	0.466***	0.421**	−0.143

*Denotes significance at the 0.05 probability level.
**Denotes significance at the 0.01 probability level.
***Denotes significance at the 0.001 probability level.

8.1), a yield response would not have necessarily been expected for a soybean crop unless the pH caused a nutrient deficiency, but a yield response would have been expected with these soil conditions if a rice crop had been grown (Norman et al., 2003). The soil pH range on the top 10 cm following land leveling is relatively high and is due to the relatively high concentration of dissolved Ca, Mg, and bicarbonates in the groundwater used for irrigation in the Mississippi River delta region (Thomas, 2001).

The lack of a linear correlation between pH and LAI, DM, and yield may indicate a non-linear relationship since areas of high HI roughly corresponded to areas of low yield (Figure 2). Perhaps the pH that relates to the optimum HI is around 7.0 and that a pH that is too low and too high relative to pH 7 results in both lower dry matter and yield.

Soybean growth and production parameters were significantly correlated with extractable soil nutrients. Of the macro-nutrients measured, only soil extractable P was significantly correlated with above-ground DM and HI, but not yield. However, soil P tends to be yield-limiting at high pH and, in this study, the entire range of post-leveling soil P concentrations was below what is considered to be a yield limitation due to inadequate P in eastern Arkansas, USA (Univ. Ark., 2000). Phosphorus deficiency in rice following land leveling is also common in the Mississippi River delta region (Walker et al., 2003). Soil extractable K, Ca, and Mg were also uncorrelated with yield, but their concentration ranges were well-above the concentrations considered to be yield-limiting for soybeans in eastern Arkansas, USA (Univ. Ark., 2000).

Similarly, Fe, Mn, Cu, and Zn, in which Zn is typically the most limiting soil micro-nutrient for many crop grown in the Delta region of eastern Arkansas, were significantly positively correlated with above-ground DM, but significantly negatively correlated

Table 5. Percentage of sequential sum of squares from regression analyses for predicting soybean growth and productivity parameters attributed to soil property classes

Soil property class[a]	$LAI_{R5\text{-}6}$	Plant population	Above-ground dry matter	Seed yield	Harvest index	Overall mean
			%			
Physical	16	6	17	8	31	16
Chemical	48	72	36	42	36	47
Biological	36	22	48	49	33	37

[a]All measured soybean parameters were pooled within each soil property class in determining the percentage of regression sum of squares.

with HI. Resulting micro-nutrient correlations with DM and HI may be related to soil pH because micronutrient availability decreases as pH increases, which leads to high above-ground DM (i.e., positive correlations) and high DM tends to decrease HI (i.e., negative correlations) (Table 4). However, the concentration ranges for Fe, Mn, Cu, and Zn following land leveling were all above that which would be considered a deficiency and yield-limiting for most agronomic crops (Hanlon et al., 1999).

Despite the numerous significant correlations among soybean growth and production parameters and soil physical, chemical, and biological properties, the correlation coefficients are relatively small. Therefore, most of the variability in soybean growth and production was not explained by measured parameters ($0.46 < r^2 < 0.53$ for whole model). This result suggests that factors other than the multitude of parameters measured in this study were important factors influencing first-year soybean growth and yield following land leveling. This conclusion was also drawn by Walker et al. (2003) for rice grown after land leveling in the Mississippi River delta region of Mississippi where the magnitude of yield reductions following land leveling was significantly correlated with the volume of soil removed from the cut areas.

The variability of first-year soybean growth and production following land leveling may also be related to soil water relations, specifically prolonged high soil moisture conditions, than strictly soil physical or biochemical properties. The resulting increased clay content in the top 10 cm following land leveling (Brye et al., 2003) likely decreased soil surface hydraulic conductivity resulting in poor internal drainage in some areas, with those areas maintaining higher water contents for longer periods of time. Standing water was observed in numerous spots throughout the study area several days following irrigation events. Excess soil moisture and poorly drained fields have been recognized as favorable soil conditions for diseases, such as Phytophthora Root Rot (*Phytophthora sojae*), Sudden Death Syndrome (*Fusarium solani* f. sp. *glycines*), and Pythium Damping-Off and Root Rot (*Pythium* spp.), to occur, develop, and potentially negatively impact soybean yield provided the pathogens are present and there is adequate inoculum (Killebrew et al., 1993; Hartman et al., 1999). However, disease may not develop if a resistant cultivar is grown even under disease-favoring environmental and soil conditions. Despite the potentially favorable environment for soybean diseases, there were no visual indications of disease or disease symptoms affecting any portion of the study area.

Upon close examination of Figures 1 and 2, there appears to be a strong dependency of LAI, above-ground dry matter, and seed yield on plant population. This dependency suggests that soil properties affecting emergence and early soybean establishment were critical to subsequent growth. However, no soil properties, except for the fungal-to-bacterial biomass ratio, were correlated with plant population (Table 4). However, similar to the lack of visual indication of disease, there were no visual observations of variable crop establishment. These results and observations also indicate that poor internal drainage and water-logging may have been important factors controlling first-year soybean production following land leveling.

Summary and conclusions

Adequate plant nutrition has also long been recognized as an important factor for crop production under any soil conditions. Similarly, the importance of soil physical properties for crop production in non-land-leveled fields has been demonstrated (Cassel, 1982; Canarache et al., 1984; Singh et al., 1996; Bakhsh et al., 2000a). However, little attention has been given to the potential importance of soil biological properties, such as fungal and/or bacterial biomass, in contributing to crop production, especially in severely disturbed soils such as those recently land leveled.

Despite being recognized as a water conservation practice, particularly for rice production, land leveling significantly negatively alters soil quality. Restoration of land-leveled fields to pre-leveling conditions make take years due to the severe impact this practice has on soil biogeochemical properties. The results of this study indicate that soil biological properties are of equal, if not greater, importance than soil physical and/or chemical properties in controlling growth and production of first-year soybean crops after land leveling. Removal and alteration of surface material may result in a shallower rooting zone for subsequent crops due to decreasing the depth to the hard pan, which is regarded as essential for rice production. Perhaps land leveling should be followed by some form of deep tillage to disrupt a shallower hard pan. Similarly, annual additions of organic amendments beyond the first year following land leveling, a practice currently not occurring widely, would help improve soil structure and promote better internal drainage. Increased organic matter levels in land-leveled fields may facilitate increased microbial activity in the disturbed soil and ultimately contribute to improved crop productivity. Since land-leveling activities will only likely increase in the mid-Southern United States, a better understanding of the short- and long-term effects of land leveling on soil properties and crop response is critical to providing reasonable agronomic recommendations after land leveling takes place and maintaining a sustainable agricultural system.

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