IMPACTS OF LAND LEVELING ON LOWLAND SOIL PHYSICAL PROPERTIES[1]

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SUMMARY

The practice of land leveling alters the soil surface to create a uniform slope to improve land conditions for the application of all agricultural practices. The aims of this study were to evaluate the impacts of land leveling through the magnitudes, variances and spatial distributions of selected soil physical properties of a lowland area in the State of Rio Grande do Sul, Brazil; the relationships between the magnitude of cuts and/or fills and soil physical properties after the leveling process; and evaluation of the effect of leveling on the spatial distribution of the top of the B horizon in relation to the soil surface. In the 0-0.20 m layer, a 100-point geo-referenced grid covering two taxonomic soil classes was used in assessment of the following soil properties: soil particle density (Pd) and bulk density (Bd); total porosity (Tp), macroporosity (Macro) and microporosity (Micro); available water capacity (AWC); sand, silt, clay, and dispersed clay in water (Disp clay) contents; electrical conductivity (EC); and weighted average diameter of aggregates (WAD). Soil depth to the top of the B horizon was also measured before leveling. The overall effect of leveling on selected soil physical properties was evaluated by paired "t" tests. The effect on the variability of each property was evaluated through the homogeneity of variance test. The thematic maps constructed by kriging or by the inverse of the square of the distances were visually analyzed to evaluate the effect of leveling on the spatial distribution of the properties and of the top of the B horizon in relation to the soil surface. Linear regression models were fitted with the aim of evaluating the relationship between soil properties and the magnitude of cuts and fills. Leveling altered the mean value of several soil properties and the agronomic effect was negative. The mean values of Bd and Disp clay increased and

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Tp, Macro and Micro, WAD, AWC and EC decreased. Spatial distributions of all soil physical properties changed as a result of leveling and its effect on all soil physical properties occurred in the whole area and not specifically in the cutting or filling areas. In future designs of leveling, we recommend overlaying a cut/fill map on the map of soil depth to the top of the B horizon in order to minimize areas with shallow surface soil after leveling.

Index terms: soil management practices, land forming, irrigated rice crop, soil movement, soil properties.

RESUMO: *IMPACTO DA SISTEMATIZAÇÃO NOS ATRIBUTOS FÍSICOS DE UM SOLO DE VÁRZEA*

A sistematização altera a superfície natural do solo criando uma área com declividade uniforme com a finalidade de facilitar todas as operações agrícolas. Os objetivos deste trabalho foram de determinar os impactos da sistematização sobre: a magnitude, a variância e a distribuição espacial de alguns atributos físicos de uma área em solos de várzea no Estado do Rio Grande do Sul; a relação entre a magnitude dos cortes e, ou, os aterros e os atributos físicos do solo, após a sistematização da área; e a distribuição espacial do topo do horizonte B em relação à superfície do solo. Em uma área constituída por dois tipos taxonômicos de solo, foi estabelecida uma malha de 100 pontos georreferenciados. Em cada ponto, na camada de 0-0,20 m, foram determinados os seguintes atributos físicos, antes e após a sistematização: densidade do solo e das partículas, porosidade total, macro e microporosidade, capacidade de água disponível, teores de areia, silte, argila e argila dispersa em água, condutividade elétrica e diâmetro médio dos agregados estáveis em água. Nos mesmos pontos, antes da sistematização, foi medida a profundidade do topo do horizonte B em relação à superfície do solo. O efeito da sistematização sobre os valores médios dos atributos físicos foi avaliado pelo teste "t" de médias pareadas. O efeito sobre a variância de cada atributo foi analisado pelo teste de homogeneidade da variância. Para avaliar o efeito da sistematização sobre a distribuição espacial dos atributos e do topo do horizonte B em relação à superfície do solo, foi realizada uma análise visual dos mapas temáticos construídos por krigagem ou pelo inverso do quadrado das distâncias. Com a finalidade de avaliar a relação entre os atributos do solo e a magnitude de cortes e aterros, foram ajustados modelos de regressão linear. A sistematização alterou a média de vários atributos físicos do solo e o efeito agronômico foi negativo. Houve aumento dos valores médios dos teores de argila dispersa e de densidade do solo e diminuição dos valores de porosidade total, macro e microporosidade, capacidade de água disponível, diâmetro médio ponderado dos agregados estáveis em água e da condutividade elétrica. As distribuições espaciais de todos os atributos foram alteradas após a sistematização; o efeito da sistematização sobre os atributos físicos ocorreu em toda a área e não especificamente nas áreas de corte ou aterro. Para futuros projetos de sistematização, é recomendado sobrepor o mapa de cortes e aterros e o da profundidade do topo do horizonte B, em relação à superfície do solo, com o objetivo de minimizar locais com solo muito raso após a sistematização.

Termos de indexação: práticas de manejo do solo, nivelamento, arroz irrigado, movimento do solo, propriedade do solo.

INTRODUCTION

Land leveling is used to adjust the soil surface and standardize its slope, facilitate the distribution of irrigation water and improve field conditions for other agricultural practices (Brye et al., 2006). Leveling has been practiced throughout the world for more than half a century (Whitney et al., 1950). It increases the efficiency of irrigation control and facilitates agricultural mechanization. In addition, leveling allows reduction in water application, increasing water conservation. Evaluating more than 40 leveled and unleveled rice (*Oriza sativa*) fields, Laughlin & Mehrle

(1996) concluded that leveling increased the profitability of the rice field by US$ 201 ha^{-1} as a result of an increase in rice yield of 550 kg ha^{-1} and of a decrease in production costs of US$ 129 ha^{-1}. Parfitt & Silva (2005) and Silva & Parfitt (2005) mentioned that in addition to these benefits for the irrigated rice crop, leveling also benefits soybean (*Glycine max* L.) and maize (*Zea mays* L.) crops because of the possibility of irrigating both field crops by surface irrigation. However, land leveling also has disadvantages due to severe soil disturbance (Eck, 1987; Miller, 1990; Brye et al., 2005).

According to the Instituto Rio-grandense do Arroz (IRGA, 2005), in the 1999/2000 crop year, the area of

leveled land in the State of Rio Grande do Sul (RS), Brazil, was estimated to be around 0.15×10^6 ha of the total of 5.4×10^6 ha of lowland area of the state (Pinto et al., 2004). However, not all the so-called lowland areas with irregular micro-topography may be leveled.

Land leveling can significantly decrease the thickness of the A horizon and expose the subsoil in the cut areas. As a consequence, crop production may be affected by leveling, and, therefore, there is a call for studies on the impact of leveling on soil physical properties and on its effect on crop growth. Brye et al. (2003) characterized the short-term impacts of land leveling on the magnitude and spatial distributions of biological and physical soil properties of an Albaqultic Hapludalf soil used for irrigated rice and soybean crops, as well as on the relationships among these properties. They concluded that leveling affected the magnitude of all soil properties and relationships: soil bulk density and sand and clay contents increased, while silt content and fungal and bacterial biomass decreased. According to the authors, the variance associated with soil biological properties changed as a result of leveling, while the variance associated with soil physical properties was not affected by this agricultural practice. However, in the study, Brye et al. (2003) did not evaluate which soil properties were most affected by the leveling process. Ferreira et al. (2003) aimed to evaluate the effect of cut and fill elevation coordinates on the yield of an irrigated rice-soybean-maize rotation in a lowland area, and they estimated a maize yield of 2.4 and 7.6 t ha^{-1} in -0.10 m cut areas and in +0.075 m filled areas, respectively. For the soybean crop, the minimum and maximum estimated yields were 0.8 t ha^{-1} (-0.10 m cut area) and 2.0 t ha^{-1} (+0.069 m fill areas), respectively. They concluded that both maize and soybean yields were more affected by leveling, in comparison to irrigated rice, and because leveling severely disturbs soil, only minimum amounts of soil should be moved. However, Ferreira et al. (2003) did not evaluate the effects of land leveling on the magnitude and spatial distributions of soil properties and which properties were most affected by the practice.

The aforementioned studies do not evaluate the relationships between the magnitude of cuts and/or fills and soil physical properties after the leveling process. They also do not pay attention to soil depth to the top of the B horizon in relation to the soil surface in lowland soils. This depth is important since the depth of the A+E horizons will be exploited by the new crop roots. Moreover, they do not associate this depth to the magnitudes of cuts and fills. It is important to mention that lowland soils of RS are mainly classified as Albaqualfs and Epiaqualfs, which have a textural B horizon in which roots are rarely found. This horizon restrictive to root development and its low fertility make these soils definitively unproductive mainly when this horizon is exposed at the soil surface. Therefore, the aims of this study were

to evaluate the impacts of land leveling through evaluation of the magnitudes, variances and spatial distributions of selected soil physical properties of a lowland area in the state of Rio Grande do Sul, Brazil; verification of the existence of a relationship between the magnitude of cuts and/or fills and the magnitudes of soil physical properties after the leveling process, and evaluation of the effect of leveling on the spatial distribution of the top of the B horizon in relation to the soil surface.

MATERIALS AND METHODS

Study area and land leveling process

The study was carried out on an area of 0.81 ha in the municipality of Capão do Leão, RS, Brazil (31° 49' 13" S; 52° 27' 59" W), to study the changes in soil physical properties after land leveling. A grid of 100 geo-referenced points at a spacing of 10 m in orthogonal directions was used for this purpose. The climate in the region is of the Cfa type according to the Köppen classification and the specific area is representative of a subtropical marine environment with a sub-humid summer and humid or super-humid conditions in the remaining seasons. The soil of the area belongs to two taxonomic classes (Figure 1a), a Typic Albaqualf in the relatively high portion and an Umbric Epiaqualf in the lower portion (NRCS, 2009).

In the area under study, the two soils do not present a sharp interface. This situation is common in the rice-growing lowland areas of RS. Before the study began, the area was planted twice to wetland rice and planted once to grain sorghum (*Sorghum vulgare*), all under conventional tillage that includes plowing operations to the depth of about 0.20 m. Before land leveling and at each geo-referenced point, one disturbed soil sample was collected from the 0-0.20 m layer to evaluate soil particle density (Pd) (Blake & Hartge, 1986), clay, dispersed clay (Disp clay), silt and sand contents (Gee & Bauder, 1986), and electrical conductivity (EC) in 5:1 soil water extracts (Rhoades, 1982). Evaluation of the distributions of aggregate size and stability (weighted average diameter - WAD) was performed on $0.05 \times 0.05 \times 0.20$ soil samples collected so as to avoid disintegration in the field (Kemper & Rosenau, 1986). Undisturbed soil samples (0.05 m diameter, 0.03 m height) were collected at the 0.10 m depth (to represent the 0-0.20 m surface layer) for determination of soil bulk density (Bd); total (Tp), macro (Macro) and micro (Micro) porosities; and soil water retention curves using the matric potentials of 0; -1; -6; -10; -33; -100 and -1500 kPa, according to methods described in Klute (1986). The available water capacity (AWC) was considered between the potentials of -10 and -1500 kPa. The depth to the top of the B horizon in relation to the soil surface was also evaluated before leveling through auger samplings.

The land leveling procedure occurred at the beginning of 2008 and was carried out with a laser-controlled scraper, using a planialtimetric survey and minimum squares approximation as described in Parfitt et al. (2004). The final average slope was 0.15 % with an approximate soil displacement of 519 m^3 ha^{-1}; about half of the area underwent cuts and the other half underwent fills. The maximum cut was 0.21 m and the maximum fill was 0.17 m (Figure 1b). The period between samplings before and after leveling was about three months. After land leveling and in the same geo-referenced points, disturbed and undisturbed samples were collected from the 0-0.20 m layer to evaluate the same soil properties described above. After leveling, the depth to the top of the B horizon was calculated by the sum of cut or fill magnitudes with the depth to the top of the B horizon evaluated before leveling.

Classical statistics and geostatistical analysis

All data were subjected to descriptive statistical analysis and analyzed to confirm normality through the non-parametric Kolmogorov-Smirnov test at the 5 % probability (p<0.05) using the maximum distance D (SAS Institute, 1985). To determine the overall effect of land leveling on all data sets, paired t tests were performed (Montgomery & Runger, 1994). For normal data distributions, the hypothesis of the applied test was parametric (t statistics), and for non-normal distributions, the test was non-parametric (Wilcoxon test). To evaluate the effect of leveling on the sampling variability of each property, the homogeneity of variance test was applied using the method of Levene (1960), modified by Brown & Forsythe (1974).

Experimental and theoretical semivariograms were calculated and evaluated by the cross validation technique through use of the Software GS+, version 9.0 (Journel & Huijbregts, 1978; Webster & Oliver, 2001; Nielsen & Wendroth, 2003; Robertson, 2008). Thematic maps were generated before and after leveling (Parfitt, 2009; Parfitt et al., 2009) through kriging when the spatial variability of the properties was properly defined and identified through semivariograms, and through the inverse of the squares of the distances when the spatial variability was not properly defined by semivariograms. Therefore, a visual analysis of the spatial distribution of the properties was made.

With the aim of determining which soil physical properties were most affected by the leveling process and to better describe future management practices to be carried out on leveled land, simple regression analysis was made using the SAS software, version 8.2 (SAS Institute, 1985) based on the depth of cut and/or fill (CF) and the values of the soil physical properties after leveling.

RESULTS AND DISCUSSION

Impacts of land leveling on the magnitudes and variances of selected soil physical properties

Average particle size distribution of the 0-0.02 m soil layer before leveling (143 g kg^{-1} clay, 399 g kg^{-1} silt and 458 g kg^{-1} sand) and after leveling (154 g kg^{-1} clay, 375 g kg^{-1} silt and 471 g kg^{-1} sand) classify the soil as having a loamy texture, in both situations (Embrapa, 2006). Mean soil bulk density increased from 1.60 kg dm^{-3} (before) to 1.67 kg dm^{-3} (after), due to intense machinery traffic during leveling. As a consequence, the mean total porosity decreased from 0.44 to 0.37 m^3 m^{-3} (Table 1). Table 1 also shows the predominance of microporosity (0.34 m^3 m^{-3}) as compared to macroporosity (0.10 m^3 m^{-3}) at a ratio greater than 3:1, indicating that this soil layer presented a restriction to water movement before leveling (Winkler & Goedert, 1972). The same behavior can be observed after leveling. The mean diameter of the water stable aggregates (WAD) decreased from 1.7 to 1.1 mm, indicating that soil mixing during leveling can cause the breakdown of larger aggregates. Mean WAD of 1.7 mm is larger than that obtained by Lima et al. (2003) for a soil of the same taxonomic
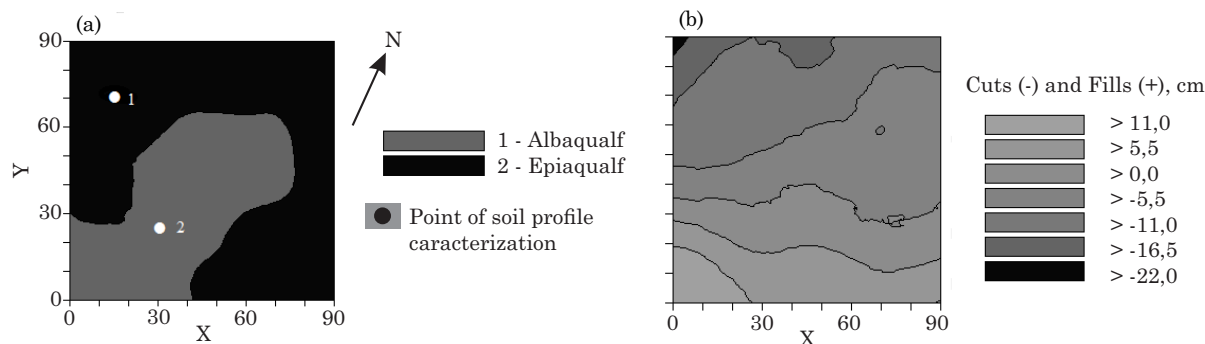

Figure 1. (a) Soil spatial distribution in the experimental area: (1) "Gleissolic Planossolo háplico eutrófico" (Typic Albaqualf) in the relatively high portion, and (2) "Solodic Gleissolo háplico Ta eutrófico" (Umbric Epiaqualf) in the lower portion. (b) Map of cut and fill depths.

Table 1. Descriptive statistics, Kolmogorov-Sminorv and normality hypothesis tests for physical properties measured before and after land leveling

Property	Mean	Minimum value	Maximum value	Variance	D
Clay (g kg^{-1})[1]	143	117	181	174	0.06[N]
Clay (g kg^{-1})[2]	154**	123	227	310[NS]	0.94[NN]
Silt (g kg^{-1})[1]	399	333	483	1096	0.04[N]
Silt (g kg^{-1})[2]	375***	276	441	1390[NS]	0.10[NN]
Sand (g kg^{-1})[1]	458	385	541	1414	0.07[N]
Sand (g kg^{-1})[2]	471***	401	538	912[NS]	0.11[NN]
Disp clay (g kg^{-1})[1]	79	50	115	190	0.07[N]
Disp clay (g kg^{-1})[2]	88***	60	125	228[NS]	0.11[NN]
Bd (kg dm^{-3})[1]	1.60	1.36	1.75	0.005	0.08[N]
Bd (kg dm^{-3})[2]	1.67***	1.43	1.92	0.008[NS]	0.08[N]
Pd (kg dm^{-3})[1]	2.52	2.11	2.68	0.006	0.07[N]
Pd (kg dm^{-3})[2]	2.48***	2.33	2.68	0.004[NS]	0.14[NN]
Tp (m^3 m^{-3})[1]	0.44	0.37	0.51	7.24	0.05[N]
Tp (m^3 m^{-3})[2]	0.37***	0.24	0.48	11.76[NS]	0.05[N]
Macro (m^3 m^{-3})[1]	0.10	0.05	0.16	4.20	0.04[N]
Macro (m^3 m^{-3})[2]	0.06***	0.004	0.13	7.90*	0.07[N]
Micro (m^3 m^{-3})[1]	0.34	0.30	0.42	3.53	0.07[N]
Micro (m^3 m^{-3})[2]	0.31***	0.18	0.38	9.86**	0.08[N]
WAD (mm)[1]	1.7	0.8	3.0	0.24	0.08[N]
WAD (mm)[2]	1.1***	0.5	1.8	0.12[NS]	0.13[NN]
AWC (mm)[1]	25	9	39	50.4	0.09[N]
AWC (mm)[2]	19***	8	33	36.5[NS]	0.08[N]
EC (μs cm^{-1})[1]	52	36	139	273.2	0.23[NN]
EC (μs cm^{-1})[2]	43***	28	61	41.7**	0.04[N]

Disp clay: dispersed clay, Bd: bulk density, Pd: particle density, Tp: total porosity, Macro: macroporosity, Micro: microporosity, WAD: weighted average diameter, AWC: available water capacity, EC: electrical conductivity. [1] Mean value of the property before land leveling; [2] mean value of the property after land leveling. *** $p<0.001$; ** $p<0.01$; * $p<0.05$ and [NS] no significant differences by the t hypothesis test (for normal data distributions) and by the Wilcoxon test (for non-normal data distributions) applied to the mean values of each property before and after land leveling, respectively. D: value of the Kolmogorov-Smirnov statistical test. N and NN: normally and no normally distributed data set at $p<0.05$, respectively.

class planted to flooded rice under conventional soil tillage practices. A decrease of 6 mm in the mean AWC was also observed as a consequence of a decrease in microporosity, which is responsible for water retention in the soil. Mean AWC, according to Pereira et al. (2002), lies within the values presented by soils of medium texture. Mean electrical conductivity decreased from 52 μS cm^{-1} (before leveling) to 43 μS cm^{-1} (after) showing a change in the distribution of dissolved ions in the soil solution. In general, mean values for soil property data before leveling (Table 1) are in agreement with those observed by Palmeira et al. (1999) for lowland soils planted to irrigated rice under conventional tillage.

Leveling altered the mean values of nearly all the properties ($p<0.001$) for the paired comparison test (Table 1), with only clay content ($p<0.01$). Table 1 also shows that the range, which is the difference between the greatest and the smallest observations of a data set, increased for most soil physical properties.

The variance parity test of Levene (1960), modified by Brown & Forsythe (1974), applied to the data sets before and after leveling showed that only the variances for EC, Macro and Micro changed significantly. Therefore, land leveling did not significantly change the variance values for the great majority of the data sets. According to Schlindwein & Anghinoni (2002), in the case of precision agriculture, an increase in the variance of a set of measurements implies an increase in the number of samples that need to be collected for a given probability level. Among the properties evaluated before leveling (Table 1), only the EC data did not follow normal distribution according to the Kolmogorov-Smirnov test ($p<0.05$), while after leveling, clay, silt, sand, Disp clay, Pd and WAD also did not follow normality, indicating that these properties showed a localized distribution in the experimental area (Grego et al., 2006), and the mean value cannot be considered the center of the distribution (Nielsen & Wendroth, 2003).

Impacts of land leveling on the spatial distributions of selected soil physical properties

Thematic maps of soil properties before and after leveling are presented in figures 2, 3, and 4. The spatial variability, before and after leveling (Parfitt, 2009; Parfitt et al., 2009), of clay, sand, silt, Disp clay and Bd properties as well as Micro (after leveling) were well described by semivariograms, and therefore their thematic maps were generated by kriging. For the other properties, the inverse of the squares of the distances was used to generate the thematic maps. Figure 2 shows that before leveling, clay presented a uniform spatial distribution with a

gradual increase from east to west. Silt and sand presented opposing behavior, with silt having the greatest concentration in the central part and the smallest in the east. The behavior of the Disp clay data set is directly related to clay. In general, distribution of Pd (Figure 3) had behavior similar to sand (Figure 2), where the largest values of particle density were found at locations with the highest sand contents. The distribution of Tp, which in a homogeneous management area is mainly related to particle size distribution, had its largest values concentrated in the center and west, approximately the inverse of sand. The spatial distribution of Bd (Figure 3), which is related to Pd and Tp, followed the behavior of these two properties, presenting the
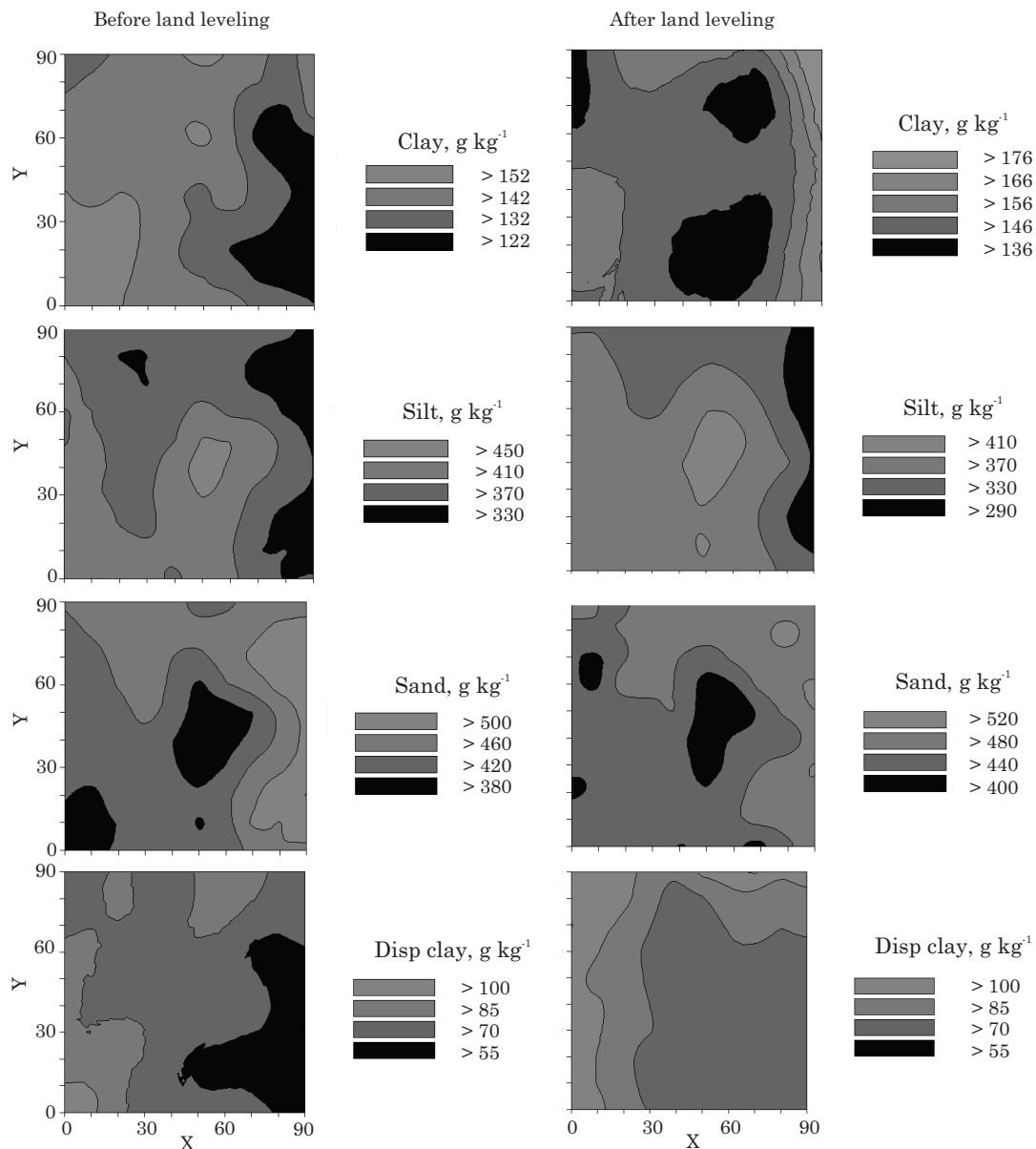

Figure 2. Maps of the spatial distribution of concentrations of clay, silt, sand and dispersed clay in water (Disp clay), before and after land leveling.

lowest values in the center and west. The distribution of Micro (Figure 4) approximately followed the inverse of sand. Macro distribution (Figure 3) appeared to be random, with the largest values in the west and it followed the inverse situation of Bd. WAD and AWC also presented random distribution before land leveling and EC had a tendency to decrease from the southeast to the northwest corners (Figure 4).

Land leveling consisted of cuts on the northern part of the experimental area, with a maximum cut of 0.21 m in the northwest portion. The soil in this part of the area was classified as a Typic Albaqualf, typical of the relatively higher portions of the land. The maximum fill of 0.17 m occurred near the southwest corner [at coordinates (0.0; 10.0)]. It was

observed that soil depth to the top of the B horizon was variable over the area such that during sampling of the 0-0.20 m layer after leveling, some points, mainly those in the extreme northeastern, presented the top of horizon B in addition to horizon E (Figure 1b). Due to the different physical characteristics of the B horizon in relation to the upper horizons, the spatial distributions of the soil properties analyzed were affected by leveling, especially those of particle sizes. In contrast, in the filled areas of the whole southern part, the soil was mixed so that an E horizon remained at the top. The value of Pd, as well as clay, presented an inverse behavior in relation to the pre-leveling condition (Figures 3 and 2). The largest values of Pd and the lowest of Tp, Macro, Micro, WAD and AWC were found in the cut
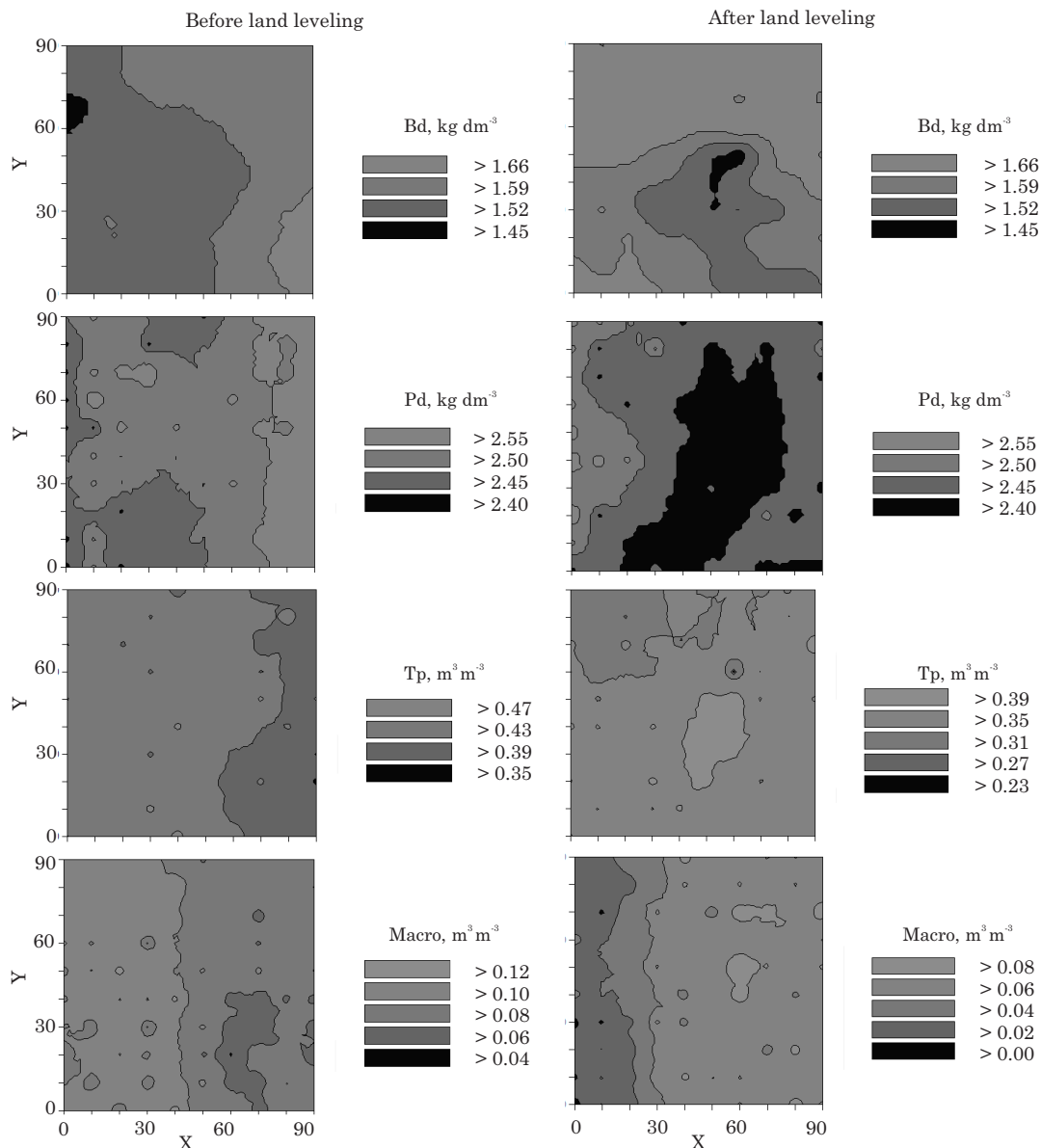

Figure 3. Maps of the spatial distribution of soil bulk density (Bd), particle density (Pd), total porosity (Tp) and macroporosity (macro) before and after land leveling.

parts (Figures 3 and 4). EC also presented a pattern that followed soil movement.

Miller (1990) observed that variability in the yield of irrigated rice was related to the spatial variability of soil properties after leveling. Dobermann et al. (1997) reported that rice yield was related to the spatial variability of soil properties after land leveling. Reichert et al. (2008) concluded that land leveling increased the spatial variability of soil chemical and physical properties of a lowland soil, which was reflected in the yield of the soybean crop. It is therefore expected that the generation of maps such as those presented here (Figures 2, 3 and 4) provides a very good tool for the establishment of soil management practices to be introduced in recently leveled land for the purpose of greater crop yield.

Relationships between the magnitude of cuts and/or fills and soil physical properties

In order to better understand the relation between soil properties and the magnitudes of cuts and/or fills resulting from leveling, mathematical relationships between them were established (Figures 5 and 6). Although most of the relationships between properties are statistically significant, it can be observed from the figures that there is no defined relationship among soil property values and the magnitudes of cuts and fills, which is confirmed by the very low R^2 coefficients. According to Charnet et al. (1999), upon increasing the number of observations, there is a tendency for an increase in the significance of the R^2 coefficient; however, based on the absolute values of R^2 (Figures 5 and 6) no satisfactory relationships can be observed
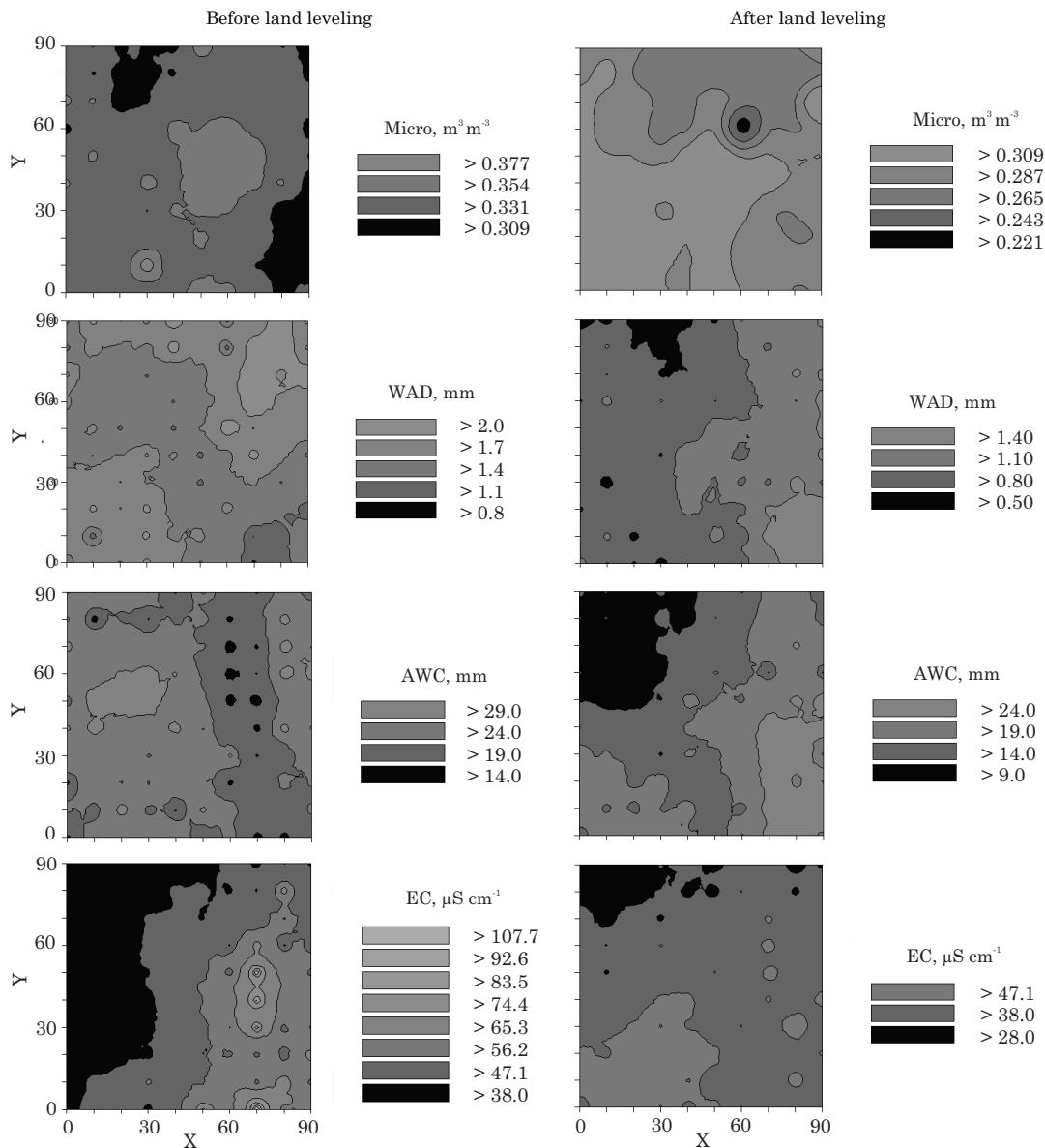

Figure 4. Maps of the spatial distribution of microporosity (micro), weighted average diameter (WAD), available water capacity (AWC), and electrical conductivity (EC) before and after land leveling.
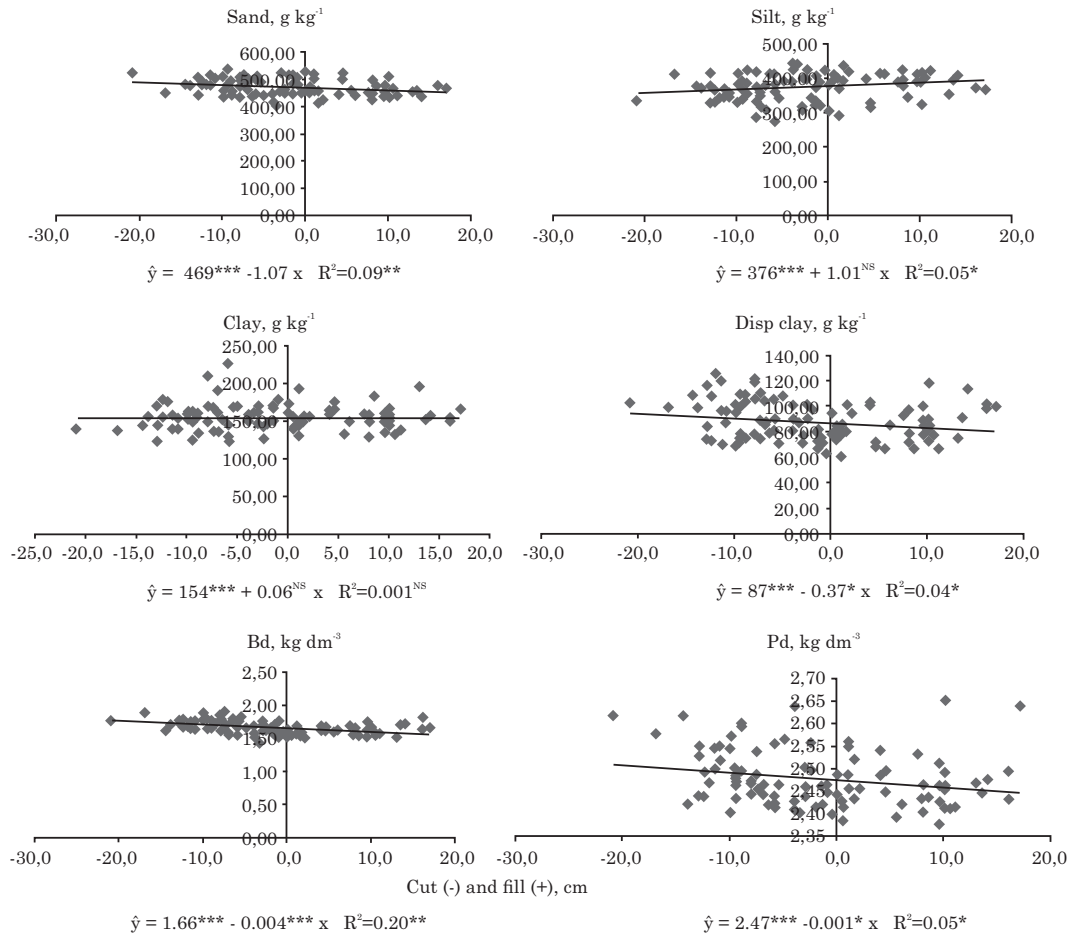
Figure 5. Regressions between cut (-) and fill (+) depths and sand, silt, clay and dispersed clay content in water (Disp clay), soil bulk density (Bd) and particle density (Pd). *** p<0.001; * p<0.05 and [NS] not significant.

between the variables. The low values of the slopes of the regressions in relation to the respective intercepts show that the effects of land leveling on the soil properties evaluated occurred mainly over the whole area, and not specifically in the cut or fill areas.

Based on the results, however, it cannot be said that leveling caused soil compaction over the whole area. Nevertheless, there was a significant increase and decrease in the mean values of Bd and Tp in the whole area, respectively, as a result of leveling (Table 1). Although there was a significant decrease in the mean value of Macro following leveling (Table 1), it can be seen that its values present a random distribution as a function of the magnitudes of cuts and/or fills (Figure 6). From this result, it can be said, in an indirect way, that there was soil compaction over the whole area after leveling, but without relationship to the magnitudes of cuts and/or fills.

The effect of leveling on the spatial distribution of the B horizon in relation to the soil surface

Another important effect of the leveling operation is the change of depth to the top of the B horizon in relation to the new soil surface, that is, the effective arable depth (Figure 7). From figure 7.1 it can be seen that this depth is highly variable in this area, ranging from 22 cm (minimum) to 120 cm (maximum), with a mean value of 77 cm. This behavior is linked to the Albaqualf and Epiaqualf soil formation processes, with their origin in a coastal plain during transgressive-regressive cycles controlled by glacio-eustatic sea level fluctuations (Tomazelli et al., 2000). Overlaying the cut and fill map (Figure 1b) on the map of the depth to the B horizon before leveling (Figure 7.1), the map of the B horizon in relation to the soil surface after leveling was obtained (Figure 7.2). In combined analysis of these figures, it can be seen that the maximum depth of cut was made in the northeast area where the soil is relatively deep. The area where the soil was shallower is located east (Figure 7.1), more specifically northeast, where cuts were also made. In order to clarify this, figure 8 shows that before leveling, the regression line between the depth to the top of the B horizon and the geo-referenced points of the area was practically horizontal. However, after leveling the depth to the top of the B horizon ranged from 40 to 66 cm. It can be seen that several

points where the effective depth was shallow, located in the northeast part (Figure 7.2), were subjected to cuts.

Implications and management strategies to remedy soil physical degradation after land leveling

Based on these results, it can be said that land leveling induces negative effects on important soil physical indicators, which most likely are not related to the specific soil, climate and land use factors. Soil quality was affected mainly by soil bulk density increases and decreases in the size of water stable aggregates, air space and water retention capacity (Table 1). To minimize these negative effects of leveling, it is essential to adopt correct management practices for selected crops, such as incorporation of

$\hat{y} = 0.37^{***} + 0.001^{**} x \quad R^2 = 0.10^{**}$

$\hat{y} = 0.06^{***} - 0.0002^{NS} x \quad R^2 = 0.01^{NS}$

$\hat{y} = 0.31^{***} + 0.001^{***} x \quad R^2 = 0.17^{**}$

$\hat{y} = 1.17^{***} + 0.004^{NS} x \quad R^2 = 0.01^{NS}$

$\hat{y} = 19^{***} + 0.28^{***} x \quad R^2 = 0.15^{**}$

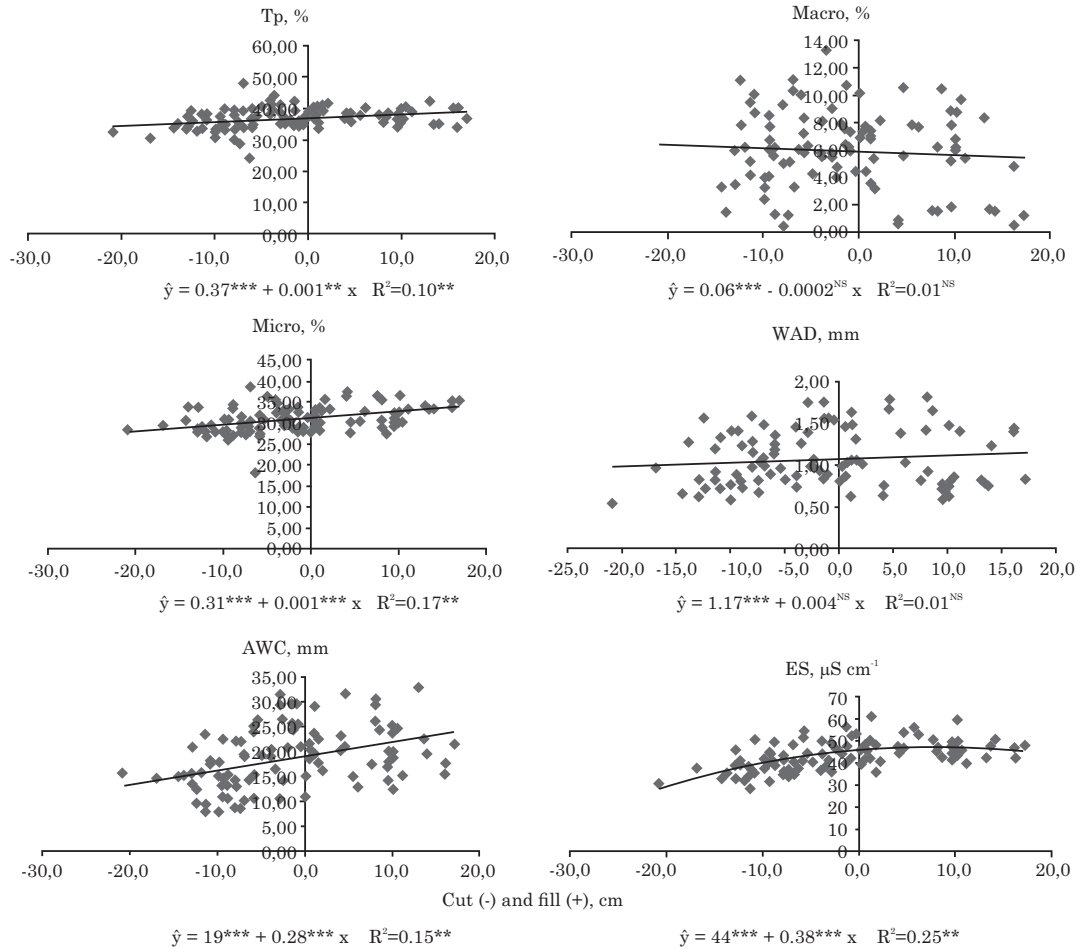$\hat{y} = 44^{***} + 0.38^{***} x \quad R^2 = 0.25^{**}$

Figure 6. Regressions between cut (-) and fill (+) depths and total porosity (Tp), macroporosity (Macro), microporosity (Micro), weighted average diameter (WAD), available water capacity (AWC) and electrical conductivity (EC). *** p<0.001; ** p<0.01; * p<0.05 and NS not significant.
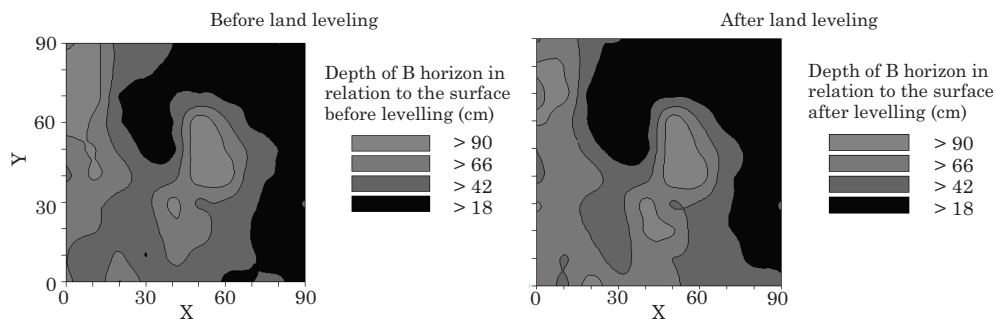

Figure 7. Maps of the spatial distribution of the distance to the top of the B horizon in relation to the soil surface before (left side) and after (right side) land leveling.
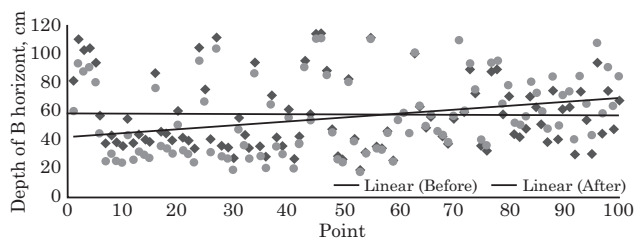
Figure 8. Depth variation of the top of the B horizon before and after land leveling. Solid line before leveling and dotted line after leveling.

organic residues applied to the soil surface or subsurface (e.g. crop residues, poultry litter, among others) (Dourado-Neto et al., 2010). The use of plants with deep and vigorous root systems, minimum tillage, incorporation of green manure and subsoiling are also recommended procedures. In several regions of the world, leveled areas lead to yield increases due to the possibility of using surface irrigation, as mentioned above. They also promote more efficient use of available water resources, thereby conserving natural resources. The main problem in such operations is the cutting of shallow soils, a practically insoluble problem for any type of soil. Management practices recommended to avoid this problem, like removal of the surface horizon so as to level the B horizon and then restore the surface horizon, become economically unviable in many situations. Future research under different environmental conditions is essential for establishing technical criteria for land leveling and for defining the cutting threshold, taking the depth to the B horizon within the area to be leveled into account.

CONCLUSIONS

1. The agricultural effects from land leveling were negative since it increased soil bulk density and dispersed clay, and decreased total porosity, macro and micro porosity, weighted average diameter of aggregates, available water capacity and electrical conductivity. The spatial distributions of all soil physical properties and the depth of the B horizon in relation to the soil surface changed.

2. The effect of leveling on all soil physical properties occurred over the whole area and not specifically in the cut or fill areas. Therefore, recovery of the physical soil quality of the leveled areas should be performed over the total area, not just specifically on cuts or fills.

3. To design a land leveling plan, a cut/fill map overlaid on the map of the depth to the top of the B horizon is recommended so as to minimize problems from shallow soils after leveling. This overlaying of maps facilitates the leveling design, and from the information contained in these maps, it is possible to determine the suitability of a site for leveling before carrying out the leveling in the field.

LITERATURE CITED

BLAKE, G.R. & HARTGE, K.H. Particle density. In: KLUTE, A., ed. Methods of soil analysis. 2.ed. Madison, Soil Science Society of America, 1986. p.377-382.

BROWN, M.B. & FORSYTHE, A.B. Robust test for equality of variances. J. Am. Stat. Assoc., 69:364-367, 1974.

BRYE, K.R.; SLATON, N.A.; SAVIN, M.C.; NORMAN, R.J. & MILLER, D.M. Short-term effects of land leveling on soil physical properties and microbial biomass. Soil Sci. Soc. Am. J., 67:1405-1417, 2003.

BRYE, K.R.; SLATON, N.A. & NORMAN, R.J. Soil physical and biological properties as affected by land leveling in a clayey Aquert. Soil Sci. Soc. Am. J., 70:631-642, 2006.

BRYE, K.R.; SLATON, N.A. & NORMAN, R.J. Penetration resistance as affected by shallow-cut land leveling and cropping. Soil Till. Res., 81:1-13, 2005.

CHARNET, R.; BONVINO, H.; FREIRE, C.A.L. & CHARNET, E.M.R. Análise de modelos de regressão linear. Com aplicações. Campinas, UNICAMP, 1999. 354p.

DOBERMANN, A.; PAMPOLINO, M.F. & NEUE, H.U. Spatial and temporal variation of transplanted rice at the field scale. Agron. J., 87:712-720, 1997.

DOURADO-NETO, D.; POWLSON, D.; BAKAR, R.A.; BACCHI, O.O.S.; BASANTA, M.V.; CONG, P.T.; KEERTHISINGHE, G.; ISMAILI, M.; RAHMAN, S.M.; REICHARDT, K.; SAFWAT, M.S.A.; SANGAKKARA, R.; TIMM, L.C.; WANG, J.Y.; ZAGAL, E. & van KESSEL, C. Multiseason recoveries of organic and inorganic nitrogen-15 in tropical cropping systems. Soil Sci. Soc. Am. J., 74:139-152, 2010.

ECK, H.V. Characteristics of exposed subsoil - At exposure and 23 years later. Agron. J., 79:1067-1073, 1987.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solo. Sistema brasileiro de classificação de solos. Brasília, 2006. 306p.

FERREIRA, L.H.G.; GOMES, A.S.; PARFITT, J.M.B.; SILVA, C.A.S. & GOMES, D.N. Produtividade do arroz, milho e soja em sistema de rotação influenciada pela altura de corte/aterro em várzea sistematizada. In: CONGRESSO BRASILEIRO DE ARROZ IRRIGADO, 3., Camboriú, 2003. Anais... Florianópolis, Sociedade Brasileira de Arroz Irrigado, 2003. v.1, p.765-767.

GEE, G.W. & BAUDER, J.W. Particle-size analysis. In: KLUTE, A., ed. Methods of soil analysis. 2.ed. Madison, Soil Science Society of America, 1986. p.383-411.

GREGO, C.R.; VIEIRA, S.R. & LOURENÇÃO, A.L. Spatial distribution of *Pseudaletia sequax* Franclemlont in triticale under no-till management. Sci. Agric., 63:321-327, 2006.

JOURNEL, A.G. & HUIJBREGTS, C.H.J. Mining geostatistics. New York, Academic Press, 1978. 600p.

INSTITUTO RIOGRANDENSE DO ARROZ - IRGA, 2005. Available: <http://www.irga.rs.gov.br/uploads/anexos/1292592973censodg3.pdf>. Accessed on: Aug. 15, 2012.

KEMPER, W.D. & ROSENAU, R.C. Aggregate stability and size distribution. In: KLUTE, A., ed. Methods of soil analysis. 2.ed. Madison, Soil Science Society of America, 1986. p.425-441.

KLUTE, A. Water retention: Laboratory methods. In: KLUTE, A., ed. Methods of soil analysis. 2.ed. Madison, Soil Science Society of America, 1986. p.635-662.

LAUGHLIN, D.H. & MEHRLE, R.K. Straight versus contour levee rice production practices in Mississipi. Mississippi, Division of Agriculture, Forestry, and Veterinary Medicine/Mississippi State University, 1996. p.1-6. (Bulletin, 1063)

LEVENE, H. Robust test for equality of variances. In: OLKIN, I.; GHURYE, S.G.; HOEFFDING, W.; MADOW, W.G. & MANN, H.B., eds. Contribution to probability and statistics. Stanford, Stanford University Press, 1960. p.278-292.

LIMA, C.L.R.; PAULETTO, E.A.; GOMES, A.S. & SILVA, J.B. Estabilidade de agregados de um planossolo sob diferentes sistemas de manejo. R. Bras. Ci. Solo, 27:199-205, 2003.

MILLER, D.M. Variability of soil chemical properties and rice growth following land leveling. Arkansas Farm Res., 39:1-4, 1990.

MONTGOMERY, D.C. & RUNGER, G.C. Applied statistics and probability for engineers. New York, John Wiley & Sons, 1994. 895p.

NIELSEN, D.R. & WENDROTH, O. Spatial and temporal statistics: Sampling field soils and their vegetation. Reiskirchen, Catena Verlag GMBH, 2003. 416p.

NRCS, 2009. Available: <http://soils.usda.gov/technical/classification/tax_keys>. Accessed: Aug. 20, 2012.

PALMEIRA, P.R.T.; PAULETTO, E.A.; TEIXEIRA, C.F.A.; GOMES, A.S. & SILVA, J.B. Agregação de um Planossolo submetido a diferentes sistemas de cultivo. R. Bras. Ci. Solo., 23:189-195, 1999.

PARFITT, J.M.B. Impacto da sistematização sobre atributos físicos, químicos e biológico em solos de várzea. Pelotas, Universidade Federal de Pelotas, 2009. 92p. (Tese de Doutorado)

PARFITT, J.M.B.; SILVA, C.A.S. & PETRINI, J.A. Estruturação e sistematização da lavoura de arroz irrigado. In: GOMES, A.S. & MAGALHÃES JUNIOR, A.M., eds. Arroz irrigado no Sul do Brasil. Brasília, Embrapa Informação Tecnológica, 2004. p.237-257.

PARFITT, J.M.B. & SILVA, C.A.S. Desempenho da soja cultivada no sistema sulco/camalhão em área de várzeas sistematizadas - Safras 2003/2004 e 2004/2005. In: CONGRESSO BRASILEIRO DE ARROZ IRRIGADO, 4.; REUNIÃO DA CULTURA DO ARROZ IRRIGADO, 28., Santa Maria, 2005. Anais... Santa Maria, Sociedade Brasileira de Arroz Irrigado, 2005. p.587-589.

PARFITT, J.M.B.; TIMM, L.C.; PAULETTO, E.A.; SOUSA, R.O.; CASTILHOS, D.D.; ÁVILA, C.L. & RECKZIEGEL, N.L. Spatial variability of the chemical, physical and biological properties in lowland cultivated with irrigated rice. R. Bras. Ci. Solo, 33:819-830, 2009.

PEREIRA, A.R.; ANGELOCCI, L.R. & SENTELHAS, P.C. Agrometeorologia: Fundamentos e aplicações práticas. Guaíba, Agropecuária, 2002. 478p.

PINTO, L.F.S.; LAUS NETO, J.A. & PAULETTO E.A. Solos de várzea do Sul do Brasil cultivados com arroz irrigado. In: GOMES, A.S. & MAGALHÃES JUNIOR, A.M., eds. Arroz irrigado no Sul do Brasil. Brasília, Embrapa Informação Tecnológica, 2004. p.75-95.

REICHERT, J.M.; DARIVA, T.A.; REINERT, D.J. & SILVA, V.R. Spatial variability of a Planosol and soybean yield on a land-leveled paddy soil: Geostatistical and regression analysis. Ci. Rural, 38:981-988, 2008.

RHOADES, J.D. Soluble salts. In: PAGE, A.L.; MILLER, R.H. & KEENEY, D.R., eds. Methods of soil analysis. Madison, America Society Agronomy, 1982. Part 2. p.167-179. (Agronomy Monograph, 9)

ROBERTSON, G.P. GS+: Geostatistics for the environmental sciences. v. 9.0. Plainwell, Gamma Design Software, 2008. 172p.

SAS Institute. Statistical analysis system: User's guide. 5.ed. Cary, 1985.

SCHLINDWEIN, J.A. & ANGHINONI, I. Tamanho da subamostra e representatividade da fertilidade do solo no sistema plantio direto. Ci. Rural, 32:963-968, 2002.

SILVA, C.A.S. & PARFITT, J.M.B. Utilização do sistema sulco/camalhão para o cultivo do milho em áreas de várzeas sistematizadas - safras 2003/2004 e 2004/2005. In: CARGNELUTTI, A.F. & BARNI, N.A., eds. REUNIÃO TÉCNICA ANUAL DO MILHO, 50., Porto Alegre, 2005. Anais... Porto Alegre, Fepagro/Emater, 2005. p.109.

TOMAZELLI, L.J.; DILLENBURG, S.R. & VILLWOCK, J.A. Late quaternary geological history of Rio Grande do Sul coastal plain, southern Brazil. R. Bras. Geosci., 30:474-476, 2000.

WEBSTER, R. & OLIVER, M.A. Geostatistics for environmental scientists. West Sussex, John Wiley & Sons, 2001. 271p.

WHITNEY, R.S.; GARDNER, R. & ROBERTSON, D.W. The effectiveness of manure and commercial fertilizer in restoring the productivity of subsoils exposed by leveling. Agron. J., 42:239-245, 1950.

WINKLER, E.I.G. & GOEDERT, W.J. Características hídricas dos solos de Pelotas, Rio Grande do Sul. Pesq. Agropec. Bras., 7:1-4, 1972.