ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.20, n.5, p.395-400, 2016
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v20n5p395-400

Rice grain yield as affected by subsoiling, compaction on sowing furrow and seed treatment

Veneraldo Pinheiro[1], Luís F. Stone[1] & José A. F. Barrigossi[1]

[1] Embrapa Arroz e Feijão. Santo Antônio de Goiás, GO. E-mail: veneraldo.pinheiro@embrapa.br; luis.stone@embrapa.br (Corresponding author); jose.barrigossi@embrapa.br

Key words:
Oryza sativa L.
no-tillage
compaction pressure
termite

A B S T R A C T
This study aimed to determine the effects of subsoiling, compaction on sowing furrow and seed treatments with insecticides on the grain yield of upland rice cultivated under no-tillage. Two experiments were carried out, one in an area with and the other in an area without subsoiling, in which five seed treatments combined with five compaction pressures on the sowing furrow were compared in a randomized block design, in a factorial scheme, with three replicates. The seed treatments were: T_0 - without treatment, T_1 - imidacloprid + thiodicarb, T_2 - thiamethoxam, T_3 - carbofuran, and T_4 - fipronil + pyraclostrobin + thiophanate methyl. The compaction pressures were: 25, 42, 126, 268 and 366 kPa. Subsoiling positively affected rice yield in the presence of higher compaction pressures on the sowing furrow. Seed treatment was effective at increasing rice grain yield only at the lowest compaction pressures. Rice yield showed quadratic response to compaction on the sowing furrow, with maximum values obtained at pressures ranging from 238.5 to 280.3 kPa.

Palavras-chave:
Oryza sativa L.
plantio direto
pressão de compactação
cupim

Produtividade do arroz afetada pela subsolagem, compactação no sulco de semeadura e tratamento de semente

R E S U M O
Este trabalho objetivou determinar os efeitos da subsolagem, compactação no sulco de semeadura e de tratamentos de semente com inseticidas na produtividade do arroz de terras altas cultivado em sistema plantio direto. Foram conduzidos dois experimentos, um em área subsolada e outro em não-subsolada em que foram comparados, no delineamento de blocos ao acaso, esquema fatorial, com três repetições, cinco tratamentos de semente combinados com cinco pressões de compactação no sulco de semeadura. Os tratamentos de semente foram: T_0 - sem tratamento, T_1 - imidaclopride + tiodicarbe, T_2 - tiametoxam, T_3 - carbofurano e T_4 - fipronil + piraclostrobina + tiofanato metílico; as pressões de compactação foram: 25, 42, 126, 268 e 366 kPa; a subsolagem afetou positivamente a produtividade do arroz na presença de maiores pressões de compactação no sulco de semeadura; o tratamento de semente foi efetivo em aumentar a produtividade do arroz apenas na presença das menores pressões de compactação e a produtividade apresentou resposta quadrática à compactação do sulco de semeadura com valores máximos obtidos com pressões variando de 238,5 a 280,3 kPa.

Received 048-2015 – 21 May, 2015 • Approved 3 Mar, 2016 • Published 4 Apr, 2016

Introduction

The no-tillage system, for the reduction in the traffic of machines and in soil disturbance associated with the use of cover crops, can preserve and even recover soil structure, maintaining the agricultural system more productive (Vezzani & Mielniczuk, 2009). However, soil compaction has been observed in some situations under no-tillage (Lanzanova et al., 2007; Almeida et al., 2008; Cunha et al., 2011), which may constitute a limiting factor for the increase in yield and the continuous use of this system (Collares et al., 2008).

When the soil is compacted, plant growth may be reduced due to the decrease in water availability, restriction to root growth and deficient aeration (Reichert et al., 2007). The layer with highest impediment to root growth is located between 0.05-0.08 and 0.12-0.15 m (Silva, 2003; Suzuki et al., 2008; Secco et al., 2009), forming the "no-till pan".

The rice crop does not adapt much to the no-tillage system due to its high susceptibility to the compaction of the superficial soil layer (Godoy et al., 2015). Sometimes, mechanical decompaction becomes necessary to break the layer that reduces plant growth.

Chiseling has proven to be effective in the reduction of soil density and increase in macroporosity (Reichert et al., 2007) and water infiltration (Vieira & Klein, 2007). Cunha et al. (2009) observed that subsoiling was effective at reducing the resistance to penetration in the layer of 0.20-0.40 m.

Soil tillage using chisel and leveling disc harrow promoted better soil physical quality in the layer of 0-0.20 m (Kamimura et al., 2009) and greater yield of upland rice (Fonseca et al., 2012), in relation to no-tillage, which was also observed with the use of the "matabroto" type of chisel (Nascente et al., 2011).

Another aspect to be considered in no-tillage is that the soil layer of 0-0.05 m usually has high total porosity, due to the action of seeder-fertilizer discs, higher concentration of roots and organic matter, greater biological activity and more wetting and drying cycles (Silva, 2003), which may hamper the contact of rice seeds with the soil.

The compaction on the sowing furrow improves the contact between the soil and the seeds, allowing them to absorb water earlier and germinate more rapidly (Silva, 2006). The use of this practice promoted increases of 40% in the stand of plants and 15% in the yield of rice cultivated in wetlands (Soares & Carrão, 1993) and 17% in the yield of upland rice under no-tillage (Portugal et al., 2013).

This practice also contributes to minimizing the damages caused by termites, which occur in most rice plantations in Cerrado soils and are one of the main causes of use of insecticides in seed treatment (Ferreira et al., 2007). Barrigossi et al. (2011) observed that the attack of termites in upland rice cultivated under no-tillage was lower in the treatments with furrow compaction and that the benefit of this practice is intensified when associated with seed treatment using insecticides.

This study aimed to determine the effect of subsoiling, compaction on sowing furrow and insecticide seed treatments on the yield of upland rice cultivated in no-tillage system.

Material and Methods

This study was carried out in the municipality of Santo Antônio de Goiás, GO, Brazil (16° 29' 15" S; 49° 18' 45" W; 823 m), and the climate in the region, according to Köppen's classification, is Aw, tropical savanna, megathermal. The rainfall regime is well defined, with rainy period from October to April and dry period from May to September, and mean annual rainfall of 1,485 mm. The soil is a typic acric Red Latosol, with clayey texture and mean contents of 311 g kg^{-1} of sand, 120 g kg^{-1} of silt and 569 g kg^{-1} of clay, in the layer of 0-0.20 m. The initial chemical analysis of this layer showed the following values: pH (H_2O) = 5.6; Ca^{2+} = 9.0 $mmol_c$ dm^{-3}; Mg^{2+} = 6.0 $mmol_c$ dm^{-3}; Al^{3+} = 1.0 $mmol_c$ dm^{-3}; $H^+ + Al^{3+}$ = 49.0 $mmol_c$ dm^{-3}; P = 0.8 mg dm^{-3}; K^+ = 108.0 mg dm^{-3}; Cu^{2+} = 4.1 mg dm^{-3}; Zn^{2+} = 1.5 mg dm^{-3}; Fe^{3+} = 151.0 mg dm^{-3} and Mn^{2+} = 58.0 mg dm^{-3}.

On January 5, 2012, two experiments were installed with upland rice; the first one in a subsoiled area and the second one in a non-subsoiled area. Subsoiling was performed at the depth of 0.35 m, using a hydraulic decompressor (IKEDA - Model DPT), with three rods and working width of 1.60 m, mounted with a leveling roll, attached to its rear end.

The areas had been used for 24 years with *Brachiaria brizantha* pasture. The experiments were conducted in no-tillage on the dried straw of the pasture, in order to compare five seed treatments combined with five compaction pressures on the sowing furrow, in a randomized block design, using a factorial scheme with three replicates. Seed treatments were: T_0 - without treatment, T_1 - imidacloprid + thiodicarb (52.5 + 157.5 mL a.i. 100 kg^{-1} seeds), T_2 - thiamethoxam (140 g a.i. 100 kg^{-1} seeds), T_3 - carbofuran (527 mL a.i. 100 kg^{-1} seeds) and T_4 - fipronil + pyraclostrobin + thiophanate methyl (62.5 + 0.625 + 50.625 mL a.i. 100 kg^{-1} seeds). The compaction pressures were: 25 kPa, promoted by the original compactor of the "V" wheel of the seeder-fertilizer; 42 kPa, promoted by the mass of 635.0 kg on the front axle of a MF 5275 4 x 2 tractor with bald 7.50-16, directional car tires (without "treads", larger contact area), without ballast; 268 kPa, promoted by the mass of 635.0 kg on the front axle of the same tractor, with 7.50-16 F2 three-tread (smaller contact area), directional tires, without additional ballast; and 366 kPa, promoted by the mass of 866.0 kg on the front axle of the same tractor with 7.50-16 F2 three-tread, directional tires, with additional ballast. The contact area of rear tires was increased and the mass was removed as much as possible, in order to reduce its influence on the sowing furrow.

The experiments were installed in 10 x 2.30 m plots with the upland rice cultivar 'BRS Pepita', at the spacing of 0.46 m, with 92 seeds per meter. Immediately after sowing, the following herbicides were applied: paraquat (400 g a.i. ha^{-1}) and pendimethalin (800 g a.i. ha^{-1}) + spreader-sticker Assist (mineral oil) (756 g a.i. ha^{-1}). Sowing was performed using a seeder-fertilizer with a system known as "guillotine knife coulter". Basal fertilization was performed using 356 kg ha^{-1} of the commercial formula 5-30-15. Three top-dressing fertilizations were performed using urea, on February 1 (118 kg ha^{-1}), February 15 (61 kg ha^{-1}) and March 8, 2012 (240 kg ha^{-1}). On March 20, 2012, the insecticide chlorpyrifos was applied (480 g a.i. ha^{-1}).

Soil resistance to vertical penetration (RP) was determined using a penetrograph (Falker PenetroLOG - Model PLG 1020), in the layer of 0-0.40 m, at three points in each plot, one in each evaluated row. The data were obtained in kPa and mean RP values were calculated for layers from 0.05 m until the considered depth. Samplings were performed one day after a rain, with soil moisture close to field capacity. The data were graphically presented, considering the mean values of each treatment of compaction pressure on the sowing furrow. Yield was determined in the evaluated area of the plots (13.8 m^2) and corrected to 13% of humidity. During crop cycle, the number of plants killed by termites was evaluated along two meters of the sowing row, in three pre-established points in the central rows of the plots.

The experiments were analyzed together and the data were subjected to analysis of variance by F test, using the GLM procedure of the statistical program SAS (SAS Institute, 1999). Means were compared by Tukey test at 0.05 probability level. In addition, regression analysis was performed when there were significant effects of compaction pressures on rice yield.

Results and Discussion

The isolated effect of subsoiling on rice yield was not significant. However, there was significant interaction between subsoiling and seed treatment and between subsoiling and compaction pressure (Table 1), besides significant effect of seed treatment, compaction pressure on the sowing furrow and their interaction.

In the presence of subsoiling, the seed treatments T_1 (imidacloprid + thiodicarb) and T_2 (thiamethoxam) did not differ from T_4 (fipronil + pyraclostrobin + thiophanate methyl) and conditioned higher rice yields than the treatments T_3 (carbofuran) and T_0 (Table 2). In the absence of subsoiling, the treatment T_1 did not differ from T_2 and T_4 and also promoted higher rice yield than the treatments T_3 and T_0.

Barrigossi & Ferreira (2001) found that seed treatment using insecticides increased the yield of upland rice in relation to the control, without treatment, because of the reduction in plant mortality caused by the attack of termites and Lesser Cornstalk Borer (*Elasmopalpus lignosellus*). Barrigossi et al. (2011) also observed that seed treatment promoted greater control of termites in the rice crop, compared with the absence of treatment.

As shown in Figure 1, rhizophagous termites caused the death of rice plants, especially in the absence of seed treatment; the termites form underground colonies and feed on the roots of rice plants, debilitating them and then causing death. The insecticide carbofuran (treatment T_3), despite being efficient for the control of sucking insects that attack rice plants in the initial development stage, has low efficiency in the control of termites, as observed by Barrigossi & Ferreira (2001).

Table 1. Summary of the analysis of variance for rice yield

Source of variation	D.F.	Mean square
Block	2	130,559.23^{ns}
Subsoiling (S)	1	57,888.80^{ns}
Seed treatment (ST)	4	4,418,420.14**
Interaction S x ST	4	838,145.45*
Compaction pressure (P)	4	5,660,356.95**
Interaction S x P	4	1,459,023.20**
Interaction ST x P	16	847,221.75**
Interaction S x ST x P	16	312,522.79^{ns}
Residue	104	311,204.90
CV (%)		18.7

^{ns},**, *Not significant, significant at $p < 0.01$ and $p < 0.05$ by F test, respectively

Table 2. Upland rice yield (kg ha^{-1}) affected by subsoiling and seed treatment

Seed treatment	Subsoiling	
	With	Without
T_0	2,100 c	2,538 c
T_1	3,409 a	3,441 a
T_2	3,626 a	3,108 ab
T_3	2,690 bc	2,842 bc
T_4	3,263 ab	3,070 ab

In the column, means followed by the same letter do not differ by Tukey's test at 0.05; T_0 - Without seed treatment; T_1 - Imidacloprid + thiodicarb (52.5 + 157.5 mL a.i. 100 kg^{-1} seeds); T_2 - Thiamethoxam (140 g a.i. 100 kg^{-1} seeds); T_3 - Carbofuran (527 mL a.i. 100 kg^{-1} seeds); T_4 - Fipronil + pyraclostrobin + thiophanate methyl (62.5 + 0.625 + 50.625 mL a.i. 100 kg^{-1} seeds)

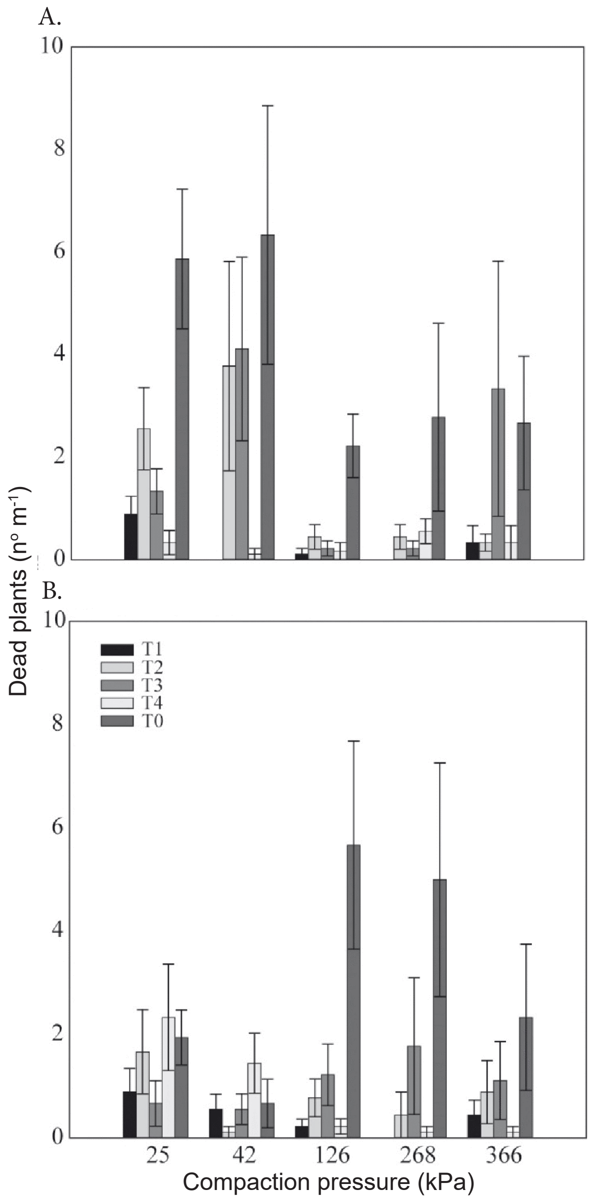

Figure 1. Mortality of rice plants caused by termites, affected by seed treatment and compaction pressure applied on the sowing furrow, in experiments with (A) and without (B) subsoiling

Considering each seed treatment, the treatments of subsoiling did not affect rice yield significantly. Both in the presence and in the absence of subsoiling, rice yield increased quadratically with the increments in compaction pressure on the sowing furrow (Table 3), with maximum estimated values of 3,965 and 3,277 kg ha^{-1}, obtained at the pressures of 248.1 and 243.7 kPa, respectively. According to the regression curves, until the value of 84 kPa, rice yield was higher in the absence of subsoiling and, from this value on, it became higher in the presence of subsoiling. Plant mortality caused by termites (Figure 1) was lower at the highest compaction pressures in the presence of subsoiling.

In soil subjected to three states of compaction, Secco et al. (2009) observed that chiseling increased corn grain yield, but it did not change soybean grain yield. Fonseca et al. (2012) and Nascente et al. (2011), respectively, observed that chiseling + leveling harrowing and the use of the "matabroto" type of chisel promoted higher upland rice yield, in relation to the no-tillage system. Seki et al. (2012), on the other hand, observed that subsoiling and sporadic chiseling in soils under no-tillage system did not interfere with plant development or corn yield. Likewise, Collares et al. (2008) did not observe effect of chiseling on bean and wheat yields in an area under six years of no-tillage system.

At the lowest compaction pressure (25 kPa), the absence of seed treatment conditioned the lowest rice yield (Table 4). The treatment T_1 did not differ from T_2 and promoted higher yields than the treatments T_3 and T_4. At the pressure of 42 kPa, the treatments T_1 and T_2 promoted higher yields in comparison to the others. At the highest compaction pressure (366 kPa), these treatments and T_4 promoted higher yield in relation to T_3 and did not differ from T_0. At the pressures of 126 and 268 kPa, there were no significant differences between the seed treatments.

The lowest rice yield in the absence of seed treatment, at the lowest compaction pressure, may be due to the greater mortality of plants caused by soil insects, especially termites, as reported by Barrigossi & Ferreira (2001) and Barrigossi et al. (2011). The increase in compaction on the sowing furrow contributes to the control of termites (Barrigossi et al., 2011) and is possibly the reason why, in general, there was no difference between seed treatments at the highest pressures.

Table 3. Regression equations of yield (Y) as a function of compaction pressure on the sowing furrow (X) (n = 75)

Equation	R^2	Maximum X (kPa)
With subsoiling		
$Y = 1,676.1 + 18.456X - 0.0372X^2$	0.46**	248.1
Without subsoiling		
$Y = 2,564.5 + 5.8499X - 0.0120X^2$	0.13*	243.7

Table 4. Upland rice yield (kg ha^{-1}) affected by seed treatment and compaction pressure on the sowing furrow

Seed treatment	Compaction pressure on the sowing furrow (kPa)				
	25	42	126	268	366
T0	1,073 c	2,391 b	3,170 a	3,185 a	3,024 ab
T1	3,139 a	3,586 a	3,524 a	3,298 a	3,578 a
T2	2,860 ab	3,373 a	3,498 a	3,501 a	3,605 a
T3	2,204 b	2,472 b	3,358 a	3,081 a	2,717 b
T4	2,640 ab	2,809 b	3,579 a	3,263 a	3,540 a

In the column, means followed by the same letter do not differ by Tukey's test at 0.05; T_0 - Without seed treatment; T_1 - Imidacloprid + thiodicarb (52.5 + 157.5 mL a.i. 100 kg^{-1} seeds); T_2 - Thiamethoxam (140 g a.i. 100 kg^{-1} seeds); T_3 - Carbofuran (527 mL a.i. 100 kg^{-1} seeds); T_4 - Fipronil + pyraclostrobin + thiophanate methyl (62.5 + 0.625 + 50.625 mL a.i. 100 kg^{-1} seeds)

Rice yield increased quadratically and significantly with the compaction pressure on the sowing furrow, in all seed treatments, except for T_1 (Table 5). Maximum yields were obtained at pressures ranging from 238.5 to 280.3 kPa. Modolo et al. (2007) observed that low pressures on the sowing furrow reduces the contact between the soil and the seed, limiting the amount of water that reaches the surface of the seed, thus decreasing emergence. On the other hand, high pressures may increase surface crusting, which impairs the entry of oxygen, causing the plant to consume more energy to emerge.

RP increased with soil depth and reached values from 2,755 to 3,460 kPa in the experiment with subsoiling and higher values, from 3,674 to 4,108 kPa, in the experiment without subsoiling (Figures 2A and 2B), agreeing with Cunha

Table 5. Regression equations of yield (Y) as a function of compaction pressure on the sowing furrow (X) (n = 30)

Seed treatment	Equation	R^2	Maximum X (kPa)
T_0	$Y = 874.5 + 22.425X - 0.0465X^2$	0.61**	241.1
T_1	$Y = 3,134.0 + 5.534X - 0.0116X^2$	0.15^{ns}	238.5
T_2	$Y = 2,913.2 + 5.140X - 0.0093X^2$	0.24*	276.3
T_3	$Y = 2,026.2 + 11.796X - 0.0257X^2$	0.37*	229.5
T_4	$Y = 2,565.3 + 7.176X - 0.0128X^2$	0.28*	280.3

T_0 - Without seed treatment; T_1 - Imidacloprid + thiodicarb (52.5 + 157.5 mL a.i. 100 kg^{-1} seeds); T_2 - Thiamethoxam (140 g a.i. 100 kg^{-1} seeds); T_3 - Carbofuran (527 mL a.i. 100 kg^{-1} seeds); T_4 - Fipronil + pyraclostrobin + thiophanate methyl (62.5 + 0.625 + 50.625 mL a.i. 100 kg^{-1} seeds)

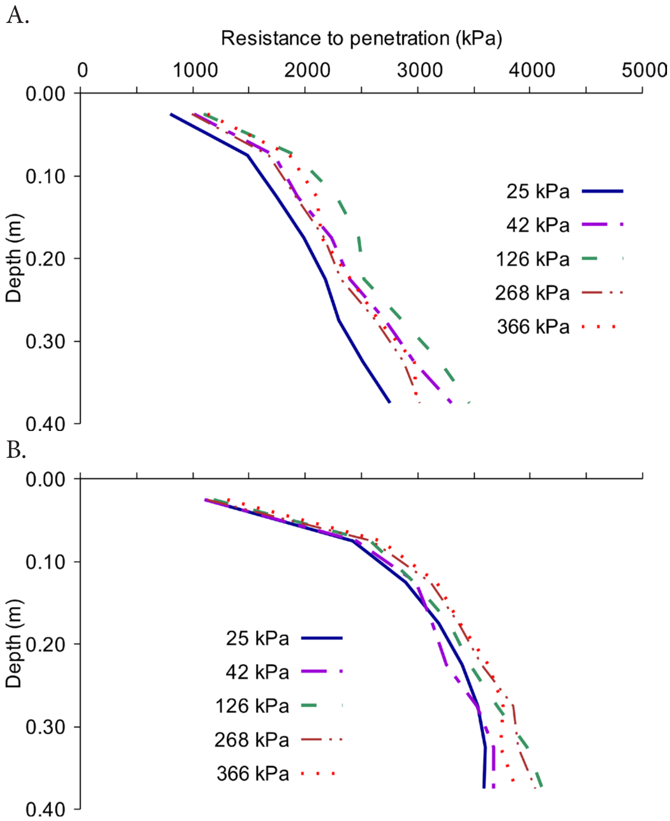

Figure 2. Soil resistance to penetration as a function of compaction pressures applied on the sowing furrow, in experiments with (A) and without (B) subsoiling

et al. (2009), who observed the effectiveness of this practice at reducing the resistance to penetration in the layer of 0.20-0.40 m. Cunha et al. (2011) also observed gradual increase in RP from the surface to 0.40 m in soils under conventional tillage and no-tillage.

In the experiment with subsoiling, the effects of the pressures applied on the sowing furrow on the increase of RP were more evident (Figure 2A); in the experiment without subsoiling, the effects of pressure on RP were similar (Figure 2B), possibly for being under greater compaction compared with the soil under subsoiling, which caused it to resist to the pressure exerted on the sowing furrow.

Considering the layer of 0-0.20 m, in which most rice roots are concentrated (Stone & Pereira, 1994), RP showed maximum values around 2,200 and 3,200 kPa, respectively for the experiments with and without subsoiling. These values probably did not damage the crop, because the RP values that restrict root growth or crop yield are close to 3,000 kPa (Reichert et al., 2007). Additionally, for Tormena et al. (2007), this value may reach 3,500 kPa in soil cultivated for a long period under no-tillage, justified by the presence of continuous and effective biopores.

Conclusions

1. Subsoiling positively affected rice yield in the presence of higher compaction pressures on the sowing furrow.

2. Seed treatment was effective at increasing rice yield only at the lowest compaction pressures on the sowing furrow.

3. Rice yield responded quadratically to the compaction on the sowing furrow, with maximum values obtained at pressures ranging from 238.5 to 280.3 kPa.

Literature Cited

Almeida, V. P. de; Alves, M. C.; Silva, E. C. da; Oliveira, S. A. de. Rotação de culturas e propriedades físicas e químicas em Latossolo Vermelho de cerrado sob preparo convencional e semeadura direta em adoção. Revista Brasileira de Ciência do Solo, v.32, p.1227-1237, 2008. http://dx.doi.org/10.1590/S0100-06832008000300031

Barrigossi, J. A.; Pinheiro, V.; Silva, J. G. da; Cobucci, T.; Eifert, E. C.; Silva, J. F. A.; Alves, T. M. Efeito da compactação de sulco de plantio e de tratamentos de sementes na infestação de cupins em arroz de terras altas, em plantio direto. In: Simpósio Brasileiro de Termitologia, 1, 2011, Anápolis. Anais... Anápolis: Universidade Estadual de Goiás, 2011. CD-Rom

Barrigossi, J. A. F.; Ferreira, E. Tratamento de sementes de arroz com inseticidas: efeito sobre os insetos e rendimento de grãos. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2001. 2p. Pesquisa em Foco, 59.

Collares, G. L.; Reinert, D. J.; Reichert, J. M.; Kaiser, D. R. Compactação de um Latossolo induzida pelo tráfego de máquinas e sua relação com o crescimento e produtividade de feijão e trigo. Revista Brasileira de Ciência do Solo, v.32, p.933-942, 2008. http://dx.doi.org/10.1590/S0100-06832008000300003

Cunha, E. de Q., Stone, L. F.; Moreira, J. A. A.; Ferreira, E. P. de B.; Didonet, A. D.; Leandro, W. M. Sistemas de preparo do solo e culturas de cobertura na produção orgânica de feijão e milho. I - Atributos físicos do solo. Revista Brasileira de Ciência do Solo, v.35, p.589-602, 2011. http://dx.doi.org/10.1590/S0100-06832011000200028

Cunha, J. P. A. R.; Cascão, V. N.; Reis, E. F. dos. Compactação causada pelo tráfego de trator em diferentes manejos de solo. Acta Scientiarum Agronomy, v.31, p.371-375, 2009. http://dx.doi.org/10.4025/actasciagron.v31i3.819

Ferreira, E.; Barrigossi, J. A. F.; Silva, J. G. da; Stone, L. F.; Moreira, J. A. A. Fatores influenciando o ataque de cupim rizófago em plantio direto de arroz de terras altas. Pesquisa Agropecuária Tropical, v.37, p.176-181, 2007.

Fonseca, A. E.; Arf, O.; Orioli Júnior, V.; Buzetti, S.; Rodrigues, R. A. F. Preparo do solo e doses de nitrogênio em cobertura em arroz de terras altas. Pesquisa Agropecuária Tropical, v.42, p.246-253, 2012. http://dx.doi.org/10.1590/S1983-40632012000300001

Godoy, S. G. de; Stone, L. F.; Ferreira, E. P. de B.; Cobucci, T.; Lacerda, M. C. Correlação entre produtividade do arroz no sistema semeadura direta e atributos do solo. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.119-125, 2015. http://dx.doi.org/10.1590/1807-1929/agriambi.v19n2p119-125

Kamimura, K. M.; Alves, M. C.; Arf, O.; Binotti, F. F. da S. Propriedades físicas de um Latossolo Vermelho sob cultivo do arroz de terras altas em diferentes manejos do solo e água. Bragantia, v.68, p.723-731, 2009. http://dx.doi.org/10.1590/S0006-87052009000300020

Lanzanova, M. E.; Nicoloso, R. da S.; Lovato, T.; Eltz, F. L. F.; Amado, T. J. C.; Reinert, D. J. Atributos físicos do solo em sistema de integração lavoura-pecuária sob plantio direto. Revista Brasileira de Ciência do Solo, v.31, p.1131-1140, 2007. http://dx.doi.org/10.1590/S0100-06832007000500028

Modolo, A. J.; Fernandes, H. C.; Schaefer, C. E. G.; Santos, N. T.; Silveira, J. C. M. da. Efeito do teor de água do solo e da carga aplicada pela roda compactadora na velocidade de emergência da soja. Acta Scientiarum Agronomy, v.29, p.587-592, 2007. http://dx.doi.org/10.4025/actasciagron.v29i5.713

Nascente, A. S.; Kluthcouski, J.; Rabelo, R. R.; Oliveira, P. de; Cobucci, T.; Crusciol, C. A. C. Produtividade do arroz de terras altas em função do manejo do solo e da época de aplicação de nitrogênio. Pesquisa Agropecuária Tropical, v.41, p.60-65, 2011. http://dx.doi.org/10.5216/pat.v41i1.6509

Portugal, J. R.; Rodrigues, R. A. F.; Arf, G. H. S.; Peres, A. R.; Souza, E. de. Doses de nitrogênio associadas à inoculação com *Azospirilllum brasilense* e compactação do solo na linha de semeadura em arroz de terras altas. In: Congresso Brasileiro de Arroz Irrigado, 8, 2013, Santa Maria. Anais... Santa Maria: UFSM; Porto Alegre: Sosbai, 2013. v.2. p.794-797.

Reichert, J. M.; Suzuki, L. E. A. S.; Reinert, D. J. Compactação do solo em sistemas agropecuários e florestais: identificação, efeitos, limites críticos e mitigação. In: Cerreta, C. A.; Silva, L. S. da; Reichert, J. M. Tópicos em ciência do solo. Viçosa: Sociedade Brasileira de Ciência do Solo, 2007. v.5. p.49-134.

SAS Institute. Procedure guide for personal computers. Version 5. Cary: SAS Institute, 1999. 552p.

Secco, D.; Reinert, D. J.; Reichert, J. M.; Silva, V. R. da. Atributos físicos e rendimento de grãos de trigo, soja e milho em dois Latossolos compactados e escarificados. Ciência Rural, v.39, p.58-64, 2009. http://dx.doi.org/10.1590/S0103-84782009000100010

Seki, A. S.; Benez, S. H.; Silva, P. R. A. Desempenho operacional de semeadora e produtividade do milho em plantio direto e cultivo mínimo. Revista Energia na Agricultura, v.27, p.1-18, 2012. http://dx.doi.org/10.17224/EnergAgric.2012v27n1p01-18

Silva, J. G. da. Desempenho de semeadora no plantio direto do arroz influenciado por tipos de sulcadores e de compactadores de sulcos. In: Congresso Brasileiro da Cadeia Produtiva de Arroz, 2, e Reunião Nacional de Pesquisa de Arroz, 8. 2006, Brasília. Anais... Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2006. CD Rom.

Silva, V. R. da. Propriedades físicas e hídricas em solos sob diferentes estados de compactação. Santa Maria: UFSM, 2003. 171p. Tese Doutorado

Soares, A. L. A.; Carrão, V. H. Plantio direto de arroz irrigado: uma ponte entre passado e futuro. Porto Alegre: Monsanto, 1993. 33p.

Stone, L. F.; Pereira, A. L. Sucessão arroz-feijão irrigados por aspersão: efeitos de espaçamento entre linhas, adubação e cultivar no crescimento, desenvolvimento radicular e consumo d'água do arroz. Pesquisa Agropecuária Brasileira, v.29, p.1577-1592, 1994.

Suzuki, L. E. A. S.; Reinert, D. J.; Reichert, J. M.; Lima, C. L. R. de. Estimativa da susceptibilidade à compactação e do suporte de carga do solo com base em propriedades físicas de solos do Rio Grande do Sul. Revista Brasileira de Ciência do Solo, v.32, p.963-973, 2008. http://dx.doi.org/10.1590/S0100-06832008000300006

Tormena, C. A.; Araújo, M. A.; Fidalski, J.; Costa, J. M. da. Variação temporal do intervalo hídrico ótimo de um Latossolo Vermelho distroférrico sob sistemas de plantio direto. Revista Brasileira de Ciência do Solo, v.31, p.211-219, 2007. http://dx.doi.org/10.1590/S0100-06832007000200003

Vezzani, F. M.; Mielniczuk, J. Uma visão sobre a qualidade do solo. Revista Brasileira de Ciência do Solo, v.33, p.743-755, 2009. http://dx.doi.org/10.1590/S0100-06832009000400001

Vieira, M. L.; Klein, V. A. Propriedades físico-hídricas de um Latossolo Vermelho submetido a diferentes sistemas de manejo. Revista Brasileira de Ciência do Solo, v.31, p.1271-1280, 2007. http://dx.doi.org/10.1590/S0100-06832007000600006