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Energy demand of a mechanized unit for the implementation of common bean crops[1]

Demanda energética de um conjunto mecanizado na implantação da cultura do feijão

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HIGHLIGHTS:

The specific energy demand was affected by the soil water contents and soil fertilizer placement depths.
The lowest grain yield was found in the plots with soil water content of 28.7% and fertilizer placement depth of 0.15 m.
The soil resistance to penetration was greater in the deeper soil layers.

ABSTRACT: Adequate soil managements and use of agricultural machinery are essential for the economic viability of these practices and for the environmental preservation. In this context, sowing and fertilizer application practices are the most important activities, since they affect crop development and present high energy demand. Therefore, the objective of this study was to evaluate the energy demand of a tractor-planter-fertilizer unit for the sowing of common bean seeds in no-tillage system as a function of three soil water contents (28.7, 36.4, and 47.6%) and three soil fertilizer placement depths (0.06; 0.11 and 0.15 m). The final common bean grain yield was also evaluated. The lowest energy demand was found for the highest soil water content combined with the lowest soil fertilizer placement depth. The highest common bean grain yield was found for plants under soil water content of 36.4% and fertilizer placement depth of 0.11 m, reaching 4,186 kg ha^{-1}.

Key words: *Phaseolus vulgaris*, water content, fertilizer placement depth, no-tillage system

RESUMO: O manejo do solo e o uso adequado do maquinário agrícola são cruciais tanto para a viabilidade econômica da operação quanto para o meio ambiente. Nesse contexto, a operação de semeadura-adubação se torna uma das atividades mais críticas, devido sua importância para o desenvolvimento da cultura e alta demanda energética. Desta forma, o presente estudo objetivou avaliar a demanda energética de um conjunto trator-semeadora-adubadora na semeadura de feijão em sistema de plantio direto na palha em função de três teores de água no solo (28,7; 36,4 e 47,6%) e de três profundidades de deposição do adubo (0,06; 0,11 e 0,15 m). A produtividade final do feijoeiro semeado foi avaliada. A menor demanda energética ocorreu no maior teor de água do solo e na menor profundidade de deposição do adubo. A maior produtividade do feijoeiro ocorreu no teor de água do solo de 36,4% e profundidade de deposição do adubo de 0,11 m, alcançando o valor de 4186 kg ha^{-1}.

Palavras-chave: *Phaseolus vulgaris*, teor de água, profundidade de adubação, sistema de plantio direto

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Introduction

Inappropriate use of agricultural machinery and soil management practices results in losses for crop producers and for the environment, such as decreases in crop grain yield, and increases in production costs and greenhouse gas emissions.

The optimization of the energy demanded by the agricultural machinery is one of the alternatives for solving these problems; since fuel consumption impacts the total production cost and greenhouse gas emissions (Tricai et al., 2016; Cavalcante et al., 2019; Farias et al., 2019).

The process combining sowing and fertilizer application is one of the main agricultural practices, since it affects the crop development and grain yield (Gabriel Filho et al., 2010). Several factors affect the energy demand of a tractor-planter-fertilizer unit, such as crop type (Bertolini & Gamero, 2010; Bertolini et al., 2012), tractor operation strategy (Silveira et al., 2013; Farias et al., 2019), tractor wheelset condition (Montanha et al., 2011; Lopes et al., 2019), seed/fertilizer placement depth (Rinaldi et al., 2009; Compagnon et al., 2013), and soil water content (Cepik et al., 2005; Lacerda et al., 2014).

Soil water content and soil fertilizer placement depth stand out among these factors, since they affect fuel consumption by agricultural machinery; these variables are essential for the crop establishment. Some crops are favored when the soil fertilizer is placed at greater soil depths, which stimulates the initial root growth (Sousa et al., 2009). Contrastingly, deeper soil layers are usually more compacted and resistant to penetration, resulting in high energy consumption (Mahl et al., 2008; Drescher et al., 2011). In such situation, financial gains from increase in grain yield would decrease by increases in the fuel consumed in these agricultural practices.

Therefore, determining conditions that reduce the energy demand in agricultural practices without causing negative impacts on crop yields is important. Despite several studies have evaluated strategies to decrease fuel consumption, little information is found about the impacts of these strategies on crop yield.

In this context, the hypothesis that energy demand in agricultural practices can be reduced without affecting the crop grain yield was raised. Thus, the objective of this study was to evaluate the energy demand of a tractor-planter-fertilizer unit and the common bean grain yield in no-tillage system as a function of soil water contents and soil fertilizer placement depths.

Material and Methods

The experiment was conducted in an area of 1 hectare with history of common bean crops; the soil of this area was classified as a Typic Hapludult. The common bean crop was sown in no-tillage system, with no soil preparation until the sowing time. The soil chemical characteristics and compaction were evaluated before the sowing for a better characterization of the experiment area.

The soil resistance penetration was determined using a digital penetrometer (PenetroLOG-PLG 1020; Falker, Porto Alegre, Brazil) equipped with a conical type II tip; 81 points were sampled in the area, in which readings were taken every 10 mm up to 0.20 m depth.

The experiment was conducted in a randomized block design, using a split-plot arrangement, with three replications. The plots consisted of three soil water contents (28.7%, 36.4, and 47.6%) and the subplots consisted of three fertilizer placement depths (0.06, 0.11, and 0.15 m). The area of each experimental unit was 370.37 m^2.

The initial soil water content was adjusted using a central pivot irrigation system (PA3-Light; Asbrasil, São Bernardo do Campo, Brazil), and monitored using a moisture sensor (FieldScout TDR-300; Spectrum Technologies, Aurora, USA).

Common bean (*Phaseolus vulgaris* L) seeds of the variety Ouro-Vermelho were used for growth in no-tillage system. Common bean was chosen because it is an important subsistence crop and one of the main sources of protein for low-income populations, mainly in Latin America and Africa (Queiroga et al., 2012).

The seeds were placed at 0.03 m depth using a 2-row planter-fertilizer set (POP-JM2670PD-SH-EX; Jumil, Batatais, Brazil) equipped with a pneumatic dispenser and a thin tip furrower; the unit was set for large seeds and distribution of 12 seeds per meter, with spacing between rows of 0.5 m. A tractor undulation control was used to ensure the longitudinal leveling, and a pantographic mechanism in the planter was used to ensure transversal leveling, preserving the depths for placement of seeds and soil fertilizer, which were adjusted in the planter-fertilizer set.

A glyphosate systemic herbicide (Roundup; Monsanto, St. Louis, USA) was applied at the rate of 3.0 L ha^{-1} before planting. Soil fertilizer was applied using the N-P-K formulation 8-28-16 at the recommended rate of 350 kg ha^{-1}, based on the results of the soil laboratorial analysis. The herbicide fomesafem (Flex 250 Syngenta, Basel, Switzerland) was applied at the rate of 600 mL ha^{-1} for the control of broadleaf weeds, and the herbicide fluazifop-p-butyl (Fusilade 250 EW; Syngenta, Basel, Switzerland) was applied at the rate of 900 mL ha^{-1} for the control of grass weeds. In addition, manual weeding was carried out to assist in weed control. Molybdenum (sodium molybdate) was applied to the crop at the rate of 80 g ha^{-1}, at 25 days after emergence of the common bean plants, focused on increase the activity of nitrogenase (Lopes et al., 2016).

The power demanded by the traction bar was obtained by the product between force demanded and operational speed, as shown in Eq. 1,

$$P_{tb} = F_t S_{op} \quad (1)$$

where:

P_{tb} - traction bar power, kW;
F_t - traction force, kN; and,
S_{op} - operational speed of the tractor, m s^{-1}.

The actual work speed of the tractor during its operation was 6.7 km h^{-1}, which was assessed by using a radar unit of Doppler effect (Radar II; Dickey John, Auburn, USA). The traction force was estimated using a load cell (Kratos, Cotia, Brazil) with capacity of 50 kN and sign response of 306.63 N mV^{-1}. All devices were connected to a data acquisition

unit (Spider 8; HBM Company, Darmstadt, Germany) installed in the tractor. The data acquisition unit was managed by the Catman 2.2 software (HBM, Darmstadt, Germany) installed in a portable computer in the operational station of the evaluated tractor.

The traction force was obtained by an indirect method known as convoy method, since the planter-fertilizer set is a mounted and not a drag machine (Figure 1). An Agrale 5085 tractor (Agrale S.A. Caxias do Sul. Brazil) with nominal power of 63 kW was used to attach the planter-fertilizer. The tractor-planter-fertilizer unit was pulled by a John Deere 5705 tractor (John Deere, Moline, USA) with power of 63 kW at nominal rotation of 2,150 rpm; it had a 4-cylinder motor, mechanic injection system, and approximately 450 hours of use. The tractors were connected by a load cell.

The Agrale tractor was operated disengaged for the planting, however, with the power takeoff moving the turbine of the planter-fertilizer set. The force required by the planter-fertilizer set was determined by subtracting from the measured values the force needed to pull only the tractor in which the planter-fertilizer set was attached, which was evaluated separately.

The fuel consumption per worked area was calculated according to Eq. 2,

$$C_a = \frac{C_h}{C_o} \quad (2)$$

where:
C_a - fuel consumption per worked area, L ha^{-1};
C_h - fuel consumption per hour, L h^{-1}; and,
C_o - effective operational capacity, ha h^{-1}.

The fuel consumption per hour of tractor work was monitored using a volumetric flow meter (LSF41C0, Flowmate M-III; Oval Co., Tokyo, Japan) installed in fuel feed system of the tractor. The tube that returns fuel to the tank was repositioned to direct the fuel to a system composed of a pressure compensating chamber and a unidirectional valve. Thus, the fuel from the tank, measured by the sensor, was totally consumed by the tractor motor. The effective operational capacity, which is the ratio between the worked area per set (theoretical work width × plot length) and the time spent in the operation, was calculated using Eq. 3,

$$C_o = \frac{A}{t} \quad (3)$$

where:
C_o - effective operational capacity, ha h^{-1};
A - area worked by the implement, ha; and,
t - time spent in the operation, h.

The total energy required for the operation was calculated by the ratio between fuel consumption (L ha^{-1}) and amount of energy released in the combustion process (calorific power). The total energy demand was obtained using Eq. 4,

$$D_t = C_a D P_c \quad (4)$$

where:
D_t - total fuel energy demand, MJ ha^{-1};
C_a - fuel consumption per worked area, L ha^{-1};
D - fuel density, kg L^{-1}; and,
P_c - lower calorific power of the fuel, MJ kg^{-1}.

The density and lower calorific power of the diesel used were based on mean values provided by the ANP (2017):
- Lower calorific power: 10100 kcal kg^{-1} (42.2594 MJ kg^{-1});
- Density: 0.8400 Mg m^{-3} (0.8400 kg L^{-1}).

In addition to total energy demand, the specific energy demand was calculated, which is the amount of energy effectively spent to pull or turn on a machine or implement. The results of both energy demands were used to estimate the fuel use efficiency, which enabled to assess whether the mechanized set was dimensioned according to the requirements determined in the field. The specific energy demand was obtained by the ratio between demanded power in the traction bar and the operational capacity, according to Eq. 5,

$$D_e = \frac{P_{tb}}{C_o} 3.6 \quad (5)$$

where:
D_e - specific energy demand, MJ ha^{-1};
P_{tb} - power in the traction bar, kW; and,
C_o - operational capacity (ha h^{-1}).

The fuel use efficiency was calculated using Eq. 6 (Mileusnić et al., 2010),

$$E_c = \frac{D_e}{D_t} 100 \quad (6)$$

where:
E_c - fuel use efficiency, %;

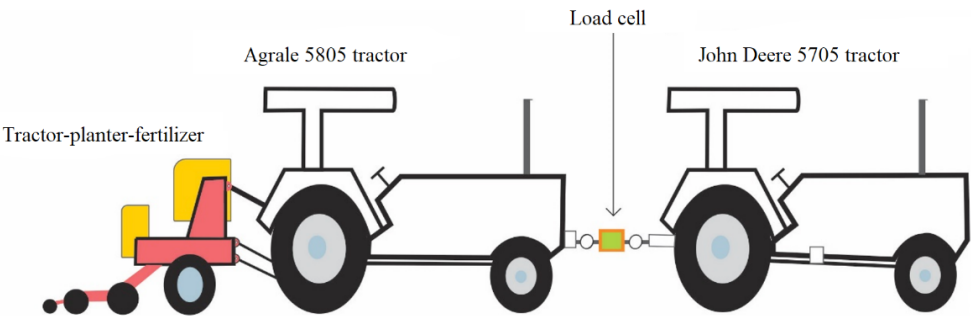


Figure 1. Model of instrumented set used to collect the experimental data

D_e - specific energy demand, MJ ha^{-1}; and,
D_t - total fuel energy demand, MJ ha^{-1}.

The common bean plants at the R9 developmental stage were manually harvested in an area of 10 m^2, in the center of each experimental plot, and then naturally dried and threshed.

The crop grain yield was estimated by weighing the grains harvested in the plots in a precision balance (0.01 g), and extrapolating the results to kg ha^{-1}. The grain weight was measured to a moisture of 13%, since this is the standard grain moisture used in the market.

The data were subjected to analysis of variance. The means of the variables that showed significant differences were compared by the Tukey's test at $p \leq 0.05$. The statistical analyses were carried out using the R program (R Core Team, 2017).

Results and Discussion

Soil resistance to penetration is a useful variable to understand the crop development (Peigné et al., 2018); it is strongly affected by the soil water content (Hamza & Anderson, 2005). The soil resistance to penetration was greater in the deeper soil layers (Figure 2). This was also found in the plots with the lowest soil water contents. A possible explanation for these results is that the water creates a lubricating effect on the soil or decreases the tensions of soil solid particles (Cepik et al., 2005).

The resistance to penetration found in the 0-0.20 m layer ranged from 0 to 3.6 MPa. Soil resistances to penetration above 2.0 MPa negatively affect crop grain yield, since more compacted soils limit the access of plant roots to water and nutrients (Tavares Filho & Tessier, 2009; Girardello et al., 2014). Therefore, a low performance in grain yield is expected when the crop is subjected to a water content of 28.7% in depths greater than 0.10 m.

The total energy demand was higher in the operations with lower soil water contents (Figure 3) and greater soil depths, as reported by Compagnon et al. (2013). However, no significant differences were found between the depths 0.11 and 0.15 m (Figure 3B), nor for the interaction between the factors ($p = 0.183$). The soil with water content of 47.6% presented 31% lower energy consumption in the planting-fertilizer placement operation than the soil with water content of 28.7%. Therefore, producers may benefit by carrying out planting-fertilizer placement for common bean crops after the rainy period or field irrigation.

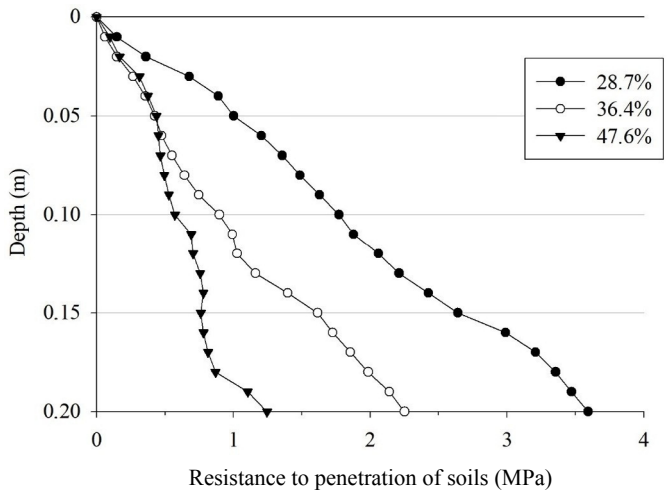
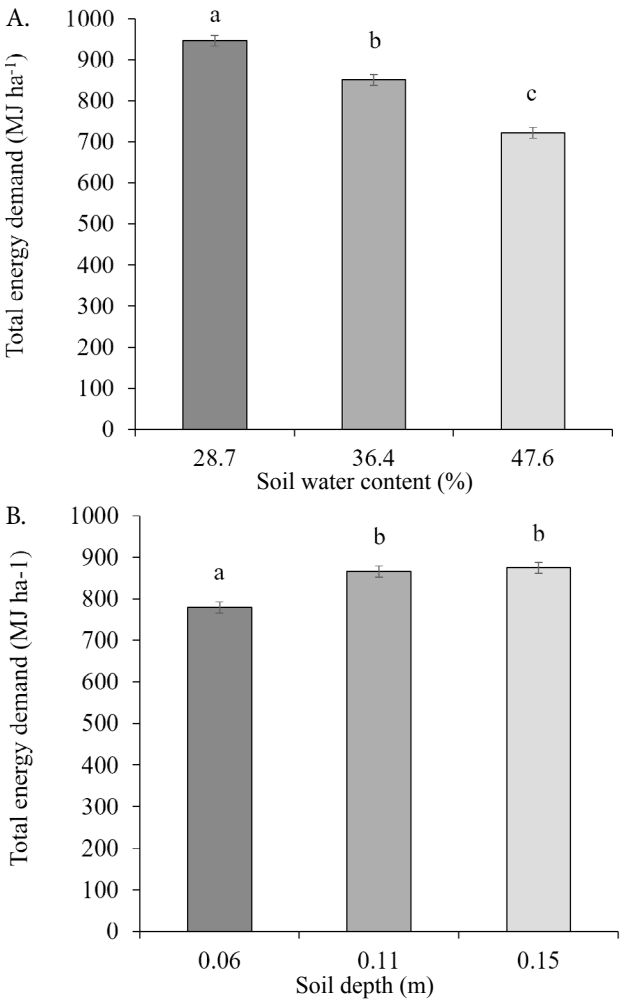


Figure 2. Resistance to penetration of soils with different water contents as a function of depth

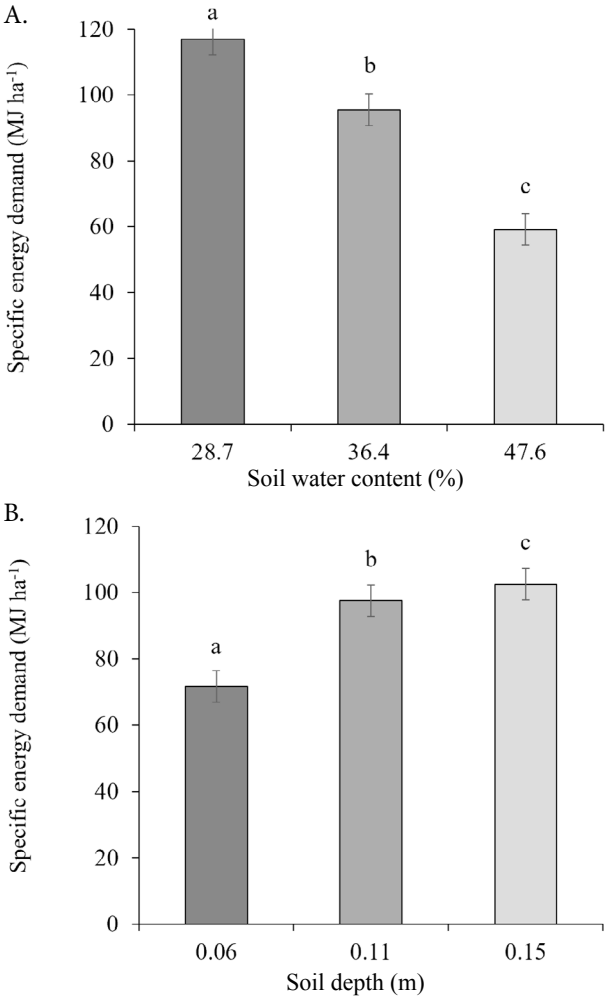


Coefficient of variation = 2.92%; Means followed by the same letter are not significantly different by the Tukey's test ($p \leq 0.05$)

Figure 3. Total energy demand as a function of soil water contents (A) and soil fertilizer placement depths (B)

The specific energy demand was also affected by the soil water contents and soil fertilizer placement depths (Figure 4). However, a more pronounced difference was found between the treatments - combinations between the different factors evaluated.

The energy required for the operations in the plots with the lowest soil water content (28.7%) was almost twice that in the plots with the highest soil water content (47.6%). Similarly, the energy consumption in the operations with soil fertilizer placement depth of 0.06 m was approximately 30% lower than that found in the other depths. A possible explanation for these more pronounced differences is the low fuel use efficiency. Low efficiencies indicate that the tractor was oversized for the operation; therefore, its contribution to the total energy demand is greater than that referring to the planter-fertilizer set (Crowell & Bowers, 1985; Turker et al., 2012). Considering that the soil water content and fertilizer placement depth affect the planter-fertilizer set, such effects are higher for the specific energy demand than for the total energy demand.



Coefficient of variation = 7.52%; Means followed by the same letter are not significantly different by the Tukey's test ($p \leq 0.05$)

Figure 4. Specific energy demand as a function of soil water contents (A) and soil fertilizer placement depths (B)

The mean test showed that the crop grain yield was affected by the soil water content and soil fertilizer placement depth, and by the interaction between these factors (Table 1). Solos with greater water contents had higher grain yield, as also found by Souza et al. (2016).

The water content in the soil also affects directly the common bean grain yield, and the water stress is one of the main stress abiotic factors that limit common bean production (Zadražnik et al., 2013). In addition, soils with low water contents have higher compaction, hindering the root development; in the case of irrigated common bean crops, 80% of their roots are concentrated in the first 0.30 m depth (Pires et al. 1991).

The lowest grain yield was found in the plots with soil water content (SWC) of 28.7% and fertilizer placement depth (FPD) of 0.15 m, and the highest in the plots with SWC of 36.4% of FPD of 0.11 m. However, the plots with SWC of 36.4% and FPD of 0.11 m presented no significant difference in grain yield from those with SWC of 47.6% and FPD of 0.06 m. This result is important because it denotes that the SWC of 47.6% and the FPD of 0.06 m result in higher grain yield and lower energy demand. Thus, the producer may benefit by carrying out planting-fertilizer placement for common bean crops in soils less compacted and with greater water contents.

Table 1. Means and Anova for grain yield (kg ha^{-1}) of common bean crops as a function of combinations between soil water contents (SWC-1 = 28.7%; SWC-2 = 36.4%; SWC-3 = 47.6%) and soil fertilizer placement depths (FPD-1 = 0.06 m; FPD-2 = 0.11 m; FPD-3 = 0.15 m)

Source of variation	Treatment	Grain yield (kg ha^{-1})
	P2 - 0.11 m	2850.84 b
	P1 - 0.15 m	2702.93 ab
Interaction between the factors SWC × FPD	SWC-1 × FPD-1	916.67 a
	SWC-1 × FPD-2	865.04 a
	SWC-1 × FPD-3	773.25 a
	SWC-2 × FPD-1	2976.35 b
	SWC-2 × FPD-2	4186.04 c
	SWC-2 × FPD-3	3936.70 c
	SWC-3 × FPD-1	3336.15 bc
	SWC-3 × FPD-2	3501.44 bc
	SWC-3 × FPD-3	3398.82 bc
F	SWC × FPD	3.63*
Coefficient of variation (%)		51.60

* - Significant at $p \leq 0.05$; Means followed by the same letter are not significantly different by the Tukey's test ($p \leq 0.05$)

The results obtained for grain yield are confirmed in Figure 5, which shows that the SWC-2 (36.4%) and SWC-3 (47.6%) resulted in a better canopy development than the SWC-1 (28.7%).

Considering the greater amount of water used to reach such soil water contents, economic studies should evaluate whether the costs of these treatments are financially compensated by the gains in grain yield and decreases in energy demand.

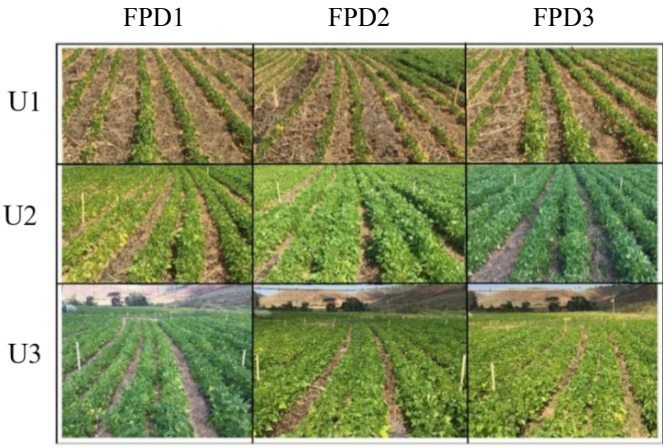


Figure 5. Common bean plants (R8 developmental stage) grown under different combinations of soil water contents (SWC) and fertilizer placement depths (FPD)

Conclusions

1. The energy demand for the operation of sowing and fertilizer application in soils with water content of 28.7% was 30% higher than that found for the operation in soils with water content of 47.6%.

2. The common bean plants reached the highest grain yield (4,186 kg ha^{-1}) when grown under a soil water content of 36.4% combined with a soil fertilizer placement depth of 0.11 m.

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