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*Full Length Research Paper*

# Operating and energetic performance of the assembly tractor-scarifier in different liquid ballasting and working depths

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**The working depth and ballasting are factors that can influence directly the operational and energy performance of a mechanized set. The objective of this study was to evaluate the operational and energetic performance of the set tractor-scarifier, working at three depths under two ballasting conditions. The study was conducted in the experimental area of mechanization of the Department of Agricultural Engineering at the Federal University of Ceará in Fortaleza. The experimental design was of randomized blocks in a factorial scheme 2 x 3, with four replications, with two liquid ballasting (0 and 75% water) and three working depths (0.15; 0.30 and 0.40 m). The parameters evaluated were the soil water content, periodic and specific consumption of fuel, the overall work rate, slipping of the front and rear wheels of the tractor, travel speed, specific operational resistance, mobilized and lifting area, blistering, strength and power in the drawbar. The ballasting with 75% of water associated with a lower depth provided greater operational field capacity, lower demand for strength and power in the drawbar with lower fuel consumption by area.**

**Key words:** Soil tillage, tyre, consumption of fuel.

## INTRODUCTION

Soil compaction and formation of the densified layer can be considered one of the main limiting factors of productivity. According to Fernandes et al. (2012) it is a process that can occur artificially by constant moving machines that compress the soil surface or naturally by rainfall and long dry spells.

Scarification or subsoiling are recommended techniques for soil unpacking, revolving hardened layers

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in the subsurface or in greater depth, however, the soil decompression process or disruption of dense layers is an operation with high energy demand and low operating performance, requiring studies on the subject.

According to Russini (2012), assessing the energy and operational performance of mechanized sets, is a complex task because of the many variables that must be analyzed within a fairly wide area of influence. In this context, the working depth and ballast to be used are factors which may directly influence the operational performance and energy assembly.

Cortez et al. (2011) reports that some implements have better operational capacity than others. Thus, Fernandes and Gamero (2010) by studying the operational performance in reduced tillage and conventional technique found that the theoretical field capacity light grid was 1.28 ha $h^{-1}$, while for the scarifier was 0.80 ha $h^{-1}$, in the speeds 5.01 and 2.87 km $h^{-1}$, respectively.

Compagnon et al. (2013) on evaluating the performance of the tractor-scarifier assembly in two different depths, concluded that the greater the depth of the scarifier work, the greater the increase in consumption and operating time, fuel tensile strength, power, and slipping of the bar and front wheeled of the tractor.

Lopes et al. (2005) evaluated the tractor performance depending on the type of ballast, tires and working speed and concluded that the combination of ballast condition and the range selected for output variables in the bar and effective field capacity, allowed the tractor to work more efficiently at the speed 4.57 km $h^{-1}$ in the tillage operation with the scarifier.

Carvalho Filho et al. (2007) evaluated the mobilization of a red Latosol, and found that the scarifier provided less tillage compared to moldboard plow. However, Mazurana et al. (2011) observed that the mobilization promoted by scarification reduces bulk density, mechanical resistance to penetration and increases water infiltration.

Therefore, the aim of the present study was to evaluate the operational and energetic performance ripper tractor set, working at three depths under two conditions of liquid tractor ballasting.

## MATERIALS AND METHODS

The study was conducted in the experimental area in the Department of Agricultural Engineering of the Federal University of Ceará, located in the geographical coordinates 03º44 'S latitude and 38º34' W longitude, with an average altitude of 26 m. According to Koeppen`s classification (1948), the region is defined as Aw ', that indicates rainy tropical climate. The soil of the area was classified with a Red-yellow Argisol, with sandy frank textural class, with approximately 82.90% sand, 10.60% clay and 6.40% silt, following the methodology of (EMBRAPA, 1997).

The experimental design was of randomized blocks in a factorial scheme 2 x 3, with four replications, being two liquid ballasting (0 to 75%) of the front and rear tires and three depths of scarification (0.15, 0.30 and 0.40 m), totalling 24 experimental units, 3.5 m wide and 15 m long.

In the scarification operation Marchesan scarifier was used, AST / MATIC 450 model, it was configured with five rods spaced 0.4 m, 0.08 m narrow tip, harrowing roller, automatic disarming security system with total mass of 1560 kg. The work depth control was carried out through the scarifier tires, with the help of rings stuck to the hydraulic cylinder.

The scarifier was pulled by the tractor BM120 4 x 2 TDA (front wheel assist), of 88, 26 kW (120 hp (cv)) in the engine in the rotation of 2000 rpm, with front-wheel drive on, equipped with bias tires, front axle with tires 14.9-24 R1 and rear axle with 18.4-34 R1 tires, with inflation pressure of 12 and 16 psi (82.8 and 110.4 kPa), respectively according to manufacturer's recommendation. The power-to-weight ratio according to liquid ballasting treatment was of 52 and 58 kg $hp^{-1}$ respectively.

Through Equation 1, the slippage was determined by counting the number of turns from the tractor wheelling in experimental part pulling the implement (with load) and the implement in transport mode (without load).

$$PR = \left[\!\left[\frac{n^1 - n^0}{n^1}\right]\!\right] \times 100 \tag{1}$$

In which:
PR = Slippage of the tractor wheels (%);
n° = Number of turns from the wheels without load;
$n^1$ = Number of turns from the wheels with load.

The overall work rate was obtained according to the working width of the implement, travelling speed and efficiency of the operation. The travelling speed was determined by dividing the length of the portion by the time reckoned by digital timer, triggered on and off according to the passage of the front wheels of the tractor laterally to the stakes that bordered the parcels.

For the acquisition of fuel consumption data and time of each route, an electronic system with pulse counters for obtaining readings from the flowmeters and a stopwatch to measure the tractor time in each parcel were used.

In order to measure the fuel consumption, two flow meters were used, both of the brand "Flowmate" Oval Model M-III and LSF 41 with a precision of 0.01 ml installed in series at the entrance and return of the injection pump, thus the volume of fuel consumed by tractor along the way in ml can be obtained, it is possible by means of Equation 2, to determine consumption in L $h^{-1}$.

$$C_H = \left(\frac{q}{t}\right) \times 3.6 \tag{2}$$

In which:

$C_H$ = Hourly fuel consumption (L $h^{-1}$);
q = Volume consumed in the parcel (ml);
t = Time to go through the parcel (s);
3.6 = Unit conversion factor.

Subsequently to the obtainment of hourly fuel consumption (L $h^{-1}$), the consumption was calculated in L $ha^{-1}$ (Equation 3)

$$C_A = \frac{C_H}{CC_e} \tag{3}$$

In which:
$C_A$ = Fuel consumption by area, L $ha^{-1}$;
$C_H$ = Hourly fuel consumption, L $h^{-1}$;
CCe = Effective field capacity (ha $h^{-1}$).

The specific fuel consumption was determined by means of

Equation 4.

$$C_E = \frac{C_H \times d}{P} \quad (4)$$

In which:
CE = specific fuel consumption (kg $kWh^{-1}$);
CH = Hourly fuel consumption (L $h^{-1}$);
d = density of the fuel (kg $L^{-1}$);
P = power in the bar (kW)

To determine the power requirement in drawbar, a load cell of the HBM brand was used. To collect the load cell data, the data acquisition system from HBM model Quantum XMX804A was used with ability to monitor and record information at a frequency of 19.200 Hz. With the values obtained, the average power on the draw bar was determined by Equation 5. The average power in the drawbar was calculated based on the average tractive force and the actual travelling speed of the set.

$$F = \left(\frac{\sum Fi}{\sum n}\right) \times 0.0098 \quad (5)$$

In which:
F = Average power on the draw bar, kN;
Fi = instant traction force, kgf;
n = Number of recorded data;
0.0098= Adequacy factor.

The mobilized area corresponds to the area between the natural soil profile and bottom profile of the furrow left by the implement, in order to determine it a wood profilometer of 3 m wide and 1 m in height with a vertical base for fixing millimetered paper was used, for that, a survey of the natural surface profile, background and ground elevation was conducted. According to the theory of differential and integral calculus after the construction of curves delimiting the natural soil profile and the bottom soil profile, we obtain the upper and lower amounts, for performing estimation of the area. Thus, lower amounts were used, with the construction of vertical rectangles with 0.005 respectively m width and height not exceeding the established lines. The mobilized area (Equation 6) is the sum of these partial areas.

$$MSA = \sum_{i=1}^{n} 0.5 h_n \quad (6)$$

In which:
$h_n$ – rectangle height of order n.
The operating specific resistance was obtained from Equation. 7, taking into account the average tensile strength and ground area mobilized.

$$SOR = \frac{F_m}{AMS} \quad (7)$$

In which:
SOR - specific operational resistance, kN $m^{-2}$;
Fm - mean traction force, kN; and
MSA - mobilized soil area, $m^2$.

Finally the decision was for the rectangle area formula to determine each partial area, following Thomas methodology et al. (2012). By using Equation 6, soil blistering was determined.

$$Em = \frac{AE}{AM} \times 100 \quad (8)$$

Where:
E = Blistering (%)
AE = Elevation Area ($m^2$)
AM = Mobilized area ($m^2$)

## RESULTS AND DISCUSSION

The data was submitted to normality test using the coefficients of symmetry and kurtosis according to Mesquita et al. (2003). After checking the normality of the data, variance analysis was carried out and when significant, the Tukey test was applied at 5% probability for weighted average.

In Figure 1, the symmetry coefficients (A) and kurtosis (B) can be found for the studied parameters. It can be observed that all the values obtained for the symmetry and kurtosis coefficients are within the range -2 to 2.

Values of symmetry and kurtosis coefficients within the range of -2 and 2 indicate that the data follow a normal distribution, since according to (Montgomery, 2004) the coefficients of symmetry and kurtosis with values less than 2 and greater than -2, represent small deviation from the normal distribution, the hypothesis of data normality can be considered, a necessary condition to carry out a variance analysis and obtain results safely.

In Table 1, for the hourly fuel consumption, according to variance analysis, it can be observed that there was no significant difference between the averages ($p < 0.05$) of the assessed ballasting and depth factors.

These results contrast with those observed by Monteiro et al. (2013) who found significant differences in fuel consumption as a function of liquid ballast in the tires. However, these authors worked in clay texture soil, a condition that requires greater force from the tractor to pull the implements and consequently higher energy demand, yet this study was developed in sandy texture soil which may have contributed to this result.

The specific consumption for different working depths presented significant difference between the average, the lowest value being in the depth of 0.40 m, a result that can be associated with greater demand for power by the implement working in greater depth P1 – 15.69; P2 – 23.96 e P3 – 25.99 kW respectively, because the specific fuel consumption is obtained as a function time and power consumption.

Similar result was found by Palma et al. (2010), that in assessing the fuel consumption of a Valtra BL 88 4X2 tractor with front-wheel assisted drive (TDA) pulling a precision fertilizer-seeder, with chisel plow at different depths (100, 150, 200 and 250 mm), biggest consumptions was observed in the smallest depth.

The specific consumption for different ballasts was not significant. These results disagree with those observed by Lopes et al. (2005), who evaluating the performance of an agricultural tractor 4 x 2 TDA, of 89 kW (121 cv (hp)) maximum engine power, pulling a drag scarifier combined with a harrowing roller and cutting wheels with seven angled straight rods and ferrules without wing with 7 cm wide, the lowest specific consumption found with

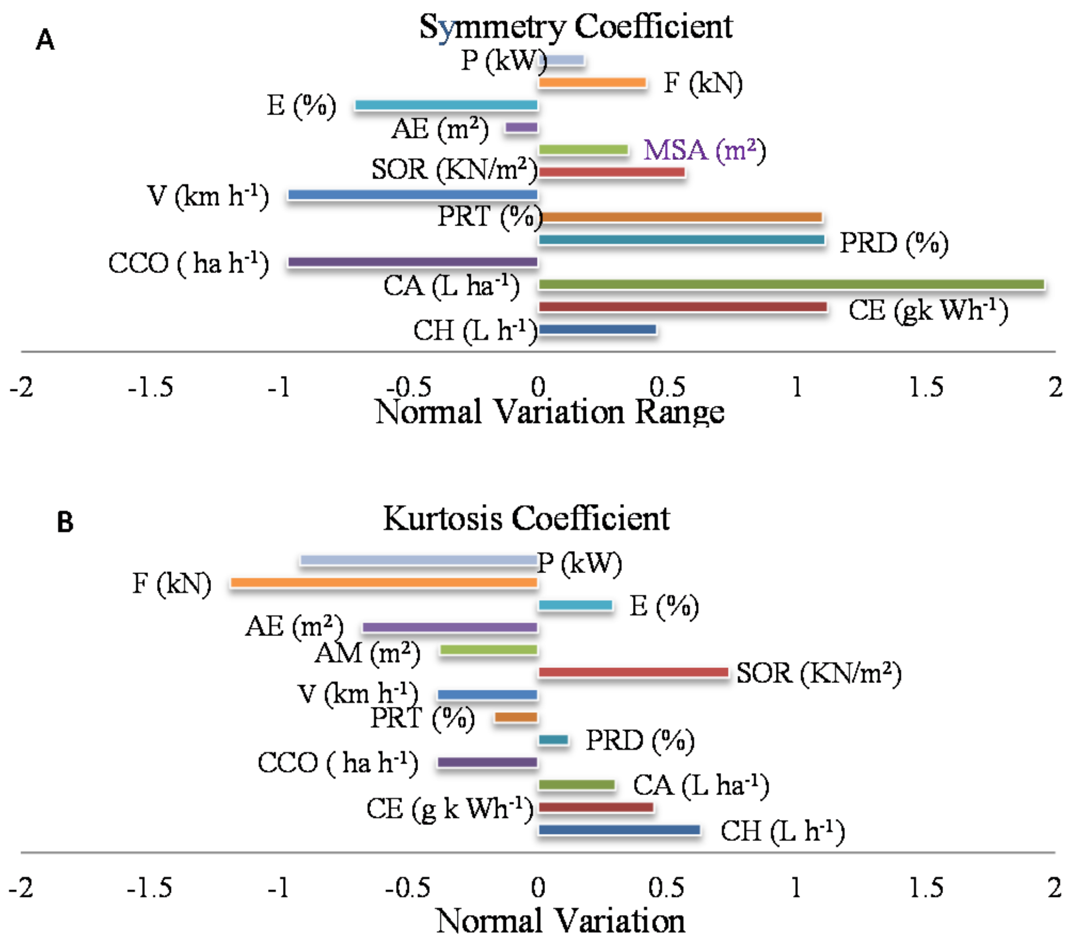



**Figure 1.** (A) Symmetry coefficient and (B) Kurtosis for all of the assessed parameters. CH- Fuel consumption in L.h$^{-1}$; CE- Specific fuel consumption; CA- Fuel consumption in L.ha$^{-1}$; CCO- The overall work rate; PRD- Slippage of the front axles; PRT- Slippage of the rear axles; V- Traveling speed; SOR- Specific operational resistance; MSA- mobilized area; AE- elevation area; E- blistering; F- Strength on the drawbar; P- Power on the drawbar.

ballasting being 75% of water in the tire. For consumption per area the result of variance analysis was significant for the working depth factor, being greater in depth of 0.40 m result that may be associated with greater ground area mobilized by scarifier rods and also by higher tensile force required by the equipment to overcome the resistance offered by the soil.

Compagnon et al. (2013), assessing the energy and operational performance of a tractor of Valtra brand, BM 125i model, 4 x 2 TDA, pulling the Marchesan scarifier, AST / MATIC 450 model, with a total mass of 1400 kg in red clayey textured eutroferric Oxisol, they also found that the greater the working depth the greater the fuel consumption in L ha$^{-1}$.

For the overall work rate it can be observed that there was a significant interaction between the analyzed variables, the consequences of the interaction are shown in Figure 2.

It can be observed in the unfolding of the ballasting in the depths (C) that the only one that differed significantly was L1, corresponding to 0% of liquid ballast, with the lowest value in the depth P3 (0.40 m) a result that may be associated with higher slippage of the tractor in that same treatment that contributed to reduce the speed and consequently lower the overall work rate. Lopes et al. (2005) evaluating the performance of a tractor on red eutroferric Oxisol also found that the field capacity was lower when he worked without liquid ballast in the tire.

According to the values presented for the unfolding of the depths within the ballasting (D), it is observed that only the depth P3 (0.40 m) shows significant difference with lower values in the evaluated ballasting L1 and L2 (0 and 75% water), a result that can be associated with the fact that greater working depth mobilize greater ground area P1 – 0.26; P2 – 0.32 and P3- 0.46 m$^2$ respectively, contributing for speed reduction, directly affecting the overall work rate. Similar results were obtained by Compagnon et al. (2013) in the depths of 0.20 and 0.30 m.

**Table 1.** Average values for fuel consumption per hour (CH), Specific consumption (CE), Consumption per area (CA) and the overall work rate (CCO).

| Sources of variation | | CH (L h$^{-1}$) | CE (kg k$^{-1}$Wh$^{-1}$) | CA (L ha$^{-1}$) | CCO (ha h$^{-1}$) |
|---|---|---|---|---|---|
| Ballasting (L) | L1 | 9.85 | 0.41 | 4.47 | 0.59 |
| | L2 | 9.67 | 0.34 | 4.18 | 0.65 |
| Depth (P) | P1 | 9.55 | 0.51$^{a}$ | 3.00$^{b}$ | 0.71 |
| | P2 | 9.69 | 0.34$^{b}$ | 4.93$^{a}$ | 0.69 |
| | P3 | 10.04 | 0.32$^{b}$ | 5.04$^{a}$ | 0.47 |
| F Value | L | 0.04$^{NS}$ | 3.81$^{NS}$ | 0.57$^{NS}$ | 28.32** |
| | P | 0.11$^{NS}$ | 4.65* | 12.51** | 191.0** |
| | L*P | 3.55$^{NS}$ | 3.51$^{NS}$ | 2.99$^{NS}$ | 5.0* |
| DMS | L | 1.78 | 0.11 | 0.79 | 0.02 |
| | P | 2.65 | 0.17 | 1.19 | 0.03 |
| CV (%) | | 21.29 | 32.74 | 21.17 | 4.40 |

Averages followed by the same letter or no letter in the columns do not differ from each other by Tukey test at 5% probability. *- significant ($p<0.05$); $^{NS}$- non significant ($p>0.05$). L- Ballasting. P- Depth. L1- Ballasting 1 (0% water); L2- ballasting 2 (75% water); P1- depth 1 (0, 15 m); P2- depth 2; (0, 30 m) P3- depth 3 (0, 40 m). DMS- minimum significant difference. CV- variation coefficient.

In Table 2 it can be observed that for the variable specific resistance there was no significant difference for the analyzed factors, demonstrating that the soil used to perform the scarification process has no resistance to shearing, as it`s a soil with sandy loam texture class.

Similar results were found by Sasaki et al. (2005), working with single-stem subsoiler attached to the hydraulic system in three points of the tractor, with depth control by mounting clip, found that the requirements of structure and soil texture is closely related to the dynamic resistance because soils with high sand contents give lower hardness due to their mineralogy.

For the slippage of the front and rear axles of the tractor and travelling speed variables it can be observed that there was a significant interaction, the developments are shown in Figures 3, 4 and 5. It can be observed for the slippage of the front wheels of the tractor in the unfolding of the ballasting at all depths (E), the only one that differed was L1, corresponding to 0% of liquid ballast, with biggest value in depth 0.40 m.

A result that can be associated with low weight to power of the tractor ratio, not being suitable for working at this depth, it requires the addition of weight, because the slipping values are above the index envisioned by the ASAE (2003), to firm ground, which is 8 to 10%.

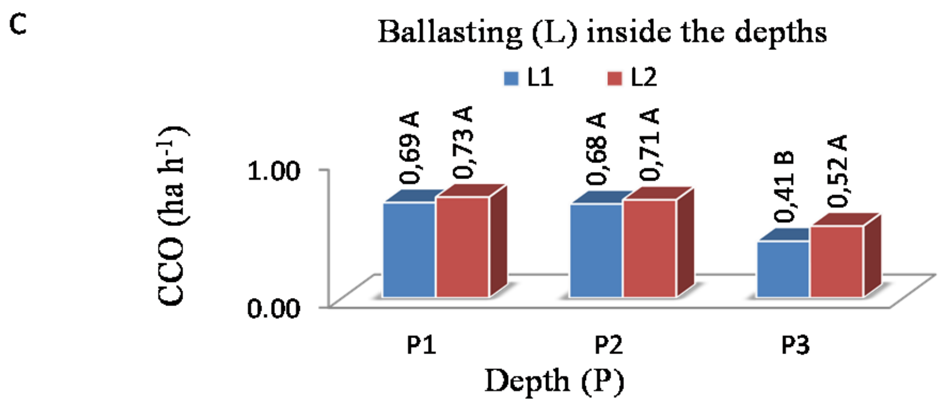
Monteiro et al. (2011) while evaluating the performance of an agricultural tractor equipped with radial and diagonal tires with three levels of liquid ballast on solid ground condition, obtained different results with slippage below that recommended with liquid ballast 0%, however, the tractor used by him was not pulling a scarifier at different depths.

In the deployment of depths in each ballast is observed that the slippage increases with increasing depth and the highest value was found working in P3 (0.40 m) with liquid ballast of 0% in the tires, indicating that the tractor is with little ballast to overcome the soil resistance at greater depths.

For the depth of 0.15 m with slippage of 5.78 and 6.92% associated with ballastings of 0 and 75% water, show the absence of need for ballasting, because these amounts are below the index envisioned by ASAE (2003) to firm ground, which is 8-10%, evincing that the tractor was with ballast above the recommended to work with scarifier, with possible ballast removal.

In the unfolding of ballasting inside the depths to the slipping of the rear wheel (G), it is observed that the only one that was significantly different was 0% of water in the depth of 0.40 m, with higher slippage and finding values above those recommended by ASAE (2003), indicating that the tractor is with inadequate ballasting for the operation. Similar results were verified by (Gamero, 2008) evaluating the operating performance of a shank subsoiler with lateral curvature ("Paraplow"), finding greater slippage in the depth of 0.35 m.

In the unfolding of depths within the ballastings (H) the depth P3 (0.40 m) in all ballastings provided greater slippage, with greater value for L1 (0% of liquid ballast in the tire). This result may be associated with greater demand for strength and power by the scarifier for it is working in greater depth, associated with a lower load on the tractor which provides a lower weight-power ratio,



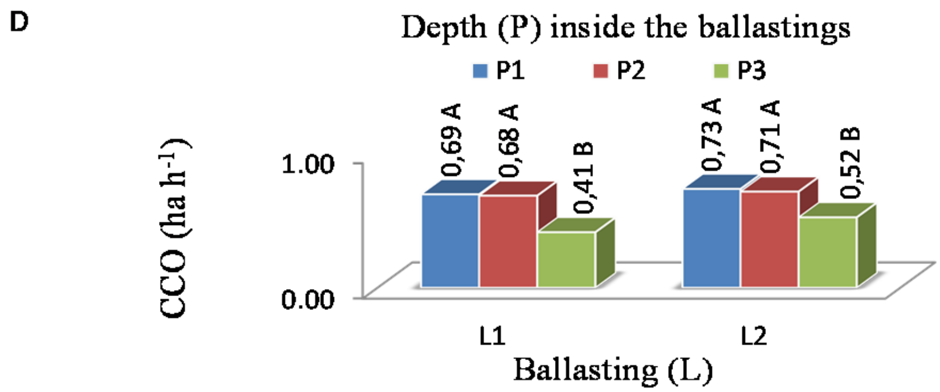




**Figure 2.** Ramifications of the interaction between factors C) working depth and D) ballasting for the overall work rate variable. Averages followed by capital letters in the columns do not differ by Tukey test 5% probability.

**Table 2.** Average values for specific operational resistance (ROS), slippage of the front axles (PRD), and rear (PRT) from the tractor and travelling speed (V).

| Variation sources | | ROS (kN $m^{-2}$) | PRD (%) | PRT (%) | V (km $h^{-1}$) |
|---|---|---|---|---|---|
| Ballasting (L) | L1 | 603.38 | 20.36 | 20.07 | 3.99 |
| | L2 | 582.03 | 14.44 | 13.93 | 4.39 |
| Depth (P) | P1 | 551.99 | 6.34 | 4.65 | 4.78 |
| | P2 | 586.84 | 11.53 | 10.11 | 4.64 |
| | P3 | 639.28 | 34.33 | 36.23 | 3.15 |
| F Value | L | $0.11^{NS}$ | 19.46* | 37.23* | 28.32** |
| | P | $0.63^{NS}$ | 163.96* | 374.90* | 191.0** |
| | L*P | $1.45^{NS}$ | 11.57* | 40.59* | 5.06* |
| DMS | L | 134.24 | 2.81 | 2.11 | 0.15 |
| | P | 199.83 | 4.19 | 3.14 | 0.23 |
| CV (%) | | 26.42 | 18.89 | 14.50 | 4.40 |

Averages followed by the same letter or no letter in the columns do not differ by Tukey test at 5% probability. * - Significant (p<0.05); $^{NS}$- non significant (p>0.05). L1- ballasting 1 (0% water); L2- ballasting 2 (75% water); P1- depth1 (0.15 m); P2- depth 2; (0.30 m) P3- depth 3 (0.40 m). CV- variation coefficient. DMS- minimum significant difference.

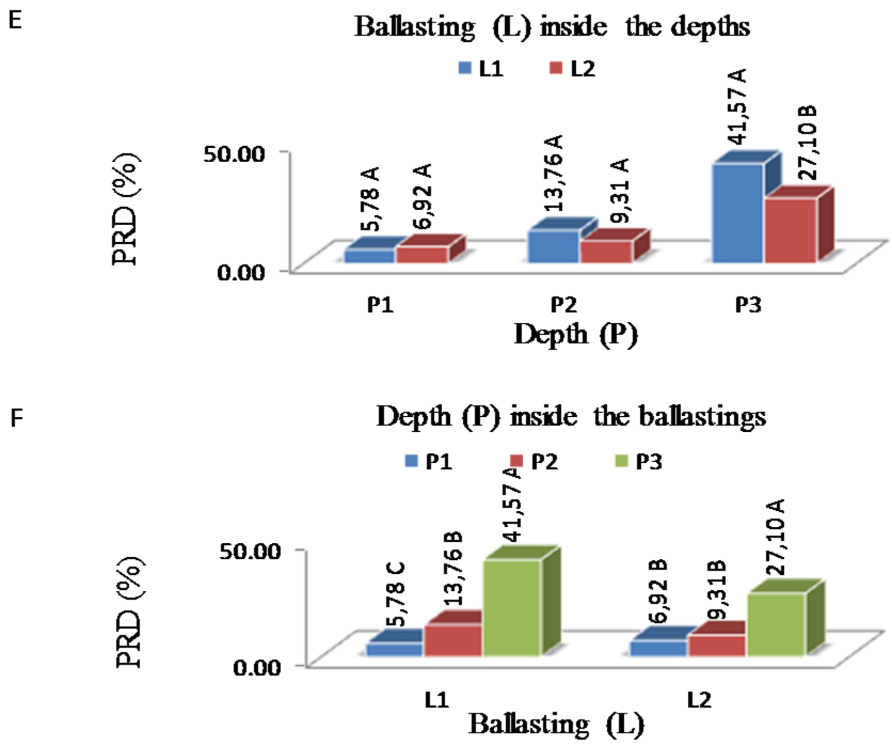



**Figure 3.** Consequences of the interaction between E) ballasting and F) rod depth factors for speed variable. Averages followed by capital letters in the columns do not differ by Tukey test at 5% probability.

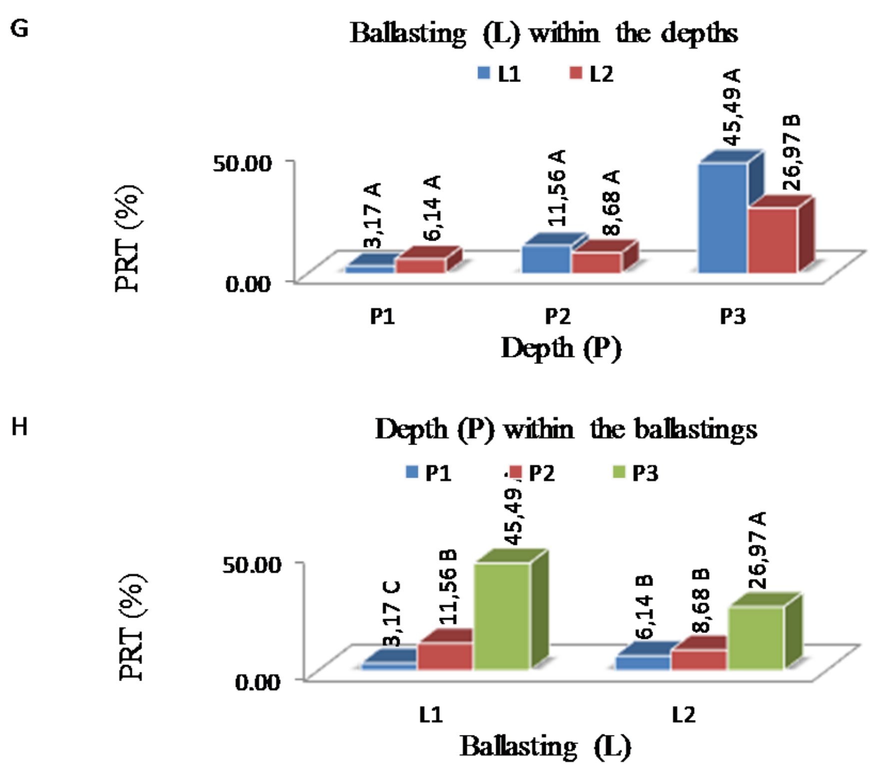



**Figure 4.** Consequences of the interaction between G) working depth and H) ballasting for slippage of the rear wheels of the tractor factors. Averages followed by capital letters in the columns do not differ by Tukey test at 5% probability.

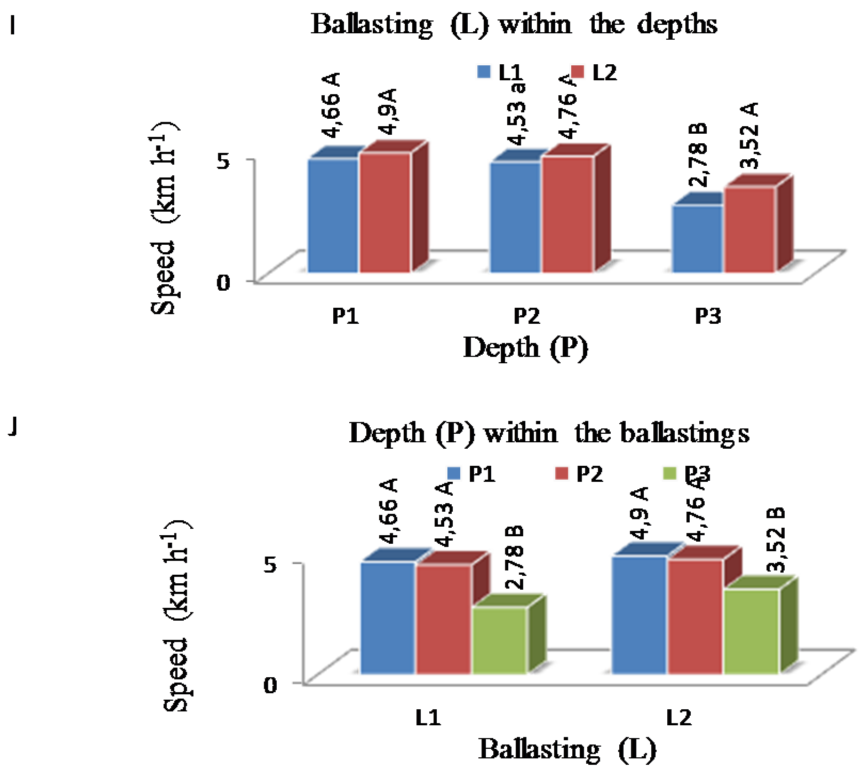



**Figure 5.** Developments of significant interaction between I) ballasting and J) rod depth factors for speed variable. Averages followed by capital letters in the columns do not differ by Tukey test at 5% probability.

thus contributing to increased slippage with values above those recommended by the ASAE (2003), indicating that the tractor is with inadequate ballast for the operation.

In the unfolding of ballasting within the depths (I) for traveling speed variable, it`s noticeable that there was a significant difference only in P3, that working with L2 (75% of liquid ballasting in the tire) provided greater travelling speed, this result may be associated with the fact that bigger cargo provide greater contact area of the wheels with the ground, possibly increasing the traction coefficient, reducing slippage and favoring greater speed. Differently, in the unfolding of depths within the ballasts (J) it was observed that there were significant differences in the greatest depth (P3) within the two ballasts, resulting in lower travelling speeds values, this result might be associated with an increased slippage of wheel sets and the bigger force demand to pull the implement. Gamero (2008) when working with different depth and marches scheduling also observed lower speed in the greatest depth pulling a subsoiler.

In Table 3, it can be observed that for mobilized area, there is no significant difference ($p > 0.05$) between averages for the ballasts used, a result which may be attributed to minimum weight transfer from the tractor to the scarifier attached to the draw-bar, whereby the addition of liquid ballast to the tractor wheels interferes little with the penetration of the rods into the ground.

For the depth of the stems, the result was significant with highest average value of 0.46 $m^2$ in the working depth 0.40 m, attributable to adjustment of greater depth, mobilizing greater amount of soil. The values obtained for mobilized ground area were close to the values found by Santos et al. (2014), evaluating soil tillage, water infiltration speed and soil coverage rate in the emerald grass under mechanized handlings with scarifier.

The elevation area presented significant result ($p < 0.05$) difference between the averages for the two factors, ballasting and depth. The L2 (75% water) was the one that provided greater area of elevation, a result that may be related to higher speed developed in the same treatment. The depth with greater elevation area was 0.40 m with an average value of 0.08 $m^2$, which may be associated with a greater soil area mobilized.

For soil blistering there was significant results only for ballasting with the highest average value of 22.36 $m^2$ to L2. Result that may be related to the higher speed developed in the ballasting of 75% of water. Rosa et al. (2011) when evaluating the effect of compaction and deformation under the action of the subsoiler tip, found no difference in elevation area at depths of 0.23 and 0.15 m, however, they found greater blistering in the depth of 0.15 m, associating this result to the occurrence of

**Table 3.** Average values for mobilized soil area (MSA), elevation area (AE), soil blistering (E), strength (F) and power (P) according to two liquid ballast and three depths of the chisel plow.

| Variation causes | | MSA ($m^2$) | AE ($m^2$) | E (%) | F (kN) | P (kw) |
|---|---|---|---|---|---|---|
| Ballasting (L) | L1 | 0.33 | $0.04^b$ | $15.84^b$ | 19.10 | 19.97 |
| | L2 | 0.34 | $0.07^a$ | $22.36^a$ | 20.64 | 23.79 |
| Depth (P) | P1 | $0.23^c$ | $0.04^b$ | 19.92 | 11.80 | 15.69 |
| | P2 | $0.32^b$ | $0.06^{ab}$ | 19.09 | 18.57 | 23.96 |
| | P3 | $0.46^a$ | $0.08^a$ | 18.29 | 29.25 | 25.99 |
| F Values | L | $0.38^{NS}$ | 8.23* | 4.69* | $3.48^{NS}$ | 13.37** |
| | P | 35.04** | 5.54* | $0.09^{NS}$ | 151.20** | 36.45** |
| | L*P | $0.32^{NS}$ | $0.09^{NS}$ | $0.21^{NS}$ | 7.0** | 12.00** |
| DMS | L | 0.04 | 0.01 | 6.39 | 17.34 | 22.22 |
| | P | 0.07 | 0.02 | 9.55 | 25.82 | 33.18 |
| CV (%) | | 16.60 | 35.84 | 38.53 | 9.62 | 11.68 |

Averages followed by the same letter or no letter in the columns do not differ by Tukey test at 5% probability. * - Significant ($p<0.05$); $^{NS}$- non significant ($p>0.05$). L1- ballasting 1 (0% water); L2- ballasting 2 (75% water); P1- depth 1 (0.15 m); P2- depth 2; (0.30 m) P3- depth 3 (0.40 m). DMS- minimum significant difference; CV- variation coefficient.

compacted layers.

For the power on the draw bar, it can be observed that there was a significant interaction between the variables analyzed, and the unfolding of the interaction are shown in Figure 6. Verifying ballasting at each depth (K), the greatest power with difference between the averages was observed in the depth of 0.40 m in ballast L2 (75% water). A result that can be attributed to larger contact area between tire and soil due to its deformation when adding liquid ballast, higher power to weight ratio, associated with greater rupture resistance of soil structures on account of greater depth. Monteiro et al. (2013) obtained a similar result, in accomplishing the energetic evaluation of a 4 x 2 TDA tractor in the light of ballasting with water, as a result, higher power values were found when increasing the ballasting.

Checking the behavior of power with respect to depth for each evaluated ballast (L) with 0% water (L1) highest power values were obtained in the greatest depths (P2 and P3). In the ballast with 75% water was found highest power value at greater depth, corresponding to 31.34 kW. The largest power values observed at greater depths may be associated with greater demand for rupturing the soil structure at greater depths. Lopes et al. (2005) when evaluating the tractor performance according to the type of ballast, tires and working speed, in the soil preparation operation with scarifier also revealed higher power values when using greater liquid ballasting.

To force values in the drawbar Figure 7, relating ballasting into the depths (M), it can be seen that only the depth of 0.40 m, the average differentiated from each other, with higher value in the ballasting 75% of Water. Result that can be attributed to larger contact area between tire and soil due to its deformation when adding liquid ballast, higher power to weight ratio with the ballast of 75% water, associated with increased resistance to rupture of the soil structures due to the higher depth.

Verifying the strength in relation to the depths for each ballast (N), with 0% water (L1) higher strength values were obtained in the greatest depth (P3). In the ballast with 75% water, the highest force value was found in the greatest depth, corresponding to 3.02 kN. The highest force values observed in the greatest depth may be associated with greater demand to rupture the soil structures for working at greater depths. Rosa et al. (2011) when evaluating the effect of compaction and deformation under the action of the subsoiler tip, also found greater demand for power in the greater depths.

## Conclusion

The ballasting with 75% of water associated with a smaller depth provides greater operational field capacity, lower demand for force and power in the drawbar with lower fuel consumption per area.

Most ripper working depth increases fuel consumption by area, slipping, speed, ground area mobilized, strength and power in the drawbar.

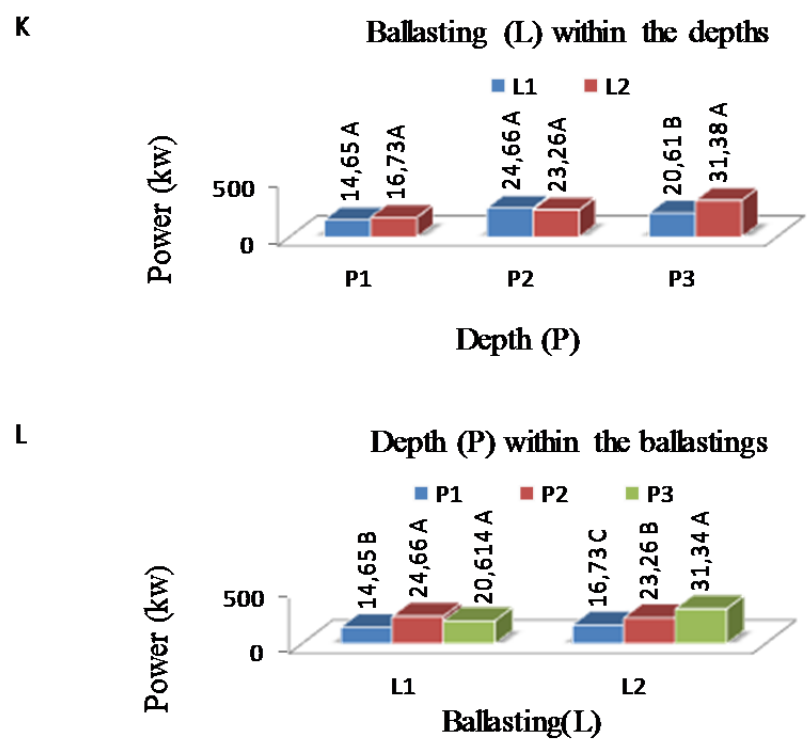



**Figure 6.** Graphical representation of the consequences of significant interaction between the factors, ballasting and depth rod for variable power. Averages followed by capital letters in the columns do not differ by Tukey test at 5% probability.

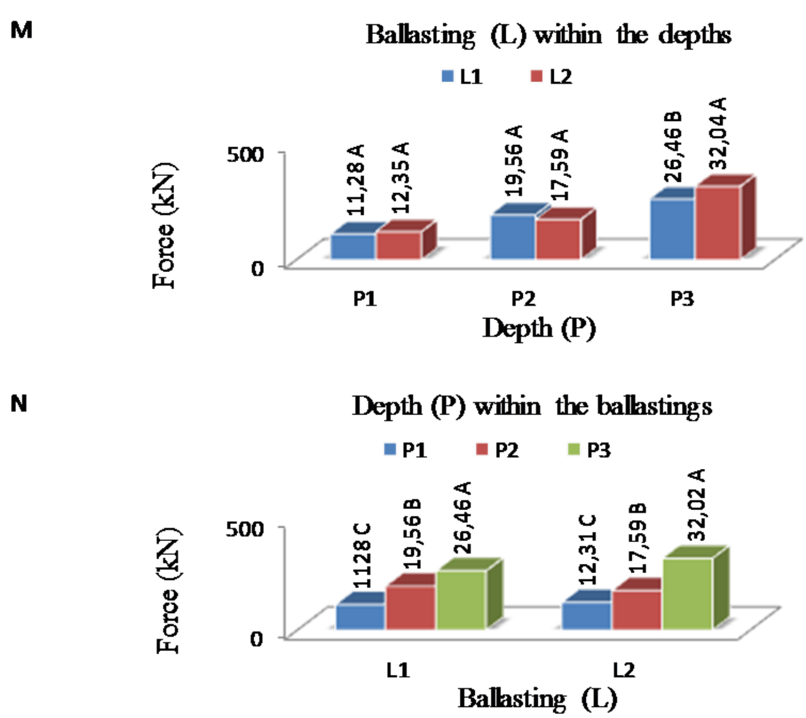



**Figure 7.** Graphical representation of the consequences of the significant interaction between ballasting and stem depth factors to the force variable. Averages followed by capital letters in the columns do not differ by Tukey test at 5% probability.

## Conflict of Interests

The authors have not declared any conflict of interests.

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