Operational performance of a tractor-seeder according to the velocity and working depth

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A B S T R A C T

The sowing process is one of the most important steps in agricultural production chain, requiring a good efficiency in order to avoid seed and plant population losses. In order to achieve a satisfactory performance of the seeder, the agricultural implement needs to be properly adjusted. Therefore, the present study aimed to verify both the operational performance and sowing quality of the agricultural equipment, depending on different working depths and different operating velocities. The experimental design was a factorial, with two theoretical velocities and three working depths. The velocity of 6.8 km h^{-1} achieved both a good operating consumption and a low fuel consumption per working area and when associated with working depth of 0.05 m provided better operational performance. However, the operating velocity of 4.8 km h^{-1} made it possible to increase the number of normal spacing of seeds, an improved quality of sowing and the possibility of greater population.

Desempenho operacional do conjunto trator-semeadora em função da velocidade e profundidade de trabalho

R E S U M O

O processo de semeadura é uma das etapas mais importantes dentro de uma cadeia produtiva, necessitando da maior eficiência a fim de evitar perdas de sementes e, consequentemente, população de plantas. A forma de se obter desempenho satisfatório do conjunto trator-semeadora é através da adequação do conjunto mecanizado; assim, objetivou-se verificar o desempenho operacional e a qualidade de semeadura do conjunto trator-semeadora de precisão em função de diferentes profundidades da haste sulcadora e velocidades operacionais. O experimento consistiu no delineamento em blocos no esquema fatorial 2 x 3 sendo duas velocidades teóricas e três profundidades de trabalho da haste sulcadora. A velocidade do conjunto a 6,8 km h^{-1} obteve o melhor consumo operacional e o menor consumo por área trabalhada e, quando associada com a haste sulcadora a 0,05 m, proporcionou melhor desempenho operacional do conjunto trator-semeadora porém a velocidade de 4,8 km h^{-1} possibilitou o aumento do número de espaçamentos normais das sementes, uma melhora na qualidade de semeadura e a possibilidade de uma população maior de plantas.

Introduction

Sowing is one of the steps that require more perfection in the execution (Almeida et al., 2010) and one of the most important ones in the production system, since a well performed sowing process tends to reduce soil disturbance and maintain greater amount of vegetal cover on soil surface (Furlani et al., 2008).

For this, the tractor-seeder set must be well adjusted with respect to the edaphoclimatic conditions of the region, since in different situations the soil may offer more resistance to penetration at higher depths, leading to problems in seedling emergence and seed depth, which makes the sowing process impracticable (Rodrigues et al., 2011). Therefore, the project of any cutting mechanism can not be limited to a single configuration and must have various depth settings, because, for the good development of seedlings, factors such as germination and emergence may be affected (Santos et al., 2010).

The operation in subsurface using plow shanks influences the need for increasing demand of power and the increase in tractor slippage, requiring more traction power to work at greater depths (Cepik et al., 2010). Conte et al. (2009), studying shanks at depths of 0.064 and 0.12 m, also observed higher requirement of power when the plow shanks were used at the greatest depth; however, these authors claim that there is a beneficial effect to combat the water stress caused by the increase in root growth through the breaking of compacted layers, which would contribute to the maintenance of soybean production under water scarcity conditions.

For the plow shank of the seeder to work efficiently, it is of fundamental importance to evaluate parameters of soil mobilization dynamics, such as soil expansion, elevation area and mobilized area (Grotta et al., 2004). One of these parameters, the mobilized soil profile, is of great importance for the initial conditions, before soil tillage, and final conditions of the prepared soil layer, after tillage (Carvalho Filho et al., 2008).

Another significant factor in the sowing process is the tractor velocity, because seed distribution uniformity is directly related to the displacement velocity (Trogello et al., 2013b) and can influence the opening and closure of the furrow and seed deposition depth (Trogello et al., 2013a).

Furlani et al. (2005), working with a precision seeder, observed that the increase in velocity caused a decrease in traction power, increase in the operational field capacity and power in the drawbar. On the other hand, Cortez et al. (2008), studying different velocities in different cultivation systems, observed that the increase in velocity caused decrease in effective and specific fuel consumptions. Silveira et al. (2013) also observed a decrease in specific fuel consumption with the increase in velocity.

The present study aimed to verify the operating performance and sowing quality of a precision tractor-seeder as a function of different working depths and operating velocities.

Material and Methods

The study was carried out in the experimental area of the Laboratory of Investigation of Accidents with Agricultural Machines, at the Department of Agricultural Engineering of the Federal University of Ceará (3° 44' S; 38° 34' W; 19.6 m). The area is intended for experiments with conventional system and there is no vegetal cover. The soil is Yellow Red Argisol with sandy loam texture and approximately 82.90% of sand, 10.60% of clay and 6.40% of silt.

The experiment was set in a randomized block design, in a 2 x 3 factorial scheme, which consisted of two theoretical velocities (4.8 and 6.8 km h^{-1}) and three plow shank depths (0.05, 0.10 and 0.15 m), with 4 replicates. Each experimental unit was 4 m wide and 20 m long.

Two tractors were used; a BM120 traction tractor, with 4 x 2 front wheel assist (FWA) of 88.26 kW (120 hp) in the engine at rotation of 2000 rpm, with activated front traction. The tractor was equipped with diagonal tires; the front axle had 14.9-24 R1 tires with inflation pressure of 18 psi (124 kPa) and the rear axle had 18.4-34 R1 tires with inflation pressure of 22 psi (152 kPa). Type-B diesel with maximum of 0.5% of sulfur was used as fuel.

The support tractor was a Massey Ferguson, model 265, with 4x2 traction, nominal engine power of 47.80 kW (65 hp), which was attached to the precision seeder. The traction tractor was adjusted to a weight/power ratio of 55 kg hp^{-1}, with distribution of 65% of the weight on the rear axle and 35% on the front axle, solid ballast (850 kg on the rear axle and 350 kg on the front axle) and liquid ballast (75% of water in each tire), air inflation pressure of 110 and 124 kPa for front and rear tires, respectively.

The traction tractor used the gears L3 and L4, which corresponded to the theoretical velocities of 4.8 and 6.8 km h^{-1} respectively, at the rotation of 2000 rpm, with the "turtle" function activated in the multi-torque system, which allows increasing or decreasing the velocity without the need to stop the tractor or engage the clutch.

Sowing and fertilization were performed using a pneumatic precision seeder-fertilizer (Jamil°, model JM2090EX.00), with approximate weight of 1,160 kg, mounted on the three-point hitch of the tractor, set with three lines spaced by 0.80 m, plow shank for fertilizer deposition and offset double disc for seed deposition, with vertical pneumatic disc for seed metering. Fertilizer and seed distribution systems were activated through a concave rear sprocket made of rubber, with central relief for seed compaction. Fertilizer and seed deposits had capacity for 39 L and were completely filled. The precision seeder was equipped with a 35-cell disc and pneumatic meter. Hybrid corn seeds were used, at a population of 62,500 plants ha^{-1} and interrow spacing of 0.80 m. The amount of fertilizer and seeds was determined according to the recommendation for the corn crop. The fertilizer NPK was used, in the proportion of 10-28-20.

Hourly fuel consumption was determined using two flow meters (Flowmate Oval, Models Oval M-III and LSF 41), with precision of 0.01 mL, installed in series. Fuel consumption was determined in all the plots in volume unit (mL) and by the difference between the volumes of fuel determined at the entrance and in the return of the injection pump. Operational fuel consumption was obtained by the ratio of hourly consumption and the operational field capacity.

The actual velocity of the tractor-seeder was obtained as a function of the distance covered in each plot by the time spent

along the course, measured using a digital timer. The power was obtained using a load cell attached between the traction tractor and the support tractor. The mean power demand on the drawbar was obtained indirectly, by the multiplication of values of power, measured by the load cell, and the displacement velocity. The operational field capacity was determined as a function of the actual velocity, seeder efficiency and capacity and dimension of the seeder (Eq. 1).

$$OFC = \frac{2.4 \times Vel}{10} \times ef \qquad (1)$$

where:

OFC - operational field capacity;

2.4 - actual working width of the seeder;

ef - efficiency (75%);

10 - transformation constant; and

Vel - velocity.

The mobilized area was measured using an iron profilometer, which had 50 vertical rods with 64 cm of length and spaced by 1 cm. Millimeter papers were placed in the device, in order to draw the curves to delimit natural and bottom profiles. The determination was performed twice, the first time to define the natural soil profile, before passing the tractor, and the second one after the passing, to verify the bottom profile. Measurements were performed considering the central line of the seeder.

The specific resistance was determined based on the ratio between the traction power obtained by the load cell and the mobilized area, obtained through the use of a metal profilometer.

The seeder was adjusted to deposit 6.2 seeds m⁻¹, spaced by 16 cm, adopting the methodology proposed by Kurachi et al. (1989). Spacings between seeds after sowing smaller than 8 cm were considered as multiple, from 8 to 24 cm as normal and larger than 24 cm as failed.

The results were subjected to analysis of variance by F test ($p < 0.05$) using the program Sisvar and, when there was significance, means were compared by Tukey test at 0.05 probability level.

RESULTS AND DISCUSSION

There were no significant differences ($p > 0.05$) in the values of hourly consumption for the evaluated treatments (Table 1), which shows that it is possible to work at higher velocity (6.8 km h⁻¹) associated with the use of plow shanks at the different studied depths and that there was no significant alteration in the values of hourly consumption of the tractor for soils with high sand contents. This fact is due to the lower resistance offered by the sandy soil and the low reactivity of sand particles, which consequently lead to low adhesion and cohesion power. When these forces are not in balance in soils with high clay contents, the operation becomes difficult, whether due to the excessive presence of clods or to the stickiness of the soil in the equipment. However, in soils with high clay content (55%), for velocities of 3 and 6 km h⁻¹, Furlani et al. (2010) observed that as the velocity increases, there is an increment in the hourly consumption; besides soil texture, the authors attributed the increase in hourly consumption to the greater requirement of power of the fastest gear and, consequently, greater tractor consumption.

Significant difference ($p < 0.05$) was observed for the actual velocity (Table 1), which is caused by the different gear selection performed in each treatment. At the actual velocity of 5.01 km h⁻¹, the tractor used a gear of lower velocity and higher power (L3), compared with the L4 gear, used at the other actual velocity (6.92 km h⁻¹). The values were close to the respective theoretical velocities and statistically different, which shows that there is a difference between the velocity treatments. As to the working depths, there was no significant difference, i.e., the working depth of the shank did not interfere with the final velocity of the set, whose behavior may have been due to the fact that soil resistance in subsurface was not enough to affect the velocity of the set. Silveira et al. (2005), working with two velocities, 5.24 and 7.09 km h⁻¹, at two seed deposition depths, also observed significant difference between the actual velocities; furthermore, the velocities did not differ statistically at the depths. Thus, these authors concluded that the depth did not interfere with the velocity of the set in the sowing operation.

Operational fuel consumption did not differ statistically between the working depths, but there was significant

Table 1. Mean values of hourly consumption, operational consumption, actual displacement velocity, normal spacing between seeds and failed spacing between seeds in corn sowing as a function of two theoretical velocities and three working depths

Source of variation		Velocity (km h⁻¹)	Hourly consumption (L h⁻¹)	Operational consumption (L ha⁻¹)	Normal seeds	Failed seeds
Velocity (V)	V1	5.01 b	10.44	11.55 a	78.48 a	22.35 b
	V2	6.92 a	10.84	8.78 b	66.55 b	33.45 a
Depth (D)	D1	5.97	11.09	10.52	74.77	25.22
	D2	6.18	9.92	9.20	69.83	31.41
	D3	5.75	10.90	10.78	72.93	27.06
F value	V	189.09*	0.11ᴺˢ	5.57*	7.28*	6.00*
	D	3.25ᴺˢ	0.38ᴺˢ	0.70ᴺˢ	0.43ᴺˢ	0.66ᴺˢ
	V*D	0.91ᴺˢ	0.14ᴺˢ	0.12ᴺˢ	1.27ᴺˢ	1.35ᴺˢ
LSD	V	0.29	2.51	2.49	9.42	9.65
	D	0.44	3.74	3.73	14.07	14.42
CV (%)		5.72	27.11	28.25	14.94	39.78

*$p < 0.05$; ᴺˢNot significant; Means followed by the same letter and without letters in the columns do not differ by Tukey test ($p < 0.05$); V1 - Velocity 1 (4.8 km h⁻¹); V2 - Velocity 2 (6.8 km h⁻¹); D1 - Depth 1 (0.05 m); D2 – Depth 2 (0.10 m); D3 - Depth 3 (0.15 m); LSD – Least significant difference

difference between the velocities (Table 1). At the lowest velocity (4.8 km h^{-1}), the consumption showed higher values and, with the increment in velocity, there was a reduction in the operation time in a same worked area; consequently, the operational consumption, per area, decreased. Furlani et al. (2006), studying three sowing velocities (4.6, 6.2 and 8.1 km h^{-1}) and two vertical loads in the fertilizer deposit (100 and 400 kg), observed higher operational consumption at the lowest velocities under uniform soil conditions and attributed this increase in consumption to the longer working time in the same area.

The normal spacing between seeds did not differ statistically ($p > 0.05$) for the working depth treatment, i.e., regardless of the working depth, there is no difference in spacing. However, for the sowing velocity treatment, the results show that the velocity of 4.8 km h^{-1} promoted increase in the values of normal spacings and lower percentage of failed spacings, statistically differing ($p < 0.05$) from the values promoted by the velocity of 6.8 km h^{-1}. With the increment in the angular velocity of the metering disc, some of the cells may not be filled, which favors the increase in failed seed percentage. Souza Júnior & Cunha (2012) attribute the greater amount of failed seeds at higher velocities to the increase in rotation; as a consequence, the cells of the discs tend to remain empty. These results corroborate those of Mello et al. (2013), who studied sowing quality and verified higher percentage of normal seeds in pneumatic seeder at lower velocities.

The values of mean power of the drawbar (Table 2) did not differ statistically between the velocities, but showed difference ($p < 0.05$) between the working depths, with higher requirement of power at the greatest depth (0.15 m). This fact can be attributed to the higher power demand of the tractor when the agricultural implements are operating at greater depths. Since the shank is at a greater depth, the tractor will need more power to disrupt a larger mobilized soil area, according to the results in Table 2. These results are similar to those obtained by Cepik et al. (2010) who worked with two seeders, one with three lines and the other with five lines, and observed higher requirement of tractor power at the greatest depths.

The values of mean power in the drawbar showed significant difference for the velocity treatment, and the velocity of 6.8 km h^{-1} required higher power (19.91 kW), almost 6 kW more

in comparison to the lowest velocity. There was also significant difference between the treatments with different working depths, and the depth of 0.15 m required higher power in comparison to the others (22.99 kW). The power is given by relationship between the velocity and the force in the drawbar; therefore, the increment in velocity leads to a gain of power and force. Thus, the treatments that require more force will require more power, as reported by Silveira et al. (2005), who observed higher requirement of tractor power in the treatments with increase in velocity and force.

The variable specific fuel consumption differed statistically for both evaluated treatments, and the highest value was obtained at the lowest velocity and at the lowest depth. The specific consumption is the fuel expenditure in mass unit per hour over power unit, which is influenced by fuel density, hourly consumption and power; the higher the power, the lower the specific consumption. As the variable power showed differences between depths and velocities, the lowest depth (0.05 m) and the lowest velocity (4.8 km h^{-1}) showed less power requirement, with the highest values observed for the lowest power requirement. Similar results were obtained by Almeida et al. (2010), who worked with different gears and rotations and observed the highest specific consumption for the gear of lowest velocity, and attributed it to the longer time and, consequently, lower effective field capacity to sow the area, and higher specific consumption at the lowest velocity.

The mobilized area was influenced by the variation in velocity and depth, with greater soil mobilization for the theoretical velocity of 4.8 km h^{-1}. However, under different conditions of soil cover management, Trogello et al. (2013a) observed no significant difference in the mobilized area for the velocities of 4.5 and 7.0 km h^{-1}. For the working depths, there was no statistical difference between 0.05 and 0.10 m, while the depth of 0.15 m mobilized more area than the others. The mobilized area consists in the difference between the natural soil profile, soil surface before the action of the equipment, and the bottom profile after the action of the equipment. There is a natural tendency for the mobilized area to be larger when the implement operates at greater depths. Grotta et al. (2007), testing a set at sowing depths of 0.03, 0.05 and 0.07 m, observed larger mobilized area at the greatest depths. These authors claim that the greater the depth, the larger the mobilized area, due to the higher amount of soil removed from the sowing furrow.

Table 2. Mean values of operational field capacity, specific resistance, mobilized area, force, power and specific consumption in corn sowing at two theoretical velocities and three working depths

Source of variation		OFC (ha h^{-1})	Specific resistance (kN m^{-2})	Mobilized area (m^2)	Force (kN)	Power (kw)	Specific consumption (kg kw h^{-1})
Velocity (V)	V1	0.90 b	139.62 b	0.08 a	10.05	13.94 b	0.68 a
	V2	1.25 a	181.67 a	0.06 b	10.45	19.91 a	0.51 b
Depth (D)	D1	1.07	131.09 b	0.06 b	7.38 b	12.23 c	0.79 a
	D2	1.11	164.55 ab	0.05 b	8.99 b	15.57 b	0.57 ab
	D3	1.03	186.28 a	0.08 a	14.37 a	22.99 a	0.42 b
F value	V	193.207*	8.66*	6.32*	0.62 NS	48.45*	6.21*
	D	3.13 NS	5.05*	6.29*	68.41*	55.05*	9.24*
	V*D	0.91 NS	2.92 NS	1.59 NS	0.24 NS	1.74 NS	0.02 NS
LSD	V	0.05	30.45	0.01	1.08	1.82	0.15
	D	0.08	45.47	0.02	1.63	2.73	0.22
CV (%)		5.67	21.78	25.11	12.20	12.41	29.30

*$p < 0.05$; NS Not significant; Means followed by the same letter and without letters in the columns do not differ by Tukey test ($p < 0.05$); V1 - Velocity 1 (4.8 km h^{-1}); V2 - Velocity 2 (6.8 kmh^{-1}); D1 - Depth 1 (0.05 m); D2 – Depth 2 (0.10 m) D3 - Depth 3 (0.15 m); LSD - Least significant difference; OFC - operational field capacity

The operational field capacity did not differ statistically for the depth variables, and the velocities differed statistically; the highest velocity (6.8 km h^{-1}) showed the highest OFC value. OFC is directly related to the displacement velocity of the set, the effective working width of the seeder and operation efficiency; thus, with the increment in the displacement velocity, there is a direct relationship for the increase in OFC. These results corroborate those of Santos et al. (2008), who observed increase in OFC with the increase in velocity, working with velocities of 4.9, 6.5 and 7.9 km h^{-1}.

The specific resistance showed statistical difference for the variables velocity and depth, with 5% degree of significance, and decreased with the increment in velocity. As to the depth, there were differences between the treatments 0.05 and 0.15 m, while the intermediate depth (0.10 m) did not differ statistically from the others. The specific resistance is the requirement of power per mobilized area (Rosa et al., 2008), i.e., the higher the power in a same mobilized area, the higher is the specific resistance, which is the reason why it can be defined as the ratio between the force and the mobilized area. The variation in specific resistance in relation to the velocity was attributed to the decrease in mobilized area with the increase in velocity, since the force did not suffer significant variation. As to the depth, despite the increase in mobilized area at the depth of 0.15 m, the increment was due to the excessive increase of force in relation to the other depths.

Conclusions

1. The velocity of 6.8 km h^{-1} promoted lower operational consumption of the tractor-seeder set.

2. The association of the velocity of 6.8 km h^{-1} (gear L4) with the working depth of 0.05 m promoted better operational performance of the tractor-seeder set.

3. The velocity of 4.8 km h^{-1} (gear L3) allows higher sowing quality for guaranteeing good seed deposition.

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