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Performance of a cascade fertilizer seeder: sowing systems and mechanisms for fertilizer deposition[1]

Desempenho de uma semeadora adubadora camalhoeira: sistemas de semeadura e mecanismos para deposição de fertilizantes

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ABSTRACT – It is necessary to use new technologies to mitigate water scarcity in the semi-arid region. As such, the aim of this study was to evaluate the operational and energy performance of a ridge planter and fertiliser, as well as the deposition depth of maize seeds and fertiliser as a function of the sowing system, and the use of different furrowing mechanisms (disc and shank) for depositing fertilisers. The experimental design was of randomised blocks, in a 6 x 2 factorial scheme with four replications, including six sowing systems: (S1 - intercropped ridge-sown maize; S2 – monocropped ridge-sown maize; S3 - intercropped furrow-sown maize; S4 – monocropped furrow-sown maize; S5 - conventional intercropping system; S6 - conventional monocropped system) and two mechanisms for depositing the fertiliser (offset double disc and shank furrower). The statistical analysis was carried out using the SISVAR software at 5% significance. It was concluded that, irrespective of the sowing system (ridge or furrow) and mechanism employed, there is no difference in the initial plant population or in the depth of the maize seeds. However, greater attention must be paid to the depth of both the fertiliser and forage seeds when these are deposited at the same time. Sowing systems that turn the soil (furrow and ridge) consume more energy, as does the shank mechanism. Sowing system S5 affords better operating performance when used together with the disk mechanism.

Key words: Furrowing shank. Offset double disc. Ridge. Furrow.

RESUMO - A escassez hídrica na região semiárida deve ser mitigada com novas tecnologias. Diante disto, objetivou-se com o presente trabalho, avaliar o desempenho operacional e energético de uma semeadora adubadora camalhoeira, bem como a profundidade de deposição de semente de milho e fertilizante em função do sistema de semeadura e do uso de mecanismos sulcadores para deposição de fertilizantes (Disco e haste). Foi utilizado delineamento experimental em blocos casualizados, em esquema fatorial 6 x 2 com 4 repetições, com seis sistemas de semeadura: (S1 - semeadura do milho em consórcio em cima do camalhão; S2 - semeadura do milho em camalhão sem consórcio; S3 - semeadura do milho em consórcio dentro do sulco; S4 - semeadura do milho dentro do sulco sem consórcio; S5 - semeadura convencional em consórcio; S6 - semeadura convencional sem consórcio) e dois mecanismos para deposição de fertilizantes (disco duplo desencontrado e haste sulcadora). A análise estatística foi realizada utilizando o programa SISVAR a 5% de significância. Foi possível concluir que independente do sistema de semeadura (camalhão ou sulco) e mecanismo usado, não haverá diferença na população inicial de plantas e profundidade da semente de milho. No entanto, é necessário maior atenção na profundidade do fertilizante e semente de forrageira quando depositados juntos de maneira momentânea. Os sistemas de semeadura que mobilizam o solo (sulco e camalhão) apresenta maior consumo energético, assim como o mecanismo haste. O sistema de semeadura S5 apresenta melhor desempenho operacional, juntamente com o mecanismo disco.

Palavras-chave: Haste sulcadora. Disco duplo desencontrado. Camalhão. Sulco.

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INTRODUCTION

Soil preparation comprises a set of operations whose purpose is to allow adequate conditions for the deposition of seeds and fertiliser at a specific depth that affords good seed germination as well as the growth and development of crops (TAVARES *et al*., 2012).

The semi-arid region of Brazil has irregular rainfall and high rates of evapotranspiration, which, together with the rapid growth of the population, increase the water deficit that is always present in these regions (KAMPF *et al*., 2016). Technologies, such as intercropping and systems of soil preparation to capture rainwater *in situ*, are alternatives that can be used to reduce the risks of agricultural exploitation in these regions (ANJOS; BRITO; SILVA, 2000), considering that intercropping can help to control weeds, as well as promote ground cover, favour nutrient cycling, and increase water infiltration into the soil (HERNANI; SOUZA; CECCON, 2013), in addition to improving the physical characteristics of the soil (SANTOS *et al*., 2018) and promoting the sustainability of agricultural activity (CORTEZ *et al*., 2016).

Furrow and ridge systems are techniques that consist in modifying the surface of the land to form an inclined plane between two successive furrows along the contour line, commonly known as ridges, that function as a catchment area for rainwater (MARTINS; NOGUEIRA, 2015).

However, in systems that prepare the soil for the *in-situ* capture of water, sowing is carried out at a different time to preparation, resulting in two or more operations for the sowing process. As a result, the use of machinery that, at the same time, allows the soil to be prepared to capture rainwater *in situ*, and intercrops to be sown together with the fertiliser, is a promising alternative, as it reduces the number of operations, and helps to conserve the soil and reduce expenses with agricultural operations in the field.

Sowing in the field demands perfection (ALMEIDA *et al*., 2010) if it is to contribute to the success of the production system (MACEDO *et al*., 2016). Several factors can affect operations using agricultural machines, and the use of mechanisms (disk or shank) is one of them. In the sowing process, the shank has greater penetration ability compared to the double disks (MODOLO *et al*., 2013; SOUSA *et al*., 2019), considering that with the increase in depth, a greater demand is expected on the traction force, with an increase in the fuel consumption of the tractor. Levien *et al*. (2011), implementing a maize crop using two types of furrowers (shank and disc), concluded that the shank furrower results in a greater need for tractive effort, with more tractor slippage and higher fuel consumption.

Considering the characteristics of low precipitation and high evapotranspiration in semi-arid regions, it is extremely important to study the performance of agricultural machinery capable of preparing the soil for *in-situ* water collection and, at the same time, sowing crops in the field. The aim of the present study, therefore, was to evaluate the operational and energy performance of a ridge planter and fertiliser as a function of different sowing systems and furrowing mechanisms (disc and shank) for depositing the fertiliser, as well as the deposition depth of the seeds (maize and forage) and fertilisers.

MATERIAL AND METHODS

The study was conducted in the experimental area of the Vale do Curu farm in Pentecoste in the state of Ceará, 120 km from the city of Fortaleza. The farm is located at 3°49’ S and 39°20’ W, at an altitude of 46 m. The soil in the experimental area is classified as a Planosol with a sandy loam texture (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2013). Before setting up the experiment, undisturbed soil samples were collected for a physical characterisation (Table 1).

Table 1 - Particle size analysis at depths of 0.00 – 0.20 and 0.20 - 0.40 m

Soil attribute	Depth (m)	
	0.00 – 0.20	0.20 – 0.40
Coarse sand (g kg^{-1})	24	17
Fine sand (g kg^{-1})	514	517
Silt (g kg^{-1})	299	301
Clay (g kg^{-1})	163	165
Natural clay	142	120
Textural class	Sandy Loam	Sandy Loam
Overall density (g/cm^{-3})	1.27	1.38
Particle density (g/cm^{-3})	2.59	2.68

Before starting the field experiment, the mechanical resistance of the soil to penetration (MRSP) was evaluated with the aid of a model PI-60 impact penetrometer, at four sampling points per treatment. At the same time, soil samples were collected at a depth of 0.00 - 0.30 m using a Dutch auger, to determine the soil water content (SWC), (Table 2). The water content was estimated using the gravimetric method (standard greenhouse method), as a function of the relationship between the weight of the water and the weight of the soil dried in an oven at 105°C (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2011).

The experiment was set up in an area previously prepared by ploughing and harrowing. The design was of randomised blocks in a 6 x 2 factorial scheme with 4 replications, including six sowing systems (S1: intercropped ridge-sown maize; S2: monocropped ridge-sown maize; S3: - intercropped furrow-sown maize; S4: monocropped furrow-sown maize; S5: conventional intercropping system; S6: conventional monocropped system) and two furrowing mechanisms for depositing the fertiliser (M1- disc mechanism and M2 – shank mechanism).

Each experimental plot occupied an area of 80 m^2 (20 x 4 m), with a space of 15 m reserved longitudinally between the plots to manoeuvre and stabilise the ridge planter and fertiliser-tractor set.

A Jumil model JM2090 PD pneumatic precision planter and fertiliser was used, weighing approximately 1,160 kg assembled, configured for 3 rows, 0.80 m apart, with a maximum fertiliser- and seed-tank capacity of 39 L. The machine allows the use of two furrowing mechanisms: shank furrower and offset double disc for the deposition of fertiliser and seeds.

The planter-fertiliser was driven by a 4x2 AFT tractor (auxiliary front-wheel drive traction) with a power of 91.9 kW (125 hp) working in 4-Low gear, with the auxiliary front wheel drive (AFT) engaged. The tractor was prepared for medium activity with a total weight of 6,270 kg (40% front and 60% rear), calculated to carry out medium operations, and a power-to-weight ratio of 52.25 kg/hp; it was equipped with 14.9-24 R1 diagonal tyres on the front axle, at an inflation pressure of 26 psi (179 kPa), and 23.1-30 R1 tyres on the rear axle at an inflation pressure of 30 psi (206 kPa).

Furrowers were used to open the furrows and form the ridges to later sow the crops. When fixing the furrower to the chassis of the planter, a straight cylindrical shank was used, which had a diameter of 5 cm and a length of 90 cm, and was made of 1045 steel. This was fixed to the chassis of the planter by means of a component already existing on the planter. on which the cutting-disc structure was placed, allowing the furrower to be regulated in the vertical direction.

The following variables were evaluated: initial plant population, depth of the seeds and fertiliser, displacement speed (m s^{-1}), hourly fuel consumption (L h^{-1}), fuel consumption per area (L ha^{-1}), operational

Table 2 - Mean values for the mechanical resistance of the soil to penetration (MRSP) and the soil water content (SWC) at a depth of 0.00 - 0.30 m for each treatment

Treatment	MRSP (Kpa)	SWC (%)
S1D	1220	19
S1S	1920	16
S2D	2200	18
S2S	2145	15
S3D	1345	21
S3S	1218	24
S4D	1345	20
S4S	1287	21
S5D	1863	14
S5S	1345	16
S6D	1262	20
S6S	1763	20

Legend: MRSP – Soil mechanical resistance to penetration; SWC - Soil water content; Kpa – Kilopascal; S1D – intercropping ridge-sown system with disk; S1S - intercropping ridge-sown system with shank; S2D – single ridge-sown system with disk; S2S - single ridge-sown system with shank; S3D - intercropping furrow-sown system with disk; S3S - intercropping ridge-sown system with shank; S4D - monocropped furrow-sown system with disk; S4S – intercropping furrow-sown system with shank; S5D – conventional intercropping system with disk; S5S - conventional intercropping system with shank; S6D – conventional monocropped system with disc; S6S – conventional monocropped system with shank fuel consumption (L ha^{-1}), operational field capacity (ha h^{-1}), wheel-slip (%), and area covered (m^2).

The theoretical working depths of the shank and disc mechanisms were 7 cm and 4 cm, respectively, when depositing the fertilisers and maize seeds. The shank employed a 20º angle of attack, and the disc had a diameter of 14 inches.

The depths of the seeds and fertiliser were measured in the central 10 m of each experimental plot with the aid of a ruler marked in centimetres. For this, a penknife was used to carefully remove the soil along the sowing row to the depth where it met the seeds and fertiliser. The initial plant population was determined 10 days after sowing by counting the number of plants in the working area of each experimental plot; these values were then extrapolated to the number of plants ha^{-1}.

The mean displacement speed was calculated by measuring the time required for the ridge planter and fertiliser-tractor set to cover each plot, as shown in Equation1.

$$Vm = \frac{S}{T} \quad (1)$$

where,

Vm = average speed (m/s^{-1});

S= space covered (m);

T= time elapsed (s);

The operational field capacity was obtained by multiplying the working width of the planter, the displacement speed, the unit conversion factor, and an efficiency conversion factor of 75% of the effective field capacity, following the recommendations of the American Society of Agricultural Engineers (1997). Equation 2.

$$OFC = WW \, x \, V \, x \, 0.36 \, x \, 0.75 \quad (2)$$

where,

OFC = operational field capacity (ha h^{-1});

WW = working width of the equipment (m);

V = actual displacement speed (m s^{-1});

0.36 = unit conversion factor;

0.75 = field efficiency of the equipment;

To measure fuel consumption, two flow meters with a precision of 0.01 ml, were installed in series at the inlet and return of the injection pump and used to quantify the volume of fuel consumed by the tractor in covering each experimental plot, calculated as per Equation 3.

$$CH = \left(\frac{q}{t}\right) \times 3.6 \quad (3)$$

where,

CH = hourly fuel consumption (L h^{-1});

q = volume consumed in the plot (ml);

t = time to cover the plot (s);

3.6 = unit conversion factor;

After obtaining the hourly fuel consumption (L h^{-1}), the consumption per area (L ha^{-1}) was calculated as per Equation 4 below.

$$CA = \frac{C_H}{FCe} \quad (4)$$

where,

CA = fuel consumption per area, L ha^{-1};

C_H = hourly fuel consumption, L h^{-1};

FCe = effective field capacity (ha h^{-1});

Operational consumption was determined from the ratio between the hourly fuel consumption and the operational field capacity, as per equation 5.

$$CO = \frac{C_H}{OFC} \quad (5)$$

where,

CO = operational consumption (L ha^{-1});

C_H= hourly consumption (L h^{-1});

OFC = operational field capacity (ha h^{-1});

Wheel-slip was obtained by counting the number of turns of the tractor wheels in the experimental plot both when pulling the planter (under load) and with the planter raised (no load). The count was made using a digital camera, starting the video when the front tyre of the tractor passed the start of the side of the plot, and stopping the video at the stakes that marked the end of each plot; wheel-slip was calculated using Equation 6.

$$WS = \left(\frac{N^1 - N^O}{NO}\right) * 100 \quad (6)$$

where,

WS = wheel-slip of the tractor (%);

N0 = number of turns made by the wheels with no load;

N1 = number of turns made by the wheels under load.

To determine the area of ground covered, a wooden profilometer was used, consisting of 20 metal rods spaced 0.005 m apart, with a support 3 m wide and 1 m high and a vertical base for fixing the sheets of 0.40 x 0.60 m graph paper. The area covered comprised the area located between the soil profile before preparation and the bottom profile of the furrow after preparation (GAMERO; BENEZ, 1990).

An analysis of variance was carried out, submitting the data to the f-test; when significant, the mean values were compared by Tukey's test at 5% probability using the SISVAR software (FERREIRA, 2011).

RESULTS AND DISCUSSION

No difference was found for the depth of the maize seeds and the initial plant population, nor was there any interaction of the factors for these variables (Table 3). These results can be explained by the low theoretical displacement speed (1.25 m s^{-1}) used in the present study, since Macedo *et al*. (2016), working with different speeds, found better quality sowing when working at the lowest speed (1.33 m s^{-1}). The similarity between the depth of the maize seeds and the initial plant population is a strong indication that the planter was properly regulated. These results must be considered, as the variables directly affect crop production. Therefore, the lack of any difference in the depth of the maize seeds presupposes the maize showing good germination and not interfering with the initial plant population per hectare as a result. However, there is a difference for the depth of the fertiliser and of the forage seeds (DFFS) (Table 3).

The depth of the fertiliser and forage seeds (DFFS) showed higher values when sown in the furrow and intercropped (S3). One probable explanation for this result may be related to the higher water content found with the above treatment when sowing, together with lower mechanical resistance of the soil to penetration - MRSP (Table 2), a result of the reduction in cohesive forces between the soil particles and the increased lubricating effect of the water, causing inverse behaviour between the water content and the mechanical resistance of the soil to penetration (SOUZA *et al*., 2014; VALENTE *et al*., 2019).

There was a difference in slippage for the sowing systems, albeit no interaction with the sowing systems and mechanisms (Table 4). Sowing systems S1, S2, S3 and S4 had the highest mean values for slippage, with systems S5 and S6 (natural) showing the lowest mean values. These results can be explained by soil turning being inherent to systems S1, S2, S3 and S4, which meant there was an increased resistance to displacement as the soil was being turned, with an increased probability of wheel-slip.

Despite the higher values for wheel-slip in the sowing systems that included soil turning (S1, S2, S3 and S4), they remain within the range recommended by the American Society of Agricultural Engineers (1989), where the appropriate slippage for turned soil is between 11% to 13%. Opposite results were obtained by Cortez *et al*. (2009), who found no statistical difference between the percentage slippage of the tractor wheels.

There was interaction between the sowing systems and furrowing mechanisms for displacement speed, with the breakdown shown in Table 5. Working with the S3 and S4 sowing systems, the shank mechanism was superior to the disk; however, with S5, the disc mechanism showed better performance. The higher speeds found with the use of the shank mechanism in systems S3 and S4 can be explained by

Table 3 - Mean values for the depth of the maize seeds (DMS), depth of the fertiliser and forage seeds (DFFS) and initial plant population

Source of Variation		DMS (cm)	DFFS (cm)	Initial plant population (Plants ha^{-1})
Systems (S)	S1	4.27	6.12 b	68750.00
	S2	3.83	6.06 b	68750.00
	S3	4.26	7.26 a	68906.25
	S4	4.21	6.73 b	69531.25
	S5	3.65	6.26 b	68593.75
	S6	3.58	6.17 b	68593.75
Mechanisms (M)	M1	3.90	6.35	68541.66
	M2	4.03	6.52	69166.66
F-value	S	3.21^{ns}	3.02*	0.56^{ns}
	M	0.74^{ns}	0.56^{ns}	2.67^{ns}
	SxM	0.42^{ns}	1.99^{ns}	0.35^{ns}
LSD	S	0.75	1.15	2001.45
	M	0.29	0.44	777.36
CV (%)		12.60	11.89	1.92

*($p < 0.05$); NS (not significant). Mean values followed by the same letter or with no letter in the columns do not differ by Tukey's test ($p < 0.05$); M - Mechanism; S - Sowing systems; S1 - Intercropped ridge-sown; S2 - Monocropped ridge-sown; S3 - Intercropped furrow-sown; S4 - Monocropped furrow-sown; S5- Conventional intercropping system; S6 - Conventional monocropped system; LSD - Least significant difference; CV – Coefficient of variation

the tendency of the mechanism to act on the surface, which, according to Silveira *et al*. (2011), is because the shank mechanism tends to approach the surface at higher speeds, the possible causes for this behaviour being the resistance to penetration, soil moisture and roughness. On the other hand, analysing the sowing systems, S3 and S4 had the lowest mean speeds when the disk mechanism was used. This may be related to a greater resistance to displacement due to the soil moving inside the seed furrow with these systems.

Table 4 - Mean values obtained for speed (V), slippage (SLP) and operational field capacity (OFC)

Source of Variation		V (m s^{-1})	SLP (%)	OFC (ha/h^{-1})
Systems (S)	S1	1.23	11.07 a	1.14
	S2	1.24	9.35 ab	1.15
	S3	1.16	10.63 a	1.07
	S4	1.15	10.36 a	1.06
	S5	1.22	7.02b	1.12
	S6	1.20	6.40b	1.11
Mechanisms (M)	M1	1.24	8.86	1.10
	M2	1.21	9.42	1.11
F-value	S	5.94*	7.31*	5.47*
	M	1.40^{NS}	0.86^{NS}	1.36^{NS}
	SxM	2.83*	0.57^{NS}	2.97*
LSD	S	0.24	3.12	0.06
	M	0.09	1.21	0.02
CV (%)		3.78	22.58	3.90

*(p < 0.05); NS (not significant). Mean values followed by the same letter or with no letter in the columns do not differ by Tukey's test (p < 0.05); M - Mechanism; S - Sowing systems; S1 - Intercropped ridge-sown; S2 - Monocropped ridge-sown; S3 - Intercropped furrow-sown; S4 - Monocropped furrow-sown; S5 - Conventional intercropping system; S6 - Conventional monocropped system; LSD - Least significant difference; CV – Coefficient of variation

Table 5 - Mean values obtained from the breakdown of the furrowing mechanisms within each sowing system for displacement speed

System (S)	Mechanism (M)	
	M1 (Disc)	M2 (Shank)
S1	1.22 a	1.24
S2	1.24 a	1.24
S3	1.12 bB	1.20 A
S4	1.11 bB	1.18 A
S5	1.25 aA	1.18 B
S6	1.21 a	1.19
F-Test		
SxM	7.14(p < 0.01)	
MxS	3.70(p < 0.01)	
LSD (S)	0.34	
LSD (M)	0.23	

Different lowercase letters in the columns and different uppercase letters on the rows differ for system and mechanism, respectively, by Tukey's test at 5% probability. Mean values with no letters do not differ statistically. M - Mechanism; M1 - Disk mechanism; M2 - Shank mechanism; S - Systems; S1 - Intercropped ridge-sown; S2 - Monocropped ridge-sown; S3 - Intercropped furrow-sown; S4 – Monocropped furrow-sown; S5 - Conventional intercropping system; S6 - Conventional monocropped system; LSD - Least significant difference

Analysing the breakdown of operational field capacity (OFC) (Table 6), no differences were found for the systems within the furrowing mechanisms. However, the mechanisms within each system showed differences, with similar results to that of the displacement speed. These results agree with those obtained by Furlani *et al*. (2008), who found an increase in OFC for an increase in displacement speed. The OFC is dependent on the displacement speed, therefore, under higher actual speeds, the OFC is higher and the consumption per hectare is lower (QUEIROZ *et al*., 2017).

According to Table 7, the S1, S2, S3 and S4 sowing systems showed higher mean values for hourly consumption (CH), operational consumption (CO) and consumption per area (CA), while the lowest mean value was found with system S6. These results can be explained by systems S1, S2, S3 and S4 having soil turning in common, to form the ridge and open the furrow during the sowing process. Furthermore, these systems also have a larger area of turned soil. Given that soil turning may demand greater tractive effort and, consequently, greater energy, Toledo *et al*. (2010) found a direct proportional relationship between the fuel consumption and traction force of a planter and fertiliser.

Analysing each mechanism within the energy consumption of the ridge planter and fertiliser, the shank mechanism (M2) was superior to the disc (M1) for all types of consumption (CH, CA and CO), as well for the area of ground covered (AC) (Table 7). These results may be directly related to the depth of the shank, turning a larger volume of soil and increasing energy consumption during the operation.

Francetto *et al*. (2016b), evaluating the traction force and power requirement of the cutting and furrowing mechanisms of a planter-fertiliser, found a mean tractive demand for the shank 22.28% greater than for the disc mechanism. The authors explain that these results are due to the design of the shank, which aims to break the compacted layers of soil, and works at a greater depth in relation to the discs, requiring more energy to overcome the friction between the tool and the soil, unlike the double discs, which open a furrow simply by cutting.

Francetto *et al*. (2016a) found a 32.10% increase in turned soil when using the shank mechanism compared to the disc. The authors attributed this result to the greater working depth of the shank mechanism, which can lead to a greater traction force (FRANCETTO *et al*., 2015). Similar results were found by Mion *et al*. (2009). According to those authors, this is related to the shank reaching a greater depth when opening the furrow due to the action of the tip, which results in a downward movement.

Chen *et al*. (2013), state that soil turning depends on the working depth, and the length and width of the tool employed, and can result in a reduction in bulk density and mechanical resistance, and an increase in macroporosity (NUNES *et al*., 2015).

Table 6 - Mean values obtained from the breakdown of the furrowing mechanisms within each sowing system for operational field capacity (OFC)

System (S)	Mechanism (M)	
	M1 (Disc)	M2 (Shank)
S1	1.12	1.15
S2	1.15	1.15
S3	1.03 B	1.11 A
S4	1.03 B	1.09 A
S5	1.16 A	1.09 B
S6	1.11	1.10
F-Test		
SxM	6.92(p < 0,01)	
MxS	0.66^{NS}	
LSD (S)	0.09	
LSD (M)	0.06	

Different lowercase letters in the columns and different uppercase letters on the rows differ for system and mechanism, respectively, by Tukey's test at 5% probability. Mean values with no letters do not differ statistically. M - Mechanism; M1 - Disk mechanism; M2 - Shank mechanism; S - Systems; S1 - Intercropped ridge-sown; S2 - Monocropped ridge-sown; S3 - Intercropped furrow-sown; S4 - Monocropped furrow-sown; S5 - Conventional intercropping system; S6 - Conventional monocropped system; LSD - Least significant difference

Table 7 - Mean values for hourly consumption (CH), consumption per area (CA), operational consumption (CO) and area covered (AC)

SouSource of Variation		CH (L/H)	CA (L/ha^{-1})	CO (L/ha^{-1})	AC (m^2)
Systems (S)	S1	12.25 a	7.91 a	10.78 a	0.05 a
	S2	12.45 a	7.94 a	10.84 a	0.06 a
	S3	12.11 a	8.28 a	11.28 a	0.05 ab
	S4	11.63 ba	8.03 a	10.96 a	0.06 a
	S5	10.75 bc	7.00 b	9.54 b	0.01 c
	S6	10.62 c	7.01 b	9.56 b	0.01 c
Mechanisms (M)	M1	11.31 b	7.54 b	10.27 b	0.03 b
	M2	11.96 a	7.85 a	10.71 a	0.04 a
F-value	S	12.69*	2.42*	12.82*	18.20*
	M	13.37*	1.19*	6.53*	19.55*
	SxM	1.94^{NS}	0.02^{NS}	0.15^{NS}	1.3^{NS}
LSD	S	0.94	0.66	0.89	0.02
	M	0.36	0.25	0.34	0.007
CV (%)		5.35	5.70	5.65	33.30

*($p < 0.05$); NS (not significant). Mean values followed by the same letter or with no letter in the columns do not differ by Tukey's test ($p < 0.05$); M - Mechanism; S - Sowing systems; S1 - Intercropped ridge-sown; S2 - Monocropped ridge-sown; S3 - Intercropped furrow-sown; S4 - Monocropped furrow-sown; S5 - Conventional intercropping system; S6 - Conventional monocropped system; LSD - Least significant difference; CV – Coefficient of variation

CONCLUSIONS

1. Irrespective of the sowing system or mechanism employed, there is no difference in the initial plant population or depth of the maize seeds. However, it is necessary to pay more attention to the depth of both the fertiliser and forage seeds when deposited at the same time;
2. Sowing systems that turn the soil (furrow and ridge) consume more energy, as does the shank mechanism;
3. The shank mechanism affords better operating performance when working inside the furrow (S3 and S4), while the conventional system (S5) together with the disc mechanism affords the best operating performance.

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REFERENCES

ALMEIDA, R. A. S. de *et al*. Desempenho energético de um conjunto trator-semeadora em função do escalonamento de marchas e rotações do motor. **Revista Agrarian**, v. 3, n. 7, p. 63-70, 2010.

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. Agricultural tractor test code. *In*: **ASAE Standards**: standards engineering practices data. San Joseph, 1989. p. 44-48.

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. **ASAE EP291.1**: standards engineering practices data. St. Joseph: ASAE, 1997. p. 254-275.

ANJOS, J. B.; BRITO, L. T. de L.; SILVA, M. S. L. da. Métodos de captación de água de lluvia *in situ* e irrigación. *In*: FAO. **Manual de práticas integradas de manejo y conservación de suelos**. Roma, 2000. cap. 15, p. 139-150.

CHEN, Y. *et al*. Selection of design parameters for a slurry injection tool. **T ASABE**, v. 56, p. 1653-1663, 2013.

CORTEZ, G. L. S. *et al*. Consorciação de culturas e o sistema de plantio direto: alternativas para a sustentabilidade do solo. **Journal of Agronomic Sciences**, v. 5, p. 61-77, 2016. Número especial.

CORTEZ, J. W. *et al.* Desempenho do trator agrícola no manejo da cultura de cobertura e pressão de inflação do pneu da semeadora. **Engenharia Agrícola**, v. 29, n. 1, p. 72-80, 2009.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Manual de métodos de análise de solo**. 2. ed. Rio de Janeiro: Embrapa Solos, 2011. 230 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Sistema brasileiro de classificação de solos**. 3. ed. Brasília, DF, 2013. 353 p.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, v. 35, n. 6, p. 1039-1042, 2011.

FRANCETTO, T. R. *et al*. Comportamento operacional de associações entre sulcadores e discos de corte para sistema de semeadura direta. **Engenharia Agrícola**, v. 35, n. 3, p. 542-554, 2015.

FRANCETTO, T. R. *et al*. Força de tração e potência demandada por mecanismos de corte e sulcadores de semeadora-adubadora. **Energia na Agricultura**, v. 31, n. 1, p. 17-23, 2016a.

FRANCETTO, T. R. *et al*. Disturbance of Ultisol soil based on interactions between furrow openers and coulters for the no-tillage system. **Spanish Journal of Agricultural Research**, v. 14, n. 3, 2016b.

FURLANI, C. E. A. *et al.* Semeadora-adubadora: exigências em função do preparo do solo, da pressão de inflação do pneu e da velocidade. **Revista Brasileira de Ciências do Solo**, v. 32, p. 345-352, 2008.

GAMERO, C. A.; BENEZ, S. H. Avaliação da condição do solo após a operação de preparo. *In*: SILVEIRA, G. M. **IV Ciclo de estudos sobre mecanização agrícola**. Jundiaí: Fundação Cargill, 1990. p. 12-21.

HERNANI, L. C.; SOUZA, L. C; CECCON, G. **Consorciação de culturas**. Brasília, DF: Agência Embrapa de Informação Tecnológica, 2013. 2 p.

KAMPF, S. K. *et al*. Rain and channel flow supplements to subsurface water beneath hyper-arid ephemeral stream channels. **Journal of Hydrology**, v. 536, p. 524-533, 2016.

LEVIEN, R. *et al.* Semeadura direta de milho com dois tipos de sulcadores de adubo, em nível e no sentido do declive do terreno. **Ciência Rural**, v. 41, p. 1003-1010, 2011.

MACEDO, D. X. S. *et al.* Operational performance of a tractor-seeder according to the velocity and working depth. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 20, n. 3, p. 280-285, 2016.

MARTINS, C. A. da S.; NOGUEIRA, N. O. Captação de água da chuva em propriedades rurais. **Nucleus**, v. 12, n. 1, p. 87-106, 2015.

MION, R. L. *et al.* Análise tridimensional de esforços em elementos rompedores de semeadoras de plantio direto. **Ciência Rural**, v. 39, p. 1414-1419, 2009.

MODOLO, A. J. *et al.* Semeadura de milho com dois mecanismos sulcadores sob diferentes intensidades de pastejo. **Engenharia Agrícola**, v. 33, n. 6, p. 1200-1209, 2013.

NUNES, M. R. *et al*. Mitigation of clayey soil compation managed under no-tillage. **Soil and Tillage Research**, v. 148, p. 119-126, May 2015.

QUEIROZ, R. F. *et al.* Cargas no depósito de fertilizante de uma semeadora-adubadora e desempenho operacional. **Revista Ciência Agronômica**, v. 48, n. 2, p. 271-277, 2017.

SANTOS, P. R. A. *et al.* Physical attributes of the soil and maize productivity under an intercrop system. **Journal of Agricultural Science**, v. 10, n. 12, 2018.

SILVEIRA, J. C. M. da *et al*. Profundidade de sulco, área de solo mobilizada e força de tração de uma semeadora-adubadora em razão da velocidade de deslocamento. **Revista Ceres**, v. 58, n. 3, p. 293-298, 2011.

SOUSA, C. M. A. *et al*. Desempenho de semeadora-adubadora de milho de segunda safra em semeadura direta. **Revista Agrarian**, v. 12, n. 45, p. 346-353, 2019.

SOUZA, E. B. *et al.* Resistência mecânica do solo à penetração em função da sua umidade e do tipo de penetrômetro. **Engenharia na Agricultura**, v. 1, n. 22 p. 67-76, 2014.

TAVARES, L. A. F. *et al*. Características agronômicas e demanda energética de cultivares de soja sob efeito dos sistemas de preparo do solo. **Revista Energia na Agricultura**, v. 27, n. 4, p. 92-108, 2012.

TOLEDO, A. D. E. *et al.* Comportamento espacial da demanda energética em semeadura de amendoim em latossolo sob preparo convencional. **Engenharia Agrícola**, v. 30, p. 459-467, 2010.

VALENTE, G. F. *et al*. Resistência mecânica à penetração em sistemas de manejo do solo. **Revista Verde**, v. 14, n. 1, p. 140-145, 2019.