PERFORMANCE EVALUATION OF A POTATO SEEDING MACHINE ADAPTED TO OPERATE UNDER NO OR MINIMUM TILLAGE SYSTEM

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ABSTRACT

Potato is one of the most important vegetable crops in Brazil. It is cultivated in a traditional way, where the soil is prepared conventionally through plowing and harrowing, differing in number and sequence. Excessive soil plowing is a common practice among Brazilian potato growers due to the belief that higher soil fragmentation results in better crop development. Alternative techniques, such as no-tillage or minimum tillage, have made good progress for cereal cultivation in Brazil, but have a negligible impact on potato cultivation. This study was done to modify a commercial potato seeder to operate in soils that have not been plowed (no-tillage) or minimally plowed (minimum tillage) and evaluate its performance in conventional, minimum and no-tillage systems. The experiment was laid down in randomized block design, with treatments consisting of three tillage systems (no-tillage, minimum, and conventional tillage) with four replications. The results showed that the potato planted in no-tillage soil saved up to 35 L ha-1 of diesel. The soil prepared with rotary hoe for the subsequent potato planting allowed the potato plants to emerge more rapidly.

Keywords: Soil tillage, consumption of fuel, agricultural mechanization.

AVALIAÇÃO DO DESEMPENHO DE UMA PLANTADORA DE BATATA ADAPTADA PARA TRABALHAR EM SISTEMAS DE PLANTIO DIRETO E CULTIVO MÍNIMO

RESUMO

A batata é uma das mais importantes olerícolas cultivadas no Brasil. O cultivo acontece de maneira tradicional, sendo o preparo do solo feito convencionalmente, usando implementos de revolvimento e destorroamento em número e seqüências variadas. O revolvimento excessivo do solo é prática usual entre os bataticultores do Brasil, que vislumbram na grande fragmentação do solo a condição ideal para o desenvolvimento da cultura. No presente trabalho, os objetivos foram adaptar uma plantadora de batata existente no mercado para operar em solo cuja superfície não havia sido revolvida (plantio direto) ou pouco revolvida (cultivo mínimo) e avaliar o desempenho da plantadora por meio de modificações da máquina e pelo plantio convencional. O experimento foi conduzido num delineamento em blocos casualizados, composto por três sistemas de plantio (plantio direto, plantio convencional e cultivo mínimo) com quatro repetições. Pelos resultados obtidos, conclui-se que: o plantio de batata em solo não revolvido permitiu economia de até 35 L ha^{-1} de óleo diesel. O solo preparado com enxada rotativa para posterior plantio permitiu que as plantas de batata emergissem mais rapidamente do solo.

Palavras-chaves: Preparo do solo, consumo de combustível, mecanização agrícola.

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1. INTRODUCTION

The few studies of the alternatives for soil preparation and potato seeding in the available literature are concerned to the countries from which the soils and climatic conditions are different from the Brazilian conditions. Therefore, their applications are usually not adequate to Brazilian conditions. There is a need for the development of new technologies in order to replace those consecrated technologies that are widely used, but rather cause degradation in the soil making it tending to losses. On the other hand, just the substitution of the actually practiced techniques by other ones ecologically more correct is not enough, it is also necessary to look for solutions that would be economically viable.

According to Bregagnoli (2000), the potato (*Solanum tuberosum L.*) is among those fifteen vegetal-originated foods that are most consumed throughout the world. It contains from 1.5 to 2.5% protein, high contents of C vitamin, potassium and carbohydrates, as well as 100 g of cooked potato contains 90 kcal. It is one of the main vegetables produced in Brazil, with a planted area around 200 thousands ha.year^{-1} and an average productivity of 15 t ha^{-1} (ABAMIG, 1998). According this same source, Minas Gerais State is responsible for 30% for the national production, with a planted area around 36 thousands ha, and an average yield of 22,437 kg ha^{-1}.

A number of plowing and disking are accomplished, and the number of each operation will vary according to the crop to be developed, the conditions of the soil itself, the crop leftovers, the vegetation state, as well as the equipments to be used in other stages of the productive process. The preparation of the soil for minimum tillage involves the use of chisel plows or disk harrows, whereas for the no-till planting it consists of managing the straw by the use of herbicides, rotary cutter and a planting machine appropriate to work on straw.

Frequently, the preparation of the soil for setting up the crop is accomplished on exaggerated way. Most potato croppers prefer to plant in a non-compact and pulverized soil, which is a favorable condition to erosive processes in the sloping terrain under irrigation and/or rainfall, as well as the nutrient leaching.

The majority of the implements commonly used in preparation of the soil for potato cropping are the disk plows, disk harrows and rotary tillers, as varying both the number and sequence of the operations, according to the original conditions of the soil as well as the potato grower's practical sense, a fact that is according to Salvador (1992), who emphasized the preparation of the soil to be rarely performed on the basis of an objective study.

Significant changes have been occurring in the viewpoint of the society on the need for maintaining and recovering the natural resources. Questionings concerning to soil loss by erosion and the water pollution have been arising. According to Gassen and Gassen (1996), one reason for the adoption of the no-till planting is related to the requirement from the international market for agricultural products obtained under lower environmental impact conditions, which would minimize the soil losses and water contamination. Referring to this matter, MION (2002) mentions that an appropriately conducted no-till planting may significantly contribute to such a fact, since it involves the interaction among machine, soil, climate, atmosphere and all organisms found in the system.

According to Braunack and McPee (1991), the minimum tillage or a reduced soil preparation is a system providing favorable conditions for the development of one or more crops, because it leaves a protective residual covering on the soil surface throughout the year.

According to these authors, it is necessary to develop new machines and techniques that would prepare the soil with a single operation.

According to Veiga and Amado (1994), the erosion risks are reduced in the conservationist preparation, as well as the crop leftovers are maintained on the soil surface, therefore delaying their decomposition and the consequent release of the nutrients to the soil at a time when the plants have more need for them.

A number of experiments have been showing that the yield of potatoes is increased, when they are cropped in a soil where there is few trafficability (DICKSON et al., 1992). Other researchers showed satisfactory results by reducing the operations of soil preparation (DALLYN and FRICKE, 1974).

When the disk harrows are used after plowing, their function is to complement the preparation of the soil, which is accomplished by the plow, in order to fragment the clods, to level the surface to facilitate seeding, to reduce the spaces among the clods and to interrupt the capillary vase systems forming in the upper layer of the soil, so hindering the evaporation of the water from the deepest soil layers. Thus, the target of the present study was:

- to adapt a potato planting machine available in the market to operate in a soil from which the surface had not been revolved (no-till planting) or just slightly revolved (minimum tillage);
- to evaluate the performance of the potato planting machine based on either its different modifications and the conventional planting.

2. MATERIAL AND METHODS

The field experiment was carried out in an area pertaining to the Universidade Federal de Viçosa - UFV, Agricultural Engineering Department, in Viçosa County, Minas Gerais State, Brazil, at 600 to 700 m altitude and 3% average sloping. The average annual temperature is 19º C, the annual precipitation ranges from 1,300 to 1,400 mm, the rainy season is concentrated on the period from October to March, and the annual air relative humidity oscillates from 80 to 85%. The studied area had a rectangle form with 48m length and 33m width, that had been uncultivated for approximately three years and was covered with dense vegetation consisting of Stylozobium aterrimum in almost its totality.

The soil was classified as a Cambic Yellow-Red Argisol, Terrace phase (EMBRAPA, 1999). The soil density, particle densities, and soil moisture were determined at layers ranging from 0 – 100 mm in depth, as presented in Table 1.

The cylinder method was used to determine the soil density, whereas the volumetric balloon method was used to determine the particle densities, and the soil moisture was determined by the standard gravimetric method (EMBRAPA, 1997). Both the granulometric and chemical analyses of the soil are shown in Tables 2, 3 and 4.

The values of the soil strength against penetration represented by the cone index (IC_{200}) were 14.64 MPa, and the standard deviation was 2.015.

When conducting the experiment, the following implements and machines were used: a Watanabe potato planting machine with two rows, that was connected to a tree-point hitch system; KAMAQ rotary cutter; Vicon ridging rake implement with four sets of teeth**;** FUJIAGRO rotary tiller with 24 L-shaped blades disposed into 6 flanges, operating at 240 rpm and an impaction plate lowered; Massey Ferguson Tractor, model MF 275 4 x 2 (TDA) with 53.73 kW of maximum power at 2000 rpm, weighing 4,650 kg.

Table 1. Properties and physical characteristics of the soil layer from 0 to 200 mm depth

Depth (mm)	Soil density (g mm^{-3})	Soil particles (g mm^{-3})	Moisture (% mass)
0 – 100	1.20	2.73	25.90
100 – 200	1.34	2.94	26.43

Table 2. Granulometric analysis[1] of the soil sample from the layer 0-200 mm in depth

Clay (%)	Silt (%)	Coarse sand (%)	Fine sand (%)	Texture classification
42	20	27	11	Clay

[1] The pipette method was used, according to EMBRAPA (1997).

Table 3. Chemical analysis of the soil samples from the layers ranging from 0-200 mm in depth, before planting and fertilization

pH	P	K	Ca	Mg	Al	H+Al	SB	CTC	V	m	MO	P-rem
H_2O	mg dm^{-3}				cmol$_c$ dm^{-3}				%		dag kg^{-1}	mg L^{-1}
5.8	65.3	89	3.2	0.7	0.0	2.6	4.13	6,.73	61	0	2.69	30.5

Table 4. Chemical analysis of the soil samples from the layers ranging from 0-200 mm in depth collectedbetween the planting rows after harvesting the tubercles

pH	P	K	Ca	Mg	Al	H+Al	SB	CTC	V	M	MO
H_2O	mg dm^{-3}				cmol$_c$ dm^{-3}				%		dag kg^{-1}
5,3	192,9	350	6,3	1,4	0,0	4,95	8,60	13,55	63	0	3,11

The treatments were defined as a function of:

a) adaptations in the potato planting machine, operating under three ways; and

b) presence or absence of the hilling.

Table 5 presents the treatments with their respective descriptions and operations.

The plots were 33 m length and 4.0 m width, and there was a space of 10.0 m at their extremities for steering and speed stabilization.

The effects of the planting systems (conventional planting, no-till planting and minimum tillage) and hilling practice (absence and presence) were studied. The randomized block experimental design (RBD) and split-plot scheme was used; the planting system was in the blocks and the hilling practice was in the split-plots. Four replicates were used.

The data were tabulated using Excel and analyzed by using the statistical program SAEG (Systems of Statistical Analyses and Genetics).

For variance analysis (ANOVA), the normality and homogeneity of the average tests were firstly performed, so corroborating those assumptions necessary to the application of the specific tests. To decide about the occurrence of significant differences among the treatments, the F test was applied, by comparing the calculated F value with the tabulated F value obtained from the random F-variable distribution table, by taking into account the significance level of the test (5%) and the degrees of freedom for the treatments and deviations.

When the F test presented significant results for the treatments and/or interaction, the test of means was applied, by using the Newman Keuls' s test.

Table 5. Description of the treatments under study

Treatment	Description
PCSA	Conventional planting without hilling, and the potato planting machine was maintained under its original condition; the soil was prepared with two overpasses of the rotary tiller operating at 240 rotations per minute, with 4 blades in each flange, totalizing 24 blades at the axis. The impaction plate of the rotary tiller was lowered.
PCCA	Conventional planting with hilling, and the potato planting machine was maintained under its original condition; the soil was prepared with two overpasses of the rotary tiller operating at 240 rotations per minute, with 4 blades in each flange, totalizing 24 blades at the axis. The impaction plate of the rotary tiller was lowered.
PDSA	No-till planting without hilling, and accomplished by adapting the potato planting machine as prescribed at item 3.6 (adaptation 1), where the potato separators were provided with plowing rods. In this soil, the natural vegetation had been removed, but the soil itself had not been revolved by the soil preparation implements.
PDCA	No-till planting with hilling, that was accomplished by adapting the potato planting machine as prescribed at item 3.6 (adaptation 1), where the potato separators were provided with plowing rods. In this soil, the natural vegetation had been removed, but the soil itself had not been revolved by the soil preparation implements.
CMSA	Planting characterized as a minimum tillage without hilling, and accomplished by adapting the potato planting machine as prescribed at item 3.6 (adaptation 2), where the ensemble of the disk harrows at the machine front and the boot-type furrower for a deeper placement of the fertilizer. In this soil, the natural vegetation had been removed, and the soil itself had not been revolved by the common soil preparation implements, but by the disk harrows adapted at the potato planting machine front.
CMCA	Planting characterized by the minimum tillage without hilling, that was accomplished by adapting the potato planting machine as prescribed at item 3.6 (adaptation 2), where the ensemble of the disk harrows at the machine front and the boot-type furrower for a deeper placement of the fertilizer. In this soil, the natural vegetation had been removed, and the soil itself had not been revolved by the common soil preparation implements, but by the disk harrows adapted at the potato planting machine front.

2.1. Adapting the potato planting machine

The machines available in the market were projected and built in such a way to accomplish the work in a prepared terrain, which should be free from obstacles and excessive cropping leftovers and provided with an easily ruptured surface layer. Therefore, the planting machine was added with mechanisms that would allow for opening the furrow into the soil without revolving or with a minimum revolving.

At adaptation 1, the original conditions of the planting machine were maintained, by connecting a chisel rod at the basis of the furrower device for placement of the potatoes, and the work was performed in a non-revolved soil, according to the experiment carried out by Ekeberg and Riley (1996), as shown in Figure 1.

At the second adaptation, a device able to revolve the soil only at the planting row was adapted to the planting machine. Two indented-border 18” disks were set in front of each planting ensemble at a horizontal angle of 15°, making the planting machine a multitask implement, as shown in Figure 2.

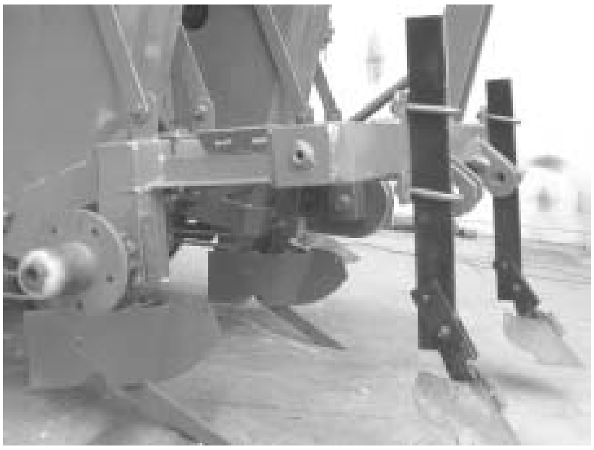

Figure 1. Side view of the mechanism adapted to the potato planting machine, showing the frontal furrower and the fertilizer separator with the plowing rod.

Figure 2. Side view of the mechanism adapted to the potato planting machine, showing the ensemble of disk harrows, boot-type furrower and fertilizer separator.

2.2. Evaluating the variables

2.2.1. Aggregate accumulated percentage (AAP)

This variable was obtained by Equation 1 that was determined with the results obtained from the screening of the soil samples. By comparing two or more samples, it indicates the ones containing higher quantities of aggregates with lower or higher diameter. The comparison between the higher values and lower ones indicates that those higher ones rather represent the samples with higher quantities of lower-diameter aggregates and vice-versa.

$$Pa = (P1) + (P1+P2) + \dots + (P1 + P2 + \dots + Pn) \quad (1)$$

where

Pa = accumulated aggregate percentages;

P1 = accumulated percentage in the sieve number 1 (<0.105 mm);

P2 = accumulated percentage in the sieve number 2 (from 0.105 to 0.25 mm);

P3 = accumulated percentage in the sieve number 3 (from 0.25 to 0.5 mm);

P4 = accumulated percentage in the sieve number 4 (from 0.5 to 1.0 mm);

P5 = accumulated percentage in the sieve number 5 (from 1.0 and 2.0 mm); and

Pn = accumulated percentage in the sieve number 6 (higher than 2.0 mm).

2.2.2. Percentage of soil aggregates retained by size class

The percentage of soil aggregates were determined according to Gamero and Benez (1990) proposal, by applying the equation.

$$P = \frac{W_i}{\sum W_i} 100 \qquad (2)$$

where

P = percent of aggregates retained by size class (%); and

W_i = aggregate mass retained in each size class (g).

2.2.3 Fineness module (FM) of the aggregates

It was determined according to Freire (1972), as:

$$FM = \frac{AP}{100} \qquad (3)$$

where

FM = fineness module of the aggregates; and

AP = accumulated percentage of the aggregates (%).

2.2.4. Average weighed diameter of the soil aggregates (AWD)

The methodology by EMBRAPA (1997) was used (wet basis), with samples collected at 0-100 mm depth, and each sample was composed by five simple samples collected at each plot. The samples were collected at two different times that is the first one soon after the preparation of the soil (before planting) and the second one after harvesting.

Five simple samples were removed from each subplot for the composition of one composed sample, which would be used for determination of AWD.

After being carefully conditioned, the samples were transported in plastic bags and air-dried until stabilization of the moisture content, then they were passed through a vertical screener, and the fractions with 4 to 2 mm were used for wet sieving.

The results obtained from the wet sieving were used for determination of the average weighed diameter (AWD), accumulated percentage in each size class (AP) and fineness module (FM).

AWD was determined according to VIEIRA (1992), as

$$AWD = \frac{\sum W_i D_i}{W} \qquad (4)$$

where

AWD = average weighed diameter (mm);

W_i = quantity retained in each size class (g);

D_i = sieve hole diameter corresponding to each W_i (mm); and

W = sample mass (g).

2.2.5. Soil and particle densities

The soil and soil particle densities were determined according to EMBRAPA (1997) at two different times: one determination was performed before seeding and after the preparation of the soil, and the other one after harvesting. The samples were collected, using a volumetric ring-type sampler with 50 mm height and 33.2 mm diameter, by taking two samples from each plot at 0-100 mm depth.

2.2.6. Microporosity and macroporosity of the soil

The non-deformed samples were collected at the planting rows, before hilling and after the collection with a volumetric ring-type sampler (50 x 33.2 mm) to determine the occurrence of modifications at 0-100 mm layer from the soil surface. These samples were left on a tension table for determination of the total porosity, microporosities and macroporosities. After determination of these variables, the samples were used to determine the both soil bulk density and soil particle densities, according to EMBRAPA (1997).

2.2.7. The tractor displacement speed

An electronic chronometer, a 30m measuring tape and land marks were used. The following equation was used to calculate the displacement speed:

$$V = (3,6)\left(\frac{e}{t}\right) \qquad (5)$$

where

V - displacement speed (km h^{-1});

e - traveled distance during the accomplishment of the work (m); and

t - time spent when travelling a determined distance (s).

2.2.8. Effective operational capacity of the implement-tractor ensemble

It was calculated, by using the following equation:

$$CO = (0,1)(V)(L) \qquad (6)$$

where

CO = effective operational capacity (ha h^{-1});

V = displacement speed of the tractor under activity (km h^{-1}); and

L = implement work width (m).

2.2.9. Fuel consumption in the soil preparation and planting operations

The fuel consumption was determined by a fuel flowmeter developed in the Agricultural Mechanization Laboratory at the Federal University of Viçosa, which consisted of a graded burette with a directional register. The burette provided the consumed volume in milliliters by unit of time, whereas the register directed the flow from the tank to the burette, then from the burette to the feeding system.

Each rotary tiller-prepared plot was subjected to a second overpass by the same implement in order to leave the soil as close as possible to the conditions left by the potato growers. At the second operation of the rotary tiller, the values (time, consumption) were also measured as performed at the first operation.

With the consumption values of each treatment it was possible to determine the variables as follows.

a) Fuel consumption per hour in the soil preparation and planting operations

The fuel consumption per hour was obtained by using Equation 7, and was used to determine the consumption in each area under study.

$$Cf = 3600\left(\frac{c}{t}\right) \tag{7}$$

where

Cf = fuel consumption per hour (ml h^{-1});

c = fuel consumption in each plot (ml); and

t = time spent in each plot (s).

b) Fuel consumption in each worked area

$$Ca = \frac{Cf}{CO} \tag{8}$$

where

Ca = fuel consumption in each worked area (ml ha^{-1});

Cf = fuel consumption per hour during the operation (mL h^{-1}); and

CO = effective operational capacity (ha h^{-1}).

2.2.10. Soil strength to penetration

The Hesler's penetrometer with an ASAE standard cone of 30°, a rod length of 700 mm, the base diameter of 200 mm^2, and the rod diameter of 10 mm was used. The registration of the data was made in an appropriate record file containing the strength to the penetration as a function of the soil depth.

Four determinations were accomplished in each plot, that is, two before setting up the potato crop and two ones after harvesting the vegetables.

The average soil strength to the penetration was calculated according to VIEIRA (1992), by taking the local strengths at 0, 50, 100, 150, and 200 mm depths. The soil strengths were summed and the obtained value was divided by the number of readings, so that the IC_{200} was obtained by the following equation:

$$IC_{200} = \frac{\sum R_{0\text{-}200}}{N_R} \tag{9}$$

where

IC_{200} = cone index from 0 to 200 mm.

$R_{0\text{-}200}$ = readings from 0-200 mm; and

N_R = reading numbers.

2.2.11. Soil moisture

Two samples were collected from each plot at the depths 0-100 and 100-200 mm, by using the volumetric ring.

The determinations were performed, by applying the standard gravimetric method based on the soil mass dried in oven at temperature from 105° to 110° C until obtaining a constant soil mass, according to EMBRAPA (1997).

2.2.12. Granulometric analysis of the soil aggregates

The soil aggregates were determined by both sedimentation and sieving methods, according to the Brazilian Norm ABNT NBR-7181 (1982).

2.2.13. Emergency speed rate of the potato plants (ESR)

The emergency speed rate of the potato plants (ESR) were evaluated, by applying the following equation:

$$ESR = \left[\frac{N_1}{D_1} + \frac{N_2}{D_2} + \dots + \frac{N_n}{D_n}\right] \tag{10}$$

where

ESR = emergency speed rate;

N_1 = number of plantlets emerged at the first count;

D_1 = number of days from the planting time to the first count;

N_2 = number of plantlets emerged between the first and second counts;

D_2 = number of days from the planting time to the second count;

N_n = number of plantlets emerged between the penultimate and last counts;

D_n = number of days from the planting time to the last counting day;

From the beginning of the stem emergency, the plants in two central rows of each plot were counted every 5 days until the emergency was completed

3. RESULTS AND DISCUSSION

3.1. Accumulated aggregate percentage, fineness module and average weighed diameter of the soil aggregates

The values corresponding to the soil aggregates are presented in Table 6 (after planting and before hilling). Independently from the planting system, the accumulated aggregate percentage (AP), fineness module (FM) and the average weighed diameter (AWD) of the soil aggregates after planting and before hilling did not statistically show significant differences at 5% probability level, by the F test.

A behavior similar to the previous one also occurred with these same variables when they were evaluated after harvesting (Table 7). The values did not show any statistical differences among each others by the F test at 5% probability. Therefore, the hilling had no influence upon the variables under study. A similar result was found by Boller (2000) for AWD.

Thus, it is possible to opt for any alternative planting systems that would provide fragmentation levels similar to the conventional systems, besides providing fuel economy and demanding less time for the accomplishment of the same tasks.

3.2. Density, microporosity and macroporosity of the soil

Table 8 shows the values for soil density (D), microporosity and macroporosity obtained from those samples collected after soil preparation and before planting at the depth of 0-100 mm. Independently from the planting system, these soil characteristics showed values that were statistically equal, therefore they were not affected by the planting system. The average values found for soil density (D), microporosity and macroporosity did not show any statistically significant differences at 5% probability level, by the F test for those samples collected after planting and before hilling.

Table 9 shows the values for density,microporosity and macroporosity of the soil, obtained from the

Table 6. Values of the accumulated percentage (AP), fineness module (FM) and average weighed diameter (AWD) of the soil aggregates evaluated after the potato planting and before hilling

Treatment[1]	AP	FM (mm)	AWD (mm)
CP	437.69	4.37	24.78
DP	480.70	4.80	31.56
MT	508.46	5.08	30.00

[1] CP- Conventional planting; DP – no-till planting; MT – minimum tillage.

Table 7. Values of the accumulated percentage (AP), fineness module (FM) and average weighed diameter (AWD) of the soil aggregates, determined after the harvest of the potato crop

Treatment[1]	AP	FM (mm)	AWD (mm)
PCSA	421.67	4.21	22.58
PDSA	420.37	4.20	22.68
CMSA	427.40	4.27	23.37
PCCA	418.55	4.18	22.00
PDCA	494.38	4.94	28.14
CMCA	432.65	4.32	23.81

[1] PCSA - Conventional planting without hilling; PDSA – no-till planting without hilling; CMSA - minimum tillage without hilling; PCCA – conventional planting with hilling; PDCA– no-till planting with hilling; and CMCA – minimum tillage with hilling.

Table 8. Values of the density (D), microporosity and macroporosity of the soil obtained from the soil samples collected at 0-100 mm depth after potato planting

Treatment[1]	D ($g.mm^{-3}$)	Microporosity (%)	Macroporosity (%)
CP	1.19	38.02	22.10
DP	1.26	39.90	14.12
MT	1.26	37.77	15.97

[1] CP - Conventional planting; DP - no-till planting; and MT - minimum tillage.

samples collected after the harvest of the potato crop.

The values found for density (D), microporosity and macroporosity of the soil (Table 9) showed no statistically significant differences at 5% probability level, by the F test for those samples collected after the harvest of the crop.

3.3. Effective operational capacity and fuel consumption

Table 10 shows the values for the effective operational capacity (CO) and fuel consumption at the first and second overpassings of the rotary tiller, respectively.

At the second overpassing of the rotary tiller, the value of the operational capacity was slightly higher, since there was an increment of 0.05 ha for each working hour. This possibly occurred because the first soil cutting and the clod crushing were performed at the first overpassing of the rotary tiller, so leaving the soil under better conditions to be worked by the second overpass.

In relation to fuel consumption, the average work value for the rotary tiller was 20.21 L ha^{-1} at the first overpass and 15.07 L ha^{-1} at the second overpass, so a decrease of 5.14 L ha^{-1} occurred when the rotary tiller performed the second overpassing in the same area, which is an expressive value if the price of the fuel is to be taken into account.

3.4. Fuel consumption

The fuel consumption was considered at three different situations:

1) by taking into account just the values for seeding;

2) by taking into account the values for seeding and one overpass with the rotary tiller; and

3) by taking into account the values for seeding and two overpasses with the rotary tiller.

The values corresponding to the fuel consumption under the above mentioned situations, as well as the respective statistical comparisons are shown in Table 11.

Values following by the same letter in columns do not statistically differ from each others, at 5% probability by the Newman Keuls's test.

When considering just the fuel consumption at the planting operation (C), it was observed that the conventional planting (CP) showed the lowest

Table 9. Average values of the density (D), microporosity and macroporosity of the soil obtained from the samples collected at 0-100 mm depth, after crop harvesting

Treatment[1]	D (g.mm^{-3})	Microporosity (%)	Macroporosity (%)
PCSA	0.92	36.45	23.37
PDSA	0.94	37.12	24.53
CMSA	0.98	35.82	22.37
PCCA	0.93	34.25	27.78
PDCA	1.00	33.17	25.58
CMCA	0.96	22.44	22,44

[1] PCSA - Conventional planting without hilling; PDSA – no-till planting without hilling; CMSA - minimum tillage without hilling; PCCA - conventional planting with hilling; PDCA – no-till planting with hilling; and CMCA – minimum tillage with hilling.

Table 10. Values found for the effective operational capacity at the first and second overpasses of the rotary tiller (CO1 and CO2) and fuel consumption in each hectare

First overpass		Second overpass	
CO1 (ha h^{-1})	Fuel consumption (L ha^{-1})	CO2 (ha h^{-1})	Fuel consumption (L ha^{-1})
0.19	20.21	0.24	15.06

values, so differing from the no-till planting and minimum tillage systems, possibly because planting was accomplished in a mobilized soil that offered a lower strength to rupture by the furrow opening tools.

Means followed by the same letter in column do not differ by Tukey test at 5% significance level.

By summing the fuel consumption for the planting operation and the fuel consumption for one and two overpasses of the rotary tillers, a significant increase was observed in both cases, which leads to the conclusion that under the viewpoint of fuel consumption either the planting without preparation and with the minimum preparing operations should be preferred.

3.5. Effective operational capacity (CO) and emergency speed rate of the plants (ESR)

In Table 12, one may observe that the minimum tillage (MT) showed the highest effective operational capacity for the planting operation (0.21 ha h^{-1}), as being statistically different from the values found for the conventional planting, (CP) and minimum tillage (MT). Such a difference was possibly due to the first action of the harrow disks that ruptured the superficial soil layer, therefore facilitating the work of the tools in opening the furrows for fertilization and planting, which also occurred with the lowest fuel consumption in the minimum tillage system.

The values of the effective operational capacity for the conventional planting (CP) and no-till planting (DP) showed no statistical differences among each others, but they statistically differed from the values found for the minimum tillage system (MT).

The conventional planting (CP) showed a higher emergency speed (**ESR**), as compared to the other planting systems. Such a fact was possibly due to the conditions of the soil surface, which in the case of the conventional planting was free from higher-diameter clods and other obstacles that might cause the delay in the emergency of the plants in the other planting systems.

According to SILVA (1992), the highest emergency speed is advantageous to the plants, since they stay less time inside the soil where they are more subjected to the attacks by soil plagues and diseases. However, no severe plague attacks or disease occurrences were observed in the treatments at the emergency phase.

Values following by the same letter in columns do not statistically differ from each others, at 5% probability by the Newman Keuls's test.

4. CONCLUSIONS

- The potato planting in a non-revolved soil allowed an economy up to 35 L ha^{-1} of diesel fuel and a time economy of 9 h ha^{-1}, by not considering the steering in the area.

Table 11. Fuel consumption for the planting operation, by not considering the operations with the rotary tiller (C), fuel consumption in the planting operation plus the fuel consumption in one overpass of the rotary tiller (C + 1) and the fuel consumption in planting operation plus two overpasses of the rotary tiller (C + 2)

Treatment[1]	C (L ha^{-1})	C + 1 (L ha^{-1})	C +2 (L ha^{-1})
CP	8.89 b	29.10 a	44.17 a
DP	9.50 a	9.50 b	9.50 b
MT	9.43 a	9.43 b	9.43 b

1- CP - Conventional planting; DP – no-till planting; and MT – minimum tillage.

Table 12. Effective operational capacity (OC) and emergence speed rate (ESR) found in different planting systems

Treatment[1]	OC (ha h^{-1})	ESR
CP	0.17 b	26.89 a
DP	0.16 b	21.65 a
MT	0.21 a	22.18 b

[1]- CP - Conventional planting; DP – no-till planting; and MT – minimum tillage.

- The following characteristics of the soil were not significantly affected by the treatments: accumulate d percentage (AP), Fineness module (FM), average weighed diameter (AWD), density (D), microporosity and macroporosity of the soil.
- The rotary tiller-prepared soil for the subsequent planting allowed the potato plants to emerge more quickly from the soil.
- The adaptation of themachine is not a difficult or onerous task, since its accomplishment is possible in any property provided with a small workshop.
- A potato planting without the conventional preparation of the soil is a viable alternative, since it is possible to save fuel, to reduce the time required for crop implantation, to preserve those soil characteristics that are inherent to its stability, and even to obtain a higher yield than that in the conventional planting.

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