INSTRUMENTED BLADES WITH AUTOMATED CONTROL USED IN CHISEL PLOUGH ACTING IN VARIABLE DEPTHS

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ABSTRACT

Soil compaction is a problem that affects most of the tilled areas of Brazil, being caused by several factors, such as overloading and intense machine traffic, use of unsuitable tires for applied load and inflation pressures outside the recommendation, machines in the field with the water content of the soil not recommended and several other problems. There are available several models and systems of measuring soil compaction in Brazil; however, the sensors of the equipment require processing and interpretation of data. The objective of this work was to design and evaluate a prototype to identify compacted layers of agricultural soils in real time and in varying depths. The equipment was designed to be mounted on the front of the tractor with the vertical movement, for introduction in the soil, controlled by the tractor's central hydraulic system. The calibration of the equipment had been carried out in the area of the NEMPA Tests – test Core of machinery and Agricultural Tires, using compaction detector device calibrator, a penetrometer, in which the index values of cone (CI) have been entered in the data collector for comparison with an average of correlation r = 0,90. After calibration of the equipment has been carried out the test response time between the data obtained by the front sensor and times of ascent and descent of the tine. Then the comparative test between the usual systems with fixed depth of 0.35 m with regular equipment of instrumented stems, with variable depth, measured the parameters of time, fuel consumption, operating force in traction bar, average power, average speed, skating, effective field capacity of tractor and equipment response time. The results showed that, with equipment commanding the operation of chisel plough is used with variable depth, obtained a reduction of 26% operational fuel consumption (L ha^{-1}) and there was an increase of 14% in effective field capacity (ha h^{-1}). The reactions of the proposed equipment to change depth of scarification coincided with the locations and values obtained from soil mechanical resistance indicated by penetrometer, showing good data accuracy. The instrumented system produced maps that showed the spatial variability of soil mechanical resistance, with resolution, sampling density and higher operational capability when compared to surveys conducted with the cone penetrometer, indicating that there had been overestimation of compression by the equipment condition.

Keywords: Precision agriculture, compaction, scarification

INTRODUCTION

The use of machines and agricultural equipment of larger mass has been searching the high efficiency operational and proportionate the use of heavy machines. Very often with overweight subjecting the soil to increasingly high tensions increases the problems of compaction. When the soil has compaction beyond tolerable limits for cultivation, decrease in agricultural productivity occurs due to several factors such as: physical impediment to penetration of the root system; Seed germination problems, low water infiltration, low aeration and others. The methods for evaluation of the compacted soil layer can be divided according to Lanças (1996) into three main groups: a) visual, subjective or coarse methods: erosion in furrows, cracks on the trails of the wheel sets, soil sealing, malformed roots, shallow and spreading root system, plants with smaller than standard sizes, slow seedling emergence and poor coloring, b) precise methods: this method involves laboratory analysis: density, percentage of macro pores, hydraulic conductivity, c) intermediate methods: evaluation of soil penetration resistance using penetrometers. The presence of soil compaction can mean serious problems for the development of root crops in general. One way to diagnose its presence is through the use of penetrometers or penetrógrafos requiring considerable time to obtain data, as reported by Adamchuk and Molin (2006). Decompression of soil operation, scarifie and sub-soilers are the implements used due to higher penetration capacity and lower soil disaggregation in relation to ploughs or disc harrows Araújo et al. (2001). Some alternatives in certain areas search for ways to improve the utilization of the potential of the soil, and consequently increased productivity. It would be through mapping of soil and crop, applications of inputs of varying manner and management of activities using tools related to precision agriculture. Girardello (2010) working with chisel plough of variable rate using maps of compacted layers concluded that in areas of low productivity, there was increased soybean productivity compared with fixed scarification. The cultivation with variable depths gives the potential to control soil compaction and conserve the energy required for cultivation according to Morgan and Ess (1997).

Adamchuk and Molin (2006) sought an alternative to the use of penetrometer through three instrumented blades, attached to a bar tool holder mounted on the three point hitch of the tractor with a GPS receiver and a system of data acquisition which generates maps soil resistance over the displacement of a blade in three depths. The system proved to be mechanically simple and reliable. The field tests demonstrated that the system could produce maps that denoted the spatial variability as referred resistance in the sampled areas, with high resolution, high sampling density and even higher operating capacity compared to surveys made with conventional methods. The penetrometers commercially available for the measurement of soil compaction are low operational capacity and have no direct means of intervention, and are unviable for large properties due to the large amount of samples or collecting necessary data.

The objective of this research was to develop and evaluate a prototype instrumented blades, being able to reading resistance of the soil in three different layers, in real-time, commanding the chisel plough to descompress the soil when needed, as well as collecting information for mapping layers for management purposes.

MATERIAL E MÉTODOS

The construction of the instrumented blades was held in partnership with Stara Company being responsible for the development of mechanical parts and electronic equipment. The basic design of which have been improved with the ideas of operation, consisted of reading data system of shear soil (blades with load cells), data acquisition system, global positioning system (GPS) and hydraulic control system (controller oil flow) by chisel plough (Figure 1). The computer programs used primarily for initial designs were AutoCAD and Solid Works for more advanced designs. The structure prototype of the instrumented blades was built on a steel chassis SAE 1020 of thickness 19.7 mm and assembled in a steel board by fixation SAE 1020 of 12.7 mm.

The blades (Figure 1) mounted in the block, have been developed in SAE 1045 steel with dimensions 100 x 700 mm and thickness 12.7 mm. The cutting edge had a 45 ° angle wedge-shape, and dimensions were based on experiments of Gill (1968). The blades were positioned in front of the other, in the longitudinal direction of the tractor, instrumented with load cells brand Flintec, M C3 model with capacity of 3 tons engaged in regulating screw of blade SAE 4140 steel, in which measurements of penetration resistance were obtained of 0.10 m by 0.10 m depicting to 0.30 m, with complete equipment the total weight of 200kg, height control was determined by a hydraulic actuator linear (Figure 2) by 400mm stroke with a load capacity of 3 tons, being responsible for the movement of ascent and descent equipment. Operation of the hydraulic system is done by the control lever of valve with a double-action of tractor, which is connected with hoses, coupled to the hookup system quickly on the back of the tractor. The chisel plough used was model Fox by the Stara brand ,with 5 blades with spacing between blades of 0.30 m, compound by 2 levelers rollers 1.4 m and cutting discs of straw, with a total weight of 2500 kg, equipped with depth control wheels, driven hydraulically through hoses connected to the hookup system quickly of tractor. The variable-depth system was composed by a sensor height position of the Elobau brand, 424A1712001 model, being use for this purpose, a data collector model Stara Topper brand that has functions to store and control the oil flow controller Hydac brand HBF model, with the function to down and up the chisel plough being configured to download 5 cm below the compacted layer.

Figure 1. Prototype of variable-depth control system composed of system reading of shear streagth of soil, GPS, data acquisition and chisel plough

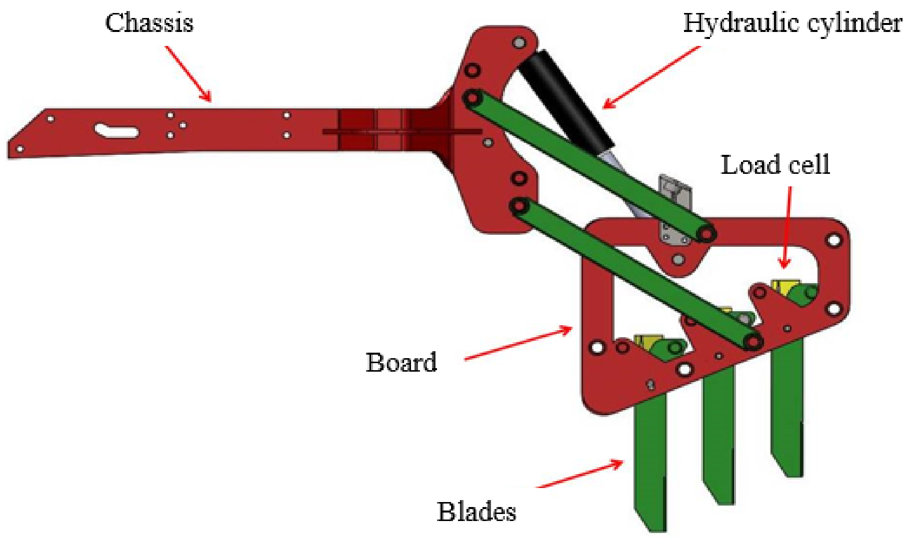

Figure 2. Instrumented blades and articulated chassis prototypo

The electronic system was made up of GPS brand Novatel, 701GG model with operating frequency of 5 Hz, band L1/CA with correction and DIF, data collector Stara brand, Topper model. The GPS data in files format NMEA (GGA) were added to the database of soil pressure by the blades and measured by load cells (MPa). Data was stored on the data collector containing information of altitude, latitude and longitude, depth and pressure of the blades in soil, being generated in files SHP DBF, SHX and PDF format and downloaded to a PC, via USB. Data were collected only for locations with more than 2 MPa pressure.

The assemble of automated system was performed on a John Deere tractor, model 6600, Auxiliary (4x2 TDA) front wheel, 6 cylinders, maximum power of 89 kW (121 hp) with 3924 N (400 kg), metallic weights on front axle and rear axle, weighing 3825 N (390 kg) mounted with tires 18.4-26 with inflation 26 psi and 23.1-30 with inflation 24 psi, respectively at the front and rear of tractor, all tires with 75% liquid weight. The load distribution of the tractor was 40% on front axle and 60% on the rear axle, with a total weight of 64696 N (6595 kg), and relative weight and power of 55 kg cv^{-1}. The flow in the hydraulic system was 66 L min^{-1} at 2400 rpm

Calibration of the instrumented blades

The experiment was conducted at the Experimental Farm from the Universidade Estadual Paulista "Julio de Mesquita Filho" (São Paulo State University), College of Agricultural Sciences/UNESP, Botucatu, state of São Paulo. The area is located geographically: 22 º 50 'South Latitude, 48 ° 25' west longitude and altitude of 791 m.

The experimental area was classified using the nomenclature of Brazilian System of Soil Classification Embrapa (1999) as Red Nitossolo Distroferric.

Table 1. Particle size analysis of the soil in the experimental area.

Depth (m)	Silt	Sand	Clay
		g kg^{-1}	
0.00-0.10	190	140	670
0.10-0.20	208	160	632
0.20-0.30	191	139	669

The experiment consisted of 4 treatments with completely randomized design with 6 repeats, totaling 24 plots. Each plot was leased-level and constitute an area of 50 m^2 (5 x 10 m) with 20 other initial and final meters reserved for stabilizing the load cell.

The area in which the experiment was conducted was totally subsoiled to 0.40 m with the aid of subsoilerJumbo brand, Jan Matic model and a tractor New Holland 7040 model, 132 kW of power with a total weight of 88290 N (9000 kgf) ,and the distribution mass 60% and 40% rear axle front axle, mounted on diagonal tires 18.4-26 and 24.5-32 with inflation pressure of 24 psi.

After subsoiled and to induce the compaction, the same tractor was used to generate soil compaction by passing the wheels of tractor (treatments P2 to P4), making the whole surface of parcel compacted. The number of times the tractor driving in the same path varied according to treatment. In the P1 treatment (Table 2), the soil compaction was performed through a passage of roller-compactor Silver Brand 1000 model, connected in 3 parts with 9810N weight each roll.

Table 2. Description of treatment

Treatment	Number of passes of the tractor	Speed (km.h^{-1})
P1	1 roller-compactor	6
P2	2	6
P3	4	6
P4	6	6

After obtaining a compaction of the soil in the treatments, samples were taken for determination of water content in the soil, a sample being made by plot in depths of 0 to 0.10; .10 To .20; 0.20 to 0.30 m. Then we measured penetration resistance using the penetrometer Falker brand, PLG 1020 model penetroLOG with a maximum depth of 0.60 m. The cone at the tip of the stem had the pattern described by "ASABE" (2009), with a 30 ° angle and tip pattern B with diameter 12.83 mm. In each plot, 5 samples were taken randomly in following of pass tractor. With the results of the average of each plot and treatment, the data were entered into the data collector in which were calibrated the 3 blades moving a distance of 20 m in contact with the soil in depth greater that 0.30 m before to start collecting data in the plot. The statistical data analysis was performed using the statistical program Sisvar, the graphs of soil mechanical resistance and cone index were obtained by regression equations to the analysis of variance by F test for linear function and polynomial, testing of hypotheses at a significance level of 5% and calculate the coefficient of determination (R^2).

Testing of the complete system in the field

The experiment consisted of 4 treatments in a completely randomized design blocks with 3 repeats, totaling 12 plots. Each plot leased level, was an area of 400 m^2 (5 x 80 m). The treatments are indicated in Table 3.

Table 3. Description of treatment

Treatment	Depth of scarification (m)	Speed (km h^{-1})
VD - Variable depth	Variable	1.62
FD - Fixed depth	0.35 m	1.62
H – Tractor + down instrumented blades + lift chisel plough	-	1.62
HS - Tractor + lift chisel plough	-	1.62

The area was previously subsoiled at 0.40 m, then the roller-compactor (described in subclause) to homogenization of area and induction of compaction. After the passage of the roller-compactor, measurements of penetration resistance were made, using a manual electronic penetrometer, 10 points were taken per plot being referenced by a GPS navagation, Garmin brand GPS map 62s model with a frequency of 0.5 Hz. The data were downloaded to the laptop and viewed through penetroLOG program. Then the data were interpolated by kriging method by SStoolbox program depths 0.10; 0.20 and 0.30 m. The data collected by instrumented blades were stored in a data logger in which was inserted into a USB Pen Drive for downloading data in DBF and PDF formats. The files had only coordinates of the points with values greater than 2 MPa.

RESULTS AND DISCUSSION

The instrumented blades mounted in front of the tractor were taken to the field for the calibration test, verifying the functionality of the system. The values related to water content in the soil in the area in which were performed the different treatments for calibration of instrumented blades (Table 4).

Table 4. Soil moisture (kg kg^{-1})

Depth	Treatment				Average (kg kg^{-1})
(m)	P1	P2	P3	P4	
0.00 – 0.10	20.19	19.33	20.60	21.60	20.43
0.10 – 0.20	21.20	21.10	22.10	22.40	21.70
0.20 – 0.30	23.22	22.80	23.40	22.60	23.00
Averege	21.53	21.07	22.03	22.20	

Analyzing the data of the rods relative to the penetrometer, obtained by regression, the R^2 values of 0.10 to 0.30 m m layer ranged from 0.72 to 0.79 and all significant by F test with a significance level of 5 % (Figure 3 to 6). The R^2 value was lower in the 0 to 0.10 m layer, which can be explained because the prototype has no pantograph system, and interference from imperfections in the soil results and other external factors (Figure 3). While the layer from 0.10 to 0.20 m was obtained the highest value of the coefficient of determination, to suffer less action variables of the machine and the ground (Figure 4).

The results showed good linear correlation on the average at all between the penetrometer and instrumented blades with r =0.90 (Figure 6).

Other researchers have obtained similar project near R^2 = 0.82 values obtained in testing the prototype (Figure 6) taking into account all the data found in the different layers of operation of the equipment. Siefken et al. (2005) designed and tested similar instrumented blades, in various types of soil and vegetation cover and obtained a value of R^2 = 0.76 and the lowest value in the layer from 0.20 to 0.30 m with R^2 = 0.61 and highest in the 0 to 0.10 m with R^2 = 0.80. Sanches et al. (2007) obtained the R^2 value = 0.95 between the CI and a system of transducers for reading the compaction of the soil profile.

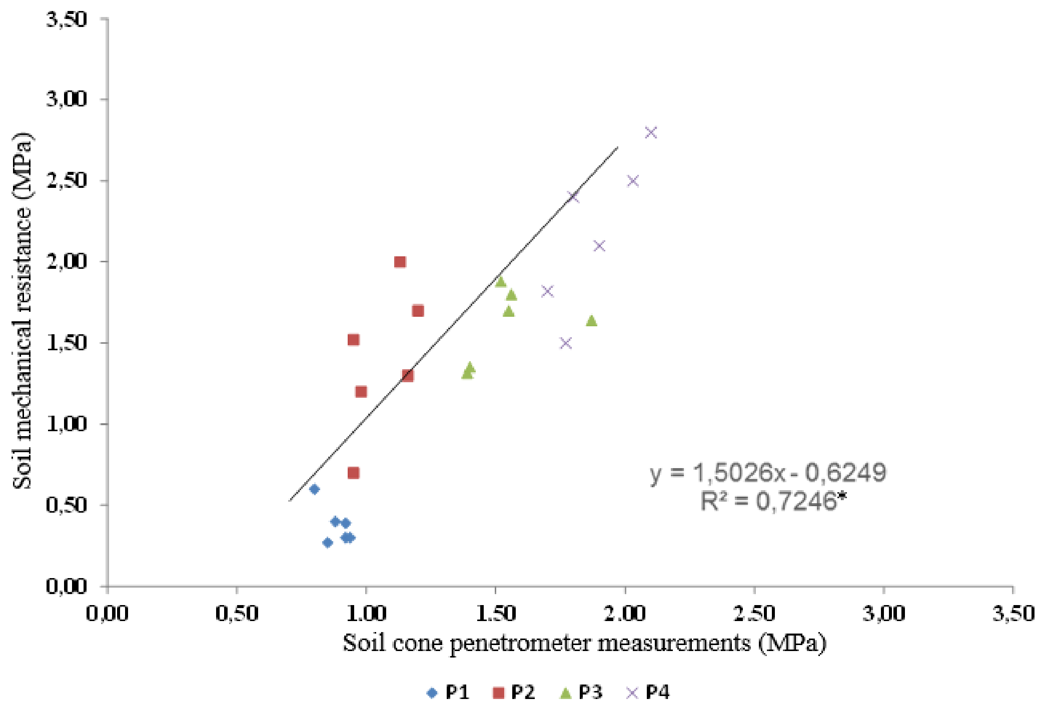

Figura 3. Soil mechanical resistance to cone index and depth 0.10-0.20 m
(*) Statistically significant value for the F test with a significance level of 5%

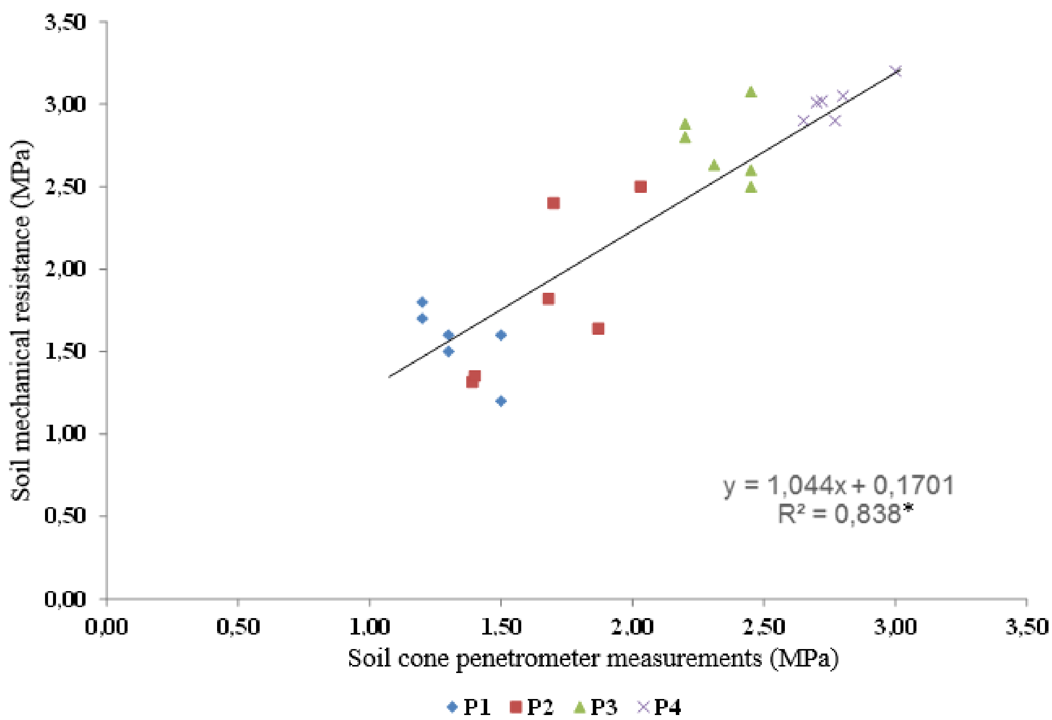

Figura 4. Soil mechanical resistance to cone index and depth 0.10-0.20m
(*) Statistically significant value for the F test with a significance level of 5%

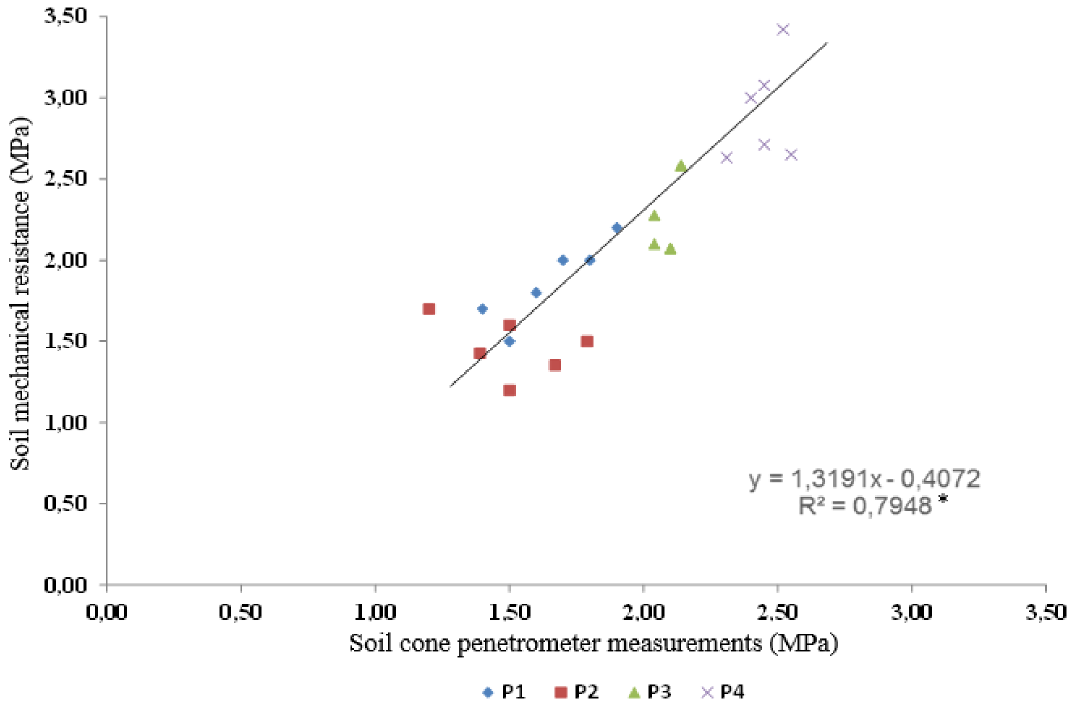

Figura 5. Soil mechanical resistance to cone index and depth 0.20-0.30m
(*) Statistically significant value for the F test with a significance level of 5%

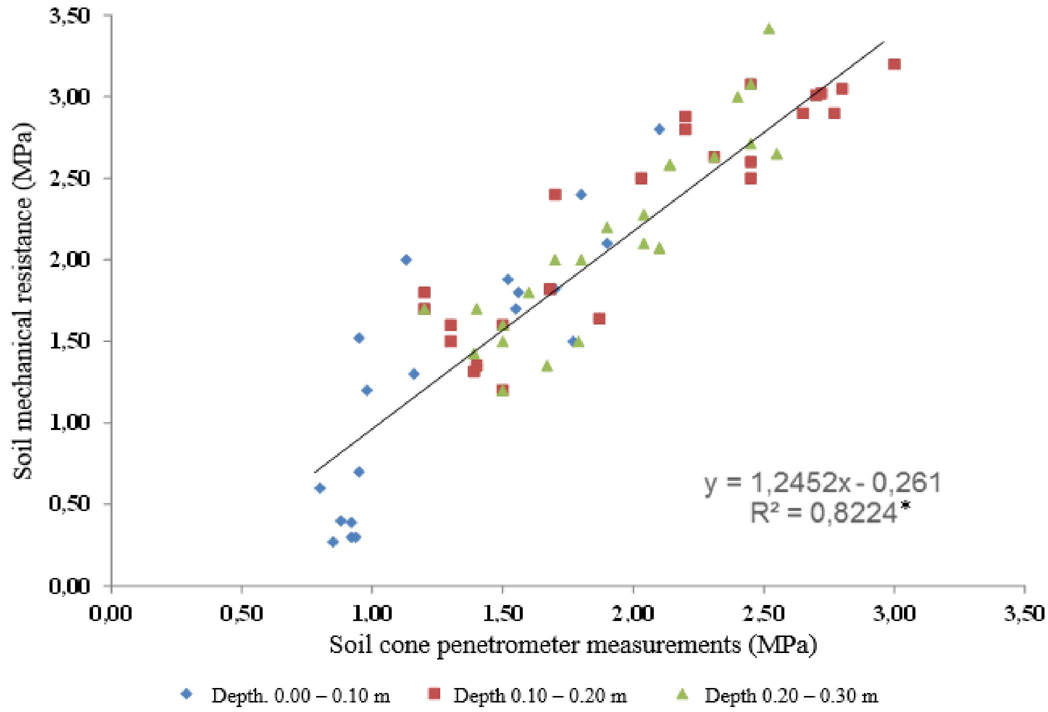

Figura 6. Soil resistance and cone index for depth of 0-0.10; 0.10 to 0.20 and 0.20-0.30 m
(*) Statistically significant value for the F test with a significance level of 5%

During the evaluation of the response times of the system, the times of descents were faster than the times lift in all tested depths (Table 5 and 6).

Table 5. Time of lift of chisel plough

Time of lift until transport position(s)		
Depth 0.15 m	Depth 0.25 m	Depth 0.35 m
3	5	8

Table 6. Time of down of chisel plough

Time of down of transport position (s)		
Depth 0.15 m	Depth 0.25 m	Depth 0.35 m
2	5	7

Test for evaluation of equipment in the field

Shows the mean values of the water content in the soil of the area listed on the day of testing.

Table 7. Water content in the soil (kg kg^{-1})

Depth (m)	Treatment				Average (kg kg^{-1})
	VD	FD	H	HS	
0.00 – 0.10	14.21	17.52	16.35	16.52	16.15
0.10 – 0.20	21.79	23.63	20.63	21.32	21.84
0.20 – 0.30	22.55	25.28	23.65	22.55	23.50
Average (%)	19.60	19.90	19.63	20.50	

It was found that the values of average speed and effective field capacity were 13.63% and 14.28% greater for the treatment (VD) in comparison with (FD). And therefore the slip has been reduced by 59.01% and fuel consumption operational 26.08% and significant amounts (Table 8). The data are similar to those obtained by Gorucu et al. (2001) who obtained 28.4% better fuel economy, testing the system variable subsoiling at a depth of 0.25 m to 0.45 compared me with fixed system with a depth of 0.45 m.

Table 8. Slip (S) in %, mean speed (V) in km h^{-1}, effective field capacity (EF) in ha h^{-1}, average force on the drawbar (FD) in N, average power drawbar (PD) in kW consumption (CH) in L h^{-1} , operating consumption (OC) in L ha^{-1}

Treat	S (%)	V (km h^{-1})	EF (ha h^{-1})	FD (N)	PD (kW)	C H (L h^{-1})	O C (L ha^{-1})
VD	2.66 b	1.50 a	0.32 ab	4137 b	1,75 b	5.18 b	16.04 b
FD	6.49 a	1.32 b	0.28 b	21660 a	8.25 a	6.26 a	21.70 a
H	2.13 b	1.50 a	0.32 ab	3116 b	1.33 b	4.85 bc	14.98 b
HS	1.69 b	1.57 a	0.33 a	2420 b	1.05 b	4.48 c	13.55 b

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

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Note that there was a decrease of 80.90% in FD and 78.78% in PD comparing treatment in DV compared to DF. Gorucu et al. (2001) obtained 42.8% energy savings between subsoiling with variable depth compared to fixed. Studying the energy performance of subsoiler, Kichler et al. (2007) observed that there was an increase in the consumption of fuel of 20% and increase in strength of 120%

when was increased the depth of 0.23 m to 0.35 m. Analyzing the results of (Table 8), it was observed that the difference between treatment H and HS treatment are not significant. So there is no statistical difference between the system and instrumented system without blades with chisel plow in the transport position, demonstrating that the project instrumented blades obtained good performance related to performance.

Descriptive statistics

The values collected by the data acquisition system are shown in Table 9. The highest CV was demonstrated in the layer 0 to 0.10 m and the lowest at 0.10 to 0.20 m layer (Table 7). The results are similar to those found by Adamchuk of Molin (2006) in which the layer 0 to 0.10 m showed higher CV compared with other layers. According to Pimentel (2000) in field experiments, the coefficient of variation is less than 10% are considered high precision from 10 to 20% are considered average accuracy of 20 to 30% accurate and above 30 % low accuracy.

Table 9. Descriptive statistics for values of mechanical strength (MPa) of the instrumented blades and values of the cone index (MPa) of the penetrometer.

Depth (m)	Minimum value	Maximum value	Average	Standard deviation	C.V (%)
		Instrumented blades			
0 a 10	0.20	4.00	2.35	1.25	53.34
10 a 20	0.90	2.60	1.86	0.50	26.68
20 a 30	0.80	2.10	1.83	0.46	25.00
		Penetrometer			
0 a 10	0.48	2.40	1.57	0.71	45.37
10 a 20	0.94	2.33	1.56	0.44	28.54
20 a 30	0.82	1.98	1.65	0.44	26.46

Maps

The map in Figure 7 shows the location where the system variable depth came into operation, together with the map of IC generated by data collected by the penetrometer in the area of all treatments. The maps shown in Figures 7 to 9 are referents to the IC in the depths of 0 to 0.10 m, 0.10 to 0.20 0.20 to 0.30 m . It is noted that the locations presented with values greater than 2 MPa in Figures 7 and 8 where the instrumented blades mapped areas of compression.

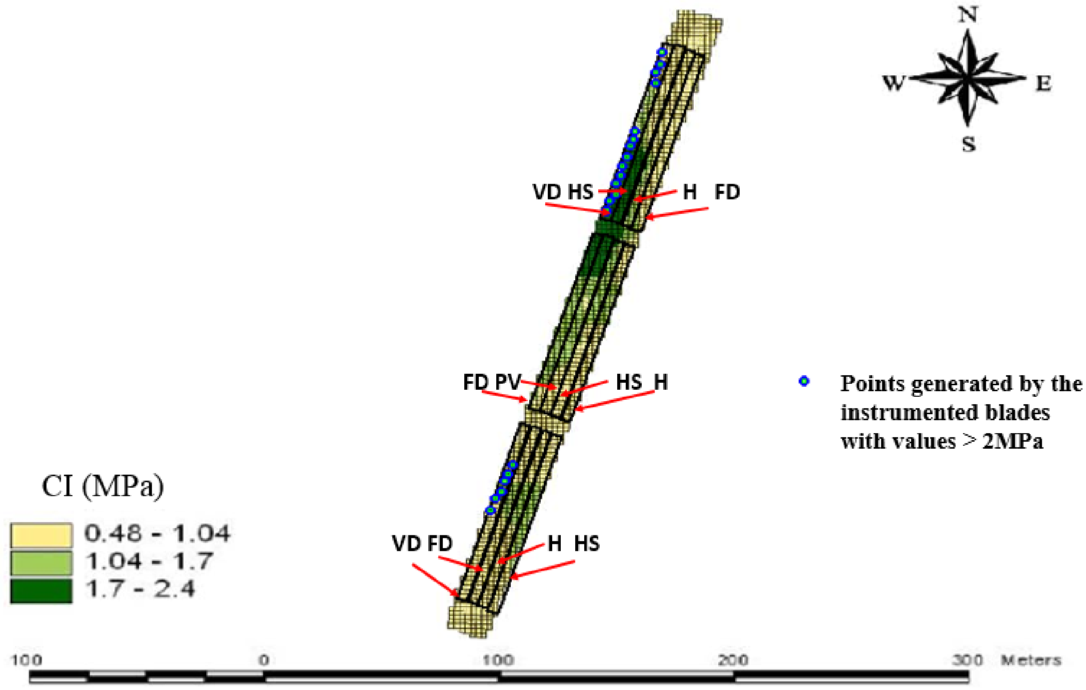

Figure 7. Map of the cone index with data of the penetrometer at depth 0 to 0.10m and points generated by instrumented blades only in locations with values greater than 2 MPa and treatments (plots)

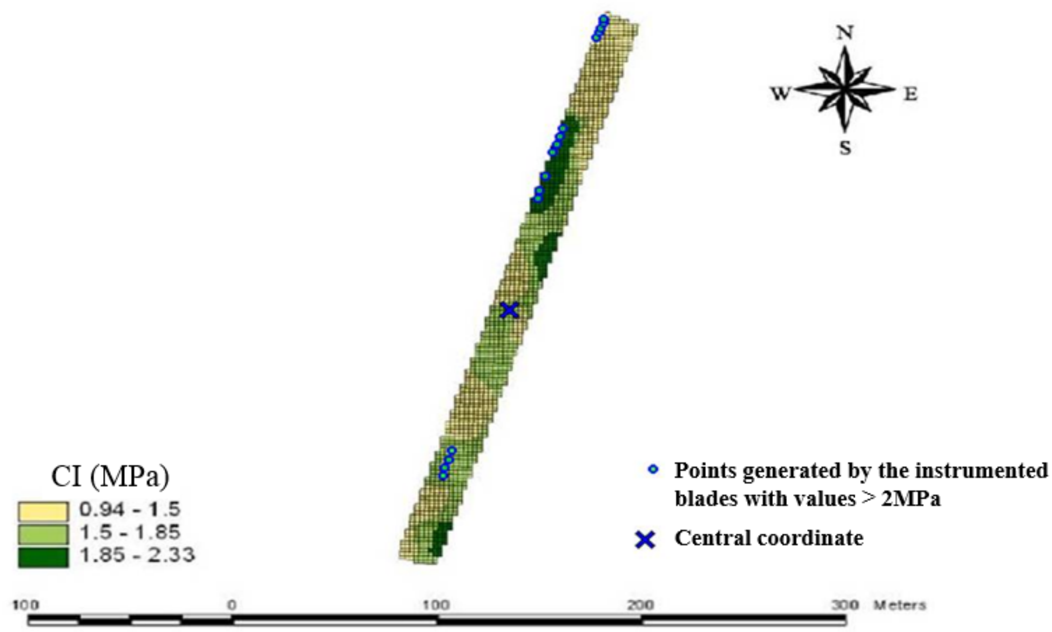

Figure 8. Map of the cone index with data of the penetrometer at depth 0,10 to 0,20 m and points generated by instrumented blades only in locations with values greater than 2 MPa

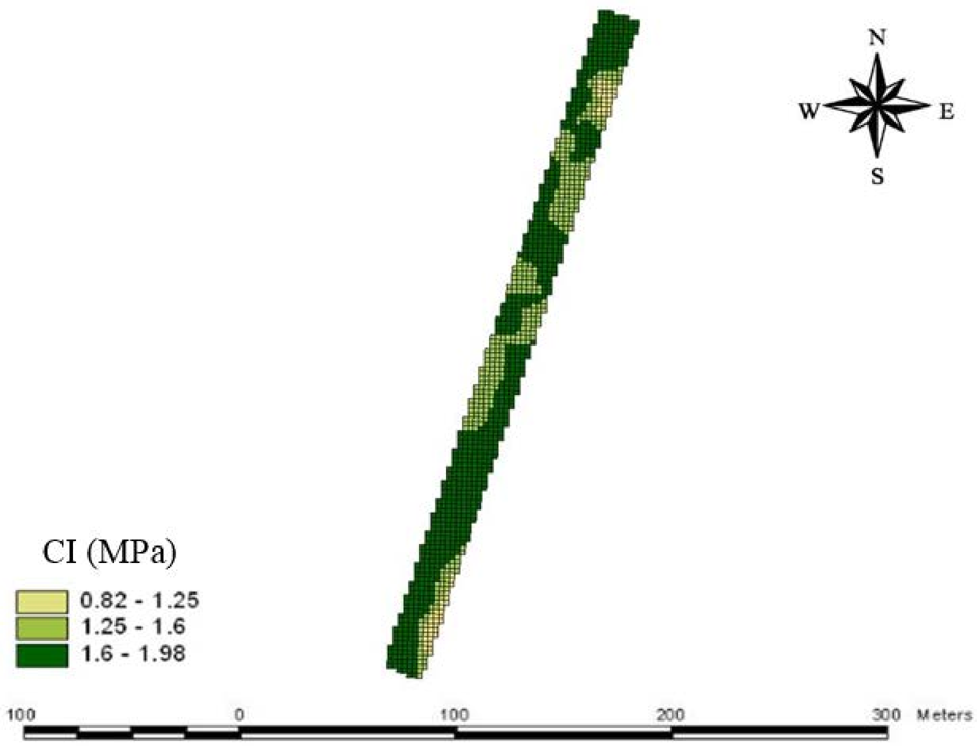

Figure 9. Cone índex at depth 0,20 to 0,30 m

In Figure 9, the automated system did not identify higher layers than 2 MPa, so the data collector did not record the path. The data collected by penetrometer not identified layers with values greater than 2 MPa.

Despite the positive results the automated system must be evaluated in regions with clayey and sandy soils under different soil water content to obtain more conclusive results of the equipment.

CONCLUSIONS

The prototype and other automated systems were functional, being able to measure the mechanical strength of the soil, store and generate maps of the paths in compacted places above 2 MPa.

The blades performed the readings of soil mechanical resistance, compared to the manual penetrometer obtaining an average correlation r = 0.90 considered good for a first prototype.

The chisel plough working variable depth, obtained a reduction of 26% in operational fuel consumption and 14% increase in effective field capacity compared to fixed depth.

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