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THE IMPACT ON SOME PHYSICO-MECHANICAL PROPERTIES OF SOIL PROCESSING USING THE VIBROCOMBINATOR IN FORESTRY NURSERY

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Abstract

The mechanization technologies of soil works have a major impact on physical state of soil. This situation is generated by the mechanical action of working parts which are involved in soil works and by the traffic of running systems of tractors and agricultural machines. In order to carry out the research, we settled in six forestry nursery of the West of Romania so that we could have six different types of soils which are representative for that specific area. From each profile was collected soil samples in three steps of 6, 12 and 18 cm. For each sample were performed six repetitions (N = 6). We started by measuring the particle size distribution (granulometric composition) and the main physical properties of the soil (moisture, bulk density, total porosity and soil compression degree). Advanced methods of statistical analysis (univariate three-way ANOVA and multivariate analysis, PCA, Manova and HCA) began to be successfully used in recent years for the study of soil behavior at the interaction with the working bodies. Vibro-cultivators are machines for seedbed preparation. They are equipped with tools sustained by elastic suspension. The elasticity of supports facilitates the oscillations of working tool - elastic support assembly. This set has a natural mode shapes which corresponds to a natural frequency of vibration. Seedbed preparation for crop establishment (sowing) is one of the most important works in forestry nursery, as is done with high energy consumption and high costs.

Key words: *vibro-combinator, soil tillage, bulk density, total porosity, compression degree.*

INTRODUCTION

Compaction causes a rearrangement of the soil particles and many properties of the soil are influenced as a result. Pore size distribution is altered, total porosity is decreased, and there are changes in the movement and content of heat, air, water and nutrients in the soil. The restricted growth of roots commonly observed in compacted soil has been variously attributed to all of these properties, and to the high mechanical resistance which compacted soil presents to plant roots (Shierlaw J. et al., 1984; Boja et al., 2013).

Soil compaction, as a consequence of frequent cultivation with heavy machinery, is one of the most important problems that modern mechanized agriculture is facing. Although the negative effects of heavy farm machinery on the physical characteristics of soil fertility, e.g. decreased aggregate stability, soil crusting, and formation of traffic pans and plough-pans, is well documented, much less is known about how soil compaction affects biological soil fertility (Neve et al., 2000).

These mechanization technologies have been tested to determine which of them correspond to the highest degree of sustainable agriculture concept and ensure protection, preservation and improvement of agricultural lands. The testing results of mechanization technologies for soil works variants which include a wide spectrum of conservative and unconventional works, performed with appropriate equipment, were compared both between them and also with witness variant which involved the classical

and conventional technologies for soil processing (Țenu et al., 2009).
The structure is a distinctive characteristic, appropriate to soil, being of great importance for physical, chemical and biological processes which are developed in soil and in the soil-plant-atmosphere system. Many authors consider the structure as a basic characteristic, on which depends the soil fertility (mainly water and air regime, thermal and nutrient regime) (Boja et al., 2018a; Boja et al., 2018b).
The degradation of the structure is determined by two groups of causes: changing the chemistry of the soil by decreasing soil humus content, and sometimes, especially as a result of unbalanced fertilization or irrigation with poor quality water by alkalization or acidification of soil; the direct destruction actions of structural elements, including soil dusting due to excessive work, or inadequate humidity, compaction due to exaggerated traffic especially when it is performed on wet ground, formation of crust under rain drops action or sprinkling-irrigations, etc. (Țenu et al., 2009).
The reduction of soil volume (a simple reduction in pore space) due to external factors is called soil compaction. Soil compaction is defined as increase in soil bulk density or decrease in soil volume and porosity (Figure. 1) due to mechanical stress on soil (e.g., from traffic of farm machinery). It can also occur due to natural reconsolidation of soil. There are two types of compaction, namely, surface compaction and subsoil compaction. The compaction that occurs in the surface “plow layer” is called surface compaction, while the compaction that occurs as a result of a surface load below the plow layer is called subsoil compaction.

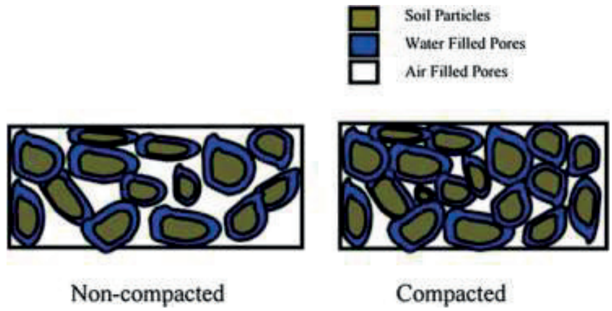

Figure 1. Effect of soil compaction on pore space (Neve et al., 2000; Boja et al., 2018b)

Nowadays, humanity is facing a major controversy over the choice of appropriate technology of soil tillage. It is the time that is required an intelligence choice between conventional technologies (classical) for seedbed preparation, assuming an intense mechanical processing of soil, which affects soil structure and soil organic matter, and the conservative tillage technologies for seedbed preparation, which removes these disadvantages in terms of an accepted decrease of the production (Benites et al., 2000).
At present, increase in the size of farm equipment used to carry out various farm operations increases the risk of soil compaction. The agricultural soil compaction can take place due to frequent movement of farm machinery. Factors responsible for compaction due to vehicular traffic include weak soil (soil density and moisture content effect) and excessive loads (size of vehicles, tire size, and number of passes are directly related to compaction). Soil tillage operations are also responsible for soil compaction (Pisante et al., 2010).
The advantages of using vibro-combinators are: required preparation of seedbed in difficult working conditions and preservation of moisture and total porosity and reducing of soil compression degree. Such important factors can ensure fast, uniform and early germination of seeds, these requirements standing at the basis of abundant harvests (Boja et al., 2018a).
The paper presents a study on the optimization of working regime of vibro-cultivators based on environmental impact assessment for use in seedbed processing. Study presents a method to determinate some phisical and mechanical

proprieties before and after soil tillage works of aggregates consisting of tractor and vibro-cultivators, in six parcels in the plains of the West of Romania.

Vibro-cultivators are machines for seedbed preparation. They are equipped with tools sustained by elastic suspension. The elasticity of supports facilitates the oscillations of working tool - elastic support assembly. This set has a natural mode shapes which corresponds to a natural frequency of vibratio (Cardei et al., 2015).

Modern agricultural operations now demand the utilization of a wide variety of equipment and specialist machinery systems, with many having rotary elements such as axles, gears, pulleys etc. With these agricultural machinery systems which have rotary elements, uncontrolled vibrations may become an important problem to consider. When the initial 'switch-on' frequency meets with the natural frequency of a machine element in the system, undesired noise, high levels of vibration and mechanical failures may occur during operation (Celik et al., 2010).

Generally, combinators consist of a vibro-cultivator A (cultivator for total processing of soil), composed of: frame 1, coupling device at the power source 2, wheels for limiting of working depth 3, soil loosening bodies 4, and a helix harrow B, which consists of frame 5, two rodrotors 6, and horizontality adjustment system 7 (Figure. 2).

Worldwide, more and more prestigious companies have incorporated into the range of products such vibro-combinators.

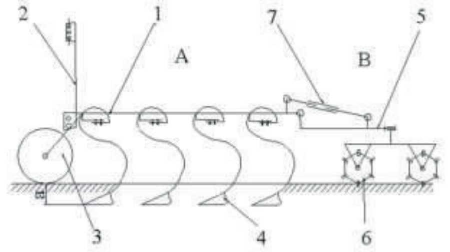

Figure 2. General scheme of a vibro-combinator (Căproiu et al., 1982; Biris et al., 2015; Boja et al., 2018b)

Deep tillage tools are one of the primary components of agricultural equipment which experience high level soil reaction forces during tillage operations. These forces may cause plastic deformation or failure which is undesirable for tillage machines/tools. The active tillage elements of agricultural machineries require extensive studies in order to obtain a proper soil fragmentation and displacement. (Petrescu et al., 2015; Boja et al., 2018a)

MATERIALS AND METHODS

In order to obtain a global image on the impact of the new vibro-combinator (the prototype SANDOKAN 2) (Table 1) in terms of the physical-mechanical properties of the soil, it was necessary to determine its properties before the passage of the equipment (in the state of the soil), and after its passage on all the six parcels and trials. These parcels will be suggestively named: soil 1 - soil 6; and the three types of active elements (Gamma, Delta1 and Delta2) (Figures 3 and 4).

Table 1 Main characteristics of the prototype vibro-combinator SANDOKAN 2

No. crt.	Characteristics	MU	Values
1	Mass	kg	5670
2	Length in transport	m	6.6
3	Height in transport	m	3.95
4	Width in transport	m	2.93
5	Width of the gamma active parts, reversible chipper type	mm	35
6	Width of the delta 1 active parts, arrow type	mm	150
7	Width of the delta 2 active parts, arrow type	mm	250

Figure 3. The prototype vibro-combinator SANDOKAN 2 equipped with the three types of active elements (GAMMA, DELTA 1, DELTA 2) (Boja et al., 2018a; Boja et al., 2018b)

Figure 4. Geometrical models for the three active elements (Petrescu et al., 2015)

The physical properties were determined by using the method of the cylinders with a constant volume of 100 cm^3, carrying out six repetitions at different depth, from 6, 12 and 18 cm. The methods of analysis and interpretation of the results as well as the work procedure for the determination of the physical – mechanical properties are those indicated in the specialized literature (Boja et al., 2012; Biris et al., 2015).

Statistical analysis. All data were subjected to univariate three-way analysis of variance (ANOVA, P = 0.05) and done with KyPlot (KyPlot Version 5.0.2, http://www.kyplot.software.informer.com) (Boja et al., 2018c; Boja et al., 2020). The ANOVA factors were: Soil (soil type), h (depth), Device (active element) and their six order interaction. The means pairwise comparisons were investigated by Tukey's post-hoc test (P = 0.05). Multivariate analysis: principal component analysis (PCA) was performed with P.A.S.T. version 3.04 statistical software, http://folk.uio.no/ohammer/past/) (Hammer et al., 2001; Boja et al., 2018c; Boja et al., 2020).

RESULTS AND DISCUSSIONS

When analysing the granulometric curves presented in Figure 5 and Table 2, one can notice the fact that there was a sandy-clay-dusty texture in soil 2, 4 and 3, 5 encompassed in the experiment at a participation quota that scarcely varies, with the exception of the 1st soil where the particle size distribution is different: clay-dusty-sandy texture.

Table 2. Average values of the granulometric analysis at different depths of prelevation

Type of soil	Depth of prelevation, (cm)	Values of the granulometric analysis		
		Sand, %	Dust, %	Clay, %
SOIL 1 (S1)	6	26.2	28.6	44.8
	12	26.8	28.7	44.3
	18	27.4	28.7	44.4
SOIL 2 (S2)	6	35.7	30.2	34.5
	12	35.1	30.2	34.8
	18	35.1	30.1	34.7
SOIL 3 (S3)	6	43.4	27.8	28.5
	12	43.2	28.1	28.7
	18	43.2	28.5	25.9
SOIL 4 (S4)	6	33.9	33.5	32.1
	12	33.1	33.1	34.5
	18	32.8	31.4	33.3
SOIL 5 (S5)	6	33.4	35.2	31.5
	12	32.9	34.8	32.8
	18	29.1	32.2	30.1
SOIL 6 (S6)	6	42.4	31.9	26.4
	12	42	31.1	26.2
	18	38.5	26.5	24.1

From the analysis of the values gathered for the participation quotas of the granulometric fractions, we could infer some interesting differentiations among the six types of soil in which we tried the vibro-combinator, as follows: All the six types of soil that we tried on the vibro-combinator are a relatively close mix, but in different proportions among the three granulometric fractions; The sand fraction (gravel + fine) is predominant in the soil 3 and soil 6 (43.2%); For the dust fraction (I + II), the differences among the three types range only for 2%, the highest value being registered on the soil 2 and soil 4 (30.1%); The participation quotas of the clay granulometric fraction are among the biggest, varying between 28.7% (soil 3) and 34.7% (soil 2), and reaching 44.5% for soil 1; The dust granulometric fraction is almost constant for all the six types of soil.

To synthesise more efficiently the data taken and to be able to describe completely the intrinsic characteristics of the sample, it was chosen a statistic processing with the aid of the program KyPlot. The results obtained are given in Table 3, having as a purpose to underline the variance of apparent density, soil moisture, total porosity and soil compression degree, and comparative with each types of soils and three active elements (Gama, Delta 1, Delta 2). Thus, for each types of soils included in the experiment resulted in eight statistical indicators for each technical work use a new vibro-combinator, but also witness sample. The mechanical processing of the soil through traditional and modern methods is currently put under question due to the high energy consumption and the continuous degradation of the arable horizon through erosion and excessive compaction.

It is known that the bulk density varies between 1 and 2 g/cm^3, according to the type soil and horizon, being generally lower in the case of the soils rich in humus and in the structured soils as compared to the unstructured soils. The values of the bulk density are in tight correlation with the degree of settlement of the soil. The high bulk density means a decrease of the capacity to retain water, of the permeability, of aeration and an increase of the mechanical resistance opposed by the soil during its sampling. On the contrary, low bulk densities can reduce the bearing of the soil, making difficult the mechanized execution of the works, even the driving of the operation machinery (Spoljar et al., 2009; Spoljar et al., 2011; Boyraz et al., 2014; Boja et al., 2016; Calistru et al., 2016; Vidrean et al., 2018).

By analyzing the values of total porosity, we can say that for the 1st type of soil we noticed an increase of the total porosity from 40.19%, which represents the initial state of the soil, to 44.36% (value obtained after the working of the soil with the vibro-combinator equipped with Gamma elements), 45.64% (with Delta 1 elements) and 45.71% (with Delta 2 elements).

The degree of settlement for the 1st type of soil presents values > 18%, which means that the soil is strongly settled for all levels of depth and after the passage with the three types of active elements of the cultivator.

The values gathered for the 2nd type of soil varies from weakly settled (1-10%) to moderately settled (11-18%). However, it is important to specify the fact that the lowest values of the degree of settlement appeared after preparing the germination bed with the aid of the active elements Delta 2.

In the case of the 3rd type of soil, we had negative values for this mechanical index of the soil at all depth, especially for the types of active elements, which means there is a soil moderately loose (-17…-10%) - fact that can be explained by the fact that this parcel has been annually worked.

Analyzing the influence of the active elements on the different types of soils, some conclusions can be made (Table 3 and Figures 5-10): in terms of apparent density values (Da), the lowest value is found on all soil types (S1-S6) when working with the active elements Delta 2; the total soil porosity has maximum values when the vibro-combinator is equipped with the Delta 2 active elements, logical situation due to the existing relation to density and porosity; soil moisture values reach peak values after processing with Delta 2 to S1 and S2, and in S3 the maximum value of soil moisture is reached after processing with Delta1; the soil compaction degree has a similar humidity variation, namely: minimum values for S1 and S2 using Delta 2 and in S3 following the use of Delta 1.

Analyzing the impact of active organisms on soil depth, some conclusions can be drawn

(Table 3 and Figures 5-10): apparent density (Da) records minimum values when using Delta 2 for all three depths (6 cm, 12 cm, 18 cm); total porosity has an inverse variation such as that of apparent density: the highest values are found for all three depths when working with Delta 2; and soil moisture values respect the same law that: for all three depths the maximum value occurs after processing with Delta 2; the soil compaction degree has a similar variation, that is, the smallest values are recorded at all depths when working with Delta 2; when working with Delta 2 active elements, all physico-mechanical soil indicators have optimal values regardless of working depth; the same legality is preserved (with few exceptions) and when analyzing the impacts of the active organ of the vibro-combinator on the soil types contained in the experimental field.

Table 3. Results for the soil physical and mechanical properties (values are expressed as mean ± standard deviation) for the interaction factor Device*h*Soil (CTRL, Gamma, Delta 1, Delta 2)

Device*h*Soil	Soil moisture (%)	Bulk Density (g/cm^3)	Total Porosity (%)	Soil compression (%)	Water retention (m^3/ha)
CTRL.06.S1	16.18j±0.09	1.50cde±0.02	42.18hij±0.63	19.23cdef±1.20	361.69ef±4.29
CTRL.12.S1	20.25r±0.09	1.56ab±0.01	40.19kl±0.40	23.16a±0.77	150.91k±1.61
CTRL.18.S1	22.25t±0.09	1.41bc±0.03	45.71jk±1.32	12.62bc±2.52	186.58m±6.33
CTRL.06.S2	22.36s±0.16	1.46ab±0.01	43.91kl±0.29	15.92defg±0.55	404.69h±5.18
CTRL.12.S2	29.86r±0.16	1.45def±0.06	44.36ghi±2.22	15.19ab±4.25	141.00lm±4.31
CTRL.18.S2	33.93mn±0.15	1.74a±0.01	33.27l±0.40	36.29cd±0.77	421.44f±3.84
CTRL.06.S3	20.93u±0.28	1.75cd±0.01	32.89ij±0.40	37.05defgh±0.77	698.62op±6.12
CTRL.12.S3	28.23l±0.28	1.41defgh±0.02	45.64efghi±0.63	12.74ab±1.20	86.92k±1.59
CTRL.18.S3	35.03mn±0.28	1.63cdef±0.19	37.31ghij±7.27	28.56cde ±13.92	343.31g ±40.44
Delta 1.06.S1	10.25f±0.19	1.31defgh±0.06	49.81efghi±2.16	1.61fghi±4.27	186.63hi±10.22
Delta 1.12.S1	20.05v±0.19	1.69fghi±0.17	34.87defg±6.51	33.24defgh±12.47	568.50q±57.85
Delta 1.18.S1	22.15g±0.19	1.44defg±0.02	44.71fghi±0.80	11.68efgh±1.59	192.88ij±2.54
Delta 1.06.S2	21.75e±0.19	1.48defg±0.02	43.17fghi±0.80	14.80fghi±1.59	529.47b±6.80
Delta 1.12.S2	28.75mno±0.19	1.52fghi±0.02	41.41defg±0.63	20.73defgh±1.20	607.34no±6.89
Delta 1.18.S2	31.25h±0.19	1.39defgh±0.01	46.54efghi±0.34	8.07fgh±0.68	179.45j±1.41
Delta 1.06.S3	21.03f±0.28	1.46defgh±0.03	44.04fghi±1.11	13.09ghi±2.19	548.55c±11.79
Delta 1.12.S3	28.43u±0.28	1.54defgh±0.03	40.83efghi±1.12	21.83efgh±2.16	717.94p±19.57
Delta 1.18.S3	35.33g±0.28	1.35efgh±0.03	48.17efgh±1.24	4.84fghi±2.46	175.88j±5.73
Delta 2.06.S1	22.03i±0.28	1.19kl±0.01	54.17ab±0.38	-9.11kl±0.76	149.62k±2.42
Delta 2.12.S1	23.13de±0.28	1.45defgh±0.04	44.42efghi±1.47	12.33ghi±2.90	498.59b±16.30
Delta 2.18.S1	25.93no±0.28	1.48hij±0.02	43.27cde±0.72	14.58hij±1.42	961.56nop±13.47
Delta 2.06.S2	23.83hi±0.28	1.18l±0.01	54.68a±0.40	-10.14l±0.80	144.60k±2.36
Delta 2.12.S2	29.43a±0.28	1.44defg±0.06	44.81fghi±2.16	11.58ghi±4.26	506.86a±24.65
Delta 2.18.S2	34.33k±0.28	1.46ijk±0.04	43.85bcd±1.36	13.44ij±2.68	821.35no±24.74
Delta 2.06.S3	20.83i±0.28	1.16l±0.01	55.42a±0.37	-11.62l±0.75	146.23kl±2.60
Delta 2.12.S3	28.03m±0.28	1.49efgh±0.02	42.79efgh±0.81	15.53ghi±1.59	908.47n±11.63
Delta 2.18.S3	34.73op±0.28	1.45ghi±0.06	44.42def±2.16	12.31jk±4.26	893.03nop±41.97
Gamma.06.S1	16.25pq±0.19	1.22l±0.02	53.05a±0.70	-7.77l±1.43	755.55p±13.88
Gamma.12.S1	17.55i±0.19	1.15kl±0.01	56.00ab±0.41	-12.79l±0.83	142.96kl±2.15
Gamma.18.S1	18.65cd±0.19	1.19kl±0.02	54.33a±0.65	-9.36l±1.31	405.10de±9.42
Gamma.06.S2	21.52q±0.15	1.21l±0.02	53.62a±0.70	-8.94l±1.43	766.76p±15.14
Gamma.12.S2	31.42bc±0.15	1.22jkl±0.02	53.08abc±0.60	-6.84l±1.20	413.25d±8.82
Gamma.18.S2	36.22bc±0.15	1.18kl±0.01	54.90ab±0.55	-10.52l±1.12	394.34de±8.03
Gamma.06.S3	20.93q±0.28	1.19l±0.02	54.20a±0.64	-10.11l±1.30	744.34p±12.74
Gamma.12.S3	28.23b±0.28	1.21kl±0.02	53.75ab±0.65	-8.20l±1.31	399.72d±8.70
Gamma.18.S3	35.03q±0.28	1.24l±0.02	52.37a±0.66	-6.40l±1.34	780.73op±14.00

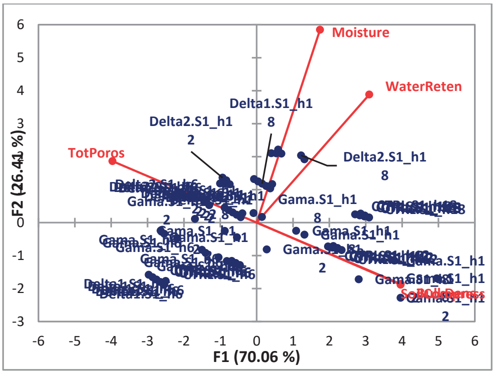

Figure 5. Interval plot for Soil 1 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

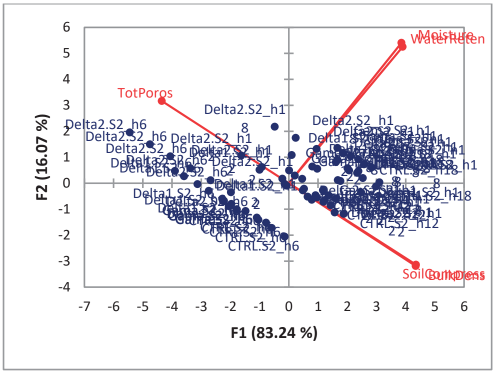

Figure 6. Interval plot for Soil 2 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

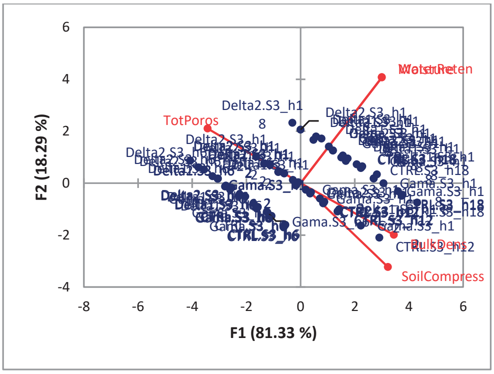

Figure 7. Interval plot for Soil 3 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

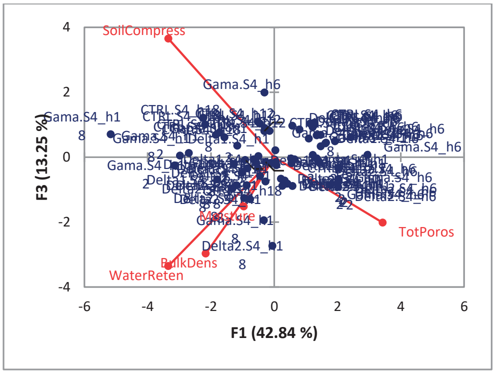

Figure 8. Interval plot for Soil 4 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

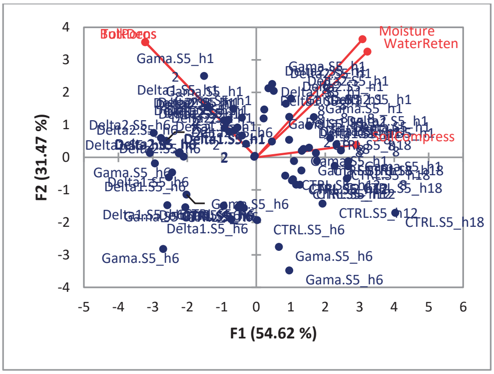

Figure 9. Interval plot for Soil 5 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

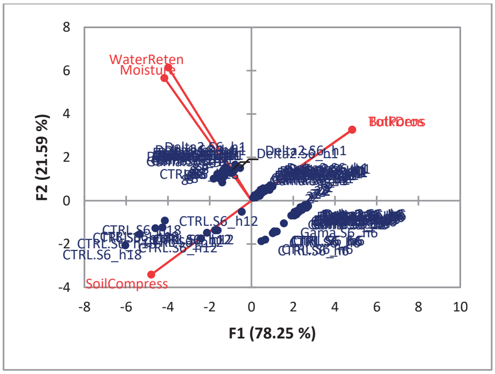

Figure 10. Interval plot for Soil 6 (from three-way ANOVA) for soil types (factor Soil), depth (factor h) and active elements (factor Device)

Multivariate analysis

To evaluate the vibro-combinators soil tillage performances were studied the variables: apparent density (g/cm^3), total porosity (%) and soil compression (%). To evaluate the soil environmental impact of the vibro-combinators were considered the variables: soil moisture (%) and water retention (m^3/ha). In order to assess simultaneously the vibro-combinators soil tillage performances and environmental impact, was involved the multivariate analysis: principal component analysis (PCA) and multivariate analysis of variance (MANOVA, P = 0.05). The PCA and MANOVA were done separately for each soil types S1 - S6. The PCA method involved as input data the variables correlation matrix and between sample groups algorithm. The MANOVA algorithm used as input data the first two principal components (PCs) coordinates of the group samples. The group samples were described by the interaction factor Device*h (i.e. active elements*depth).

For all soil types the first two PCs present eigenvalues greater than unity and a cumulative percentage of explained variance greater than 95.0%. Due to this reason these PCs are sufficient to describe the experiment with statistically significance.

The PCAs biplots gathers in the same graphical representation the samples scores and variable loadings (Figure 11). The sample groups are marked by points inside a convex hull and the variables are represented by vectors with the staring points in the coordinate system origin. The variable vectors end points shows the direction that describes the highest abundance (or levels) of the corresponding variables. This means that the group samples placed in the one vector direction (marked by its end point), have high abundance/level of that variable. When the sample groups are placed in the opposite direction, they have lowest abundance/levels for that variable. Analysing Figure 11, for the soil type S1, the PCA biplot prescribe (Tables 4-6).

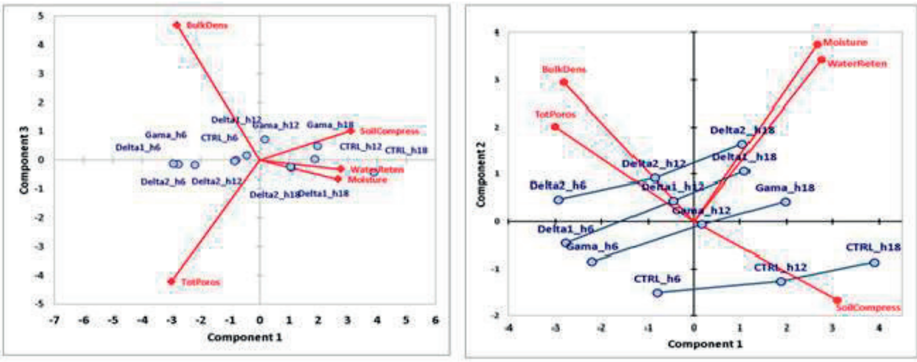

Figure 11. Principal component analysis (PCA) biplot for different depths (factor h) and for the three active elements (factor Device) for soil type S1-S6

Table 4. Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S1-S2

MANOVA	CTRL.6.S1	Delta1.6.S1	Delta2.6.S1	Gama.6.S1	CTRL.12.S1	Delta1.12.S1	Delta2.12.S1	Gama.12.S1	CTRL.18.S1	Delta1.18.S1	Delta2.18.S1	Gama.18.S1
CTRL.6.S1		0.000	0.000	2.239	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S1	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S1	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S1	2.239	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S1	0.000	0.000	0.000	0.000		3.940	0.001	0.002	0.000	0.000	0.000	0.000
Delta1.12.S1	0.000	0.000	0.000	0.000	3.940		0.001	0.003	0.000	0.000	0.000	0.000
Delta2.12.S1	0.000	0.000	0.000	0.000	0.001	0.001		0.000	0.000	0.000	0.000	0.000
Gama.12.S1	0.000	0.000	0.000	0.000	0.002	0.003	0.000		0.000	0.000	0.000	0.000
CTRL.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.241	0.000	0.000
Delta1.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.241		0.000	0.000
Delta2.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
Gama.18.S1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Table 5. Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S3-S4

MANOVA	CTRL.6.S2	Delta1.6.S2	Delta2.6.S2	Gama.6.S2	CTRL.12.S2	Delta1.12.S2	Delta2.12.S2	Gama.12.S2	CTRL.18.S2	Delta1.18.S2	Delta2.18.S2	Gama.18.S2
CTRL.6.S2		0.793	0.001	0.352	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S2	0.793		0.001	2.592	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S2	0.001	0.001		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S2	0.352	2.592	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S2	0.000	0.000	0.000	0.000		0.069	13.997	0.004	0.000	0.000	0.000	0.000
Delta1.12.S2	0.000	0.000	0.000	0.000	0.069		0.327	0.000	0.000	0.000	0.000	0.000
Delta2.12.S2	0.000	0.000	0.000	0.000	13.997	0.327		0.002	0.000	0.000	0.000	0.000
Gama.12.S2	0.000	0.000	0.000	0.000	0.004	0.000	0.002		0.000	0.000	0.000	0.000
CTRL.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.938	0.000
Delta1.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000
Delta2.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.938	0.000		0.002
Gama.18.S2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	

Table 6. Statistical significance values of multivariate analysis of variance (MANOVA, P = 0.05) for the soil type S5-S6

MANOVA	CTRL.6.S3	Delta1.6.S3	Delta2.6.S3	Gama.6.S3	CTRL.12.S3	Delta1.12.S3	Delta2.12.S3	Gama.12.S3	CTRL.18.S3	Delta1.18.S3	Delta2.18.S3	Gama.18.S3
CTRL.6.S3		0.957	0.210	42.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta1.6.S3	0.957		21.324	3.674	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delta2.6.S3	0.210	21.324		0.564	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gama.6.S3	42.092	3.674	0.564		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CTRL.12.S3	0.000	0.000	0.000	0.000		1.358	1.110	2.199	0.000	0.000	0.000	0.000
Delta1.12.S3	0.000	0.000	0.000	0.000	1.358		36.244	3.884	0.000	0.000	0.000	0.000
Delta2.12.S3	0.000	0.000	0.000	0.000	1.110	36.244		2.363	0.000	0.000	0.000	0.000
Gama.12.S3	0.000	0.000	0.000	0.000	2.199	3.884	2.363		0.000	0.000	0.000	0.000
CTRL.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		2.540	1.089	0.278
Delta1.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.540		4.215	0.228
Delta2.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.089	4.215		1.277
Gama.18.S3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.278	0.228	1.277	

CONCLUSIONS

The advantages of using vibro-combinators are: perfect preparation of seedbed in difficult working conditions and preservation of soil moisture. Such important factors can ensure fast, uniform and early germination of seeds, these requirements standing at the basis of abundant harvests. The research investigated the soil tillage performances and the environmental impact of several active elements of the vibro-combinators, at certain soil depths and soil types.

The multivariate analysis allowed to assess for each soil type which active elements performs both best soil tillage and environmental protection of the soils. From the technical point of view, the 6 cm depth is the most important to soil tillage for crop production. For this depth the active elements of the vibro-combinator: Delta 2 and Delta 1 are those that performs both best soil tillage and environmental protection of the studied soils.

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