

**DYNAMICS OF SEEDLING PLANTING MACHINE EQUIPPED WITH  
VERTICAL DISTRIBUTOR AND ARTICULATED BUCKETS PLANTING UNIT**  
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**DINAMICA MAȘINII DE PLANTAT RĂSADURI ECHIPATĂ CU APARAT DE  
PLANTAT CU DISTRIBUTOR VERTICAL ȘI CUPE ARTICULATE**

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DOI: <https://doi.org/10.35633/inmateh-63-31>

**Keywords:** *dynamic, bucket planting, efficiency*

**ABSTRACT**

*In this work we make a comparative analysis of the dynamics for two variants of seedling planting machines equipped with distributors and articulated buckets respectively: with the seedlings being placed in the furrow opened by a coulter; with the seedling being planted directly into the ground. The dynamics of the seedling planting machine equipped with vertical distributors and articulated buckets is seen from the perspective of the working process involving the placement of the seedling in the ground, its release, its covering with earth and its additional compaction. In principle, furrow opening is performed by a coulter and the vertical distributor with articulated buckets places and releases the seedling in the furrow, in the first variant, and in the second one, the seedling is inserted and released directly into the ground. In the paper are written the mathematical relations describing the dynamics of the seedling planting machine, in the two variants, and we perform their testing, make recordings, interpret the results, reach conclusions and make recommendations on the optimum variant. The agro-technical parameters and tensile strength of the planting machine are analysed in the two functional variants. The experiments were performed under the same working conditions for both variants analysed.*

**REZUMAT**

*În lucrarea de față s-a efectuat o analiză comparativă a dinamicii pentru două variante de mașini de plantat răsaduri echipate cu distribuitoare și cupe articulate respectiv: cu plasarea răsadului în rigola deschisă de un brăzdar; cu plasarea răsadului direct în sol. Dinamica mașinii de planta răsaduri echipată cu distribuitoare verticale și cupe articulate, este privită din perspectiva procesului de lucru care presupune plasarea răsadului în sol, eliberarea acestuia, acoperirea cu pământ și tasarea suplimentară a acestuia. În principiu, deschiderea rigolei este realizat a de către un brăzdar iar distribuitorul vertical cu cupe articulate plasează și eliberează răsadul în rigolă, în prima variantă, iar în varianta a doua, răsadul este introdus și eliberat direct în sol. În lucrare s-au scris relațiile matematice ce descriu dinamica mașinii de plantat răsaduri, în cele două variante, testarea acestora, efectuarea înregistrărilor, interpretarea rezultatelor, concluzii și recomandări privind varianta optimă. S-au analizat parametrii agrotehnici și rezistența la tracțiune realizați de mașina de plantat răsaduri în cele două variante funcționale. Experimentările s-au efectuat în aceleași condiții de lucru pentru ambele variante analizate.*

**INTRODUCTION**

The advantages of seedling planting technology produced in nutrient pots led to its adoption by more and more vegetable growers, sufficient motivation for manufacturers of technical equipment for planting seedlings to develop and make such types of equipment in more varied dimensions and technical solutions.

On the basis of studies carried out by various authors (Mitrache et al., 2020; Ciuperca et al., 2012, Poenaru, 2014; Voicu, 2014), which analysed most of the types of equipment for planting seedlings produced, in which the technical solutions, advantages and disadvantages of each were presented, it was concluded that planting equipment equipped with disk planter and articulated buckets, is the simplest from a constructive point of view and achieves the working parameters, specific to the seedling planting work, in accordance with the agro-technical requirements.

This type of equipment has been made by many companies, more or less famous, which have adopted solutions from the simplest and with low working capacity, intended for small producers, to medium and large capacity types, semi-automatic and culminating with high capacity machines, whose working process is automated and electronic.

In an interesting study (*Ciuperca et al., 2012; Muraru-Ionel, 2009*) two of the most used types of vegetable seedling planting machines were compared, respectively: with section equipped with rotary bucket distributor and with section equipped with feeding chain with clamps and flexible discs for planting. The study unequivocally concluded the advantages of articulated bucket equipment.

A planting machine equipped with a relatively cheap planting device with discs and articulated buckets, designed especially for small areas, which is now on the market, is the Checchi & Magli planting machine - Wolf model ([www.checchiemagli.com/en/transplanting-machines](http://www.checchiemagli.com/en/transplanting-machines)). This machine model can be equipped with one or two planting sections. There is also the Wolf Compact model in which the number of planting sections can be increased to 6, and the distance between rows can be reduced to 30 cm.

As there are several planting machine manufacturers on the market, there is also a wide variety of planting machines that operate based on the planting system, with articulated bucket distributor, to which small aesthetic or functional changes have been made (<https://www.duijndam-machines.com/en/machines/2318/hortech-over-1-row-planting-machine/#>; <https://autoline.ro/-4-rijige-plantmachine-Duijndam-Machines--17090611134281090900>).

A semi-automatic planting machine, for planting in two rows, equipped with disc and articulated buckets was made at the National Institute of Research Development for Machines and Installations Designed to Agriculture and Food Industry - INMA Bucharest and tested with very good results in Romania, thus demonstrating the viability of these types of equipment.

Many authors have done research over time to continuously improve the working process of seedling planting equipment, both in terms of kinematics and dynamics, as well as working capacity or process control.

An automatic machine for planting potted tomato seedlings was designed (*Xin et al., 2018*); this machine is composed of a horizontal and vertical seedling supply mechanism, a planting part featured with an eccentric disk, parallelogram and a control system. The control system included position sensors, stepper motor, variable-frequency motor and program controller. The result demonstrated that the machine was feasible to transplant the potted tomato seedlings efficiently.

Research has also been carried out to solve functional synchronization problems when the seedling stem describes a circular arc in the area where it falls into the furrow. This is done by a special rotating mechanism (*Nakanishi et al., 2007*).

Given the high intensity of current work on planting seedlings with low efficiency, a machine was designed based on a motion controller. Tests have shown that it can perform the planting process automatically and can improve efficiency and reduce the cost of the process (*Zhao and Liu, 2015*).

Besides the realization of the agro - technical working parameters, specific to the planting operation of the vegetable seedlings, of great importance are also the qualitative working indices (*Popescu V., and Popescu A., 2006; SR 13215:1994*).

## MATERIALS AND METHODS

To identify and quantify the energy indices, it is necessary to know the dynamics of this equipment in order to adopt the optimal constructive and functional solutions.

From this perspective, in order to approach in terms of work dynamics, a planting machine with two-row planting, was used, equipped with a vertical distributor and articulated buckets, made at INMA Bucharest in 2018, in two working variants, namely:

- with a planting device which places the seedling in a furrow made by a coulter, followed by the covering of the nutritious bale with earth, by two paddles and the additional fixing by means of two compaction wheels, called **Variant I**;
- with a planting machine which places the seedling directly in the ground followed by an additional fixing of it by means of two compaction wheels, called **Variant II**.

**Planter with vertical distributor with buckets, Variant I, fig. 1** - consists mainly of an assembled frame (1) in the shape of a deformable parallelogram, a rotary distributor with buckets (2) and a coulter for furrow opening (3).

The working depth is adjusted by means of a screw mechanism (4) which ensures the adjustment of the position of the ground copying wheel (6), mounted articulated on the frame of the section, with respect to the bottom of the coulter. Keeping the working depth constant is achieved by means of a tension spring (5) mounted on the deformable parallelogram.

The opening of the buckets, in order to place the seedling in the furrow, is made by means of a mechanism with adjustable cam. The transmission is a kinematic mechanism consisting of two chain transmissions that ensure the transmission of movement from the drive wheel axle to the axle of the rotary distributor with buckets.

The dynamics of the planting machine is seen from the perspective of the work process which involves the performance of two main operations, namely the opening of the furrow by the coulter and the effective planting of the seedling by the bucket planter, acted by the drive wheel. These two operations generate the tensile strength of the planting machine.

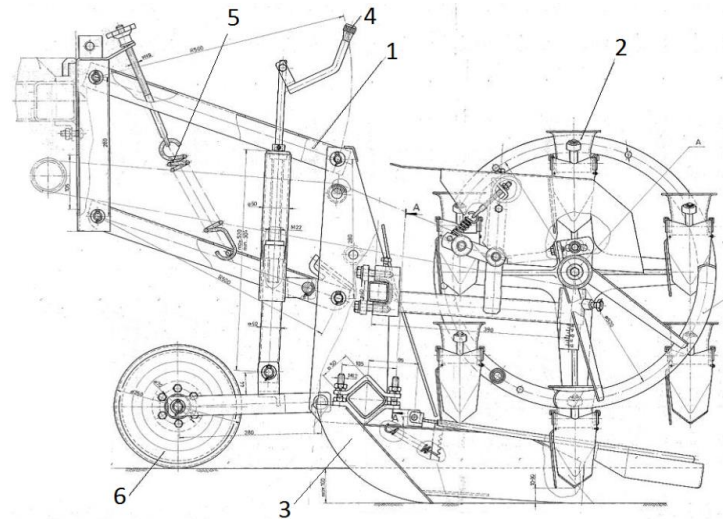


Fig. 1 - Planter with vertical distributor and articulated buckets equipped with coulter - Variant I

#### a) Dynamics of furrow opening

The opening of the furrow, by the coulter, involves cutting the soil vertically at a set depth and width, deforming and moving the soil cut horizontally in order to make the furrow.

Along with the deformation of the soil, a slight upward movement is made, at a volume equal to the difference between the volume of the furrow and the deformed soil.

The tensile strength  $R_{tr}$  at the opening of the furrow is determined by the relation (1):

$$R_{tr} = R_r + R_{td} + R_f \quad (1)$$

where:

$R_r$  - resistance to the own movement of the machine at work [daN];

$R_t$  - resistance to cutting and soil deformation [daN];

$R_f$  - resistance caused by the friction between coulter and the soil [daN].

Replacing in relation (1) the terms with their expressions, relations (2) result:

$$\begin{aligned} R_r &= f \cdot G_b \\ R_{td} &= k_0 \cdot a \cdot b \\ R_f &= \mu \cdot G_b \end{aligned} \quad (2)$$

where:

$f$  - rolling resistance coefficient;

$G_{mb}$  - the weight of the planting machine, less weight taken over by the coulter [daN];

$k_0$  - specific resistance of the soil to cutting and deformation [daN/cm<sup>2</sup>];

$a$  - working depth of the coulter [cm];

$b$  - working width of the coulter [cm];

$\mu$  - the coefficient of friction between the coulter and the soil;

$G_b$  - weight taken by the coulter [daN].

The relation (1) becomes (3):

$$R_{tr} = f \cdot G_b + k_0 \cdot a \cdot b + \mu \cdot G_b \quad (3)$$

In the working process of the planting equipment, the parts, in the form of paddles, for covering the nutrient bale with soil, which offer an additional resistance to the movement of the equipment,  $R_{ac}$ , according to the relation (4), also intervene.

$$R_{ac} = k_{ac} \cdot a_a \cdot b_a \quad (4)$$

in which:

$R_{ac}$  - the result of elementary resistance to covering the nutrient bale with soil [daN];

$k_{ac}$  - specific resistance of the soil to the lateral displacement of the paddles left-right [daN/cm<sup>2</sup>];

$a$  - working depth of the paddle [cm];

$b$  - working width of the paddle [cm].

### b. Planter drive wheel dynamics

The moment of rolling resistance acts on all the drive, the torque transmitted to the active parts, respectively the bucket disc, this moment being transmitted by means of two chain transmissions, fig. 2.

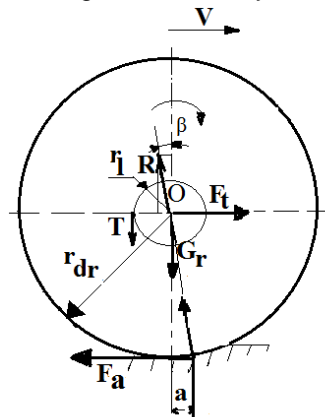


Fig. 2 - Drive wheel dynamics

The moment of friction in the wheel bearings has a negligible value and the moment of inertia of the wheel is zero, considering the movement with constant speed.

Under these conditions, the equilibrium equations are according to the relations (5):

$$\begin{aligned} F_t - R \cdot \sin \beta - F_a &= 0 \\ G_r - R \cdot \cos \beta &= 0 \\ F_a \cdot r_{dr} - R \cdot \cos \beta \cdot r_{dr} - T \cdot r_l &= 0 \end{aligned} \quad (5)$$

where:

$F_t$  tangential traction force at the drive wheel [daN];

$R$  - the result of the soil reactions in the contact surface [daN];

$F_a$  - the adhesion force of the drive wheel on the soil [daN];

$T$  - tangential force developed in the transmission chain [daN];

$r_{dr}$  - dynamic radius of the drive wheel [m];

$r_l$  - splitting radius of the chain wheel [m].

The adhesion force of the drive wheel and the rolling resistance force are considered as shown in relation (6).

$$F_a = f_a \cdot G_r$$

$$F_f = R \cdot \sin \beta = \frac{a}{r_{dr}} \cdot G_r = f \cdot G_r \quad (6)$$

where:

$f_a$  - adhesion coefficient;

$f$  - rolling resistance coefficient;

$G_r$  - the weight of the machine taken over by the drive wheel [daN].

By replacing in the relation (6) the forces  $F_a$  and  $F_f$  with their expressions, the relations (7) result.

$$\begin{aligned} F_t - f \cdot G_r - f_a \cdot G_r &= 0 \\ G_r - R \cdot \cos\beta &= 0 \end{aligned} \quad (7)$$

$$f_a \cdot G_r \cdot r_{dr} - R \cdot \cos\beta - T \cdot r_l = 0$$

For normal, non-slip operation, the traction force must satisfy the relation (8):

$$F_t \geq f \cdot G_r + f_a \cdot G_r \quad (8)$$

On the other hand, the moment generated by the force of adhesion to the drive wheel must overcome the resistance of the rotating moment  $M_{rd}$  of the bucket distributor, having its own weight  $G_d$  according to relation (9) and the force necessary to open the bucket  $F_{dc}$  which is equal to the force of the two traction springs arranged on it.

$$M_{rd} = f_a \cdot G_r \cdot r_{dr} = \frac{G_d}{g} \cdot \frac{r_{cd}^2}{2} \quad (9)$$

$$F_{dc} = k_a \cdot f_a$$

where:

$G_d$  - the weight of the bucket disc [daN];

$r_{cd}$  - radius of the centre of gravity of the bucket disc [m];

$k_a$  - stiffness of the traction spring of the bucket [daN/cm<sup>2</sup>];

$f_a$  - the working arrow of the bucket spring [m].

Thus, the relation (8) becomes (10).

$$F_t \geq f \cdot G_r + \frac{\frac{G_d \cdot r_{cd}^2}{g}}{r_{dr}} \quad (10)$$

In conclusion, for the Variant I of planting, the total traction force,  $F_{tI}$  necessary for the operation of the planting machine with the placement of the seedling in the furrow, is according to the relation (11).

$$F_{tI} = f \cdot G_{mb} + k_0 \cdot a \cdot b + \mu \cdot G_b + k_{ac} \cdot a_a \cdot b_a + \frac{\frac{G_d \cdot r_{cd}^2}{g}}{r_{dr}} + k_a \cdot f_a \quad (11)$$

**Planter with vertical distributor with buckets Variant II** - for variant II, from a constructive and functional point of view, the planting machine, according to fig. 1, is no longer equipped with a coulter for opening the furrow and the covering paddles, fig. 1 item 3.

Considering those mentioned above, in the case of planting variant II, the resistance of the coulter at the opening of the furrow and the resistance to covering the seedling with soil no longer appear, but the resistance to the penetration of the bucket into the soil appears. Also, the total weight of the machine intervenes when calculating the resistance when moving the car. The other resistance are the same as for variant I.

The relations written for variant I are valid for the common resistances of the two variants, when moving the machine under operation.

### Dynamics of bucket penetration into the soil, Variant II

The resistance to the penetration of the bucket into the soil and to the opening of the bucket for releasing the seedling, in the case of Variant II, in which we have the situation of planting the seedling directly in the soil and not in the furrow, is according to relation (12).

$$R_{pc} = k_0 \cdot a_c \cdot b_c \quad (12)$$

where:

$R_{pc}$  - resistance to penetration of the bucket into the soil [daN];

$k_0$  - soil resistance to cutting and deformation [daN/cm<sup>2</sup>];

$a_c$  - the depth of penetration of the bucket into the soil [cm];

$b_c$  - working width of the bucket [cm].



Taking into account those mentioned, the total traction force  $F_{tII}$  necessary for the operation of the planting machine with the placement of the seedling directly in the soil, Variant II, is according to relation (13).

$$F_{tII} = f \cdot G_t + k_0 \cdot a_c \cdot b_c + \frac{G_d \cdot r_{cd}^2}{r_{dr}} + k_a \cdot f_a \quad (13)$$

where:  $G_t$ - the total weight of the planting machine [daN].

The experimental research was carried out with the planting equipment in the two variants in aggregate with a 45 HP agricultural tractor, New Holland TCE 50. To perform the measurements for the traction force, strain gauges were mounted on the frame and on the frame of the equipment coulters.

To perform the experiments, inductive displacement system, MGC plus data acquisition - HBM (Hottinger-Baldwin-Messtechnik), Catman DAQ data acquisition software, data processing software nCode were used. Images during the experiments are shown in fig. 3.



Fig. 3 - Aspects during the experiments of the aggregate New Holland TCE50 tractor + MPA planting machine

## RESULTS AND DISCUSSIONS

The experiments were carried out at planting tomato and pepper seedlings for working speeds ranging from 1.46 to 1.61 km/h, for working depth of  $a=70$  mm and  $a=100$  mm, in the two variants.

The traction forces calculated according to the relations (11) and (13) are:

- Variant 1: For  $a = 70$  mm,  $F_{t1} = 171.8$  daN and for  $a = 100$  mm,  $F_{t1} = 182.8$  daN;
- Variant 2: For  $a = 70$  mm,  $F_{t2} = 135.4$  daN and to  $a = 100$  mm,  $F_{t2} = 155.5$  daN.

After the experiments were carried out, the traction forces were obtained when moving the machine tested under operation, the comparative diagram for the two variants tested being presented in fig. 4 and fig. 5.

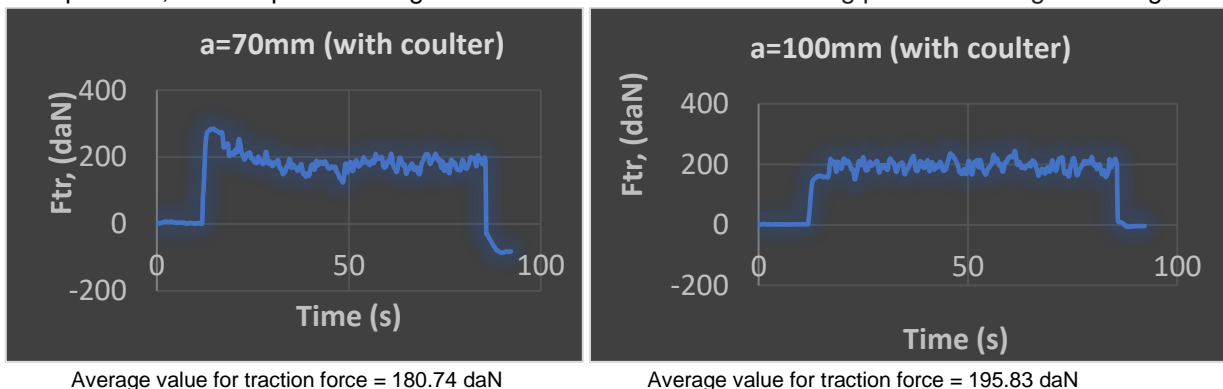
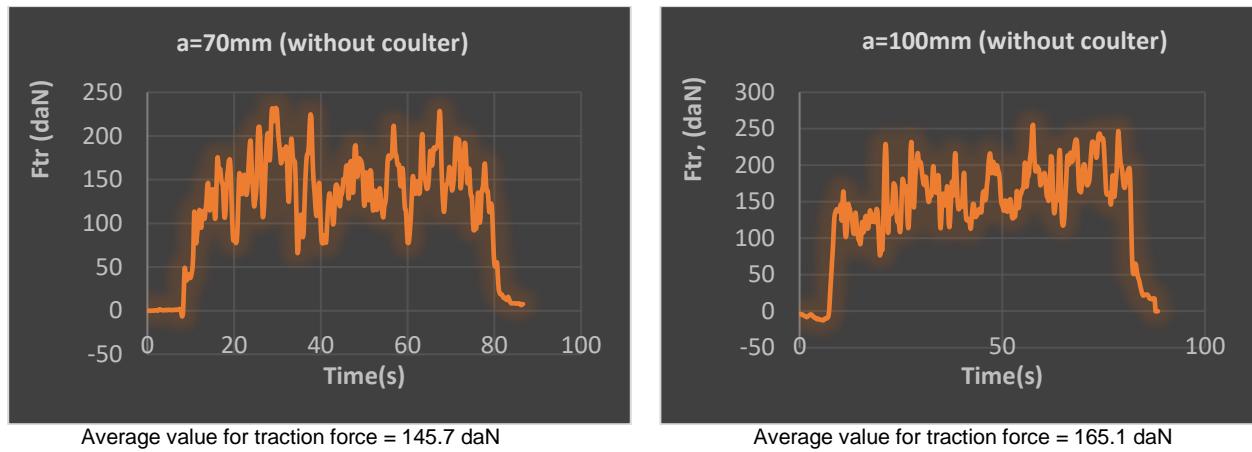


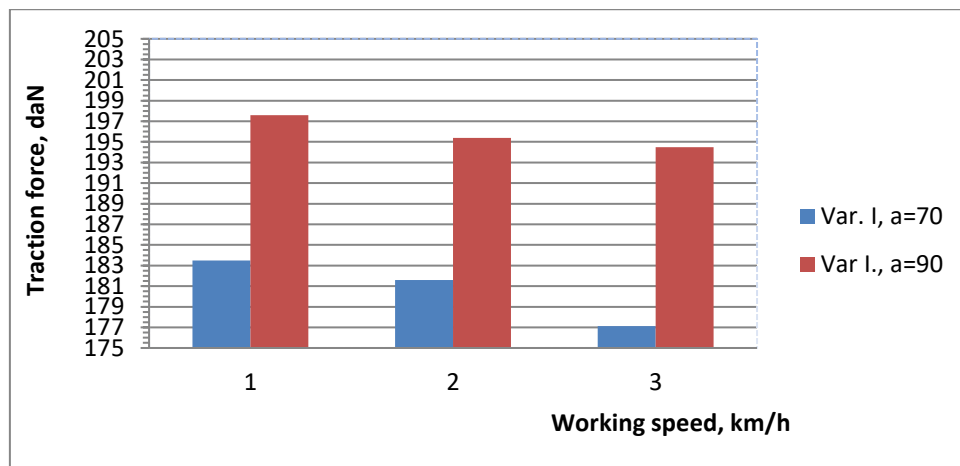
Fig. 4 - Traction force diagrams for seedling planter, for working depth of 70 mm, respectively 100 mm, Variant I



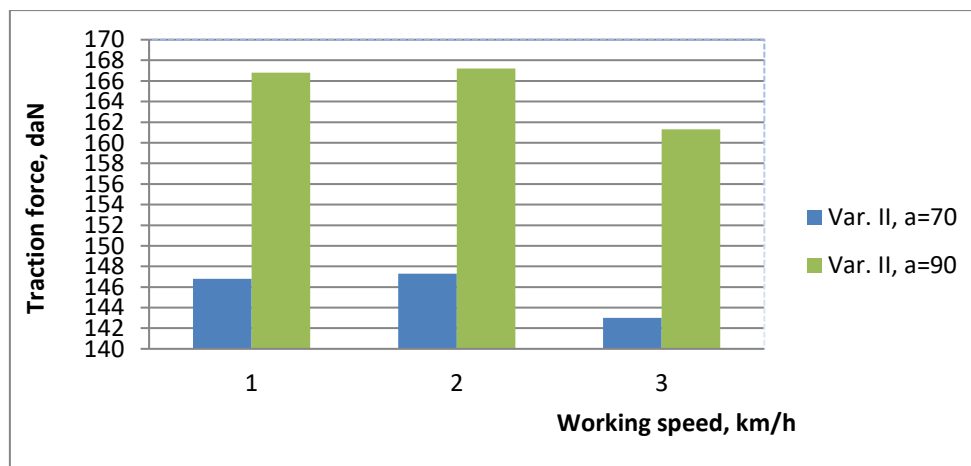
**Fig. 5 - Traction force diagrams for seedling planter, for working depths of 70 mm, respectively 100 mm, Variant II**

The tests performed found a slip of the drive wheel of 7-10%, although from a numerical check of the mathematical relations presented in the chapter Material and method, it resulted that the adhesive force developed at the drive wheel level is sufficient to drive the disc with buckets, in both equipped variants.

The variation of the traction forces with the working speed, for the two experienced variants, is presented in fig. 6.7.



**Fig. 6 - The variation of the traction forces with the working speed, Variant I**



**Fig. 7 - The variation of the traction forces with the working speed, Variant II**

## CONCLUSIONS

After the experiments were carried out, the following conclusions can be drawn:

1. From the multitude of studied bibliographic references, it resulted that the seedling planting equipment, equipped with planting machines with bucket distributors is, by far, the most used at present, this being distinguished by constructive simplicity and high efficiency in achieving qualitative working indices;

2. Traction forces when moving the tested machine, equipped with a planting equipment which places the seedling in a furrow made by a coulter, followed by the covering of the nutritious bale with soil by two paddles and the additional fixing by means of two compaction wheels, Variant I, have significantly higher values than those obtained with the machine equipped with a planting equipment that places the seedling directly in the soil followed by an additional fixing of it with the help of two compaction wheels, called, Variant II, in a percentage of 18-24%, depending on the working depth;

3. The traction forces determined in experiments differ by an additional 5 to 7% from those calculated in theory.

4. The variation of traction forces, with working speed, is insignificant. It was observed a decrease of this, once with the increase of the working speed, in a percentage of 2-3%.

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