1. INTRODUCTION

The primary objective of modern production technologies is to reduce the amount of applied chemicals and to make their use effective. Besides plant protection, scientifically based harmonic nutrient supply plays a key role in this field, and it can be realized by the optimal combination of a complex system of conditions. These conditions are partly preparatory (soil investigation, yield assessment, preparation of digital field maps etc.), partly based on the knowledge of the most typical characteristics of nutrients and partly of technical nature.

In Hungary, artificial fertilizers are dominant in nutrient supply, as the organic manure producing capacity of the country can only cover one fifth (0.5 animal /ha) of total nutrient demand. However, it is natural and important to utilize available organic manure, compost and their by-products in a targeted way.

Today a significant part of fertilizers are spread by spinning disc fertilizer spreaders all over the world, and it is general in Hungary as well. Therefore, my set objective in this study is to make further developments related to these machines. It is of primary importance for these machines to be well-adjustable, capable of the exact measurement and control of the spread fertilizer quantity and of even spreading. Efficient nutrient spreading can be influenced by several factors. The following are of key importance:

- the properties of fertilizers;
- the construction of machines;
- the professional calibration and operation of machines.

Production-site specific nutrient supply, taking the above factors into consideration, can enhance the effectiveness of production, provide environmental-friendly management and yields of tested quality. All the above conditions are of equal importance, as the lack of one of them can have a negative impact on farmers' objectives.

The physical properties of fertilizers can influence the effective operation of machines essentially, so their understanding is indispensable.

In the design and operation of spinning disc fertilizer spreaders the key issue is the optimal working quality of machines. To achieve this, we primarily have to identify the main factors influencing the transversal spreading of fertilizers. From among the factors influencing the location of fertilizer grains in transversal spreading patterns, the most important are those, which have an effect on the movement of fertilizer grains on the surface of spinning discs and blades and define the velocity and the direction on the way the grains leave the disc and the spreading blade as compared to the direction of movement, and the factors affecting them during their movement in the air. As the physical properties of the applied fertilizers are different, spreading devices have to be designed to provide optimal working quality in the case of spreading fertilizers with different physical characteristics. Besides all the above mentioned, this can be achieved through the professional operation of fertilizer spreaders.

TORNÁDÓ INTERNATIONAL Ltd. and its predecessor have produced fertilizer spreaders for decades. The technical level of their mass-produced machines fulfilled the agro-technical requirements in the period of their development and production. However, these requirements have been gradually tightened, mainly to spread fertilizers more effectively, to improve the quality of products and to reduce environmental stress.

Therefore, the continuous development of fertilizer spreaders is an essential prerequisite for a producer to maintain its market position. Our accession to the European Union has placed a strong emphasis on the regulations relating spreading machines, as the regulations agreed by the EU are to be complied with in the development and operation of these machines.

Taking all these into consideration, my objective is to work out the appropriate basis for the development of the new generation of our mass-produced machines, satisfying all the regulations in force in the EU. To realize this objective, I study the most important factors affecting the working quality of spinning disc fertilizers, analyse the theory of spreading, investigate the potential variations of the most significant devices and then define the basic requirements for the further development of the studied machines.

2. MATERIALS AND METHODS

My research objectives required the design of an experimental spinning disc fertilizer, which facilitates the study and analysis of the most significant factors affecting the working width of our mounted and trailed machines and the evenness of their spreading.

Therefore, I studied the following factors in the function of working width and spreading evenness:

– the physical properties of applied fertilizers;
– the location of dosage on the surface of the spinning disc ;
– the volume of fertilizer flow,
– the number of spinning blades;
– the shape of blades;
– the angle of spinning discs included with the direction of the radius.

The hopper of the machine is only capable of storing the volume of fertilizers necessary for the experiment. Fertilizers leave the hopper by a chain or a belt-system. The difference between the two feeders is mainly manifested in the rate of unevenness in the direction of movement. Longitudinal spreading unevenness is smaller in the case of the feeder with the belt-system. I suggest the maintenance of the two feeders as potential alternatives for each other, because current practice prefers the former, usual type with chains. The cyclic application of fertilizer doses by the chained feeder can be diminished by the appropriate development of the machine's bottom panel.

The volume of fertilizer for a unit of area can be varied through the adjustment of the slot. At the usual chain and belt velocity, the applied slot regulator can facilitate the calibration of the fertilizer quantity of 1000kg/ha, which is accepted practice today.

Fertilizers get from the feeder to the distributor, which calibrates the location of feeding as well. The exact calibration of the location of feeding with a matrix-system provides the precise identification of parameters and facilitates reproducibility **(Figure 1.).**

The two-disc spreader of the experimental machine can be equipped with two and three-bladed spinning discs. The blades are of different length. The rear walls of blades are perpendicular to the plane of the disc, or enclose an obtuseangle with it

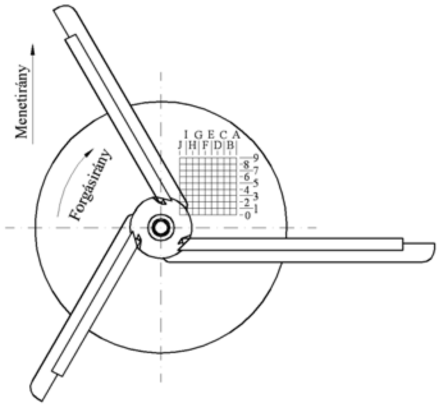


Figure 1. ***Locations of feeding related to the surface of the spinning disc (Menetirány:Direction of the spreader; Forgásirány:direction ot rotation of the spinning disc)***

I performed my examinations on transversal spreading unevenness in the measuring track of the Department of Machinery, Faculty of Agricultural Sciences, Debrecen University. Depending on the spreading width determined by the parameters of the applied spreading device, I used the measuring track of 42 or 50 meters. I processed the data by a target software, which facilitated the computerised determination of the working quality properties for the spreader. I used three values to characterize the transversal unevenness of fertilizer spreaders, in compliance with international standards, and I defined them with the following correlations:

Medium deviation (e_k)

$$e_k = \frac{100}{\bar{x}_i} \frac{\sum_{i=1}^{n} |x_i - \bar{x}_i|}{n} \qquad [1]$$

Where: x_i is the average of fertilizer quantities from three replications on one measuring site;

$\bar{x}_i$ is the average of grain volume from three replications on all the measuring sites

n is the number of measuring sites.

Permissible value of e_k is 10%.

Variation coefficient (CV)

$$CV = \frac{100}{\bar{x}_i} \frac{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x}_i)^2}}{n-1} \qquad [2]$$

Permissible value of CV is 15 %.

Greatest deviation (e_{max})

$$e_{\max} = \frac{100}{\bar{x}_i} \left| x_i - \bar{x}_i \right| \max \% \qquad [3]$$

Permissible value of $e_{\max}$ is 20 %.

The results of measurements can be presented on measuring protocols.

Varying properties in the course of examinations:

- adjustment of the feeder;
- the location of feeding;
- the number of spreading blades;
- the length of spreading blades;
- the angles of spreading blades included with the radius;
- the angular offset of the rear walls of the spreading blades

Unvarying properties in the course of examinations:

- the height of the spinning disc above the row of the collection of trays	700 mm;
- the plane of the spinning disc:	horizontal
- the axial distance of the spinning disc:	900 mm;
- the rpm of the spinning disc:	840 1/min;
- travelling speed applied during measurement:	8 km/h.

I used five types of fertilizers with different physical properties.

3. RESULTS

3.1. Definition of the most significant parameters of the hopper

In the improvement of mounted machines, two hopper volumes are worth consideration, of 800 and 1500 dm^3, which allow increased volumes with adjustments to 1000-2000 dm^3. In the case of trailed machines, the targeted hopper volume is 4000 dm^3, which can be increased to 5000 dm^3 with adjustments. In the case of one-disc machines, the shape of the hopper is a truncated cone or a truncated pyramid, in the case of two-disc machines it is a dual truncated cone or a dual truncated pyramid, with a form of a unified prism at the top. It is advisable to prepare the hopper to be the widest and lowest possible to facilitate easy filling. When we define the width and the lateral angle of the hopper, we must concentrate on the fertilizers' angle of repose. The starting point is the fertilizer with the greatest angle of repose, which is the angle of repose (38^o) for cold-granulated fertilizers from among the ones used these days. In order to avoid technological disorders, a screen which can be folded up and taken out is to be placed in the hopper, excluding clod size over 30 mm. The cover of the hopper can be opened.

3.2. Anti-blockage system

To facilitate the continuous flow of fertilizers, a rotating or oscillating anti-blockage system is to be placed into the hopper of machines with a gravitational system of feeding. In order to avoid the fragmentation of fertilizers, the rpm or the number of oscillations of the anti-blockage system should not exceed the value of 200 1/min and its surface should not be sharp.

3.3. Conveyor

In the case of trailed machines, conveyors carry the fertilizer to the feeding slot.

Alternatively, conveying belt and chain can be used. The conveyor is driven by a friction wheel operated by the wheel. In this case, variance in the velocity of the machine does not influence the quantity of fertilizer per a unit of area. The volume of fertilizer can be calibrated by adjusting the slot of the feeder. In order to reduce longitudinal spreading unevenness, fast, narrow conveyors and smaller feeding slots are preferred. Great conveying velocity with a small slot considerably loads the rear wall of the hopper and breaks the fertilizer into small pieces. In this respect, a small conveyor with a greater slot size is more favourable. We need to make compromises to be able to select the adequate proportions.

I defined the velocity of the conveyor (v_{sz}) on the basis of the following relation:

$$v_{sz} = \frac{Bv_h Q_n}{600ab\gamma} \text{ [m/min]} \qquad [4]$$

where:

- B is the working width of the machine [m]
- v_h is the moving speed of the group of machines [km/h]
- Q_n *is* the quantity of fertilizer to be spread on one hectare [kg/ha]
- a is the width of the feeding slot [m]
- b is the height of the opening of the feeding slot [m]
- γ is the volume mass of the applied fertilizer [kg/m3]

On the basis of the data gained from the design of the machines, a chain speed of 3,5 m/min is advisable to be used for greater volumes of fertilizers (above 450 kg/ha), whereas a chain speed of 1.5 m/min for smaller fertilizer volumes (under 450 kg/ha).

3.4. Slot-adjusting devices

A device facilitating gravitational feeding is placed at the bottom part of mounted machines. When we select the shape of the slot, we should be careful that it must provide a favourable cross-section in the case of a small dose as well, and the applied quantity should vary preferably linearly with the size adjustments of the slot. We can move the slot-adjusting devices by hand in the case of smaller machines and mechanically in the case of larger ones, directed by the driver of the machine from the cockpit. In towed machines, the layer thickness of the fertilizer carried by the conveyor and thus the quantity of fertilizers applied in a unit of time can be adjusted by the slot adjusting device. The slot adjuster is a bolt which can be moved by a hand screw and its position is calibrated by a scale. The largest size of the feeding slot is 420/170 mm (the minimum recommended slot size is of 20mm). For site-specific nutrient application, we have to construct the electro motored movement of slot adjusters as alternative solutions.

3.5. Device for the distribution and the adjustment of feeding location

Besides other parameters, the location of feeding determines the direction and the velocity of fertilizer grains leaving the spreader, compared to the direction of movement.

The location of feeding can vary the type of spreading patterns (trapezium and triangle).

Symmetric spreading patterns can only be obtained if the location of feeding is calibrated precisely. Therefore, the calibration of the location of feeding is of outmost importance. The symmetric spreading of fertilizer particles with different physical properties is available through the calibration of different locations of feeding. For two-disc fertilizer spreaders it is significant that the feeder should provide equal quantities of fertilizers onto the two discs. If the quantities are not equal, the ensuing spreading pattern is asymmetric, blocking the formation of the required transversal spreading evenness.

The location of feeding exerts a significant influence on the transversal spreading unevenness of machines (**Figures 2. and 3.**).

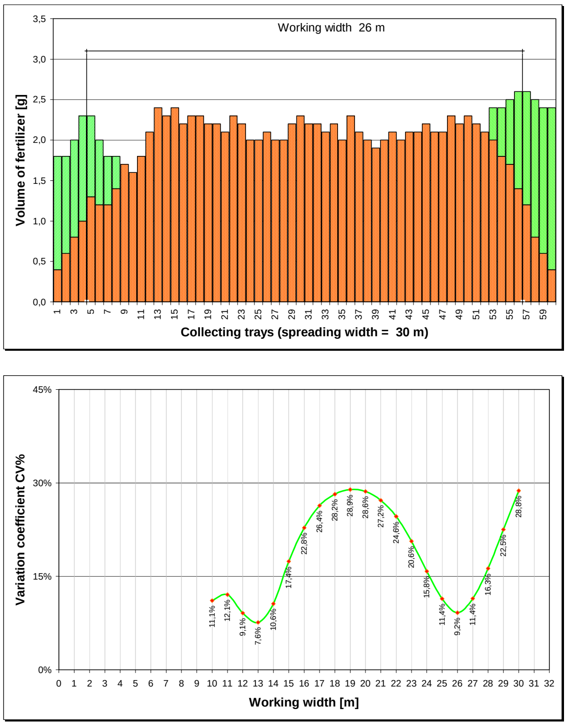


Figure 2. ***Measurement with B3 feeding location***

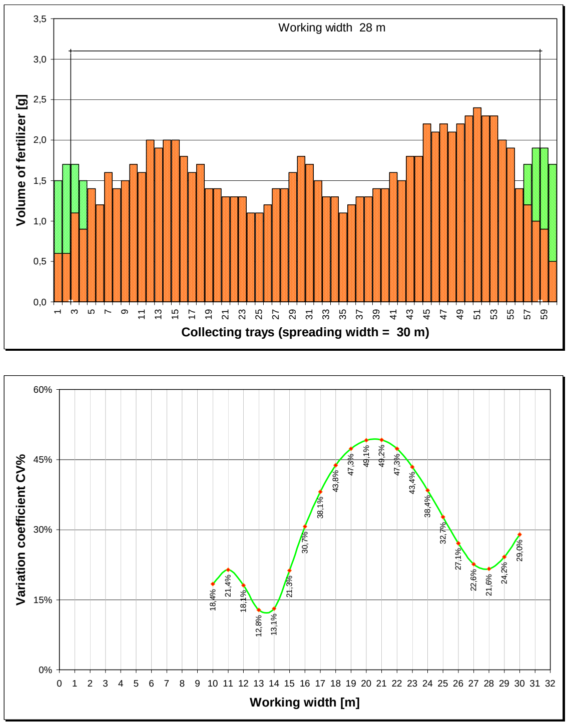


Figure 3. ***Measurement with B2 feeding location***

The two figures show the results of equal calibrations, only the location of feeding was modified (applied fertilizer: ammonium nitrate, feeding position: 3, feeding location: B3/B2, number of blades: 2, shape of blades: A90^{o}). On the basis of the figures we can conclude that with the feeding location (B3) precisely calibrated as above mentioned, the experimental machine, with a working width of 26 m provided a CV value of 9.2%.

With the above calibration, the symmetry of the spreading pattern was 99,82 %. As a result of modifying the feeding location (B2) with one grade, which called forth the displacement of the feeding location by less than 10 mm, the nature of the spreading pattern changed completely. Larger quantities of fertilizers were spread on the two sides of the spreading pattern, thus increasing the working width slightly (28m), whereas spreading unevenness (CV=21.6 %) grew by 12.4%, and the symmetry of the spreading pattern reduced to 83.54%. Therefore we can state that the optimal location of feeding can be defined by an appropriate experimental background.

Fertilizers with different physical properties require different feeding locations. Only machines with adjustable feeding locations can be used effectively. As an example, I present the findings of measurements with ammonium nitrate and potassium salt fertilizers (**Figures 4 and 5).**

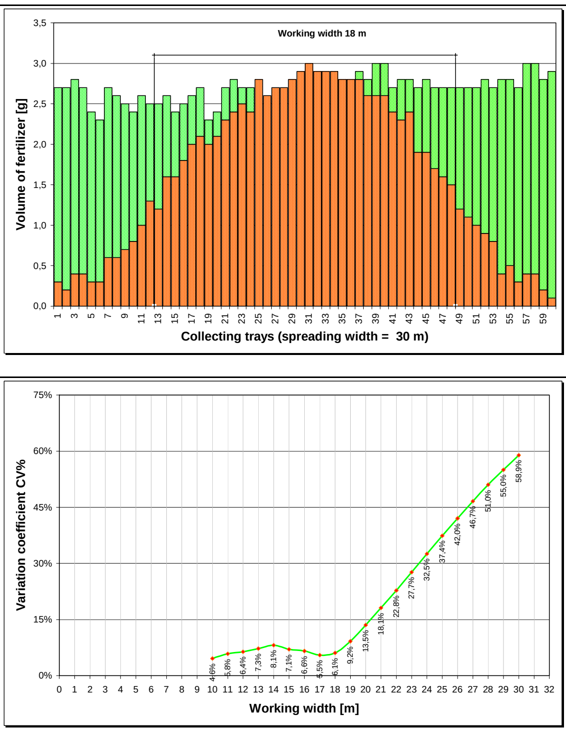


Figure 4. ***Measurement with ammonium nitrate***

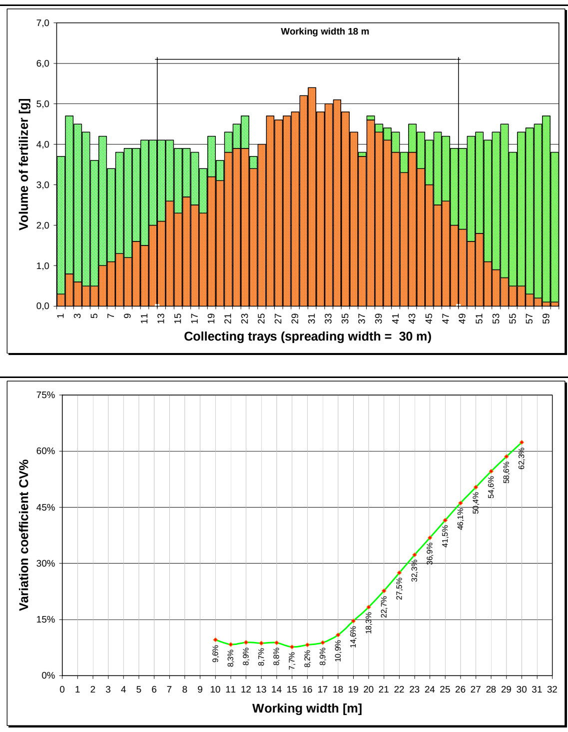


Figure 5. ***Measurement with potassium salt***

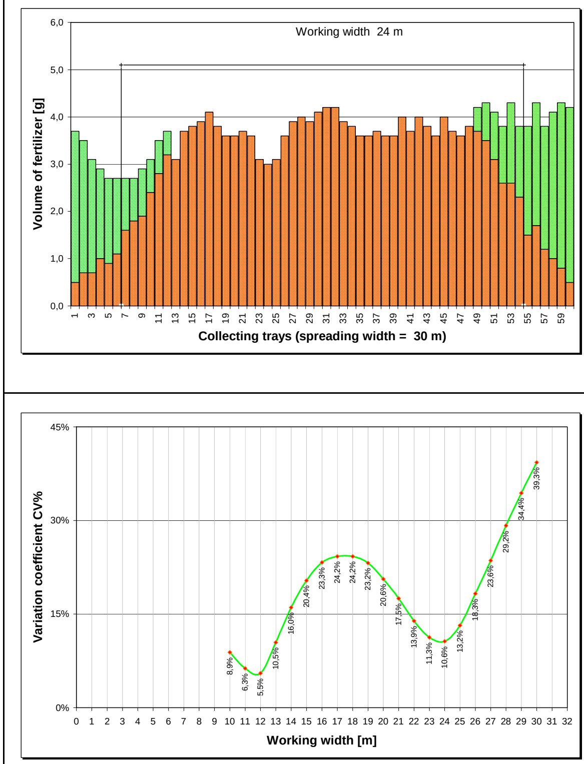
When performing measurements with the two fertilizers, we sought to select the proper calibration values used for a working width of 18 m (applied fertilizer: ammonium nitrate/potassium salt, feeder position: 3, feeding location: B4/C7, number of blades: 3, shape of blades: A90^o). In order to get similar spreading patterns and working width when we use fertilizers with different physical properties, we had to modify the feeding location considerably. The results of the two measurements lend themselves to other analyses as well. The aim was to create trapezium spraying patterns, of which CV value, under a certain working width, can satisfy all the requirements related to spreading unevenness for all the different working width types. In the case of ammonium nitrate fertilizer, the CV value reached the standard 15% at the working width of 20m. At the working width of 19m, the CV value was 9.2% and it remained under this value at all the narrower working width types. In the case of potassium salt, the CV value reached the standard 15% at the working width of 19m. At 18m, the CV value was 10.9% and it remained under this value at all the narrower working width types. This characteristic of the spreading patterns is advantageous for the operation of machines, as e.g. at the working width of 18m, with the deviation of $\pm$ 1m, working quality does not deteriorate considerably. However, farmers can use the machines at any smaller working width types without losing the machines' excellent working quality.

It is also advisable to modify the location of feeding if we vary the quantity of the applied fertilizers **(Figures 6. and 7.)** The two figures show the results of equal calibrations, only the quantity of doses was modified (applied fertilizer: NPK 15-15-15, feeder position: 6/16, feeding location: C4, number of blades: 2, shape of blades: A90^{o}). On the basis of the figures we can draw the conclusion that in the case of small doses (153 kg/ha), at the working width of 24m, the CV value is of 10.6%. In the case of a large dose (517 kg/ha) the spreading pattern changed completely.

The trapezium spreading pattern changed towards a triangle spreading pattern, at the working width of 24m the CV value grew by 5.8% and did not reach the standard 15%.

Appropriate CV value could only be achieved at the working width of 18m, and with a spreading unevenness value of 6.1% the CV optimum decreased to 15m. Therefore, we can conclude that spinning disc fertilizers are sensitive to variations in the volumes of doses and that the modification of the volumes of doses always requires the adjustment of the feeding location as well.

Figure 7. presents other useful findings as well. The enhancement in the middle of the spreading pattern was also caused by the fact that a greater volume of fertilizer could not settle in one layer on the surface of the blade, and the multi-layered movement lessened the velocity along the blade and the landing distance. Therefore, the hypothesis that above a certain volume of doses the application of several blades is needed, is verified.



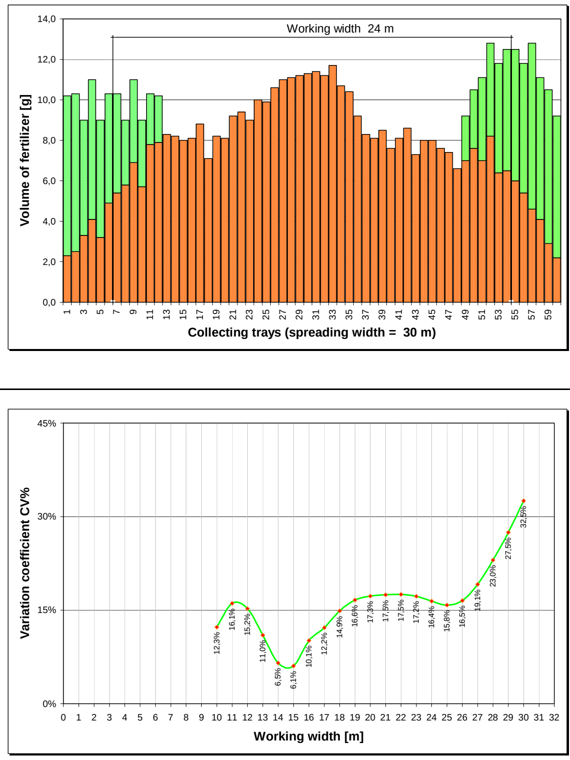


Figure 6. ***Measurement at the 6. position of feeder***	**Figure 7.** ***Measurement at the 16. position of feeder***

With an appropriately selected feeding location the spreading pattern can be modified. However, in the case of such volume of doses, a considerable increase in the working width can only be obtained by the application of a multi-bladed spreading device.

3.6. The spreader

We determined the most significant parameters of the spreader based on studies concerning the theoretical understanding of fertilizer particles' movement on the surface of the spreading blades and on practical examinations on different machines. When determining the parameters, our objective was to extend the working width in such a way that spreading unevenness should be kept under permissible agrotechnical standards. Working width is the function of the landing distance of fertilizer particles. In the case of horizontal landing, in vacuum, we can describe the landing distance by the following function:

$$x = v_o \sqrt{\frac{2h}{g}} \qquad [5]$$

where:

– x – is the anding distance [m]

– v_o – is the the initial velocity of fertilizer particles [m/s]
– h – is the spreading disc's height above the ground [m]
– g – the gravitational acceleration [m/s^2]

During the rotation of the disc, the direction of initial velocity (v_o) alters. From the viewpoint of the machine's spreading width, the largest landing distance can be measured when the direction of the particles' initial velocity is perpendicular to the direction of movement. In this case, the initial point is near the edge of the disc. We must take this fact into consideration when we determine the spreading width of the given machine. The machine's spreading width (Sz) in vacuum is:

$$Sz = 2x + a + 2R \qquad [6]$$

where :

– a – is the axial distance of the two spreading discs [m];
– R – is the projection (perpendicular to the direction of movement) of the distance between the initial point and the distance from the centre of the disc [m].

If we study the landing distance of particles under the influence of aerodynamic resistance, we must consider that particles are affected by the force of aerodynamic resistance (F):

$$F = \kappa A \frac{\rho_l}{2} v^2 , \qquad [7]$$

where:

– κ - is the shape factor of particles;
– A – is the largest cross-section of particles perpendicular to the direction of flow [m^2];
– ρ_l – is the density of air [kg/m^3];
– v – is the current horizontal velocity of particles [m/s].

Based on the equilibrium of forces affecting the particles:

$$ma = -\kappa A \frac{\rho_l}{2} v^2 \quad \text{out of this} \quad a = -\frac{\kappa A \rho_l}{2m} v^2 = -k_v v^2 \qquad [8]$$

where „k_v" is the sailing ship effect, which we can express by the following function:

$$k_v = \frac{\kappa A \rho_l}{2m} = \frac{\kappa A \rho_l}{2V\rho_a} \qquad [9]$$

where:

– V – is he volume of the particles [m^3];

– ρ_a – is the density of the particles [kg/m^3].

On the basis of formula 9. we can state that the sailing ship effect factor depends on the volume of A/V. In the case of spherical bodies:

$$\frac{A}{V} = \frac{3}{2d} \qquad [10]$$

where: d- is the diameter of the particles [m].

Function 10. shows us that the sailing ship effect factor is inversely proportional to the diameter of particles, so the sailing ship effect factor of larger particles is smaller, therefore they can be spread further. On the basis of data from the literature, at the initial velocity of 50m/s the landing distance of larger particles decreases by about 50% as a result of aerodynamic resistance, whereas with minute particles, the rate of decrease can be as much as 75%. So we need to examine the following factors:

For mechanical reasons, the value of „*h*" in formula 5. can only be increased in a restricted way, its impact is insignificant. From the viewpoint of increasing the landing distance and by this, the spreading width, the greatest effect can be achieved by increased initial velocity (v_0).

In formula 6. the value of „*a*" cannot be considerably increased for technical reasons, although several firms which use suspended machines with large working width, have tried this. Its effect is also not significant. Taking the order of magnitude of the spreading width into consideration, the value of „*R"* is insignificant.

Formula 7. shows that „κ", the shape property of grains can be considered constant if we assume that the shape of fertilizer particles is similar to that of spherical bodies. Naturally, there exist fertilizer grains of different shapes (e.g. crystallized potassium salt).

Formulas 8. and 9. present that larger spreading width can be achieved by particles of larger size (d) and greater density (ρ_a).

Summing up all the above mentioned, we can conclude that spreading width is mostly affected by initial velocity (v_0), the size of particles (d) and their density (ρ_a). The properties of fertilizer particles are production-technological variables, although the operators of machines can influence the process by selecting the appropriate fertilizer type.

Out of the constructional issues of machines, we need to further investigate initial velocity. Initial velocity depends on the peripheral speed measurable at the end of the spreading blade and on the velocity of fertilizer particles along the blades.

Peripheral speed is regulated by the blade length and the rpm of the spinning disc. The velocity along the blades is the function of accelerative forces affecting the grains:

$$F = F_c - F_{cor}\mu_1 - G\mu_2 \qquad [11]$$

where:

- F – is the accelerative force on the fertilizer particles [N]
- F_c – is the centrifugal force on the fertilizer particles [N]

$$F_c = mr\omega^2 \qquad [12]$$

where:

- m – is the mass of the fertilizer particles [kg]
- r – is the distance of the fertilizer particles from the centre of the disc [m]
- ω – is the angular velocity of the spinning disc [1/s]

F_{cor} – is the Coriolis force pressing the fertilizer particles to the surface of the blade [N]

$$F_{cor} = 2mv_1\omega \qquad [13]$$

where: v_1 – is the velocity of the fertilizer particles along the blade [m/s]

μ_1 – is the force of friction between the fertilizer particles and the blade

G – is the weight of the fertilizer particles [N]

μ_2 – is the force of friction between the fertilizer particles and the spinning disc/spreading blade

Accelerative forces on the fertilizer particles moving along the blade:

$$mr'' = mr\omega^2 - 2mr'\omega\mu_1 - G\mu_2 \qquad [14]$$

The solution of the differential equation provides proof to determine the initial velocity of certain fertilizer particles. The resultant accelerative force can be increased on the basis of the above mentioned as follows:

1. *By increasing the centrifugal force*

   It is primarily available by increasing the angular velocity of the spinning disc and the length of blades.

2. *By decreasing the frictional force caused by the Coriolis force*

   Decreasing the velocity of particles (r') and ω results in the reduction of the centrifugal force, so the only remaining opportunity is to alter the frictional relations. It is advisable to use blades, which are shaped in a way that the Coriolis force should not press the particles against the perpendicular surface. We can partly achieve this by a blade surface including an obtuseangle with the surface of the spinning disc and partly by calibrating the blades backwards in the direction of rotation. In both cases, rolling movements develop on the surface of the blade.

3. *By reducing the frictional force induced by the weight of the fertilizer particles on the surface of the disc/blade.*

   We can reduce it by improving frictional relations between the spinning disc/blade and the fertilizer particles. Its effect is not significant, as the fertilizer particles mostly moves on the rear wall of the blade.

Taking all the above mentioned into consideration, we can increase the velocity of fertilizer particles along the blades by the following:

- increasing the rpm of the spinning disc;
- using a favourable blade shape;
- selecting the appropriate blade length;
- selecting the angle of blades included with the direction of the radius appropriately;
- selecting advantageous feeding locations.

Compared to horizontal landing, the flying distance of particles can be increased by slanted landing. Therefore, it is advisable to further investigate the conditions of slanted landing, partly by the proper development of the spinning disc's plane and partly by that of the shape of the blade. For this reason, the spinning disc is conical, its planned conicity is 172°. Conical formation increases the rigidity of the disc. The outward flanging of the discs serves the same function.

The rpm of the spinning disc is 840 1/min, its fitting is horizontal. 2/3 pieces of spreading blades can be adjusted to the spreading discs. With equal calibration, the number of blades affects the nature of the machine's spreading pattern. If we reduce the number of spreading blades, the CV (unevenness of spreading) value also decreases; it results in the improvement of the working quality. At the same time, the spreading width correlating with equal CV values and also the working width increase. (**Figures 8. and 9.).** The two figures are the results of equal calibrations, only the number of blades was modified (applied fertilizer: ammonium nitrate, feeder position: 3, feeding location: B4, number of blades: 2/3, shape of blade: A90°).

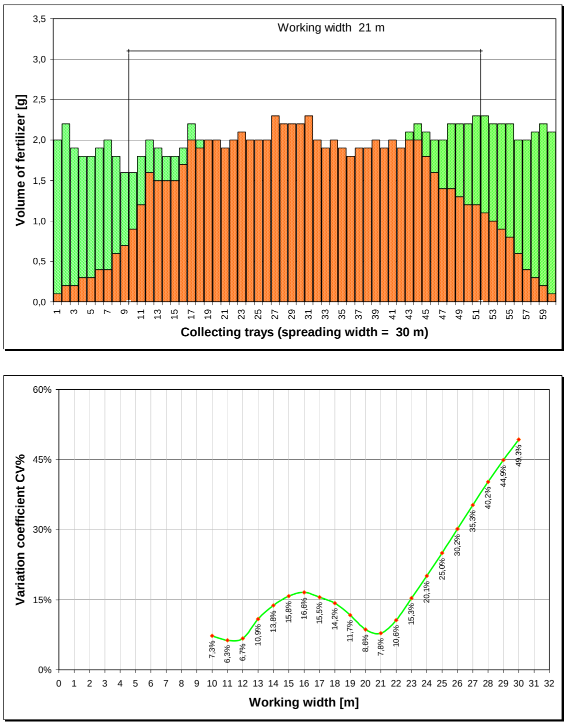


Figure 8. ***Spreading pattern with two blades***

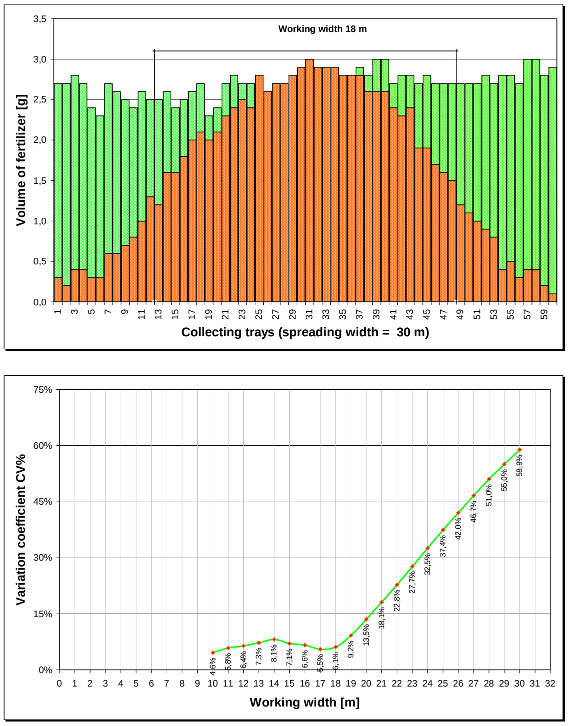


Figure 9. ***Spreading pattern with three blades***

With a two-blade spreading device (Figure 8.) we get a trapezium spreading pattern and the optimum CV value is 7.8% in the investigated domain. With equal calibration, in the case of the three-blade spreader, the third blade (of medium length) reinforces the middle of the spreading pattern (Figure 9.), so the resulting spreading pattern is a triangle. The CV value is of 18.1% at 21m, so it is 10.3% higher than in the case of a two-blade spreader. Naturally, the CV value decreases in proportion to the rate of overlapping, and reaches the optimum value only at 17m, whereas at narrower working width, just like in the case of triangle spreading patterns, it remains under the required value. Therefore, we can conclude that the two-blade and the three-blade spreaders require different feeding locations.

The application of more than two blades is based on theoretical background knowledge and it is related to the volume of the applied fertilizer. The available working width is the function of not only the physical properties of different fertilizers, but also that of the peripheral speed at the blade-ends and the velocity of fertilizer particles along the blade. Velocity along the blade can be increased if fertilizer particles move in one layer on the surface of the blades, as the force of friction is always smaller on the surface of the blade than the inner friction of the fertilizer. If we estimate the volume of fertilizer flowing through the spreader in a unit of time and the affected surface of the blades, we can calculate the surface and the number of blades necessary for the given volume of fertilizer. The necessary data for the approximation of the *number of blades* are the following:

- B is the working width of the machine [m]
- v_h is the driving speed of the group of machines [km/h]
- Q_n is the quantity of fertilizer to be spread onto one hectare [kg/ha]
- γ is the volume mass of the applied fertilizer [kg/m3]
- z is the number of spinning discs [piece]
- c is the number of blades on one disc [piece]
- e is the active height of the blade [mm]
- l is the active length of the blade (action length) [mm]
- d is the average grain diameter [mm]
- m is the average particle mass [g]

Based on the above data, the quantity of fertilizer on one blade during one rotation Q_1 [g] is:

$$Q_1 = \frac{60 B v Q_n}{36 zcn} \text{ [g]} \qquad [15]$$

The value of Q_1 defined by concrete data is 95.24 g, where:

- the working width of the machine is: B=24 m
- the velocity of the fertilizer spreader is: v=8 km/h
- the quantity of fertilizer is: Q=1000 kg/ha

– the number of spinning discs is: z=2 pieces
– the number of blades on the spinning discs: c=2 pieces

The number and mass of particles on the surface of the blade can be calculated by the average particle diameter and mass Q_2 [g]:

$$Q_2 = \frac{elm}{d^2} \text{ [g]} \qquad [16]$$

The value of Q_2 with concrete data:

– e is the active height of the blade 50 mm
– l is the active length of the blade length (action length) 250 mm
– d is the average particle diameter [mm]
– m is the average particle mass [g] that vary according to different fertilizers.

The limit value of single-layered movement can be determined by the data of the given fertilizers. **(Table 1.)** As there is 95.3 g of fertilizer on one blade, single-layered movement, as the last row of the table shows, is only provided by NPK 0-10-14,5 cold-granulated fertilizer and ammonium nitrate salt**.** In all the other cases we could see multi-layered movements.

Approximation for the number of blades ***Table* 1.**

Applied fertilizers	Kemira	NPK-15-15-15	NPK-0-10-14,5	Potas-sium salt	Amm-onium nitrate salt	Amm-onium-nitrate	Carba-mide
Average diameter of particles [mm]	3,25	3,25	3,0	3,0	2,5	2,0	1,75
Average mass of particles [g]	0,067	0,069	0,205	0,057	0,068	0,026	0,01
Total particles mass on the active surface of the blade [g]	62.31	64,17	219,8	61,10	108,8	65,0	31,92

At a practical operation speed (8km/h), if the fertilizer volume on one blade is 1000kg/ha, and the volumes in Table 1. are proportionated, we can conclude that with the exception of two fertilizers, by a two-blade spreader, ideal spreading is only available under the volume of 650 kg/ha, moreover, this limit is 330 kg/ha for Carbamide. Above these limit values, three-blade spreaders are to be used. This hypothesis is underpinned by Figures 8. and 9.

Variations in the length of blades are the most significant potentials if we would like to increase working width. Peripheral speed should be increased by the length of the blade. The working width of 24 m can be achieved at a peripheral speed of 25-30 m/s. To achieve this, besides the above mentioned rpm, we need the blade length of 300-350 mm. Based on our experimental findings, we can state that in the best case scenario, the applied blade length of 400mm facilitates the working width of 28-30 m. In order to reduce both horizontal and longitudinal spreading unevenness, it is advisable to use blades of different lengths on one disc. Blades of different lengths work with different spreading widths, and this increases the potentials of developing the preferred triangle spreading pattern. Moreover, it is advantageous in the reduction of transversal spreading unevenness. Fertilizer stretches spread during one rotation by the blades of different lengths cover larger surfaces, and this reduces longitudinal spreading unevenness.

The shape of blades is a laid u (⊃). It is favourable if the blade is arched at the corners, as it reduces the sticking of fertilizer particles. It is significant that nothing should interfere with the movement of fertilizer particles on the inner surface of the blade. This should be tested when the blades are fixed.

The *height of blades* is 50 mm. Lower blades are more advantageous, as fertilizer particles spread in a solid stream reduce the spreading unevenness of the machine. However, in the case of higher blades, single-layered movement can be achieved even at greater fertilizer particles streams. The height of blades has to be calculated by compromises. With top fertilizers, where the spread amount of fertilizer is not significant, lower blades are of better use. However, in case of spreading greater amounts of fertilizers, it is preferable to use higher blades.

The formation of the blade ends can be stepped, so it can multiply the effect of the blades with various lengths. With two spreading blades, the development of the properly selected blade length and stepped form can be as advantageous as using four blades of different lengths. The optimal value of step size can only be calculated experimentally.

The material of blades, to prevent corrosive effects, is stainless steel.

The modification of the *angle of blades included with the radius* alters two significant parameters. If we set them forward in the direction of movement, it increases the spreading width and spreading unevenness as well. If we set them backwards in the direction of movement, spreading width and spreading unevenness decrease **(Figures 10. and 11.)**. The reason is the slight decrease of peripheral speed and also the significant modification in the direction of the velocity along the blade. These two factors result in the considerable decrease of initial speed in the case of blades set backwards.

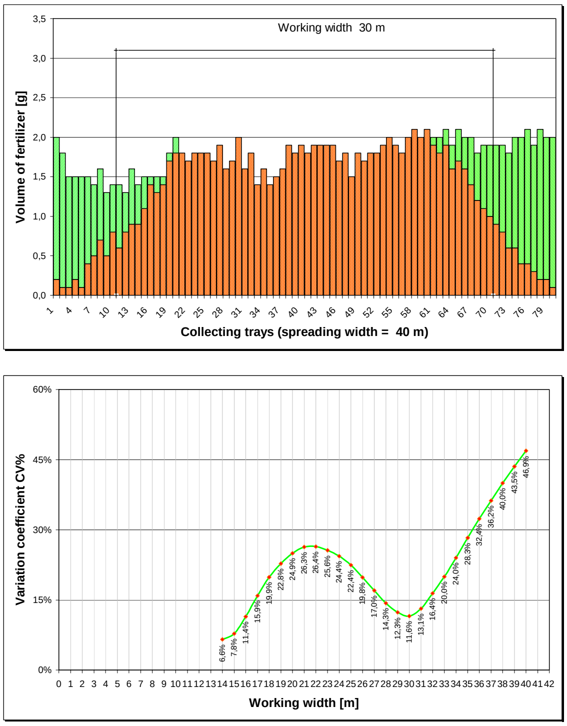


Figure 10. ***Spreading pattern with blades set forward***

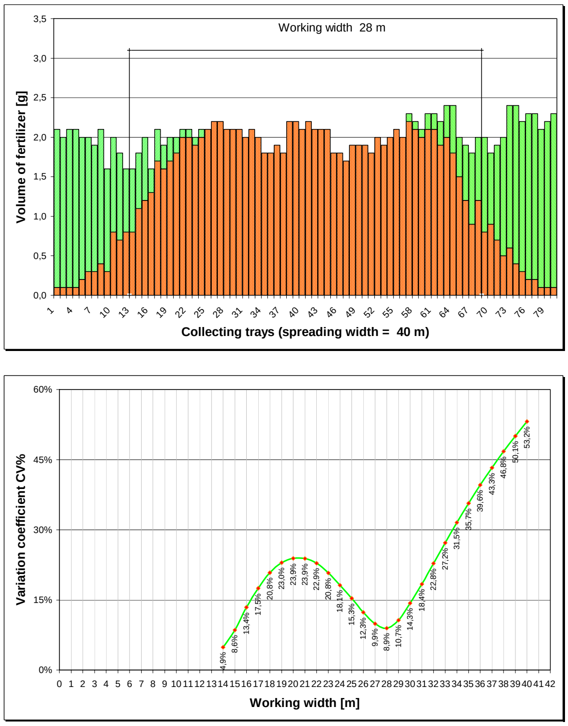


Figure 11. ***Spreading pattern with blades set backwards***

The two figures reflect the results of equal calibrations, only the angle of blades with the radius was modified (applied fertilizer: ammonium nitrate, feeder position: 3, feeding location: C2, number of blades: 2, position of blade: A/C, shape of blade 98^{o}). With blades calibrated forward in the direction of movement, the working width was 30m, the CV value was 11.6%. By calibrating the blades backwards, the working width decreased by 2m to 28m, and the CV value improved by 2.7% to 8.9%.

Therefore, for the modification of working width and spreading unevenness, the calibration of blade angles is a useful method. Larger working width steps are to be achieved by the variations in the blade lengths, smaller ones by the calibration of blade angles.

There are several ways to increase the velocity along the blade. The angular calibration of the blades is an effective method to reduce frictional resistance caused by the Coriolis force. By calibrating the blades backwards in the direction of movement, the frictional resistance reduces and thus the velocity along the blades increases. These counteract the facts that peripheral speed at the blade ends reduces and the relation between the velocity along the blade and peripheral speed varies. The other method to reduce the Coriolis force is to modify the angle at the rear wall of the blade related to the plane of the spinning disc. Most machines use blade surfaces perpendicular to the plane of the spinning disc. My objective in my investigations was to find out if the relief angle of the blade exerted a considerable influence on the above examined phenomena **(Figures 12. and 13.)**

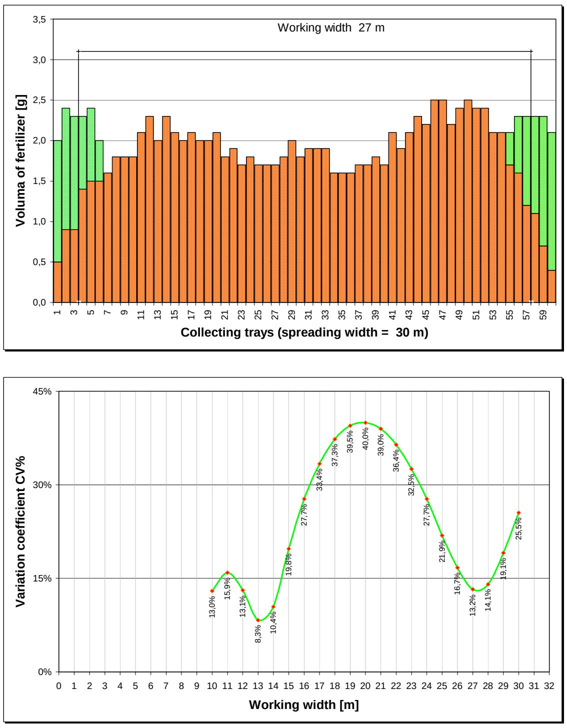


Figure 12. ***Measurement with a blade of 90°***

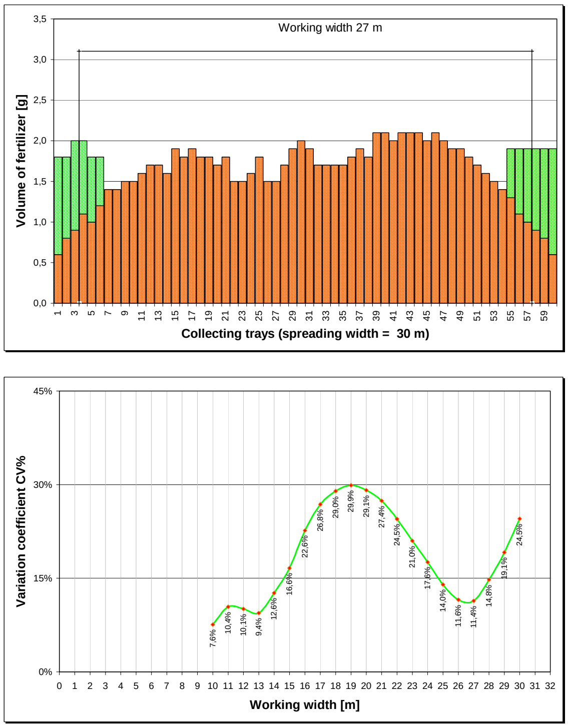


Figure 13. ***Measurement with a blade of 98°***

The two figures reflect the results of equal calibrations, only the angle of blades with the radius was modified (applied fertilizer: ammonium nitrate, feeder position: 3, feeding location: C2, number of blades: 2, calibration of blade: A/C, shape of blade 90/98°). With blades of 90° the working width was 27m, the CV value was 13.2%, (Figure 12.) When setting the blades backwards (blades of 98°), the CV value reduced by 1.8% (Figure 13.) at unchanged working width. A closer investigation of the figures reveals that in the examined domain the CV optimum values were 27-28 m for blades of 90° and 26-27 m for blades of 98°, so the working width slightly decreased by increasing the blades' angle of relief, although it was levelled off by the decreased CV value. The above favourable tendency failed to continue when the relief angle of the blades was further increased. Therefore, we can state that we should only increase the relief angle of blades to a certain degree (my findings indicate a maximum of 98^{o}). We can also conclude that if we bend the blades backwards, to some extent we achieve the same effects as if we calibrated the blade backwards in the direction of movement, although the effect is not that significant.

3.7. Characteristics of operation

The working quality of fertilizer spreaders is determined, besides the properties of the applied fertilizer and the constructional characteristics of the machines, by professional operation. The most important out of its conditions are the following:

– fertilizer-specific calibration of the machines (based on accredited laboratory findings);
– the test of the tractor (TLT rpm, wheel parameters, stability);
– the test of the spreader (trial operation);
– the test of the transversal spreading pattern (test on the field by the appropriate means);
– correct following pass.

As a result of the transversal spreading pattern of spinning disc fertilizers, the even distribution of fertilizer can only be achieved if spreading patterns are overlapped in subsequent spreading. When we study the working quality of machines, we determine the data necessary for the calibration of various working widths. Large working widths require supplementary devices for precise following pass (tramline system, system for parallel driving, automatic navigation). When we keep to the appropriate working width, permissible deviation depends on the nature of the transversal spreading pattern. Transversal spreading unevenness (CV) cannot exceed the permissible value (15%) in the course of the deviation, as it can result in the loss of the quantity and the quality of the products as well. Therefore, if we analyze the deviation from the permissible working width, we always have to keep the CV value at the appropriate level. **(Figures 14. and 15.).**

Figure 14. shows that at the working width of 18 m, at a following pass error of +1m, the CV value is at the limit, so exact following pass is needed to achieve the expected working quality. Negative deviation does not cause errors. Figure 15. presents that at

the working width of 18m, the value of the following pass error can be up to +3 m, and the negative deviation does not cause errors. This is typical of triangle spreading patterns. Therefore, this spreading pattern is in the focus of present day machine construction. Trapezium spreading patterns are more critical from the viewpoint of following pass **(Figures 16. and 17.).**

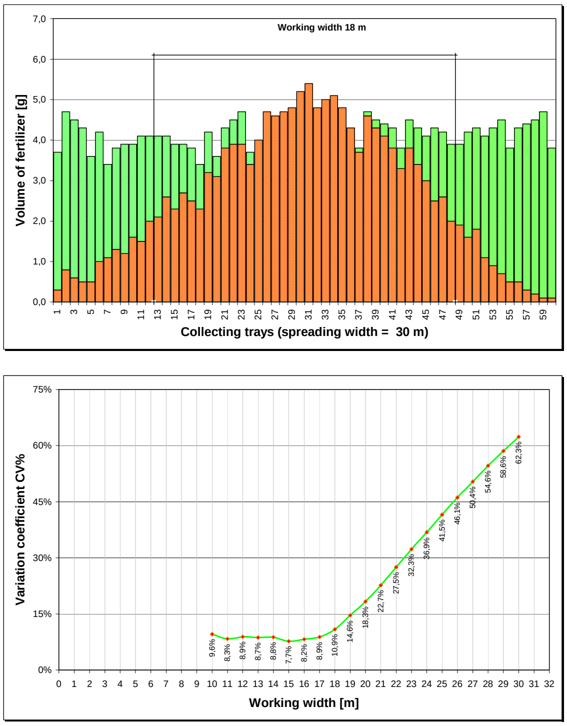


Figure 14. ***Need for precise following pass***

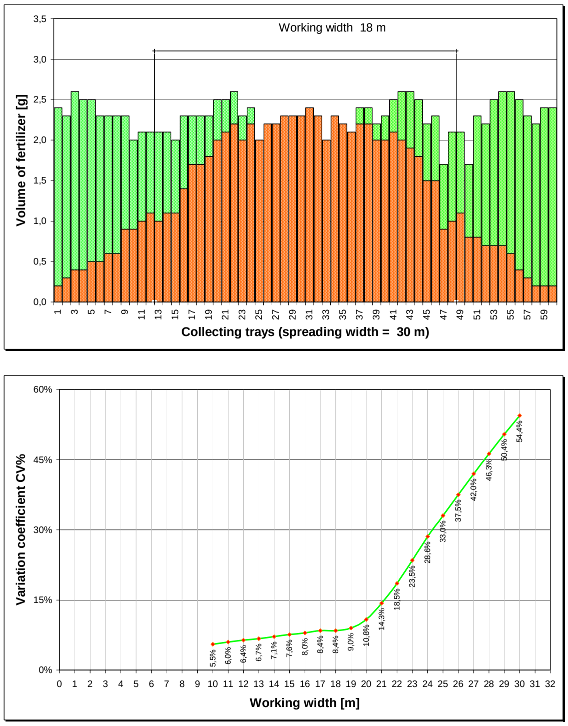


Figure 15. ***Need for less precise following pass***

The above mentioned examples gave evidence to support that the expected working quality can only be achieved by highly precise following pass. Its modern solution is the tramline system in production or a system for parallel movement based on GPS or the application of automatic navigation.

In order to protect our environment and to cut costs, spreading patterns should be trimmed at the edge of the fields, roads and trenches. An advantageous solution for this is the application of a directing device, which can be turned in next to the spinning disc and can modify the fertilizer particles' flight direction and flight distance on the required side.

Modifying the developed machine it will be possible to use it for site-specific application of fertiliser.

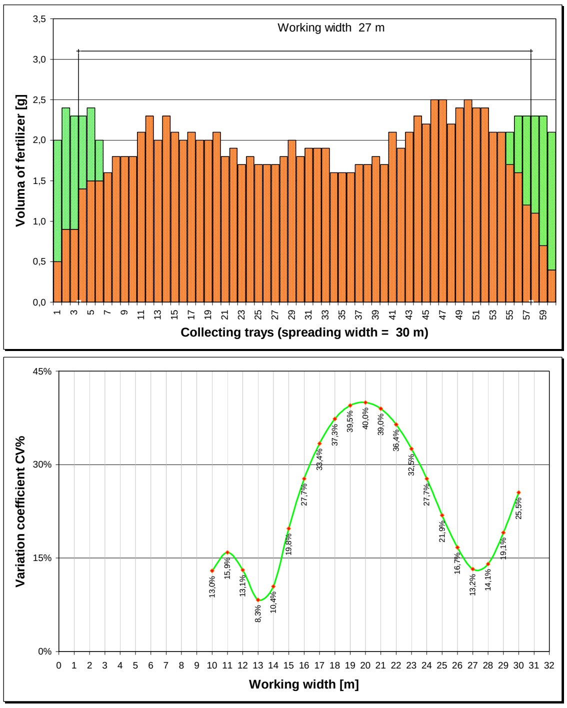


Figure 16. ***Need for precise following pass***

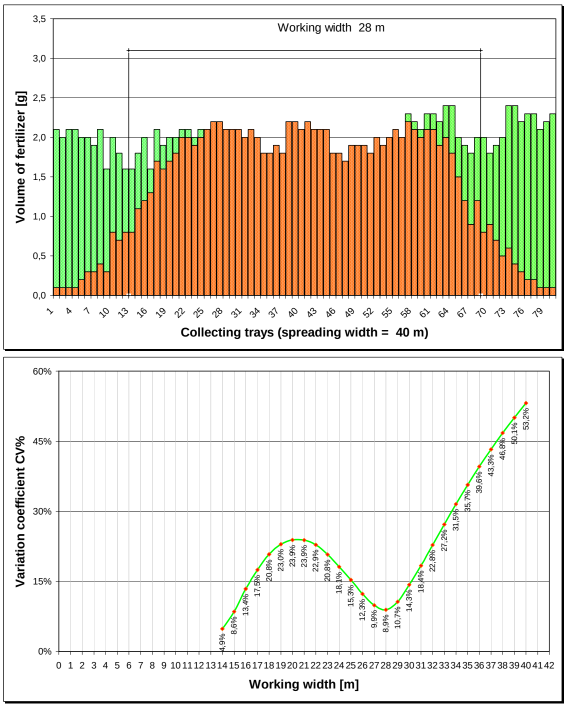


Figure 17. ***Need for less precise following pass***

4. NEW SIENTIFIC RESULTS

1. I have proved the different feeding location needs of different fertilizer quantities.
2. I have determined a correlation between the movement of a single-layer fertilizer quantity on the surface of blades and the number of blades. I have given experimental findings to support the correlation.
3. I have determined the impact of blades included in different angles with the radius on the working width and the unevenness of spreading.
4. I have determined the impact of blade surfaces including an obtuseangle with the plane of the spinning disc on the working width and the unevenness of spreading.
5. I have determined the correlation between the nature of transversal spreading patterns and the preciseness of following pass.

5. APPLICABLE PRACTICAL RESULTS

1. I suggest the use of the correlation which determined the velocity of the conveyors of towed fertilizer spreaders for machine design.
2. I suggest that the correlation between asymmetry and symmetry in the dosage of fertilizers, which I determined during my examinations on the calibration and operation of machines, should be taken into consideration.
3. On the basis of my experiments, it is worth considering that in the design and calibration of machines, fertilizers with different physical properties require various feeding locations.
4. On the basis of my experimental results it is worth considering that the selection of the feeding location exerts a significant effect on transversal unevenness.
5. Before launching the production of the planned fertilizer spreader variants, thorough market research should be performed on expectable customer needs and intentions. Working quality examinations by various firms can be followed up in the literature, however the detailed analysis of price-quality-productivity relations should be carried out by companies which are engaged in the improvement and sale of the machines, with special respect to the fact that producers do not promote the publication of such data.
6. Newly developed fertilizer spreaders should be supplied with supplementary devices for the calibration of the volume of fertilizer doses and for the control of transversal spreading patters on the fields.
7. The actual operation speed influences the feeding locations of trailed fertilizer spreaders driven by wheel-proportional conveyors.
8. Newly developed fertilizer spreaders should be capable of site-specific nutrient spreading.
9. Newly developed fertilizer spreaders should be supplied with devices suitable for border spreading.
10. Manuals should be prepared for fertilizer spreaders, including the calibration data necessary for the types and volumes of fertilizers and for different speeds and working widths.

6. PUBLICATIONS IN THE SUBJECT AREA OF THE THESIS

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3. Z.-Csizmazia - **A. Kőkuti** (1991). Development of Fertilizer Spreaders for Small Farms. Workshop for Research and Development, Gödöllő.
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14. Z. Csizmazia, N. I. Polyák, **A. Kőkuti** (2005). Basic Research for Development of Fertiliser Spreaders. Journal of Agricultural Sciences, (in press)
15. E. Ancza, **A. Kőkuti** (2005) Technical Conditions of Environment Protecting Fertiliser Application. Sustainable Agriculture Across Borders in Europa, University of Debrecen-University of Oradea.