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Effect of drill machine operating speed on quality of sowing and biomass yield

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Abstract. The paper is focused on the study and evaluation of quality of the seeding of seeds and its effect on the biomass yield. The aim was to evaluate the space arrangement of the seeds by using of polygon method on one field with the repetition for different forward speeds of the drill machine. For the evaluation there were used digital photographs, which were taken during repeated measurements of the each value of the forward speed after sprouting of crop. These images have been used in order to determine the shape and size of the surface area belonging to the plant. Own software TfPolyM was used for the image analysis. The shape of the polygons belonging to the individual plants was expressed by values of the shape factor T_f. This factor characterises the suitability the shape of polygon surface related to the individual plant. By comparing of the values of the shape factors for different forward speeds of the drill machine we can determine the optimal value of the forward speed from the point of seed placement uniformity in horizontal level. During harvest of the crop there was analysed the variability of the biomass yield in relation to values of the forward speed used during seeding. The most suitable values of shape factor T_f (0.8519) was recorded for speed of drill machine set on 12 km h^{-1}. For other tested speeds 8, 10, 15 km h^{-1} were recorded lower values of shape factor 0.7994, 0.8173 and 0.8449, respectively. In determination of biomass production for drill machine speed 12 km h^{-1} the greatest yield from 1 m^2 was observed. Subsequently, for speeds 8 and 10 km h^{-1} was lower about 4.26% and 1.83%, respectively. For tested speeds of drill machinery 15 km h^{-1} and above was observed only a small descent of yields about 0.6%. Fluctuation in yields affected by working speed then demonstrates fluctuation in sowing rate. It was also observed that the working speed of sowing machinery also affect the amount of yield directly. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains.

Key words: drill machine, sowing quality, biomass, operating speed, yield.

INTRODUCTION

The quality of sowing is affected by a various number of factors (Findura et al., 2005; Findura et al., 2006; Jobbágy et al., 2007; Turan et al., 2014; Turan et al., 2015). During the evaluation of seeds placement in the soil is needed to take into account the depth of its placement (Rusu et al., 2009) but also the spatial (horizontal) distribution of seeds in the sowing area (Maga et al., 2015). This spatial distribution of seeds in soil affects not only field germination of plants but also further development of plants and therefore yields in the results. Blackmore et al. (2009) concluded that optimization of the area location of the seeds during seeding process and subsequently of the emerged plants is very important for the increasing of the field emergence rate, for further plant grows and yield obtained. In the same time the competitive effects of growth factors among plants (light, water and nutrients) are decreasing with increasing distance between plants. However, Ramseier & Weiner (2006) concluded, there is a negative linear relationship between the relative growth rate of target plants over an interval and the biomass of their neighbours at the beginning of the interval. The size of the target plant itself did not make a significant additional contribution to predicting its growth rate. There is a limit on the growth in biomass of the population (target + neighbours), and growth of individuals occurs within this constraint. Local biomass density, which can be primarily determined by neighbouring individuals, can be much more important for an individual's growth than its own size. There was no evidence of size-asymmetric competition. The size of neighbours was the primary determinant of a target plant's relative growth rate, but the effect of a given amount of neighbour biomass was the same for neighbours larger and those smaller than the target plant.In addition, Korres et al. (2016) stated that crop ability to suppress weeds can be considered in two ways, namely (a) the ability to tolerate weed competition which can be measured by the ability of the crop to maintain high yields under weedy conditions and (b) the ability of the crop to suppress the growth of weeds, usually determined by comparing different biological characteristics in mixtures with that in pure stands, known as weed suppression ability or competitive ability (Callaway, 1992; Korres & Froud-Williams, 2004; Andrews et al., 2015).

Spatial distribution of seeds in soil then represents an essential production and technical measures which affects directly into the process of crop yields production. A polygon method is one of the possible evaluation forms of spatial distribution of seeds assessment (Griepentrog, 1999). This method allows to evaluate the spatial distribution of seeds by distribution of polygons and definition of areas occupied by individual plants, an individual growing spaces (Griepentrog et al., 2005a; Griepentrog et al., 2005b). It was further found that the spatial distribution of seeds in soil is dependent on quality of longitudinal distribution of seeds along with spacing of rows and also on specific quantity of seeds per area unit (Griepentrog & Nørremark, 2001; Hanzlik & Gerowitt, 2011). Moreover, Findura et al. (2005) and (2006) concluded that the seeders do not sow seeds at the same distance even within the same row.

As a criterion for description of longitudinal distribution quality can be considered also evaluation of the spatial distribution of seeds even indirectly. In addition, the distribution of seeds in the same row do not fit into normal distribution (Gauss distribution) but most often fit into exponential distribution (Maga et al., 2015; Torres et al., 2017). Disadvantage in this kind of assessment procedures is decommissioning of other and essential parameters such as the inter-row distance and specific quantity of seeds per area unit while quantity of seeds also affects living area per plant, inter-row distance and also the shape of living area per plant (Jha et al., 2017). Nevertheless, these assessment criteria of the quality of seeders work will be used, although direct comparisons should be fair and meaningful only when the same inter-row distances and equal quantity of seeds per area unit will be applied (Maga et al., 2015). Subsequently, Heege & Feldhaus (1997) suggested and later Nørremark et al. (2007) expanded that with lower inter-row distances usually also improves the spatial distribution of seeds in the soil. Based on this conclusions, it appears to be competitive to aim for a lower inter-row distances in the seeding processes.

Criteria which characterize only the mean distance of seed to neighbouring seed (plant) are able to describe the spatial distribution of seeds only limited due to its low level of explanatory and are not suitable for further analyzes or modelling of images. These methods of evaluation are still in progress of development. One of the reason of this low level accuracy is namely eccentricity which can be defined as a specific (real) position of plant (seed) in produced polygon and therefore its distance to another plant inside neighbouring polygon also affected by this eccentricity in another level. These criteria however, are applicable as a first assumption and formulation for inscription of spatial distribution of seeds (Bechar & Vigneault, 2016; 2017).

The main focus of the study was to evaluation of quality of the placement of seeds and its effect on the biomass yield. To achieve this, the main objectives were to evaluate the space arrangement of the seeds by using of polygon method on one field with the repetition for different forward speeds of the drill machine.

MATERIALS AND METHODS

Since the aim of the study was the evaluation of spatial distribution of seeds (plants) by polygon method the variety of winter wheat was selected and used along with commonly used Väderstad Rapid RD – 800 A seeding unit. In order to determine the dependencies (namely: effect of drill operational speed on placement of seeds, dynamic proportions of seeds impact on the soil and distances of seeds inside the same row) a various operation speeds of seeding units was applied.

Identification of plants and methods of picture analysis

In order to facilitate the description and evaluation of competitive situation among crop plants it was established so called 'specific area' which represents the living area for a single plant. This area is bordered from all sides by areas occupied by neighbouring plants and it has the multi-angle shape or polygon.

For calculation of polygon areas values is therefore critical which plant is neighbouring with those evaluated and for polygon creation is essential. In this case as suitable appears to be a Denaunays triangulation or Thienssens distribution of polygons (Kashyap et al., 1983; Tüceryan & Jain, 1990; Okabe et al., 2008).

Denaunays triangulations can be understood as the: there are 3 visible points as neighbours which form the circuit together and do not contain any other point at the same time (Fig. 1, A). Point 'B' is not a neighbour to point 'O' since the common circuit does not contain point 'B'.

Voronois method can be explained as the: as a neighbouring point is considered those which polygons as a result of polygon decomposition show the common polygon edge (Fig. 1, A). Point 'A' is not a neighbour to point 'O' since a half of distance 'OA' is greater than 'a'. As it is showed at Fig. 1 identification of the neighbouring seeds (which seed is a neighbour to which) by both methods are equal and the difference is only in the resulting shapes of geometric patterns. It means that both procedures are suitable as a solution of selected issue.

As it is showed in Fig. 1, B, area attributable to the plant and defined by a specific polygon is characterized by: (i) size of the area (ii) shape of the area and (iii) location of plant (eccentricity). There is no doubt that the most important factor among all is the size of area for a single plant. Accordingly, the same quantity of seeds per area results in the same size of area attributable to one plant. It was proven that longitudinal distribution of seeds, row spacing and size of area per plant affects the final yields. In addition, shape of the polygon area also affects the plant development. The ideal would have been round shaped area however it is not achievable in common practise. When balanced precise sowing is applied the area have the shape of rectangle while triangular sowing results in hexagonal shape of the area.

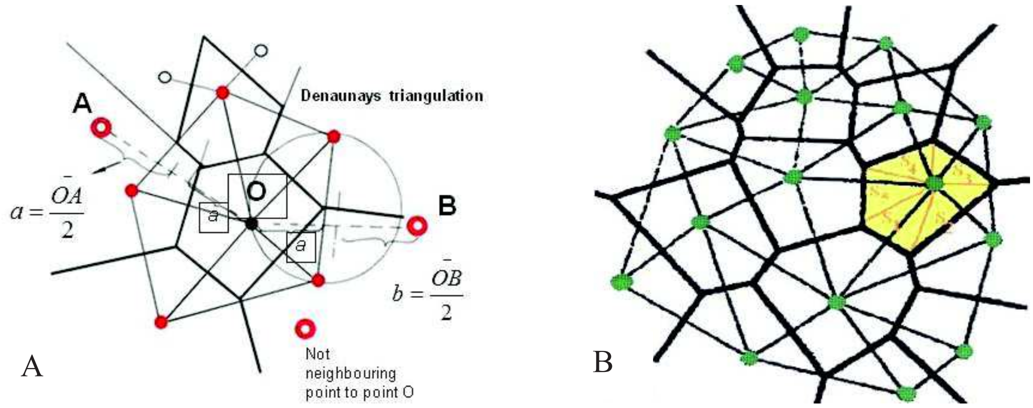

Figure 1. A: The example of Denaunays triangulation and Voronois polygon (where A, B and O are individual plans/seeds); **B:** Polygon on sown seeds (where the area of single polygon is defined as a sum of areas S_1 to S_n).

For evaluation of area shape Griepentrog (1999) introduced so called shape coefficient T_f which is calculated by following equations:

$$\bar{T_f} = \frac{1}{n}\sum_{i=1}^{n}\frac{O_{ideal}i}{O_{real}i} \quad (1)$$

$$O_{ideal} = 2\sqrt{\pi S_i} \quad (2)$$

where $O_{ideal}i$ – ideal perimeter of polygon *i*; $O_{real}i$ – real perimeter of polygon I; *n* – number of polygons; S_i – area of polygon i (as a sum of areas $S_{1\text{-}n}$ – see Fig. 1, A).

For the described concurrence between individual plants contingent by plant location is the distribution of polygons particularly significant due to high similarity of the size and shape of real polygon areas. The method of polygon distribution is dependent on the selected method of sowing. It is applicable on the line sowing, strip sowing or even wide sowing when the position coordinates of seeds are known. At the same time, measurements of seed distances in case of seeding machines studies can be used as a base for calculation of polygon distributions. Optimization of spatial distribution of seeds during process of seeding and subsequent plant emergence should be of value in improving the plant field emergence but also in improvement of following plant development and subsequent yields while competing effects of growth factors between plants (light, water and nutrition) should decrease.

It is obvious that besides the size and shape of polygon attributable for one plant the inside position of plant in polygon (eccentricity) will play an important role (Jiang et al., 2013).

Machinery and conditions of field study

Field measurements were conducted at the fields of PD Gemerská Ves, agricultural company (48°28'13.1"N 20°16'14.3"E). Winter wheat was sown, variety Antoniusz, specifically. Soil type of selected field was determined as loamy clay which belongs to hevier soil types. Väderstad Rapid RD – 800 A seeding unit was used which consist of disk heel coulters with a pitch of 125 mm. The seeding machine was set to apply the quantity of seeds at 220 kg ha^{-1} along with seeding depth at 30 mm (confirmed by measurements after seeding at value 29 mm ± 2 mm). The sowing mechanism of selected seeding machine works on pneumatic principles, overpressure specifically with cylindrical roller dosing system. The crossings of sowing assembly was realised with various speeds 8, 10, 12 and 15 km h^{-1}, respectively. Those different crossings were then labelled for later identification when plans emerged. For every sowing speed (factor) a multiple (5 × 10) pictures (samples) were taken diagonally to crossing vector.

Description of used software

It was used the evaluation software TfPolyM developed at Department of Machines and Production Biosystems. Software was developed in development environment of Delphi. It is designed for determination of polygon distribution of plants in the horizontal plane in relation with distribution of neighbouring plants. Program is able to process digital pictures which were taken after the plant emergence (Fig. 2, A). Algorithm of this program can be divided into 3 phases which follow each other and are executed in following order: (i) determination of individual points – identification of plants on the pictures (Fig. 2, B), (ii) determination of neighbouring points (Fig. 2, C) and (iii) production of polygons (Fig. 2, D).

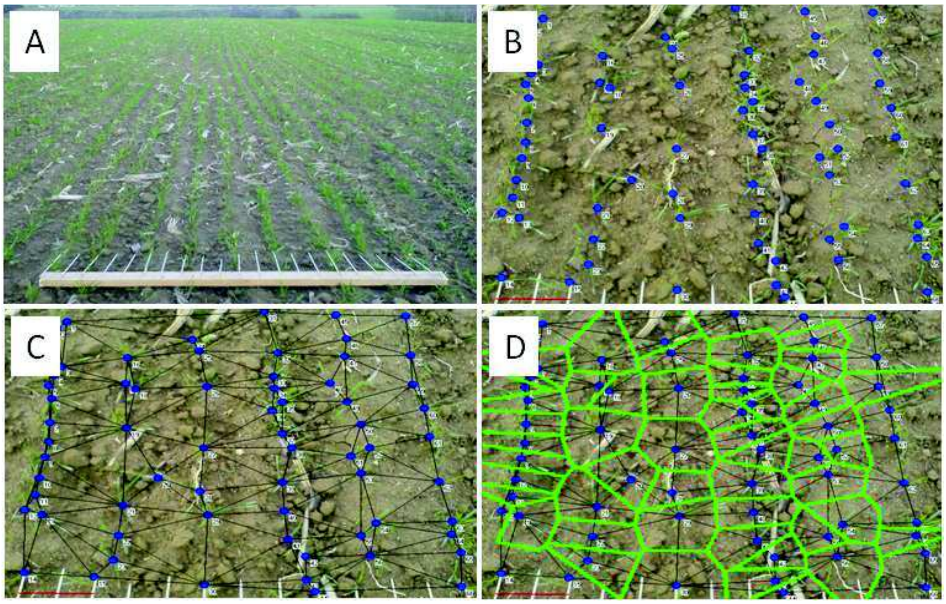

Figure 2. Picture of the field after plant emergence: A – measurement frame; B – Plant identification; C – Determination of neighbouring points; D – Production of polygons.

RESULTS AND DISCUSSION

Results of image analysis

Digital pictures were used in the evaluation which was taken from repetitive measurements of all selected speeds of seeding machinery assembly and full emergence of all plants. Those pictures were taken when all of the plants were visible and fully emerged, the crop were not involved into full cover and were easy to identify. The evaluation was then carried out by specific software TfPolyM defined in above chapter. These pictures were then used for determination of the shape and size of area attributable for selected single plants. The shape of polygons defined for plants was then expressed as the shape factor value 'T_f' (Table 1). This factor serves as a tool to identify the suitability of shape polygon for selected plant and its proper development (Findura et al., 2005; Findura et al., 2006).

Table 1. Forward speed effect of the drill machine on the seeding parameters, *n = 10*

Forward speed, Km h^{-1}	Mean value of the shape factor, T_f					Average, T_f	s.d.
8	0.7779	0.7899	0.8316	0.7875	0.8101	0.7994^a	± 0.0215
10	0.8070	0.8392	0.8113	0.8057	0.8235	0.8173^a	± 0.0141
12	0.8553	0.8322	0.8684	0.8398	0.8640	0.8519^b	± 0.0155
15	0.8727	0.8942	0.7679	0.8328	0.8570	0.8449^b	± 0.0485

Different letters $^{(a,b)}$ denotes statistically significant difference, α = 0.05.

By comparison of those shape factors in relation with selected working speed of seeding machinery (Fig. 3) it can be concluded and determine the most suitable speed of seeding machinery from the perspective of distribution uniformity of seeds in horizontal direction (Griepentrog et al., 2005a; Griepentrog et al., 2005b).

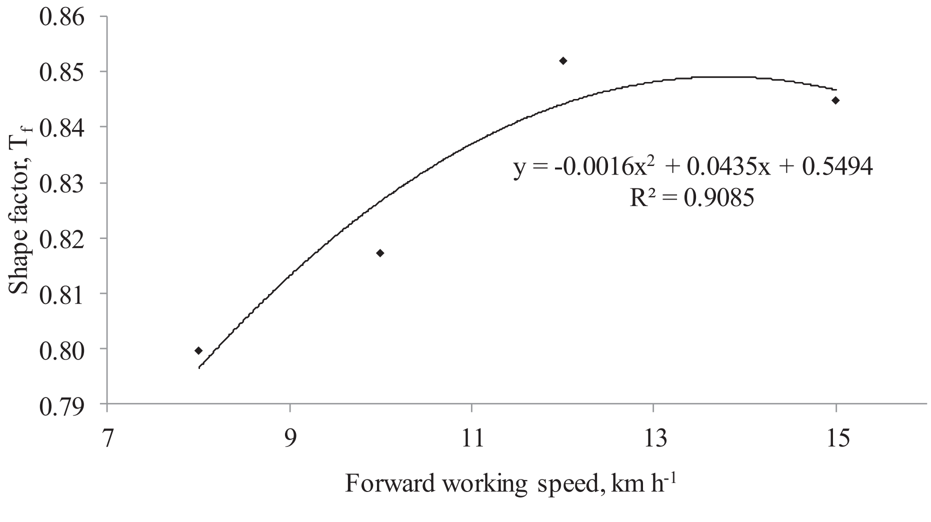

Figure 3. Forward speed effect of drill machine on the values of the shape factor.

The most suitable values of shape factor T_f (0.8519) was recorded for speed of drill machine set on 12 km h^{-1}. For other tested speeds 8, 10, 15 km h^{-1} were recorded lower values of shape factor 0.7994, 0.8173 and 0.8449, respectively. This phenomenon represents that decreasing and increasing values of drill machinery speed (below and over 12 km h^{-1}) results in decreasing T_f value which therefore means the lower work quality of seeding machinery assembly. The effect of operation speed of drill machinery on seeds placement was also observed by Nørremark et al., 2007 in their study. It was also pointed out that inclusion of seeders altitude data in the data processing significantly improved the accuracy of the estimation of geo-referenced plant positions and therefore it was concluded that a dual axis tilt sensor should be a required part of the instrumentation. Furthermore, it was shown that high accuracy of the estimation of geo-referenced plant positions required a zero horizontal velocity of the seed released from the seeding mechanism. In general, the overall accuracy of the estimation of geo-referenced plant positions was satisfactory to allow subsequent individual plant scale operations (Nørremark et al., 2007).

Also the average sizes of polygons were observed (Fig. 2). Based on the results obtained it can be concluded that increasing working speed resulted in increased average size of polygons up to 12 km h^{-1} and then is relatively stable till the speed of 14 km h^{-1} even has a gradual decreasing trend. There are some indications that this phenomenon is connected with physical attributes of individual seeds. Specifically, with increasing speed of drill machinery it gives to individual seed a different momentum which then affect final placement of seeds. This momentum then affect the distance where the individual seed is able to roll in row till finally placed. This rolling force is dependent on the shape of individual seeds, physical (e.g. dimensions, shape, and weight) and mechanical properties of individual seed (Ren et al., 2001). Perfect & McLaughlin (1996) also observed the effect of soil properties on final seed placement in the row.

As it was mentioned before, placement of the seed in produced polygon is also highly effected by eccentricity phenomenon (Griepentrog & Jørgensen, 2008) and therefore all of these variables have the final effect of T_f. As Krzaczek et al. (2006) concluded, working speed of seeders affects the quality of sowing procedure due to its high impact on the precision of seed distribution in a row. This phenomenon could be also explained by non-ideal feeding of sowing mechanism which works on the gravity basics (Turan et al., 2014).

Results of biomass production

The samples of biomass yield were harvested in full ripeness of plants straight before harvest of whole crop (Fig. 4). The samples (ale 1 m^2) were harvested from the same locations where the digital pictures were taken for the evaluation of shape factor (T_f) in above chapter. The samples were analysed (Table 2) and values represents fresh biomass before drying process. Moisture content of grains and for all samples taken was determined at 15% ± 0.5%.

An above-ground portion of plants was cut roughly 10 cm above ground. Every sample was collected individually for all of selected drill machine speed 8, 10, 12 and 15 km h^{-1}. Samples were taken in 10 replications. For evaluation of samples it was needed do separate ears from straw and subsequently grain from straw. Efficient threshing was performed manually.

Figure 4. Biomass samples – harvested from 1 m^2.

In determination of biomass production for drill machine speed 12 km h^{-1} the greatest yield from 1 m^2 was observed (Table 2 and Fig. 4). Subsequently, for speeds 8 and 10 km h^{-1} was lower about 4.26% and 1.83%, respectively. For tested speeds of drill machinery 15 km h^{-1} and above was observed only a small descent of yields about 0.6%. Fluctuation in yields affected by working speed then demonstrates fluctuation in sowing rate. In this case it means negative performance. Also Guberac et al. (2000) suggested the same phenomenon which was later supported by Carr et al. (2003a; 2003b) and finally proved by Schillinger (2005).

Table 2. Forward working effect of speed of the drill machine on the biomass yield, *n = 10*

Parameter	*Unit*	*Values* (± *s.d.*)			
Speed of the drill machine	km h^{-1}	8	10	12	15
Average weight of the sample	g m^{-2}	1,570^a ± 4.01	1,610^b ± 3.30	1,640^c ± 6.39	1,630^c ± 4.18
Average weight of the straw	g m^{-2}	650^a ± 7.76	630^a ± 5.70	590^b ± 6.43	570^b ± 4.75
Average weight of the weight of ears	g m^{-2}	920^a ± 2.07	980^a ± 5.89	1,050^b ± 8.32	1,060^b ± 7.58
Average weight of the grains	g m^{-2}	760^a ± 6.35	786^a ± 4.43	810^b ± 6.18	805^b ± 4.13

Different letters $^{(a,b,c)}$ denotes statistically significant difference, α = 0.05.

In the whole experiment there was observed an unbalanced number of (seeds/plants) individuals in greater extent. The reason of unbalance in number of individuals (seeds/plants) could be affected also by the impact of seeds on soil during sowing process as also suggested Botta et al. (2010). In addition, individual seeds were falling very close to each other which results in insufficient space for plants growth and further development as it was stated by Maga et al. (2015). Working speed of drill machinery 15 km h^{-1} is not efficient even does not comply the conditions while it was observed that increasing working speed resulted in extrusion of sowing coulters which results into violations of necessary sowing depth.

As it is showed in Table 2 and Fig. 5, working speed of sowing machinery also affect the amount of yield directly. In addition, it was observed that for speed of drill machinery 15 km h^{-1} the average yield was 805 g from 1 m^2. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains. The conclusion that the working speed of drill machinery, quality of sowing and even sowing mechanism affects the individual plants performance and therefore final yields was also supported by various researchers in their studies, however by a different levels (e.g.: Arvidsson et al., 2000; Naresh et al., 2011; Kahloon et al., 2013).

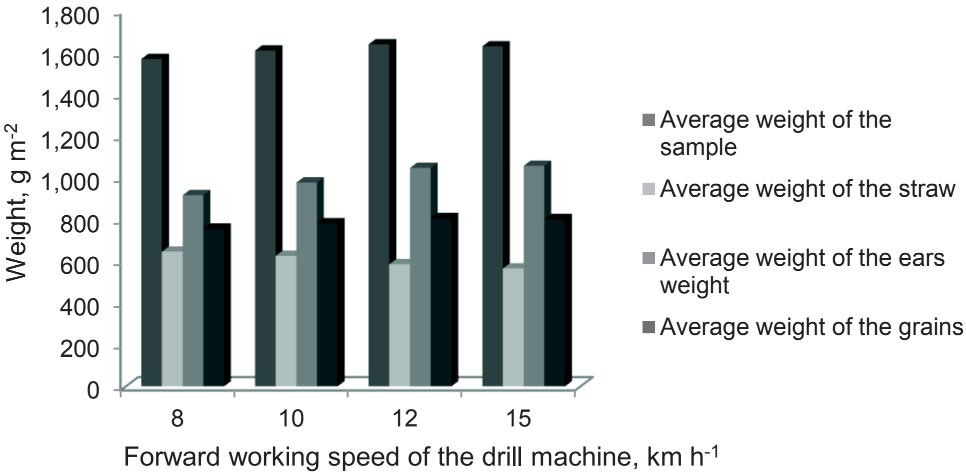

Figure 5. Relationship of yield (weight) of biomass (straw, ears and grains) and working speed of sowing machinery assembly.

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CONCLUSIONS

It can be concluded that the relationship between shape factor (T_f) and working speed of drill machinery was found. As an optimal value of shape factor is considered 0.952 however this value is not achievable in practice. In our experiment, the best possible values of shape factor were recorded for working speed of drill machinery 12 km h^{-1}. For lower and higher tested speeds the decrease in value of shape factor was observed. The lowest value of shape factor was recorded for working speed 8 km h^{-1} and working speed 15 km h^{-1} was found to be even not applicable due to violation of other requirements for quality of sowing process, e.g. sowing depth.

As it is apparent from the results, with increasing working speed of drill machinery the average size of polygons is also increasing until speed 15 km h^{-1} and then decrease by moderate trend. However, average size of polygon in dependence with working speed of drill machinery should not fluctuate because it result into fluctuation of specific amount of seeds for area unit which should be stable. This phenomenon could be caused by insufficient filling rate of sowing mechanism or insufficient seeds amount and following the lower gravitational force exerted by seeds on the sowing system.

In determination of biomass production was observed that working speed of drill machinery 12 km h^{-1} result in the highest yields from 1 m^2. Other tested speeds, 8 and 10 km h^{-1} resulted in decreased yields. In case of working speed 15 km h^{-1} was observed only small decrease in yields (0.6%) however other parameters of sowing quality was violated due to extrusion of sowing coulters from the soil.

It was also observed that the working speed of sowing machinery also affect the amount of yield directly. However, in case of lowest yield of straw recorded it was observed even 20% decrease in yield of grains.

REFERENCES

Andrew, I.K.S., Storkey, J. & Sparkes, D.L. 2015. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. *Weed Research* **55**(3), 239–248.

Arvidsson, J., Rydberg, T. & Feiza, V. 2000. Early sowing – A system for reduced seedbed preparation in Sweden. *Soil and Tillage Research* **53**(2), 145–155.

Bechar, A. & Vigneault, C. 2016. Agricultural robots for field operations: Concepts and components. *Biosystems Engineering* **149**, 94–111.

Bechar, A. & Vigneault, C. 2017. Agricultural robots for field operations. Part 2: Operations and systems. *Biosystems Engineering* **153**, 110–128.

Blackmore, B.S., Fountas, S., Gemtos, T.A. & Griepentrog, H.W. 2009. A SPECIFICATION FOR AN AUTONOMOUS CROP PRODUCTION MECHANIZATION SYSTEM. *Acta Hort. (ISHS)* **824**, 201–216.http://www.actahort.org/books/824/824_23.htm

Botta, G.F., Tolon-Becerra, A., Lastra-Bravo, X. & Tourn, M. 2010. Tillage and traffic effects (planters and tractors) on soil compaction and soybean (Glycine max L.) yields in Argentinean pampas. *Soil and Tillage Research* **110**(1), 167–174.

Carr, P.M., Horsley, R.D. & Poland, W.W. 2003a. Tillage and seeding rate effects on wheat cultivars: I. Grain production. *Crop Science* **43**(1), 202–209.

Carr, P.M., Horsley, R.D. & Poland, W.W. 2003b. Tillage and seeding rate effects on wheat cultivars: II. Yield components. *Crop Science* **43**(1), 210–218.

Findura, P., Jobbágy, J. & Simoník, J. 2005. Evaluation of sowing quality during sugar beet establishment. *Acta technologica agriculturae* **8**(4), 85–88 (in Slovak).

Findura, P., Maga, J., Jobbágy, J. & Ponjičan, O. 2006. The effect of sowing method on biomass production. *Acta technologica agriculturae* **9**(3), 75–78 (in Slovak).

Callaway, M.B. 1992. A compendium of crop varietal tolerance to weeds. *American Journal of Alternative Agriculture* **7**(4), 169–180.

Griepentrog, H.W. 1999. Zur Bewertung der Flächenverteilung von Saat gut. *Agrartechnische Forschung* **5**(2), 117–124.

Griepentrog, H.W. & Jørgensen, H. 2008. Update and expand the scope of Biosystems Engineering programs of studies placing emphasis in the areas of bio-fuels, bio-materials and quality of products in Denmark. In: *2nd Workshop - Education and Research in Biosystems or Agricultural and Biological Engineering in Europe (ERABEE)*, Dublin, Ireland, 13.10.2008, available at the web: http://www.erabee.aua.gr/publications.

Griepentrog, H.W. & Nørremark, M. 2001. Bestandesführung mittels kartierter Pflanzen Positionen In: *Proceedings VDI Verlag*, Düsseldorf, Germany pp. 285–290.

Griepentrog, H.W., Nørremark, M., Nielsen, H. & Blackmore, B.S. 2005a. Seed mapping of sugar beet. *Precision Agriculture* **6**(2), 157–165.

Griepentrog, H.W., Skou, P.T., Soriano, J.F. & Blackmore, B.S. 2005b. Design of a seeder to achieve highly uniform sowing patterns. In: *5th European Conference on Precision Agriculture, ECPA 2005*, Uppsala, Sweden, 9 June 2005 through 12 June 2005, pp. 675–682.

Guberac, V., Martincic, J., Maric, S., Bede, M., Jurisic, M. & Rozman, V. 2000. Grain yield components of winter wheat new cultivars in correlation with sowing rate. *Cereal Research Communications* **28**(3), 307–314.

Hanzlik, K. & Gerowitt, B. 2011. The importance of climate, site and management on weed vegetation in oilseed rape in Germany. *Agriculture, Ecosystems and Environment* **141**(3–4), 323–331.

Heege, H.J. & Feldhaus, B. 1997. On the go control of seeds per unit area for grain drills. In: *Proceedings of the 1997 ASAE Annual International Meeting. Part 1 (of 3)*, Minneapolis, MN, USA, 10 August 1997 through 14 August 1997, Volume 1, 12 p.

Jha, P., Kumar, V., Godara, R.K. & Chauhan, B.S. 2017. Weed management using crop competition in the United States: A review. *Crop Protection* **95**, 31–37.

Jiang, G., Wang, Z. & Zhao, C. 2013. An algorithm of detecting crop rows based on known-points. *Yingyong Jichu yu Gongcheng Kexue Xuebao/Journal of Basic Science and Engineering* **21**(5), 983–990.

Jobbágy, J., Simoník, J. & Findura, P. 2007. Evaluation of the spatial variability of soil texture on selected field. *Acta technologica agriculturae* **10**(3–4), 69–72 (in Slovak).

Kahloon, M.H., Iqbal, M.F., Farooq, M., Ali, L., Fiaz, M. & Ahmad, I. 2012. A comparison of conservation technologies and traditional techniques for sowing of wheat. *Journal of Animal and Plant Sciences* **22**(3), 827–830.

Kashyap, R.L., Chellappa, R. & Chellappa, R.1983. Estimation and Choice of Neighbors in Spatial-Interaction Models of Images. *IEEE Transactions on Information Theory* **29**(1), 60–72.

Korres, N.E., Norsworthy, J.K., Tehranchian, P., Gitsopoulos, T.K., Loka, D.A., Oosterhuis, D.M., Gealy, D.R., Moss, S.R., Burgos, N.R., Miller, M.R. & Palhano, M. 2016. Cultivars to face climate change effects on crops and weeds: a review. *Agronomy for Sustainable Development* **36**(1), 1–22.

Korres, N.E. & Fround-Williams, R.J. 2004. The interrelationships of winter wheat cultivars, crop density and competition of naturally occurring weed flora. *Biological Agriculture and Horticulture* **22**(1), 1–20.

Krzaczek, P., Szyszlak, J. & Zarajczyk, J. 2006. Assessment of the influence of selected operating parameters of S071/B KRUK seeder on seeding Sida hermaphrodita Rusby seeds. *International Agrophysics* **20**(4), 297–300.

Maga, J., Nozdrovicky, L. & Macak, M. 2015. Effect of drilling quality on biomass yield. *Agricultural Engineering International: CIGR Journal* **2015**, 234–240.

Naresh, R.K., Gupta, R.K., Gangwar, L.K., Kumar, A., Singh, P.K. & Tomar, S.S. 2011. Wheat cultivars and nitrogen placement on yield and yield contributing characters of wheat in relation to resource conservation technologies. *Plant Archives* **11**(2), 665–671.

Nørremark, M., Søgaard, H.T., Griepentrog, H.W. & Nielsen, H. 2007. Instrumentation and method for high accuracy geo-referencing of sugar beet plants. *Computers and Electronics in Agriculture* **56**(2), 130–146.

Okabe, A., Satoh, T., Furuta, T., Suzuki, A. & Okano, K. 2008. Generalized network Voronoi diagrams: Concepts, computational methods, and applications. *International Journal of Geographical Information Science* **22**(9), 965–994.

Perfect, E. & McLaughlin, N.B. 1996. Soil management effects on planting and emergence of no-till corn. *Transactions of the American Society of Agricultural Engineers* **39**(5), 1611–1615.

Ramseier, D. & Weiner, J. 2006. Competitive effect is a linear function of neighbour biomass in experimental populations of Kochia scoparia. *Journal of Ecology* **94(**2), 305–309.

Ren, L.-Q., Tong, J., Li, J.-Q. & Chen, B.-C. 2001. Soil adhesion and biomimetics of soil-engaging components: A review. *Journal of Agricultural Engineering Research* **79**(3), 239–263.

Rusu, T., Gus, P., Bogdan, I., Moraru, P.I., Pop, A.I., Clapa, D., Marin, D.I., Oroian, I. & Pop, L.I. 2009. Implications of minimum tillage systems on sustainability of agricultural production and soil conservation. *Journal of Food, Agriculture and Environment* **7**(2), 335–338.

Schillinger, W.F. 2005. Tillage method and sowing rate relations for dryland spring wheat, barley, and oat. *Crop Science* **45**(6), 2636–2643.

Torres, G.M., Koller, A., Taylor, R. & Raun, W.R. 2017. Seed-oriented planting improves light interception, radiation use efficiency and grain yield of maize (Zea mays L.). *Experimental Agriculture* **53(**2), 210–225.

Turan, J., Višacki, V., Mehandžic, S., Findura, P., Burg, P. & Sedlar, A. 2014. Sowing quality indicators for a seed drill with overpressure. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **62**(6), 1487–1492.

Turan, J., Višacki, V., Sedlar, A., Pantelić, S., Findura, P., Máchal, P. & Mareček, J. 2015. Seeder with different seeding apparatus in maize sowing. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **63**(1), 137–141.

Tüceryan, M. & Jain, A.K. 1990. Texture Segmentation Using Voronoi Polygons. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **12**(2), 211–216.