Using satellite navigation for seeding of wide-row and narrow-row crops

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Abstract

Macák M., Žitňák M., Nozdrovický L., 2011. **Using satellite navigation for seeding of wide-row and narrow-row crops**. Res. Agr. Eng., *57 (Special Issue)*: S7–S13.

The present paper is aimed at the use of satellite navigation of field machinery during seeding, this operation belonging to the most important field practises. Our attention was focused on the determination of the accuracy of the satellite navigation system based on using the correction signal real-time kinematic and its correct application for planting a wide-row crop (sunflower) and seeding a narrow-row crop (spring barley). The aim of the field experiment was also to specify the level of the necessary accuracy of satellite navigation systems during planting and seeding. The length of seeding/planting equipment was confronted with the accuracy of navigation of individual passes, especially when turning on the headlands. In the conclusion, the importance is highlighted of the automated tractor headland control during satellite navigation of combined field machines in the crop production.

Keywords: precision farming; satellite navigation; accuracy; quality of seeding

In the context of increasing competitiveness on the open European market, the farmers have currently to face an important requirement – to increase the production efficiency of field products. Among the tools that can match such requirement, the field guidance systems are considered. Tillett (1991) nearly twenty years ago tried to classify automatic guidance sensors for agricultural field machines. Zuydam et al. (1994) have conducted test of an automatic precision guidance system used for guidance of cultivation implements. Fulton et al. (1999) analysed a variable-rate spinner spreader, equipped with DGPS and a variable rate control system to assess its distribution accuracy using a 13 by 13 matrix of collection pans and following the test procedures outlined in ASAE Standard S341.2. They performed uniform and variable rate tests to characterise the application variability of the spreader and test the effect of the rate changes via GPS control. From the collected data, a uniform and a variable rate application models were developed. The authors found that the models can be considered as an efficient tool for projecting the actual application rates for the uniform and variable-rate applications. The quality of the fertiliser application depends upon the accuracy of the guidance system used. Ehsani et al. (2002) studied important issues related to testing and comparing the guidance systems which they defined and explained, and a method of evaluating GPS guidance systems while following a straight line was introduced. According to their results, comparing the performance of the guidance systems with a real-time kinematic (RTK) GPS is the easiest method and probably the most accurate way of field-evaluating guidance systems. The advantage of this method is that it reflects the overall performance of a guidance system on the

The paper reflects the results obtained within the research, Project NFP No. 26220220014: „Application of the information technologies to increase the environmental and economical sustainability of the production agrosystem (Activity 3.1 Creation of the department of transfer of innovative technologies to the practice)“ (OPVaV– 2008/2.2/01-SORO).

farm and the results can be used directly by the end user. It is possible to agree with Fadel (2004), who stated that, due to the environmental concerns in addition to economical considerations, the variable rate of fertilisers is widely applied in the agriculture. Granular fertilisers broadcasting is one of the most growing applications employing variable rate technologies (VRT) and GPS guidance technologies. Such systems are commercially produced. For the performance assessment ASAE Standard S341.2 can be used which provides a standard procedure for broadcasters performance testing. Anyway, this standard does not cover the testing of broadcast spreaders used within the variable-rate technology. According to Griffin (2009), the use of the guidance systems to guide the farm machines during their work on the field brings several benefits including the reduction in overlap, increased working speed during the field operations, workday expansion, and appropriate placement of spatially sensitive inputs. During recent years, many researchers studied different effects of using the guidance systems in view of accuracy, economical efficiency, etc. Lawrence and Yule (2007), developed a model within a geographic information system (GIS) environment using the transverse spread pattern and GPS driving track during spreading to map the actual fertiliser application at any point in a paddock. The spreading vehicle required a GPS of sufficient accuracy to provide the proof of placement and guidance assistance to the driver. The method was used to assess the effects of the field size and shape on the actual application rate and application variation. Macák et al. (2009) developed a methodology for the evaluation of the accuracy of the satellite machine guidance for fertiliser application in the field conditions. According to Macák, Žitňák (2010), this methodology was practically used for the evaluation of satellite guidance accuracy with centrifugal and pneumatic fertiliser spreader, and minimal accuracy requirements were determined.

Ehsani et al. (2004) investigated the potential use of RTK GPS receiver for seed mapping with a high level of accuracy. Their hypothesis was based on the presumption that high-accuracy seed mapping can be potentially used in the weed control and plant-specific crop management. Findura and Maga (2006) stated that the accuracy of the seeding machine passes during the seeding operation significantly affects the crop establishment and subsequently also the yield of the field crop. The use of the field guidance systems has some specific economical consequences, and therefore Griffin et al. (2008) and Griffin (2009) used a linear programming model to compare 5 types of the guidance system:

(1) a baseline scenario with foam, disk, or other visual marker reference,
(2) lightbar navigation with basic GPS availability (+/–0.3 m accuracy),
(3) lightbar with satellite subscription correction GPS (+/–0.1 m),
(4) automated guidance with satellite subscription (+/–0.1 m),
(5) automated guidance with a base station RTK GPS (+/–0.01 m).

The results obtained indicate that RTK automated guidance becomes the most profitable alternative when farm size is increased while maintaining the same equipment set. The results also indicate that the relative profitability ranking is sensitive to years to depreciate the technology.

The specific objectives of this research were:

– to verify the function of the navigation system Trimble EZ Guide 500 RTK (Trimble Navigation, Ltd., Sunnyvale, USA) based on using the correction signal RTK for planting a wide-row crop (sunflower) and seeding a narrow-row crop (spring barley),
– to test the effect of the length of the combined field machine (rotary harrow + seeding machine) on the accuracy of navigation during the field operation.

MATERIAL AND METHODS

The field experiments were conducted on the Cooperative farm in Vrable, district Nitra, Slovak Republic. The satellite navigation systems were used for the guidance of the tractor-machine set used in sunflower planting and spring barley seeding.

Characteristics of the machine used in the experiments

The experiments were focused on the measurement of the guidance accuracy during the field operation when the seedbed preparation was combined with the seeding. For this operation, we used a tractor John Deere 7820 (John Deere Tractor Works, Waterloo, USA) (with dual tyres on the rear axle) and combined machines (Table 1).

a) for sunflower planting:
rotary harrow Amazone KG 452 (Amazonen-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany) with vertical tines driven by power take-off shaft and a horizontal compacting roller,
precision planter Kuhn Planter 2 (Kuhn S.A., Saverne, France) with a unit allowing the application of granular fertilizer containing nitrogen, phosphorus and potassium and micro-granules,
b) for spring barley seeding:
rotary harrow Amazone KG 452 + tyre roller,
drill seeder Amazone AD 452 (Amazonen-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany).

The above combined machines were assembled directly on the farm.

The planter Kuhn Planter 2 and drill machine Amazone AD 452 (Table 2) were equipped with mechanical markers used only on the field headlands in order to obtain more accurate guidance for the next pass without skips as the field was cultivated in runs parallel to one another (one way pattern). The machine started to move at one boundary of the field and ended on the opposite side with turns being made on the headlands.

In ordinary conditions (using the satellite navigation system with the autopilot), there would have been no need to use markers. In our case, the markers were used due to insufficient experience of the operator.

Characteristics of the navigation system with autopilot used in the experiments

During seeding, the satellite navigation system Trimble EZ Guide 500 RTK (Trimble Navigation, Ltd., Sunnyvale, USA) with the autopilot was used. The system consisted of the following parts:
a) ightbar with the colour monitor and control unit EZ Guide 500,
b) receiver of the satellite and correction signals,

Table 1. Specifications of the tractor John Deere 7820

Parameter	Value
Engine power (ECE-R24) (kW)	147
Number of gears (F/R)	20/20
Number of cylinders/displacement (–/cm^3)	6/6,780
Max. forward speed (km/h)	50
Power-take-off shaft (rpm)	540/540E or 1000/1000E
Max. lift capacity of hydraulic (kN)	90

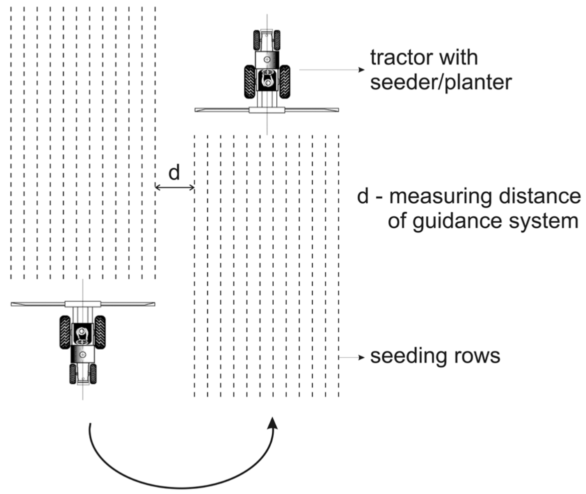

Fig. 1. Principles of measuring the navigation accuracy in the inter-rows by using the metric measure

c) control unit,
d) electric stepper motor EZ-Steer T2.

Principle of measuring the accuracy of the satellite navigation RTK during seeding

During experiments, we used a guidance system using the correction signal RTK with the accuracy ±2.5 cm. The method used for measuring the guidance accuracy should be highly accurate in order to reduce the measurement error. We tried to use a laser range-finder (distance meter) but after some experience we decided to use a new method. This method was based on measuring the distance between the outer rows of the crop after the crop emergency. The first planter/seeder pass was marked with a wooden peg. As we knew the number of the planter/seeder rows, it was sufficient to find the wooden peg marking the first pass. Then, the next passes were identified according to the number of the crop rows. In the inter-row area between the neighbouring passes, we measured the distance between the individual plants during the machine navigation. For the measuring, we used the metric measure (Fig. 1).

The required (theoretical) row spacing was given by agronomy requirements related to the given crop. The final values of the skips and overlaps were calculated using the difference between the measured values and the row spacing required for the given crop.

The row spacing for sunflower was 75 cm and for spring barley 12.5 cm. Statistical data processing

Table 2. Basic specifications of the used machines

Parameter	Value
Vertical rotary harrow	Amazone KG 452
Working width (m)	4
Requested tractor power (kW)	140
Type of drive	Tractor PTO
Machine weight (kg)	1,500
Precision planter	Kuhn Planter 2
Number of seeding units	6
Weight of planting unit (kg)	55
Hopper capacity (l)	25
Row spacing (cm)	38–80
Seeding drill	Amazone AD 452
Working width (m)	4.5
Number of rows (–)	36
Row spacing (cm)	12.5

was done using the analytical module spreadsheet MS Excel 2003 and also by software Statistica 6.0 (StatSoft CR, Ltd., Prague, Czech Republic).

RESULTS

Using the given methodology, we conducted the measurements of the guidance accuracy of the tractor-machine sets:

– tractor John Deere 7820 + rotary harrow Amazone KG 452 + horizontal compacting roller + planter Kuhn Planter 2 for sunflower precision planting,
– tractor John Deere 7820 + rotary harrow Amazone KG 452 + tyre roler + drill seeder Amazone AD 452 for spring barley seeding.

Table 3. Basic parameters of descriptive statistics of measured deviations of the satellite navigation with the RTK correction signal

Statistical parameter	Calculated value	
	sunflower planting	spring barley seeding
Average (cm)	2.76	2.62
Error of average value (cm)	0.224	0.231
Median (cm)	2.5	2.5
Mode (cm)	1	1.5
Minimum (cm)	0	0
Maximum (cm)	7.5	7.5
Sum (cm)	191	170.5
Number of values	69	65

RTK – real-time kinematic

The guidance system Trimble EZ-Guide 500 with the correction signal RTK was used. For the evaluation of the guidance accuracy, the deviations were measured of the individual points from the ideal trajectory which was determined by the initial "zero pass". From the methodology point of view, the negative values represented the overlaps and the positive values represented the skips. For the correct evaluation of the results obtained, all data were *t*. In terms of a fair evaluation, all data obtained were converted to absolute values, which were further evaluated in a spreadsheet MS Excel 2003. The deviations measurements were done for two types of crops: sunflower (wide-row crop) and spring barley (narrow-row crop).

Bar graphs in Figs 2 and 3 present the distribution of the deviations during the sunflower planting and spring barley seeding. Table 3 present the basic descriptive statistics indicators, which were determined by statistical data analysis module in a spreadsheet MS Excel 2003.

During sunflower planting, the average value of the deviations was 2.76 cm (total number of measurements was 69). 52.2% of the values were found in the interval from 0 to 2.5 cm, and 88.5% of the values were found in the interval from 0 to 5 cm.

During spring barley seeding, the average value of the deviations was 2.62 cm (total number of measurements was 65). 66.15% of the values were found in the interval from 0 to 2.5 cm, and 89.23% of the values were found in the interval from 0 to 5 cm.

For both crops, maximal value of deviation found was 7.5 cm. Histograms of the measured deviations are shown in Figs 2 and 3.

According to the navigation system producer, the navigation accuracy is ±2.5 cm the producer guarantees such accuracy for parallel passes within 15 min. The average values of deviations found in our measurements were higher by 0.12–0.26 cm. It is possible to state that within the guaranteed range from 0 to 2.5 cm, only a few data were located which did not reach the statistically significant level. When analysing the range 0–5 cm, we achieved in both cases a high proportion of the measured deviations, which approached 90%. Thus, we can conclude that the satellite navigation using the autopilot works correctly in view of the basic agro-

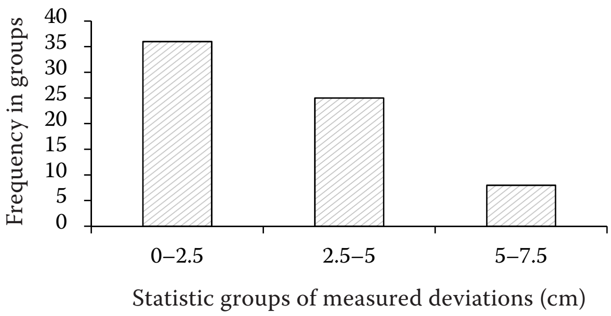

Fig. 2. Frequency distribution bar chart presenting the deviations of the satellite navigation with the RTK correction signal (planting of sunflower)

nomic requirements. In the next step, we analysed the insufficient proportion of the measured values within the range 0–2.5 cm and the reasons for such results. After the consultations with the production manager, we found out that as the main reason could be considered the action of the clearance of the clamping of the three-point hitch. There was also an adverse effect of the articulated joint between the rotary harrow and the planter/seeder as a combination for tillage and seeding. The angle of the swing of the low arms of the three-point hitch matched the requirements and the clearance of the three-point hitch clamping was small. For the total length of the combined machine (6.5 m), even a small angle of swing was sufficient to deflect the side seeding units for 5–8 cm.

As the field where the seeding experiments were conducted was almost completely flat (with maximal slope 0.5° in some marginal areas), the effect of the clearance of the three-point hitch clamping was not very evident. When working on the fields with a higher slope, the inaccuracy was much higher. The slope effect can be compensated by changing the driving direction so that the machine should be more inclined in the longitudinal direction than in the transverse direction. On the basis of the experience gained, we recommend not to use long combined machines when satellite navigation guidance systems with RTK are used. It is also necessary to reduce the mechanical clearance between the linked machines. The length of the combined machines (6.5 m), has also an adverse effect when starting a new pass on the field headland. Small skip areas having a triangular shape have occurred (Fig. 4). This phenomenon was best observed first of all in the case of spring barley but also in the case of the wide-row crop – sunflower. The length of skips varied from 6–32 m and their initial width on the side nearer to the field border varied from 25 to 75 cm. The skips where the seed was not applied occurred during the run-out of the machine when the machine after completing the turn on the headland was directed to the approximate direction for the next parallel pass.

During the machine start-up, it was necessary to engage the correct gear, to lower the rotary harrow to the requested depth, to engage the power-take-off (PTO), to lower the seeding units to the working position, to switch on the fan, and finally to activate the autopilot for it to start to guiding the machine accurately in the requested direction. All these operations had to be done during the machine movement, and it was necessary at the same time to navigate the tractor in order to reach the next parallel pass as accurately as possible. The machine operator tried to make all these operations easier by indicating the axis parallel to the next drive with a mechanical marker, which was mounted on the drill. The marker was activated manually from the cab on the headland in the distance of 20–40 m from the field boundary. Such solution was not sufficient from our point of view, thus the headland management system (HMS) was used which greatly reduces the operator's fatigue in row-cropping and tillage applications through the automatic sequencing of the tractor functions normally associated with headland turns. HMS was programmed to control the following tractor functions: mechanical front-wheel drive on/off, rear PTO on/off and hitch raise/lower.

In the case of HMS not being available on the tractor, it is necessary at the beginning to engage a lower gear to set the tractor in motion on a lower forward speed. This will give the operator more time to carry out all operations manually. The activation of the autopilot should be done as the first step as the machine must be correctly navigated

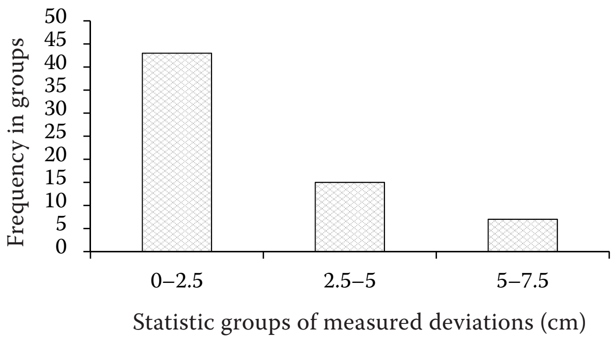

Fig. 3. Frequency distribution bar chart presenting the deviations of the satellite navigation with the RTK correction signal (seeding of spring barley)

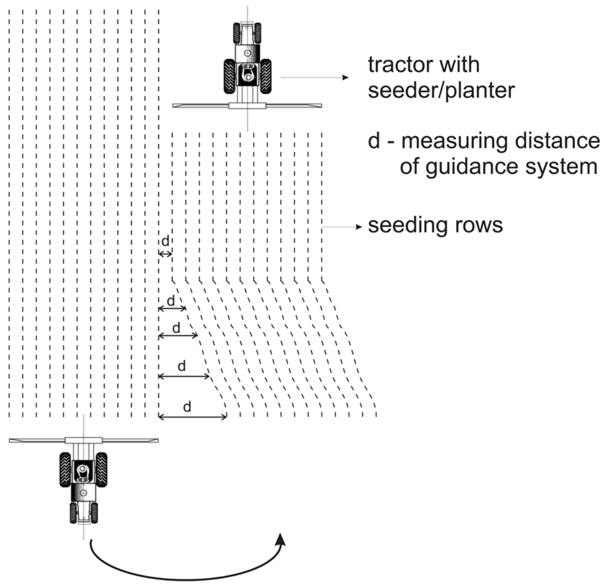

Fig. 4. Skips area of the field near the headland (the area of the field without seeding) – emerged crop stand of spring barley

from the field boundaries and the operator has time enough to control the tractor/machine functions in the correct order. In the next step, it is possible to increase the working speed to the level required.

In Fig. 5 are Box-and-Whisker diagrams to show the spread of the data. The diagrams show the quartiles of the data, using these as an indication of the spread of deviations (skips and overlaps) from the ideal machine trajectory when planting/seeding both crops. The diagrams also display the upper quartile, lower quartile, and inter-quartile ranges of the data set. It can be seen in the diagrams that among the data obtained, there were no extreme values (outliers), which could have been caused either by the measurement error or a failure of the correction and satellite signals. Regarding the planting of sunflower, the medium was on the level of 0 cm. As it can be seen from Fig. 5b, the value of median reached the level of 0.5 cm during spring barley seeding and it means that the difference between the seeding of both crops was small.

On the basis of the results obtained, we can state that, if there is the same number of deviations above and below the value of the median, we can confirm that the guidance navigation system has the same tendency to create skips and overlaps in the ideal trajectory.

The negative values represent the overlaps of the working widths while the positive values represent the skips. That means that if the row spacing was 12.5 cm and we measured 14.5 cm, the skip value was 2 cm.

In the case of spring barley seeding (Fig. 5b), the value of the lower quartile (25%) was at the level of –2.5 cm and that of the upper quartile (75%) was at the level of 2.5 cm. According to these data, we can state that there were 50% of the data within the range ±2.5 cm. In the case of sunflower planting (Fig. 5a), the values of the lower and the upper quartiles were on the level from –2.5–3.0 cm.

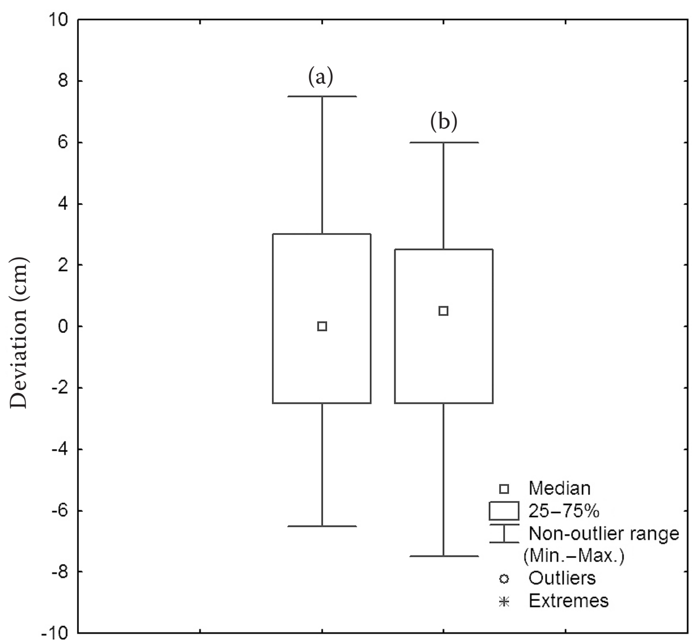

Fig. 5. Box-and-Whisker diagram of a deviations from ideal trajectory
(a) sunflower planting, (b) spring barley seeding

CONCLUSIONS

We can state that the use of the satellite navigation system with the RTK correction signal is suitable for the planting of wide-row crop (sunflower) and seeding of narrow-row crop (spring barley). The accuracy and work quality claimed by the manufacturer (deviation ±2.5 cm) were observed only with minor deviations. The average value of deviation was 2.76 cm with sunflower planting and 2.62 cm with spring barley seeding. The above deviations were caused due to the clearance in the articulated joint between the rotary harrow and seeder/planter, which created one unit – combined machine. In view of the agronomy requirements for wide-row crops planting and narrow crops seeding, the accuracy of the satellite navigation at the level of ±5 cm is sufficient.

On the basis of the results obtained, we recommend to join the seeder/planter only with a tractor. The creation of combined machines is connected with the occurrence of clearances in joints which cause the deviations in the machine trajectory, especially when working on the slope.

There may be cases needing to use a combined machine together with the satellite navigation with automatic machine control. From the point of view of the process technology, it is necessary in such cases to use a tractor with the automatic HMS. If the HMS in not available on the tractor, it is necessary to use the above mentioned procedure.

References

Ehsani M.R., Sullivan M., Walker J.T., Zimmerman T.L., 2002. A Method of Evaluating Different Guidance Systems. St. Joseph, ASAE Paper No. 021155.

Ehsani M.R., Upadhyaya S.K., Mattson M.L., 2004. Seed location mapping using RTK GPS. Transactions of the ASABE, *47*: 909–914.

Fadel M.A., 2004. Performance assessment of VRT-based granular fertilizer broadcasting systems. CIGR e-Journal, *6*: 1–12.

Fulton J.P., Shearer S.A., Chabra G., Higgins S.G., 1999. Field Evaluation of a Spinner Disc Variable-Rate Fertilizer Applicator. Toronto, ASAE Paper No. 991101.

Findura P., Maga J., 2006. Vplyv spôsobu sejby na tvorbu biomasy (Effect of seeding technology on the biomass creation). Acta Technologica Agriculturae, *3*: 75–78.

Griffin T., 2009. Whole-farm Benefits of GPS-enabled Navigation Technologies. St. Joseph, ASABE.

Griffin T.W., Lambert D.M., Lowenberg-Deboer J., 2008. Economics of GPS-enabled navigation technologies. In: Proceedings of the 9th International Conference on Precision Agriculture, July 21–23, 2008. Denver, USA.

Lawrence H.G., Yule I.J., 2007. A GIS methodology to calculate in-field dispersion of fertilizer from a spinning-disc spreader. Transactions of the ASABE, *50*: 379–387.

Macák M., Žitňák M., 2010. Efektívne využitie satelitnej navigácie v systéme presného poľnohospodárstva (Effective using of satellite guidance in precision farming system). 1st Ed. Nitra, SUA in Nitra: 124.

Macák M., Nozdrovický L., Krupička J., 2009. Vplyv fyzikálno-mechanických vlastností priemyselných hnojív na funkciu rozhadzovačov z pohľadu požiadaviek presného poľnohospodárstva (Effect of physical and mechanical properties of the fertilizers from the point of view of precision farming requirements). 1st Ed. Prague, Czech University of Life Sciences: 209.

Tillett N.D., 1991. Automatic guidance sensors for agricultural field machines: A review. Journal of Agricultural Engineering Research, *50*: 167–187.

Zuydam R., Van P., Sonneveld C., 1994. Test of an automatic precision guidance system for cultivation implements. Agricultural Engineering Research, *59*: 239–243.

Received for publication January 17, 2011
Accepted after corrections June 22, 2011

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