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Using real-time kinematic (RTK) global positioning system (GPS) for the determination of seedling distributions over the field

Davut KARAYEL¹, Mehmet TOPAKCI¹, Ilker UNAL², Egidijus ŠARAUSKIS³,
Murad CANAKCI¹

¹Department of Agricultural Machinery, Faculty of Agriculture, Akdeniz University
Antalya, Turkey

E-mail: dkarayel@akdeniz.edu.tr; mtopakci@akdeniz.edu.tr; mcanakci@akdeniz.edu.tr

²Bucak Hikmet Tolunay Vocational School, Mehmet Akif Ersoy University
Burdur, Turkey

E-mail: ilkerunal@mehmetakif.edu.tr

³Institute of Agricultural Engineering and Safety, Aleksandras Stulginskis University
Kaunas, Lithuania

E-mail: egidijus.sarauskis@asu.lt

Abstract

We investigated the potential use of real-time kinematic (RTK) global positioning system (GPS) to determine seedling distribution and plant growing area mapping by evaluating the obtained level of accuracy. High-accuracy seed and plant growing area mapping can potentially be used in the evaluations of seeding machine performance, weed control, and plant-specific crop management. Actual plant locations were determined using a measuring tape. Seedling locations, plant growing area, and shape ratio values were compared between RTK GPS and tape measurements. RTK GPS was shown to be reliable to monitor millimetre-level accuracy for seedling locations, as well as for generation of shape ratios and growing areas of cotton, soybean, and watermelon plants.

Key words: GPS, seeding, seed distribution, Voronoi polygon.

Introduction

The main objective of sowing is to put seeds at a desired depth and spacing within the row. An important criterion in evaluating seeding machine performance is seed distribution uniformity. A uniform distribution of seeds provides maximum space for each plant and increases yields due to the reduction of intra-specific competition (Heege, 1993). Also, weeds are suppressed due to complete crop canopies resulting from prevention of misses. The quality of horizontal and vertical distribution of seeds is influenced by row spacing, sowing depth, soil conditions, seeder design, seed density, and operator skill.

The mean spacing, the standard deviation of the spacing between plants, and the coefficient of variation are commonly used for describing seed distribution uniformity. These parameters of the seed spacing/location are useful but do not completely characterize the distribution of plant spacing for single-seed planters. The multiple index, the miss index, the quality of feed index, and the precision should be considered in addition to the mean and standard deviation of the seed spacing, because the distance between plants within a row is influenced by a number of factors including multiple seeds dropped at

the same time, failure of a seed to be dropped, failure of seeds to emerge, and the variability around the drop point (Kachman, Smith, 1995; Karayel et al., 2004).

Most procedures to describe seed distribution operate in one dimension, but conditions for plant development are described as two- or better three-dimensional problems. The disadvantage of one-dimensional parameters is that they do not directly include row width and seed density. Griepentrog (1998) presented a new method to describe the arrangement of plants in row crops by allocating a polygonal area of ground to each plant. This two-dimensional method requires a workable solution to the problem of determination of the coordinates of the seeds over the field. The possibility of using real-time kinematic (RTK) global positioning system (GPS) technology for the determination of two-dimensional positions of seedlings, as undertaken in this research, may resolve this problem. The GPS technologies provide improved resolution positioning, timing and location data, and are becoming lighter, more efficient, more reliable and adaptable for agriculture. For agricultural tasks like mechanical intra-row weed control or thinning of crop plants, a high level of geolocation

accuracy and precision is required. Research has been conducted to develop crop plant sensors for identification of individual plants in agricultural fields (e.g., Brown, Noble, 2005; Scotford, Miller, 2005; Slaughter et al., 2008). Most of the recent crop plant sensing research has focused on machine vision techniques but it has not been commercialized for precision (~1 cm range) intra-row plant mapping in agricultural applications. Common environmental factors such as leaf occlusion, leaf damage, missing plant structures and leaf twisting caused by wind present significant challenges to precision machine vision applications at this demanding level of performance (Nørremark et al., 2003; Ehsani et al., 2004; Sun et al., 2010; Verhulst et al., 2011). High georeferencing accuracy (~1 cm range) and precision is available using RTK GPS. For example, Abidine et al. (2004) demonstrated the application of RTK GPS autoguidance technology for precision inter-row cultivation and deep tillage operations in close proximity to buried drip-irrigation tubing (5 cm target distance between crop row or drip-tape and cultivation or tillage tools) without damage to crop plants or the drip-tape. Sun et al. (2010) demonstrated the feasibility of using a RTK GPS to automatically map the location of transplanted row crops. Field test results showed that the mean error between the plant map locations predicted by the planting data and the surveyed locations after planting was 2 cm, with 95% of the predicted plant locations being within 5.1 cm of their actual locations. Along-track errors were greater than transverse-track errors indicating that some improvement in plant map accuracy might be obtained by characterization of dynamic planting effects on final plant location. Overall, the system was capable of automatically producing a millimetre-level accuracy plant map suitable for use in precision plant care tasks such as intra-row weed control. Commercial RTK GPS autoguidance systems have generally been described as being capable of steering with precision errors of 25 mm or less from pass to pass in crop rows where the RTK GPS autoguidance system was used to form the beds (Leer, Lowenberg-DeBoer, 2004). To achieve this level of accuracy in practice for RTK GPS, a GPS base station must be located close (~10 km) to the mobile GPS used to control the tractor steering (Gan-Mor, Clark, 2001).

The objective of the research reported in this work was to investigate the effectiveness of RTK GPS technology to determine two-dimensional seed distribution uniformity over the field, as compared with the results from tedious manual measurements.

Materials and methods

The study was conducted in June 2009 at the Aksu Centre Unit of Bati Akdeniz Agricultural Research Institute. The dominant soil type of the larger part of this region is *Endohypogleyi-Eutric Fluvisol (FLe-gln-w)* according to FAO/UNESCO (1997). The soil, consisting of 15% sand, 55% silt, and 30% clay, was classified as silty clay loam. Cotton (*Gossypium hirsutum* L. var. 'Fantom'), soybean (*Glycine max* L. var. 'Ataem-7') and watermelon (*Citrullus lanatus* L. var. 'Crimson sweet') seeds were used for the experiments. The mean weights per thousand seeds of cotton, soybean and watermelon were 105, 124 and 49 g, respectively. Crop varieties were selected to suit the geographic region and site-specific conditions of the field plots.

A general-purpose tractor-drawn three row vacuum seeder, designed for row crops such as maize and cotton, was operated in all field treatments. Seeder metering vacuum plate was 230 mm in diameter, with holes drilled along a 200 mm diameter pitch circle. Metering holes in the vacuum plates were 3.5 mm in diameter for soybean and cotton and 2.5 mm for watermelon. Seed plates operated in a vertical plane. Air suction from the holes of a seed plate caused the seed to be attached to the holes. Attached seeds were released from the rotating plate by temporarily preventing airflow. This absence of suction allowed the seed to be dropped into the furrow in the soil. The seeder had no seed tube and the seed drop height (12 mm) was designed to reduce the chance of non-uniform spacing which can occur due to the bouncing of seed, if dropped from a high plane. The vacuum level was regulated by adjusting the size of an opening in the vacuum line of the seeder and measured with a manometer. The seeder was operated at a ground speed of 1 m s⁻¹. Seeder drive ratio was adjusted to deliver nominal in-row seed spacing of 105 mm for soybean, 170 mm for cotton, and 550 mm for watermelon. The emergence rates of maize, cotton and soybean seeds were 96, 95 and 91 % for laboratory and 91, 90 and 86 % for field conditions, respectively. A rear presswheel controlled the overall depth of the furrow opener to achieve desired depths for seed placement. The shoe-type furrow opener was adjusted to 50 mm for soybean and cotton sowing and 30 mm for watermelon sowing below the presswheel. Seeding depth was not a component of this study. Lateral movement of the seeder was possible due to tractor steering and soil forces.

A real-time kinematic (RTK) global positioning system (GPS) "Promark 500" ("Magellan", USA) was used to monitor seedling locations. The receiver has 75 channels and up to 20 Hz data output rate. It has multiple operating modes, configurations, communication modules (UHF, GSM/GPRS, EDGE), and protocols. It can be connected to Corse-TR (Continuously Operating Reference Stations, Turkey) via a telephone data card for receiving correction signals. The receiver has a 99% confidence interval. Accuracy of the position obtained varies (according to the manufacturer's data) within 10 mm with correction signals. The Receiver has RS-232, Bluetooth, and USB ports to allow NMEA 0183 data transfer to a computer.

After emergence of all seedlings, the location of each seedling was determined by RTK GPS using a handheld control unit interfaced to a rover RTK GPS and configured for surveying with the GPS antenna mounted on a 150 cm survey pole. The location of each seedling was determined by placing the lower tip of the pole against the seedling stem at the soil surface with the pole held vertical by aid of a bubble level. RTK GPS coordinates were transformed into actual coordinates using *NETCAD 5.0* ("Netcad Software", Turkey). The actual location of the each seedling was determined using a measuring tape, to the nearest 1 mm, in both the x and y directions.

The performance of the RTK GPS seed distribution mapping was evaluated by calculating the distances in the Easting (x) and Northing (y) directions between the RTK GPS mapped plant positions, $Q(x_i, y_i)$, and actual plant positions (using measuring tape), $P(x_i, y_i)$. For each seedling, the Euclidean distance (total error),

e_{QP} between the actual point P and the RTK GPS mapped location Q was determined by:

$$e_{QP} = \sqrt{(X_Q - X_P)^2 + (Y_Q - Y_P)^2} \quad (1).$$

The root mean square (RMS) displacement and standard deviation (SD) of error of Easting and Northing displacement were calculated for each plant in the trial.

The plant growing area and shape ratio for RTK GPS coordinates and actual coordinates of each seedling were calculated (as explained below) and compared. Independent sample t-tests were used to compare the plant growing area and shape ratio values calculated from RTK GPS with actual coordinates.

The plant growing area and shape ratio were analyzed using the methods described in Griepentrog (1998) and Karayel (2010). They presented a new two-dimensional method to describe the arrangement of plants in row crops by allocating a polygonal area, “plant growing area”, of ground to each plant. The new method characterizes plant competition for plant growing space better than one-dimensional methods, because it includes size and shape of plant growing area, main parameters of seedling distribution. Distribution of polygon size and shape ratio was analyzed to describe seedling distribution pattern. The shape ratio was a ratio between the circumference of a polygon and ideal circle centered on the seedling.

The Delaunay triangulation and its dual Voronoi diagram were used in the design of polygons. Polygons were formed by the perpendicular bisectors of the lines between plant coordinates (Fig. 1). The polygon around a plant includes all points in the plane which are closer to that plant than to any other. The polygon also defines the immediate neighbours of an individual. The saved RTK GPS and actual coordinates were processed with *MATLAB* (“MathWorks”, USA) in the design of Delaunay triangulation and its dual Voronoi diagrams. The area of each polygon was calculated using following m-file written in *MATLAB* software:

$[v,c] = \text{voronoin}(x)$, for $j = 1: \text{length}(c)$; $A = \text{polyarea}(v(c\{j\},1), v(c\{j\},2))$, end.

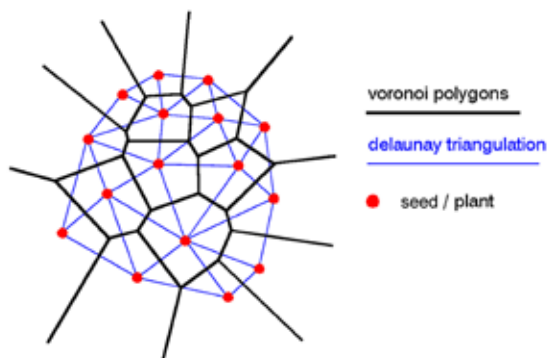


Figure 1. The construction of Delaunay triangulation and its dual Voronoi polygons (Griepentrog, 1998)

The polygon method produces a system of only convex areas. Therefore an even distribution over the area will create patterns which are merely an approach to ideal circular areas. A circular ground area is the ideal shape to be aspired for single plants in the plant populations.

The circumference of the ideal circular ground area is calculated by the polygon area. To qualify the

pattern by determining the deviation from ideal circles a mean value called shape ratio (r_{ort}) is defined (Griepentrog, 1998; Karayel, 2010):

$$C_{ideal} = 2\pi \sqrt{\frac{A_i}{\pi}} \quad (2),$$

$$r_{ort} = \frac{1}{n} \sum_{i=1}^n \frac{C_{ideal}}{C_{polygon}} \quad (3),$$

where C_{ideal} – circumference ideal, A_i – polygon area, $C_{polygon}$ – circumference real, r_{ort} – mean shape ratio.

Results and discussion

In total, an area of 0.5 hectare was sown, and when the seedlings had emerged, 750 soybean, cotton and watermelon seedlings were used for the analysis of deviations between measured plant positions, growing area and shape ratio using RTK GPS and tape meter (actual locations).

The data in Table 1 show the RMS displacement and SD values for Northing and Easting between the plant positions obtained with RTK GPS and manual measurements. The mean root mean displacement in the direction transverse to the driving direction (North/South) and longitudinal to the driving direction (East/West) was lower than 12 mm for all plants. The differences between plant mapping accuracy for Northing and Easting directions were not statistically significant. Because the RTK GPS was not mounted on planter, there were no dynamic effects, as reported by Ehsani et al. (2004) and Nørremark et al. (2007) who observed increased error in the along-track direction due to dynamic effects during planting.

Table 1. Geospatial seedling mapping performance of real-time kinematic (RTK) global positioning system (GPS)

Plant	Northing displacement mm		Easting displacement mm		Total error (e_{QP}) mm	
	RMS	SD	RMS	SD	Mean	SD
Soybean	11.81	10.01	9.53	8.56	9.67	8.84
Cotton	9.40	9.94	9.20	8.98	9.48	9.09
Watermelon	8.20	7.28	7.61	6.60	8.02	8.08

RMS – root mean square, SD – standard deviation

The RMS displacement for Northing and Easting directions for cotton and watermelon seedling locations was lower than 0.95 cm, which was superior to the results obtained by Nørremark et al. (2003) for a 24-h RTK GPS static trial yielding a RMS error of 0.95 cm. Row spacing and intra-row spacing of soybean was lower than for watermelon and cotton and therefore northing displacement, easting displacement and total error may have been higher.

The mean total error in plant map accuracy was less than 10 mm, as shown in Table 1, but this amount of error may indicate that a small systematic mapping error is present. Overall, use of the RTK GPS system provided plant-site/location maps suitable for determination of

the seedling distributions over fields for many precision plant care tasks including weed control.

The seedling locations and plant growing area maps generated from the RTK GPS coordinates and actual plant positions measured with tape meter are shown in Figures 2–4. Shapes of growing zones of all seedlings generated from RTK GPS and actual coordinates are visually similar. The shapes of growing

zones of watermelon plants generated from RTK GPS seem to be more similar to the shapes of growing zones generated from real coordinates, than for the other crops. Row spacing and intra-row spacing of watermelon was higher than for soybean and cotton and therefore the effect of error in plant map accuracy on the shape of growing zones of watermelon plants may have been lesser.

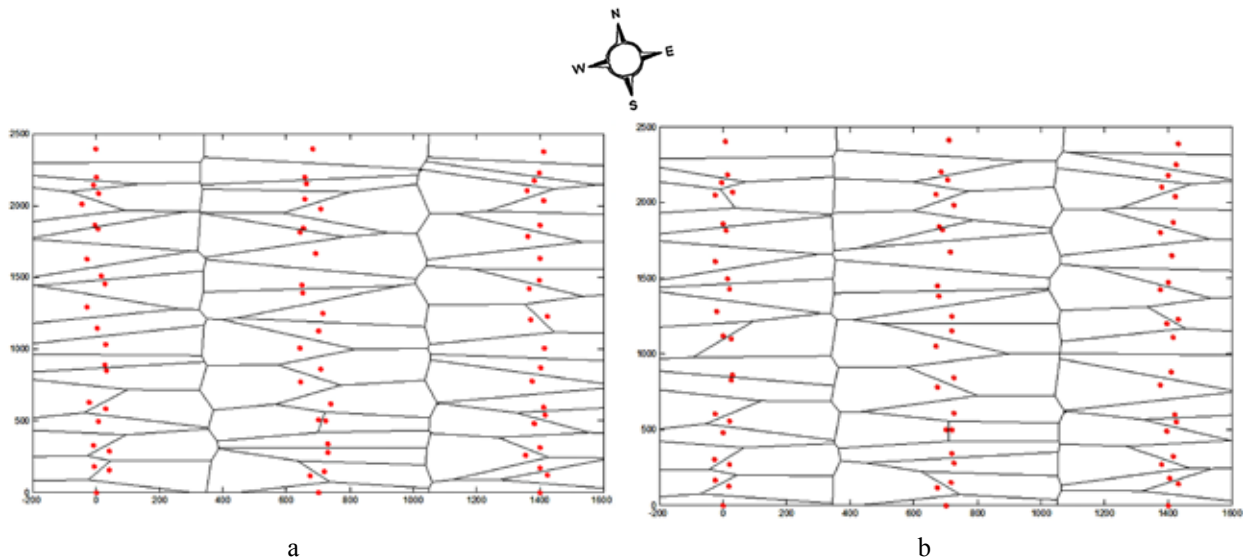


Figure 2. Cotton seedling location and plant growing zone maps: a – cotton seedling locations and plant growing zones generated from RTK GPS coordinates, b – cotton seedling locations and plant growing zones generated from actual coordinates

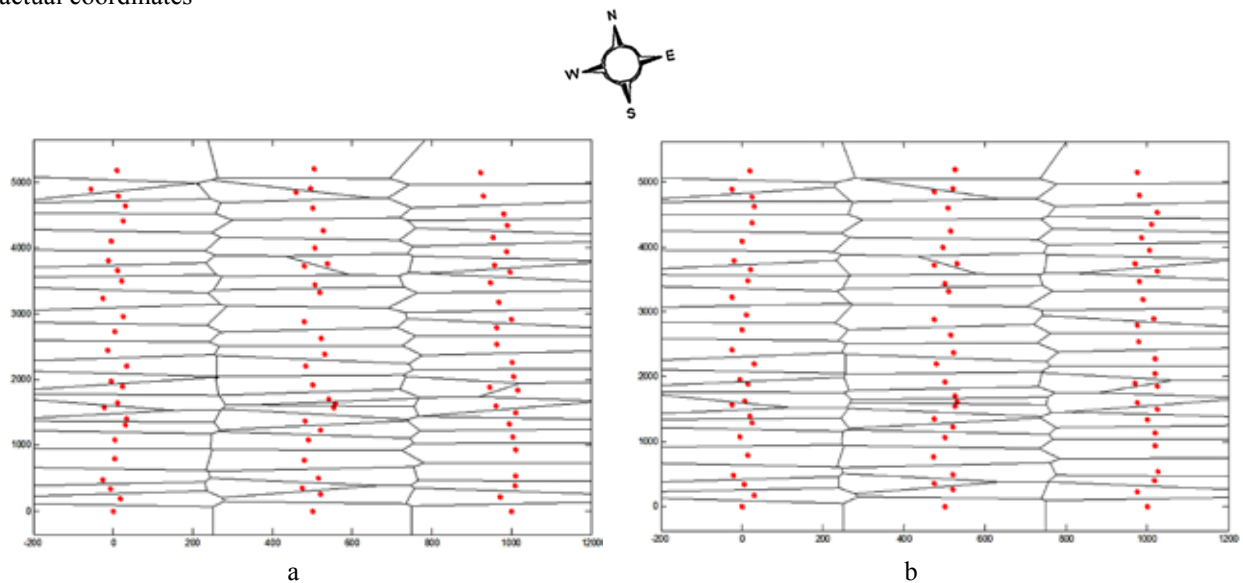


Figure 3. Soybean seedling location and plant growing zone maps: a – soybean seedling locations and plant growing zones generated from RTK GPS coordinates, b – soybean seedling locations and plant growing zones generated from actual coordinates

The data in Table 2 show the comparison of plant growing areas obtained from RTK GPS and actual measured coordinates. The results of the analyses show that the differences between plant growing areas obtained from RTK GPS and actual coordinates were not statistically significant for all plants in this research. Similar results were obtained for shape ratio.

The differences between shape ratios obtained from RTK GPS and actual coordinates were not

statistically significant for all plants. After viewing Figures 2–4, it is intuitive that circles will not represent plant growing areas as well as polygons, especially on closely-spaced seedlings such as found in cotton and soybean crops. Therefore, the shape ratio of cotton, soybean and watermelon plants is a less useful parameter than plant growing area.

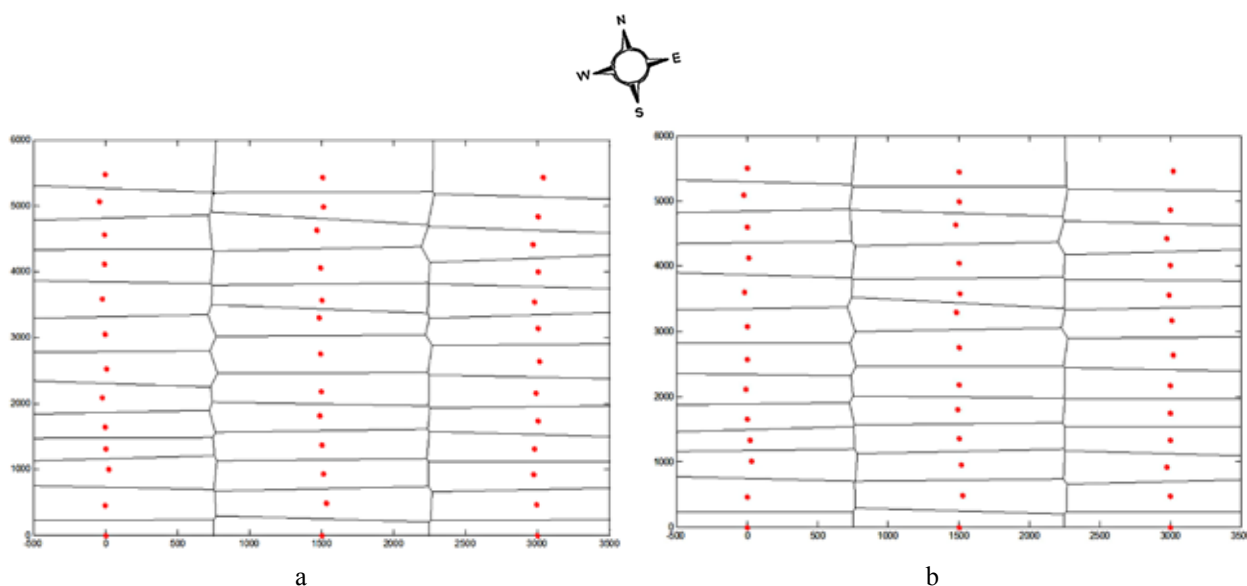


Figure 4. Watermelon seedling location and plant growing zone maps: a – watermelon seedling locations and plant growing zones generated from RTK GPS coordinates, b – watermelon seedling locations and plant growing zones generated from actual coordinates

Table 2. Plant growing areas and shape ratios obtained from real-time kinematic (RTK) global positioning system (GPS) and actual coordinates

Methods	Plant growing area (mm ²)	Shape ratio
	± standard error of mean	± standard error of mean
Cotton		
GPS	100093 ± 6657	0.78 ± 0.031
Actual	102012 ± 6568	0.77 ± 0.019
<i>P</i>	0.972	0.273
<i>t</i>	0.035	1.096
<i>df</i>	1498	1498
Soybean		
GPS	63224 ± 4040	0.73 ± 0.018
Actual	63711 ± 4115	0.76 ± 0.006
<i>P</i>	0.592	0.148
<i>t</i>	0.536	1.447
<i>df</i>	1498	1498
Watermelon		
GPS	677332 ± 25561	0.74 ± 0.017
Actual	677071 ± 24724	0.74 ± 0.021
<i>P</i>	0.896	0.716
<i>t</i>	0.131	0.364
<i>df</i>	1498	1498

Note. Means were different at the ‘P’ level of significance.

Conclusion

A millimeter-level accuracy soybean, cotton and watermelon plants’ maps could be generated using a real-time kinematic (RTK) global positioning system (GPS). The mean distance between the RTK GPS generated map location and the actual plant location (tape measurements) was less than 10 mm. The differences between plant growing area and shape ratios obtained from RTK GPS and actual coordinates were not significant for all plants.

The shape ratio may not be useful for closely-spaced plants. Therefore, the use of the RTK GPS system produced useful data of spatial plant characteristics and it can successfully replace manual measurement techniques.

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Augalų daigų pasiskirstymo lauke tyrimai, naudojant realaus laiko kinematinę (RTK) padėties nustatymo sistemą (GPS)

D. Karayel¹, M. Topakci¹, I. Unal², E. Šarauskis³, M. Canakci¹

¹Akdeniz universiteto Žemės ūkio fakulteto Žemės ūkio technikos katedra, Turkija

²Mehmet Akif Ersoy universiteto Bucak Hikmet Tolunay profesinė mokykla, Turkija

³Aleksandro Stulginskio universiteto Žemės ūkio inžinerijos ir saugos institutas

Santrauka

Tirtos galimybės naudoti realaus laiko kinematinę (RTK) padėties nustatymo sistemą (GPS) sudygusių daigų ir augančių augalų plotų žemėlapiams sudaryti, įvertinant žemėlapių tikslumo lygį. Itin tikslūs sėklų ir augalų plotų žemėlapiai sudaro galimybę įvertinti sėjamųjų darbą, piktžolių kontrolę ir specializuotų augalų auginimo technologijų taikymą. Tikslios augalų augimo lauke vietos nustatytos naudojant matavimo juostą. Buvo palygintos atliktų RTK GPS ir matavimų juosta daigų vietos lauke, augalų augimo plotų ir formos santykio reikšmės. RTK GPS tyrimai parodė, kad tai patikima matavimo sistema, galinti milimetro tikslumu nustatyti daigų augimo vietas ir medvilnės, sojų bei arbūzų auginimo plotus.

Reikšminiai žodžiai: GPS, sėja, sėklų pasiskirstymas, *Voronoi polygon* metodas.