Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi 24 (Özel Sayı):78-90, 2019
(*Mustafa Kemal University Journal of Agricultural Sciences* 24 (Special Issue):78-90, 2019)
e-ISSN: 2667-7733
http://dergipark.org.tr/mkutbd

1st Int. Congress on Biosystems Engineering 2019 ARAŞTIRMA MAKALESİ/RESEARCH ARTICLE

# Effectiveness of GNSS-based tractor auto steering systems in crop spraying

İlaçlama işleminde GNSS esaslı traktör otomatik dümenleme sistemlerinin etkinliği

**Mustafa TOPÇUERİ[1], Muharrem KESKİN[1]**
[1]*Hatay Mustafa Kemal University, Faculty of Agriculture, Department of Biosystems Engineering, Antakya-Hatay, Turkey.*

MAKALE BİLGİSİ / ARTICLE INFO

***Makale tarihçesi / Article history:***
Geliş tarihi /Received:09.10.2019
Kabul tarihi/Accepted:16.12.2019

***Keywords:***
GNSS, Auto Steering, Spraying, Overlap, Gap, Error.

Corresponding author: Muharrem KESKİN
✉: mkeskinhatay@gmail.com

Ö Z E T / A B S T R A C T

***Aims***: This study aimed to compare pass-to-pass overlaps and spacings in adjacent parallel passes in spraying with and without tractor automatic steering (AS).
***Methods and Results***: The data were obtained from 13 farmer fields (cotton, corn and peanut) to assess the performance of AS systems in real farmer conditions. Root mean square errors (RMSE) of overlaps and spacings were determined on the maps generated from the coordinates of the tractor recorded while spraying. Variations between the fields were also examined. The RMSE was lowest (7.5 ± 1.7 cm) in the fields on which farmers used AS (with RTK correction signal) in all three operations of tillage, sowing and spraying. RMSE values were comparatively higher for the fields on which farmers used AS only in ridge tillage but not in sowing and spraying (CORS-GSM: 46.1 ± 6.5 cm, SBAS: 76.5 ± 13.9 cm). The fields with manually-steered ridge tillage, sowing and spraying (all three) had the highest RMSE value of 100.8 ± 27.8 cm ($p<0.05$). The mean RMSE in the manual spraying (without AS) were found to be significantly higher than those using the AS ($p<0.05$).
***Conclusions***: AS systems were found to be beneficial in reducing the mean pass-to pass overlap and spacing errors (RMSE) in spraying. However, most of the farmers used AS only in soil ridge tillage and made the spraying without AS by referencing marking flags and/ or soil ridges which were formed using AS. Main reason of this is the high cost of the AS systems and farmers cannot afford to equip all of their tractors. The use of AS systems not only in ridge tillage but also in planting and spraying reduced the errors and increased the benefit of AS usage. The level of benefit from the AS could change from farmer to farmer; thus, farmers should use the AS systems carefully with appropriate equipment settings to obtain a higher level of benefits.
***Significance and Impact of the Study***: Appropriate use of AS systems in spraying offers benefits to reduce overlap and gaps and the amount of pesticides resulting in lower amount of environmental pollution and pesticide residues on crops, lower application time, lower fuel and labor consumption.

**Atıf / Citation**: Topçueri M, Keskin M (2019) Effectiveness of GNSS-based tractor auto steering systems in crop spraying. *MKU. Tar. Bil. Derg.* 24 (Özel Sayı) :78-90

## INTRODUCTION

Auto Steering (AS) or Auto Guidance is one of the most widely used Precision Agriculture (PA) technologies (Morgan and Ess, 2003; Keskin and Görücü Keskin, 2012). AS enables the driver to move the tractor along the specified route. For the purpose of AS in agriculture, different techniques have been developed such as mechanical following, mechanical contact, geomagnetic, electrical, image processing, ultrasonic and satellite based navigation (GNSS) (Reid et al., 2000; Reichhardt, 2012). Most widely used steering method is GNSS based method (Global Navigation Satellite System). In orchards and greenhouses, AS is established by sensing the distance to trees or rows of plants using LASER, LIDAR or ultrasonic sensors (Mousazadeh, 2013; Bayar et al., 2015).

A GNSS-based AS system consists mainly of three components: GNSS antenna, steering system (using electric motor or electro-hydraulic unit) and computer with integrated display. With AS systems, a starting route or line (A-B Line) is established between two points and parallel passes to this A-B line as the working width of the equipment mounted to the rear of the tractor are provided. AS systems can be divided into two models: 1) In semi-automatic systems; the driver does the steering by looking at an indicator (lightbar) that helps to steer and allows him to stay on the route. 2) In fully automatic systems; steering is done automatically without the driver touching the steering wheel. When the driver arrives at the end of the field, he can manually turn the tractor to the side by looking at the screen. Work is underway to make the turns automatically. In this method, steering is carried out in two different means: a) An electro-hydraulic control system is mounted to the tractor's steering system. b) The existing mechanical steering wheel is replaced with a steering wheel with an electric motor on it.

Fully automatic steering systems provide many benefits in agriculture (Lowenberg-DeBoer, 1999; Grisso et al., 2009; Li et al., 2009; Baillie et al., 2018; Müller Electronics, 2018): Easy to use and learn. Makes the job easier. Reduces workload and fatigue on the driver. Provides safer working conditions. Provides equally-distanced parallel passes. Creates parallel and flat ridges in soil tillage. Provides desired distance between plant rows in parallel passes in planting. Reduces the amount of overlap and skips in crop spraying. There is no need to use foam or marking flags in spraying; thus, environment is protected and work efficiency increases. Overlaps and spaces are reduced in fertilizer and lime application with centrifugal spreader. Provides maximal usage of equipment width in harvesting and losses are reduced. In irregular fields, double-spraying is prevented with section control. No need to use markers in sowing. Allows work at night. Provides precise operation at high speeds. Saves fuel and labor. Reduces plant damage, losses and soil compaction and increases yield by allowing passes in same routes each time. Allows workings in adverse weather conditions (fog, dust, sun flare). Increases the quality of the work (tillage, sowing, fertilizing, spraying, harvesting).

Studies have been conducted on the performance, benefits and profitability of automatic steering (AS) systems in the world. Morrow (2002) reported that GPS steering systems reduce the amount of overlap and gaps as compared to foam marking. Whelan and Taylor (2013) reported a 2-4% saving in inputs (fuel, fertilizer, pesticide) when the overlap is 2 cm with AS as compared to conventional marking (0.5-1.0 m). Santos et al. (2018) reported that AS systems significantly increase efficiency and reduce overlaps in parallel passes. Ashworth et al. (2018) reported that AS systems reduce carbon equivalent emission, fuel consumption and chemical input in cotton and soybean farming. Kunz et al. (2018) reported that mechanical weed control with camera-based steering (78%) provided higher weed control efficiency than manual steering (65%). Farmers started to use AS by 2009 in Turkey much more later than American farmers (in 1990s). The adoption level of AS systems in the world reaches up to 80% in some countries (Norwood and Fulton, 2009; Leonard, 2014; Erickson and Widmar, 2015; USDA, 2015a; USDA, 2015b; Verma, 2015; Silva et al., 2011; Keskin, 2013; Say et al., 2017). In Turkey, precision agriculture awareness and adoption has an increasing trend (Akdemir, 2016; Keskin and Sekerli, 2016) and about 850 AS units are in use as of February 2019 mostly in provinces of Adana, Aydin, Konya, Izmir, Tekirdag, Sanliurfa (Topcueri, 2019).

Studies on AS are very limited in Turkey. Unal and Topakci (2012) reviewed information about different steering systems and driverless tractors. Altinkaradag (2014) developed GNSS based electro-hydraulically controlled AS system for tractors. Keskin et al. (2018) reported that farmers use AS mostly for soil tillage (98.2%) and farmers have benefits such as creating straight soil ridges (98.2%), providing flexible working hours (92.7%), saving time (80.0%) and saving fuel (80.0%). Evrenesoglu and Karatas (2019) reported higher operation speed and field capacity in tillage with chisels with AS (9.5 km $h^{-1}$; 2.8 ha $h^{-1}$) as compared to the tillage without AS (4.0 km $h^{-1}$; 1.1 ha $h^{-1}$).

In chemical spraying in agriculture, sprayed parts of the fields should not be re-sprayed and some parts should not be left un-sprayed in adjacent passes. For this goal, foam marking is applied in some countries. However, spraying without any precautions is common and in this case, some of the sprayed area is re-sprayed (overlaps), which leads to the use of extra pesticides and water, increased costs, damage to the plants (toxicity), longer work hours and pollution of the environment. On the other hand, spraying against disease and other harmful factors is not successful in the untreated areas (gaps, spacings). In contrast, when AS is used in spraying, it is not necessary to mark the field by foam or flags and overlaps and/or gaps can be reduced to cm level in parallel passes with optimal equipment settings.

AS systems are generally tested on concrete or asphalt surfaces. However, the working conditions are very different at field level. No study has been available in Turkey on the performance of AS systems on creating equal pass-to-pass distances in tillage, sowing and spraying. Thus, the aim of this study was to determine the effectiveness of GNSS based tractor AS systems in pest control spraying applications in farmer level in Adana province. This study is the first one on this subject in Turkey to the best knowledge of the authors.

## MATERIAL and METHODS

### *Field Data Collection*

Field data were obtained from a total of 13 different fields in the summer months of 2018 (Table 1). Fields were located in Mersin (near the city of Tarsus) and Adana (near the cities of Ceyhan, Saricam, Yuregir) provinces where automatic steering (AS) systems are extensively used. The data were collected directly from the farmer fields; thus, the effectiveness level of AS systems under real farmer conditions was investigated. Variances among the fields were also examined. In the preliminary interviews with the farmers, it was found that some farmers only used the AS system for forming the ridges in soil tillage and aligned the tractor with reference to the ridges during planting and spraying. In this case, these farmers do not use AS for planting and spraying. The reason is that the system is expensive and they do not afford to install AS systems on every tractor. In our previous study, we determined that some farmers wanted to install this system on all tractors if the systems were cheaper (Keskin et al., 2018).

Table 1. Number of fields investigated in the study

| Auto Steering (AS) Usage* | GNSS Correction Signal Source | Number of Fields |
|---|---|---|
| Tillage:+<br>Sowing:+<br>Spraying:+ | RTK | 2 |
| Tillage:+<br>Sowing:−<br>Spraying:− | SBAS | 5 |
| Tillage:+<br>Sowing:−<br>Spraying:− | CORS-GSM | 2 |
| Tillage:−<br>Sowing:−<br>Spraying:− | − (Manual steering) | 4 |
| | **Total** | **13** |

### *Automatic Steering (AS) Systems*

Three sources of GNSS augmentation signal used in tractor automatic steering (AS) systems are described below. These methods provide a pass-to-pass accuracy of up to 2-3 cm:

a) RTK (Real Time Kinematic): This method uses an additional GNSS receiver which is located in stationary position near the field or on the roof of a nearby building and provides correction signal (up to a distance of <3-5 km). This additional receiver sends the error correction data to the GNSS receiver on the tractor. This is an expensive method as it requires an extra receiver.

b) CORS-GSM (CORS: Continually Operating Reference Stations): In this method, the correction data are sent from at least several fixed reference stations to a data center and then it is sent to the GNSS receiver on the tractor via GSM mobile phone with a SIM card. Annual subscription fee must be paid to the related company to receive this service.

c) SBAS (Satellite Based Augmentation System): The correction signal is sent from a satellite to the GNSS receiver. Farmers pay annual subscription fee to receive precise signal correction service.

### *Calculation of the Overlaps and Spacings*

The geographical coordinates (latitude, longitude, elevation) of the tractor were recorded using a GNSS receiver (Trimble AG25), monitor (Trimble FMX) and laptop (Figure 1) on the tractors (power: 90-100 HP) during spraying. When the distance between the two adjacent parallel passes is greater than the spraying width, a gap is formed meaning that some parts of the field remain un-sprayed. Conversely, overlap occurs when the distance between the two passes is smaller than the spraying width meaning that some parts of the field are sprayed twice, once in the forward direction and the second in the backward direction. Both cases are undesirable because ideally, the distance between the two passes should be the same as the spraying width (W) in parallel passes to minimize the overlaps and gaps.

Figure 1. Laptop computer (left), monitor (middle) and GNSS receiver (right) used in the study to record coordinates of the tractor and sprayer

The collected raw geographical coordinate data were processed and maps were produced using the software of Ehesap7, NMEA2xyz and Eghas7 (Graftek, Istanbul, Turkey). Ehesap7 was used to calculate XYZ coordinates from raw data recorded from the GNSS receiver. NMEA2xyz was used for converting the coordinate system into UTM coordinate system. Finally, EGHAS7 (Interactive Map Graphic System) which is the first local map package program produced in 1988 in Turkey for generating maps from the data obtained in the field was used to obtain maps for each field. The maps were opened in AutoCAD (v.2007) software and then the distances (m) between two parallel passes were determined for each of the 13 fields. Then, the overlap or gap values were calculated by comparing the distance between the two adjacent passes (DPi) with the spraying width (SW). The root mean square error (RMSE) values were calculated using the equation below in MS Excel software (Gisgeography, 2018) for two points in the beginning of the row (RB), the middle of the row (RM) and the end of the row (RE). Finally, the average values were computed from the six values (two from RB, two from RM and two from RE).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(DP_i - SW)^2}{N}} \quad \text{Eq. (1)}$$

where;
RMSE= Root mean square error (m)
DPi= Distance between two parallel passes (m)
SW= Spraying width (product of number of nozzles and distance between nozzles) (m)
N= Number of parallel passes in the field.

***Data Analysis***

Statistical comparisons were carried out based on the variations among the automatic steering (AS) systems, variations between the automatic and manual steering, variations among the fields and among the row beginnings (RB), row middles (RM) and row ends (RE) using Duncan multiple comparison test in SPSS software (v.17; IBM, New York, USA).

**RESULTS and DISCUSSION**

Overlap and gap RMSE values in adjacent passes in the sprayed fields were determined and examined. RMSE values are presented in Table 2 in spraying for the fields on which soil ridge tillage, sowing and spraying (all three) were carried out by using auto steering (AS) systems. Table 3 displays RMSE values in fields on which only soil ridge tillage was carried out by AS systems (sowing and spraying were done with manual steering) while Table 4 shows RMSE values for the fields on which AS was not used in soil ridge tillage, sowing and spraying (all manual steering).

The average overlap and spacing error (RMSE) value of the two farmer fields on which AS system (RTK correction signal) was used in all three operations (soil ridge tillage, planting and spraying) was found to be 6.7 ± 1.60 cm and 8.4 ± 1.52 cm (Table 2). The difference between the fields was found to be very low.

In case of AS system usage (SBAS or CORS-GSM correction signal) in soil ridge tillage but not in sowing and spraying (manual steering), the RMSE values of adjacent parallel passes in seven farmer fields were found to be 98.0 ± 1.54 cm, 71.1 ± 1.46 cm, 72.7 ± 2.05 cm, 83.0 ± 2.32 cm, 57.4 ± 3.43 cm, 51.7 ± 2.33 cm and 40.5 ± 3.45 cm, respectively (Table 3).

Finally, in four fields where all soil ridge tillage, sowing and spraying were performed manually (no AS usage), the RMSE values in parallel passes were 69.9 ± 2.34 cm, 86.3 ± 2.52 cm, 140.6 ± 5.09 cm and 108.2 ± 2.95 cm, respectively (Table 4). It was observed that the error levels in two of the fields that were manually tilled, planted and sprayed (Field1 and Field2) were similar to those on which AS system was used in ridge tillage but not in sowing and spraying (SBAS correction signal) (Table 3 and Table 4).

The reasons for the variations in RMSE values among the fields treated with same treatments could be the following: a) the driver does not take sufficient care during spraying, for example, when the quality of the GNSS correction signal displayed on the monitor is low, the operator does not stop and continue working manually b) the sprayer adjustments may not be suitable, such as improper three-point hitch mounting settings c) careless operation in sloped fields. Santos et al. (2017) reported that performance of AS systems is affected by the settings of the machine mounted on the back of the tractor and also it should be capable of making corrections according to the field slope. For this reason, machine settings during operation are very important.

As a general evaluation, it was observed that the use of AS in spraying significantly reduces the margin of error (RMSE) of overlap and spacings (as low as 6.7 cm; Table 2) in parallel adjacent passes as compared to manual steering (as high as 140.6 cm; Table 4).

Table2. Overlap and space RMSE values in spraying in fields on which soil ridge tillage, sowing and spraying were carried out by auto steering (AS) systems

| Field (Location) | AS Usage | GNSS Correction Signal | Crop and SW* | DP* Min, Max | Data Point* | RMSE (cm) Mean±SD |
|---|---|---|---|---|---|---|
| Field1 (Mersin) | Tillage:+ Sowing:+ Spraying:+ | RTK | Cotton 15.05 m | 14.92 m 15.21 m | RB | 6.2 ± 2.41 |
| | | | | | RM | 6.7 ± 1.08 |
| | | | | | RE | 6.9 ± 1.71 |
| | | | | | **Mean±SD** | **6.7 ± 1.60 (%0.4)** |
| Field2 (Mersin) | Tillage:+ Sowing:+ Spraying:+ | RTK | Cotton 15.05 m | 14.91 m 15.06 m | RB | 7.0 ± 1.24 |
| | | | | | RM | 9.5 ± 1.35 |
| | | | | | RE | 8.6 ± 1.43 |
| | | | | | **Mean±SD** | **8.4 ± 1.52 (%0.6)** |

* SW: Spraying width (m); DP: Distance between two adjacent passes (m); RB: row beginning, RM: row middle, RE: row end

Table 3. Overlap and space RMSE values in spraying in fields on which only soil ridge tillage was carried out by auto steering (AS) systems (AS was not used in sowing and spraying)

| Field (Location) | AS Usage | GNSS Correction Signal | Crop and SW* | DP* Min, Max | Data Point* | RMSE (cm) Mean±SD |
|---|---|---|---|---|---|---|
| Field1 (Adana) | Tillage:+ Sowing:– Spraying:– | SBAS | Cotton 17.15 m | 15.01 m 17.96 m | RB | 97.7 ± 2.39 |
| | | | | | RM | 97.5 ± 1.47 |
| | | | | | RE | 98.9 ± 1.27 |
| | | | | | **Mean±SD** | **98.0 ± 1.54 (5.7%)** |
| Field2 (Adana) | Tillage:+ Sowing:– Spraying:– | SBAS | Cotton 17.15 m | 16.37 m 17.95 m | RB | 71.4 ± 1.66 |
| | | | | | RM | 70.8 ± 1.73 |
| | | | | | RE | 71.2 ± 2.13 |
| | | | | | **Mean±SD** | **71.1 ± 1.46 (4.2%)** |
| Field3 (Adana) | Tillage:+ Sowing:– Spraying:– | SBAS | Cotton 17.15 m | 16.35 m 17.99 m | RB | 74.2 ± 1.78 |
| | | | | | RM | 72.8 ± 1.71 |
| | | | | | RE | 71.1 ± 2.30 |
| | | | | | **Mean±SD** | **72.7 ± 2.05 (4.2%)** |
| Field4 (Adana) | Tillage:+ Sowing:– Spraying:– | SBAS | Peanut 17.15 m | 15.17 m 17.99 m | RB | 82.9 ± 2.50 |
| | | | | | RM | 82.5 ± 2.43 |
| | | | | | RE | 83.6 ± 3.68 |
| | | | | | **Mean±SD** | **83.0 ± 2.32 (4.8%)** |
| Field5 (Adana) | Tillage:+ Sowing:– Spraying:– | SBAS | Peanut 17.15 m | 15.17 m 17.98 m | RB | 56.0 ± 3.96 |
| | | | | | RM | 57.6 ± 4.77 |
| | | | | | RE | 58.7 ± 3.68 |
| | | | | | **Mean±SD** | **57.4 ± 3.43 (3.4%)** |
| Field1 (Adana) | Tillage:+ Sowing:– Spraying:– | CORS-GSM | Corn 21.35 m | 20.19 m 21.91 m | RB | 52.1 ± 2.40 |
| | | | | | RM | 50.2 ± 1.33 |
| | | | | | RE | 52.9 ± 3.47 |
| | | | | | **Mean±SD** | **51.7 ± 2.33 (2.4%)** |
| Field2 (Adana) | Tillage:+ Sowing:– Spraying:– | CORS-GSM | Corn 21.35 m | 20.44 m 21.21 m | RB | 39.3 ± 3.98 |
| | | | | | RM | 39.4 ± 1.35 |
| | | | | | RE | 42.9 ± 4.98 |
| | | | | | **Mean±SD** | **40.5 ± 3.45 (1.9%)** |

* SW: Spraying width (m); DP: Distance between two adjacent passes (m); RB: row beginning, RM: row middle, RE: row end

Figure 2 shows the map of the trajectories of the tractor and sprayer during the spraying as well as the distances between adjacent parallel passes for the first field (Field1) sprayed using AS system with RTK correction signal while Figure 2 shows the same data for the fourth field (Field4) tilled, planted and sprayed manually (no AS system usage). In the field on Figure 3, it was observed that the adjacent pass-to-pass distances varied between 14.92 and 15.15 m (spraying width was 15.05 m). In the field on Figure 3, the adjacent pass-to-pass distances changed from 13.95 to 19.89 m (spraying width was 17.64 m). Also, in the manually sprayed field (Figure 3), an unsprayed part in the middle of the field can be seen in which the sprayer ran out of mixture of water and pesticide and the farmer drove the tractor to the field edge for refill but after that, he was not able to find the location where he stopped the spraying leading to a portion of the field unsprayed. The use of AS is also useful in eliminating such problems that could be seen in manual spraying.

Table 4. Overlap and space RMSE values in spraying in fields on which AS was not used in soil ridge tillage, sowing and spraying (all manual steering)

| Field (Location) | AS Usage | Crop and SW* | DP* Min, Max | Data Point* | RMSE (cm) Mean±SD |
|---|---|---|---|---|---|
| Field1 (Adana) | Tillage:– Sowing:– Spraying:– | Corn 17.15 m | 16.20 m 16.76 m | RB | 67.0 ± 1.78 |
| | | | | RM | 67.3 ± 2.79 |
| | | | | RE | 69.5 ± 2.99 |
| | | | | **Mean±SD** | **69.9 ± 2.34 (4.1%)** |
| Field2 (Adana) | Tillage:– Sowing:– Spraying:– | Corn 17.15 m | 15.17 m 16.88 m | RB | 85.8 ± 1.59 |
| | | | | RM | 85.4 ± 1.17 |
| | | | | RE | 87.8 ± 4.63 |
| | | | | **Mean±SD** | **86.3 ± 2.52 (5.0%)** |
| Field3 (Adana) | Tillage:– Sowing:– Spraying:– | Corn 17.64 m | 15.11 m 20.81 m | RB | 142.5 ± 4.66 |
| | | | | RM | 140.1 ± 9.33 |
| | | | | RE | 139.2 ± 2.96 |
| | | | | **Mean±SD** | **140.6 ± 5.09 (8.0%)** |
| Field4 (Adana) | Tillage:– Sowing:– Spraying:– | Corn 17.64 m | 15.28 m 18.20 m | RB | 109.4 ± 3.40 |
| | | | | RM | 106.8 ± 3.99 |
| | | | | RE | 108.5 ± 3.01 |
| | | | | **Mean±SD** | **108.2 ± 2.95 (6.1%)** |

* SW: Spraying width (m); DP: Distance between two adjacent passes (m); RB: row beginning, RM: row middle, RE: row end

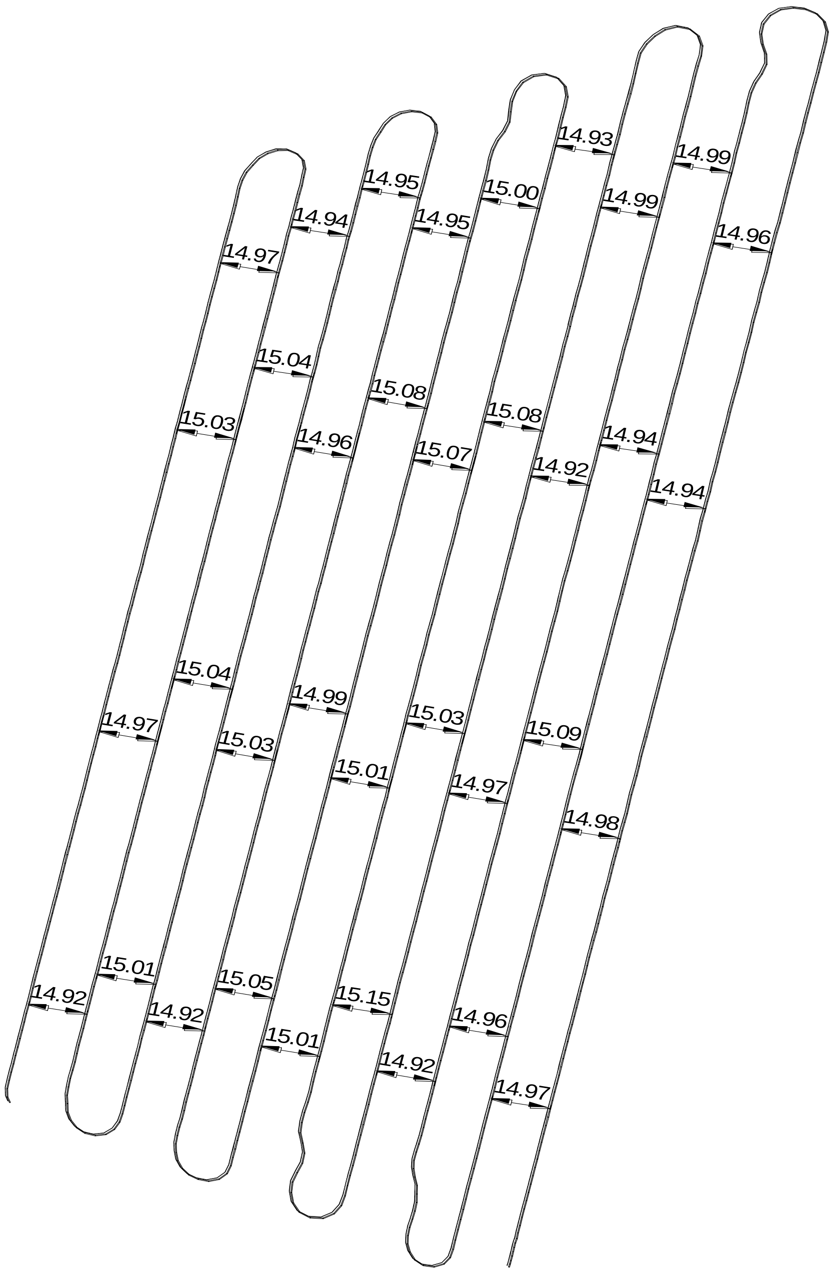


Figure 2. Adjacent pass-to-pass distances in spraying (Field1) on which AS system (with RTK signal) was used in soil ridge tillage, sowing and spraying (Spraying width: 15.05 m) (Adjacent pass-to-pass distances varied between 14.92 m and 15.15 m)

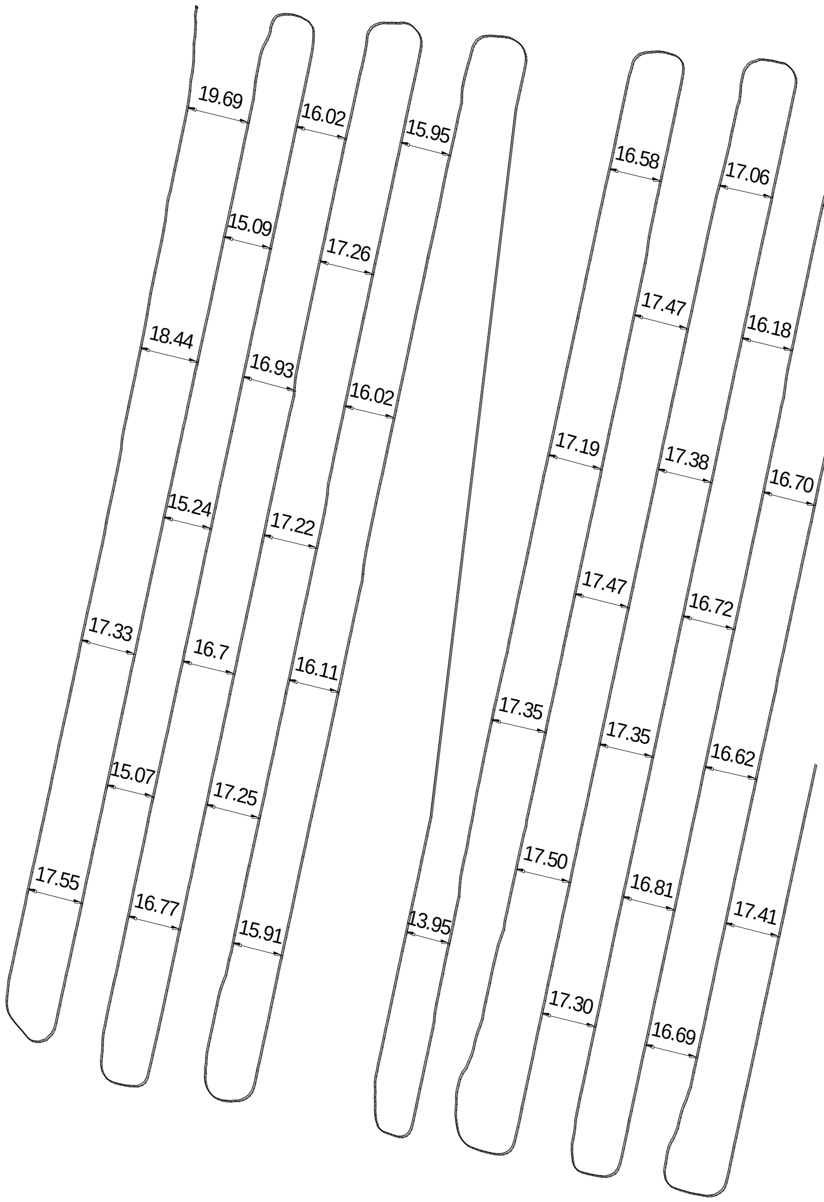


Figure 3. Adjacent pass-to-pass distances in spraying (Field4) on which AS system was not used in soil ridge tillage, sowing and spraying (all manual) (Spraying width: 17.64 m) (Adjacent pass-to-pass distances varied between 13.95 m and 19.89 m)

***Data Analysis***

Overlap and gap error values (RMSE) of manual and AS systems are given in Table 5. According to the data analysis results, the RMSE values in spraying with the manual steering method were significantly higher than those in the spraying with using auto steering (AS) ($p<0.05$) (Table 5). On the other hand, the difference between AS systems using different correction signal was also significant ($p<0.05$). Also, the lowest error values (RMSE) were obtained from the fields tilled, sowed and sprayed using AS (RTK correction signal) as 7.5 ± 1.72 cm. The reason of the lower error value in AS system with RTK method is that this system is more accurate and more importantly, AS was utilized in all three operations of soil tillage, sowing and spraying. In other words, it was determined that some farmers do not use AS systems in spraying resulting in higher amount of overlap and gap errors. The reason why farmers do not use AS systems in spraying is that the system is expensive and that they do not have enough investment to install the AS system on every tractor. Keskin et al. (2018) reported the willingness of the farmers to install AS systems on every tractor they possess if the cost was lower.

Table 5. Overlap and spacing RMSE values in spraying according to auto steering (AS) usage

| AS Usage | GNSS Correction Signal | RMSE (cm) Mean± SD |
|---|---|---|
| Tillage:+ Sowing:+ Spraying:+ | RTK | 7.5 ± 1.72 a |
| Tillage:+ Sowing:− Spraying:− | CORS-GSM | 46.1 ± 6.50 b |
| Tillage:+ Sowing:− Spraying:− | SBAS | 76.5 ± 13.91 c |
| Tillage:− Sowing:− Spraying:− | Manuel steering | 100.8 ± 27.83 d |

Different letters in same column indicate statistically significant differences ($p<0.05$)

The overlap and spacing error values (REMSE) in different fields for each auto steer (AS) usage method are presented in Table 6 and Figure 4. Mean RMSE values were found to be statistically different among the steering systems of manual and AS systems with different correction signals (RTK, SBAS, CORS-GSM) and among the fields treated with tillage, planting and spraying with AS system and without AS system (manual) ($p<0.05$). It was observed that the differences were in low levels (insignificant) in two fields (Field1 and Field2) in which the tillage, planting and spraying were all carried out with AS system with RTK correction signal (Table 6 and Figure 4). In two of the five fields (Field2 and Field3) tilled using AS system with SBAS correction signal but planted and sprayed manually by referencing the soil ridges were similar but different from the other fields (Field1, Field4 and Field5). In general, the reasons for the differences among the fields which were treated in same manner can be attributed to the fact that the fields may have been treated by different drivers, different tractor and equipment settings, different locations of the fields which may affect the GNSS signal quality, and sprayed at different times (important for signal quality).

Table 6. Overlap and spacing error values (RMSE) in spraying according to fields and steering methods

| AS Usage | GNSS Correction Signal | Fields | RMSE (cm) Mean± SD |
|---|---|---|---|
| Tillage:+ Sowing:+ Spraying:+ | RTK | Field1 | 6.7 ± 1.60 a |
| | | Field2 | 8.4 ± 1.52 a |
| Tillage:+ Sowing:– Spraying:– | CORS-GSM | Field2 | 40.5 ± 3.45 a |
| | | Field1 | 51.7 ± 2.33 b |
| Tillage:+ Sowing:– Spraying:– | SBAS | Field5 | 57.3 ± 3.43 a |
| | | Field2 | 71.1 ± 1.46 b |
| | | Field3 | 72.7 ± 2.05 b |
| | | Field4 | 83.0 ± 2.32 c |
| | | Field1 | 98.0 ± 1.54 d |
| Tillage:+ Sowing:– Spraying:– | – (Manual steering) | Field1 | 67.9 ± 2.34 a |
| | | Field2 | 86.3 ± 2.52 b |
| | | Field3 | 108.2 ± 2.95 c |
| | | Field4 | 140.6 ± 5.09 d |

Different letters in same column indicate statistically significant differences ($p<0.05$)

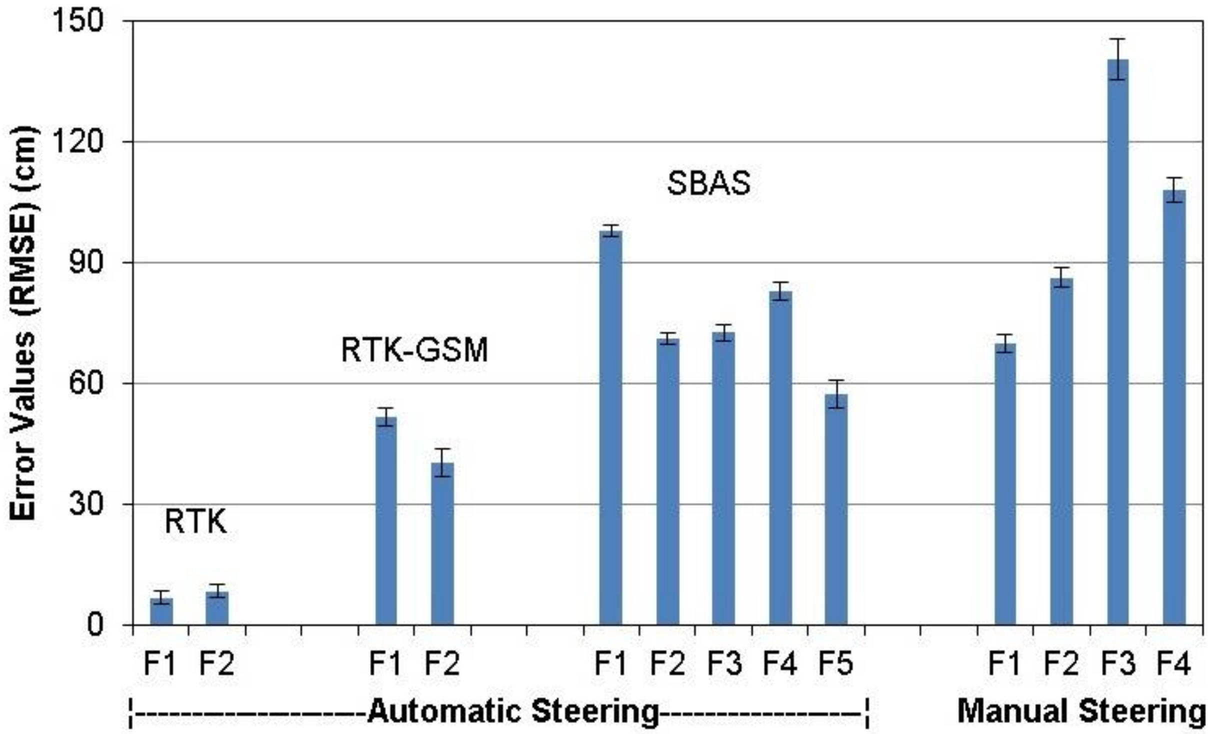


Figure 4. Overlap and spacing error values (RMSE) in spraying according to fields and steering methods

Table 7 shows the mean overlap and spacing error values (RMSE) in spraying according to the steering methods and data points as row beginnings (RB), row middles (RM) and row ends (RE). Sometimes, the error values may be expected to be higher in the start of the new pass (row beginning) as compared to the middle and end of passes after turning at the end of the previous pass; hence, the error data were averaged according to row beginning (RB), row middles (RM) and row ends (RE) and were compared using Duncan's test to investigate this factor. Based on the statistical analysis, no significant differences were observed among the error values in different data points of row beginning (RB), row middles (RM) and row ends (RE) (Table 7) in manual steering and auto steering (AS) with different correction signals.

Table 7. Overlap and spacing error values (RMSE) in spraying according to steering methods and data points (RB: Row beginnings, RM: Row middles, RE: Row ends)

| AS Usage | GNSS Correction Signal | Data Point | RMSE (cm) Mean± SD |
|---|---|---|---|
| Tillage:+ | | RB | 6.6 ± 1.63 a |
| Sowing:+ | RTK | RM | 8.1 ± 1.89 a |
| Spraying:+ | | RE | 7.9 ± 1.71 a |
| Tillage:+ | | RB | 45.7 ± 7.90 a |
| Sowing:− | CORS-GSM | RM | 44.8 ± 6.34 a |
| Spraying:− | | RE | 47.9 ± 6.74 a |
| Tillage:+ | | RB | 76.4 ± 14.57 a |
| Sowing:− | SBAS | RM | 76.3 ± 14.14 a |
| Spraying:− | | RE | 76.7 ± 14.52 a |
| Tillage:− | | RB | 101.2 ± 30.25 a |
| Sowing:− | − (Manual steering) | RM | 99.9 ± 29.25 a |
| Spraying:− | | RE | 101.2 ± 27.82 a |

Different letters in same column indicate statistically significant differences ($p<0.05$)

In previous studies on the overlap and spacing errors on adjacent parallel passes in spraying, it was reported that auto steering (AS) systems reduced the amount of error compared to manual method or foam marking method. Buick and Lange (1998) found that the foam marking resulted in a higher overlap area (2.0-2.6%) than the light-bar steering system with one meter accuracy (1.0%-1.5%) and the AS system with cm level accuracy (0.6-1.1%). Buick and White (1999) reported that the use of lightbar steering provided higher average efficiency by 2.5% and 22.0% in spraying with experienced driver and with inexperienced driver, respectively. Torres et al. (2000) reported that the average error obtained in lightbar steering method was lower (0.14 m) as compared to the foam marking method (0.67 m). McDougall et al. (2001) mentioned that the mean overlap area was lower at 5.5% in DGPS based steering method as compared to 6.9% in foam marking method and they stated that drivers using foam marking method caused higher overlaps by 20%. Similarly, Morrow (2002) reported that the foam marking method produced more overlap and gaps than the GPS steering system. Also, Hudson et al. (2007) reported that the foam marking system had a higher error than the lightbar and auto steering system with electric motor-based steering.

Similar results were found in this current study. Auto steering (AS) systems reduced the overlap and spacing error (RMSE) considerably as compared to the manual steering in adjacent parallel passes in spraying operations. The lowest RMSE error values in spraying were obtained with AS (with RTK correction signal) when used for all three operations of soil ridge tillage, sowing and spraying (7.5 ± 1.72 cm; 0.4-0.6%). On the other hand, error values were higher when soil tillage was done using AS systems while planting and spraying were carried out manually by referencing the soil ridges (CORS-GSM: 46.1 ± 6.50 cm; 1.9-2.4% and SBAS: 76.5 ± 13.91 cm; 3.4-5.7%) as compared to the manual steering in all three processes of tillage, planting and spraying (100.8 ± 27.83 cm; 4.1-8.0%). In sum, AS systems have been found to significantly reduce the overlap and gap errors in parallel adjacent passes in spraying. Farmers should utilize AS systems not only in soil ridge tillage but also in planting and spraying.

## CONCLUSIONS

This study aimed to determine the effect of GNSS-based automatic steering (AS) systems on average overlap and spacing errors (RMSE) in parallel adjacent passes in spraying. According to the data analysis, error (RMSE) values in manual spraying method were found to be statistically higher than those using AS ($p<0.05$). When AS system (with RTK signal) was used in all three operations of soil ridge tillage, sowing and spraying the error was minimal (7.5 ± 1.72 cm; 0.4-0.6%). However, the error values were relatively higher when the AS system was used only in soil ridge tillage but not in planting and spraying (CORS-GSM: 46.1 ± 6.50 cm; 1.9-2.4%; SBAS: 76.5 ± 13.91 cm; 3.4-5.7%). Manual steering resulted in highest errors (100.8 ± 27.83 cm; 4.1-8.0%).

As a result, it was determined that the AS systems are beneficial in reducing the overlap and spacing errors in parallel adjacent passes in spraying as compared to the manual steering. The use of AS systems in spraying offers benefits of less pesticide and water consumption, less environmental pollution, shorter spraying time, less fuel, less labor, lower costs, higher profit and less operator fatigue. In addition, it was observed that farmers' use of AS systems in sowing and spraying besides soil ridge tillage increased this benefit. Farmers should use AS systems not only in soil ridge tillage but also in planting and spraying. It was determined that some farmers do not use AS systems in spraying resulting in higher amount of overlaps and gaps in spraying. The reason why farmers do not use AS systems in spraying is that the system is expensive and that they do not have enough investment to install the AS system on every tractor. Farmers would install AS systems on every tractor they possess if the cost was lower. In addition, it was observed that the benefit from the AS systems can vary from farmer to farmer. For this reason, farmers should use these systems carefully with appropriate equipment settings.

## ÖZET

**Amaç**: Bu çalışmada, traktör otomatik dümenleme (OD) sistemi ile ve manuel dümenleme ile yapılan ilaçlamada yan yana paralel geçişlerdeki örtüşme ve boşluk miktarları karşılaştırılmıştır.

**Yöntemler ve Bulgular**: Veriler, OD sistemlerinin gerçek çiftçi koşullarındaki performansını değerlendirmek için 13 çiftçi tarlasından (pamuk, mısır ve yerfıstığı) elde edilmiştir. İlaçlama sırasında traktörün izlediği noktaların koordinatları kayıt altına alınmış, bu noktalardan oluşturulan haritalar üzerinden ortalama örtüşme ve boşluk hata değerleri (Hataların ortalama kare kökü; Root mean square error: RMSE) belirlenmiş ve analiz edilmiştir. Tarlalar arasındaki değişkenlik de incelenmiştir. RMSE değerinin çiftçilerin sırta toprak işleme, ekim ve ilaçlama işlemlerinin her üçünde OD

kullandığı (RTK düzeltme sinyaliyle) tarlalarda en düşük değerde (7.5 ± 1.7 cm) olduğu gözlemlenmiştir. Çiftçilerin sadece sırta toprak işlemeyi OD sistemiyle, ekim ve ilaçlamayı manuel olarak (OD kullanmadan) yaptığı tarlalarda ortalama hata değerinin daha yüksek olduğu tespit edilmiştir (CORS-GSM: 46.1 ± 6.5 cm, SBAS: 76.5 ± 13.9 cm). Sırta toprak işleme, ekim ve ilaçlamanın hepsinin manuel dümenleme ile yapıldığı tarlalarda ise ortalama hata değerinin en yüksek düzeyde olduğu (100.8 ± 27.8 cm) görülmüştür ($p<0.05$). Manuel ilaçlama durumunda (OD kullanılmadan) ortalama hata değerinin OD kullanılan tarlalara göre önemli derecede daha yüksek olduğu bulunmuştur ($p<0.05$).

**Genel Yorum**: OD sistemlerinin, ilaçlamada yan yana paralel geçişlerdeki ortalama ötüşme ve boşluk hata değerini azaltmada yararlı olduğu tespit edilmiştir. Ancak, çiftçilerin çoğunun OD sistemini sadece toprak sırtı oluşturmada kullandığı, ekim ve ilaçlamayı toprak sırtlarını referans alarak OD kullanmaksızın elle dümenleme ile yaptığı belirlenmiştir. Bu durumun temel nedenlerinden biri, OD sistemlerinin maliyetinin yüksek olması ve çiftçilerin tüm traktörlerini OD sistemi ile donatacak mali gücünun olmamasıdır. OD sistemlerinin sadece sırta toprak işlemede değil, aynı zamanda ilaçlamada da kullanımının örtüşme ve boşluk hatalarını azalttığı ve OD kullanımının yararını arttırdığı gözlenmiştir. OD'den elde edilen fayda düzeyinin çiftçiden çiftçiye değişebildiği tespit edilmiş olup, daha yüksek düzeyde faydalar elde etmek için çiftçilerin OD sistemlerini uygun ekipman ayarlarıyla dikkatli bir şekilde kullanmaları gereklidir.

**Çalışmanın Önemi ve Etkisi**: OD sistemlerinin ilaçlama işleminde uygun şekilde kullanımı, örtüşme ve boşluk miktarında azalmaya bağlı olarak tarım ilacı kullanımında azalma, bitkiler üzerinde daha az toksik etki, ürün üzerinde daha düşük miktarda pestisit kalıntısı, daha az çevre kirliliği, daha düşük ilaçlama süresi, daha düşük yakıt tüketimi ve daha düşük işçilik masrafı potansiyeline sahiptir.

***Anahtar kelimeler***: GNSS, otomatik dümenleme, ilaçlama, örtüşme, boşluk, hata

**ACKNOWLEDGEMENTS**

The authors thank Mr. Omer Selim Alporal (from Graftek), Dr. Yunus Emre Sekerli, Dr. Selcuk Ugurluay and all farmers who made contributions in data collection and analysis. This paper was produced from the MSc thesis of Mr. Mustafa Topcueri under the supervision of Dr. Muharrem Keskin.

**CONFLICT OF INTEREST**

The authors declare no conflict of interest in the study.

**REFERENCES**

Akdemir B (2016) Evaluation of precision farming research and applications in Turkey. 10.7251/AGRENG1607227. pp.1498-1504.

Altinkaradag A (2014) Development of Automatic Steering System for Tractors. PhD Dissertation. Namık Kemal University, Tekirdag, Turkey. 135 pp.

Ashworth AJ, Lindsay KR, Popp MP, Owens PR (2018) Economic and Environmental Impact Assessment of Tractor Guidance Tech. Agric. & Envir. Letters. 5pp.

Baillie CP, Lobsey CR, Diogenes LA, McCarthy CL, Thomasson JA (2018) A review of the state of the art in agricultural automation. Part III: Agricultural machinery navigation systems. ASABE Annual International Meeting, 29 July - 1 August 2018, Detroit, MI, USA.

Bayar G, Bergerman M, Koku AB, Konukseven EI (2015) Localization and control of an autonomous orchard vehicle. Comput. Electron. Agric. 115: 118–128.

Buick R, Lange AF (1998) Assessing Efficiency of Agricultural Chemical Application with Differential GPS, ArcView and Spatial Analyst. Precis. Agric. P.C. Robert, R.H. Rust and W.E. Larson (Ed.). p. 1035-1045.

Buick R, White E (1999) Comparing GPS Guidance with Foam Marker Guidance. Fourth International Conference on Precision Agriculture. pp.1035-1045.

Erickson B, Widmar DA (2015) Precision agricultural services dealership survey results. Purdue University. West Lafayette, Indiana, USA. 37pp.

Evrenesoglu M, Karatas U (2019) The Effect of Automatic Steering on Agro-Technical Success in Deep Chisels. 32nd National Agric. Mech. and Energy Congress, 4-6 September 2019, Canakkale, Turkey. pp 10-11.

Gisgeography (2018) How to Calculate Root Mean Square Error (RMSE) in Excel. https://gisgeography.com/root-mean-square-error-rmse-gis (Accessed on: 30.12.2018)

Grisso R, Alley M, Groover G (2009) Precision Farming Tools: GPS Navigation. Virginia Cooperative Extension. Publication No 442-501. 7 pp.

Hudson G, Shofner R, Wardlow G, Johnson D (2007) Evaluation of three tractor-guidance methods for parallel swathing at two field speeds. Discovery, 8:61-66.

Keskin M, Görücü Keskin S (2012) Precision Agriculture Technologies (Hassas Tarım Tek.). Book (In Turkish). Mustafa Kemal University, Turkey. No: 35. 212 pp.

Keskin M (2013) Factors Affecting the Adoption of the Precision Agric. Technologies and the Adoption Rate of these Technologies in the World (In Turkish with Abstract in English). J. Agric. Mach. Sci. 9(4): 263-272.

Keskin M, Sekerli YE (2016) Awareness and adoption of precision agriculture in the Cukurova region of Turkey. Agron.Res. 14(4): 1307-1320.

Keskin M, Sekerli YE, Say SM, Topcueri M (2018) Farmers' Experiences with GNSS-Based Tractor Auto Guidance in Adana Province of Turkey. J. Agric. Fac. Gaziosmanpasa Univ. 35(2):172-181.

Kunz C, Weber JF, Peteinatos GG, Sökefeld M, Gerhards R (2018) Camera steered mechanical weed control in sugar beet, maize and soybean. Precis. Agric. 19: 708–720

Leonard E (2014) Precision Agriculture Down Under. www.precisionag.com/guidance/precision-ag-down-under.

Li M, Imou K, Wakabayashi K, Yokoyama S (2009) Review of research on agricultural vehicle autonomous guidance. J. Agric. & Biol. Eng. 2(3):1-26.

Lowenberg-DeBoer J (1999) GPS Based Guidance Systems for Agriculture. 6 December 1999.

McDougall K, Gibbings P, Wolski I (2001) Comparison of a d-GPS system and conventional guidance for spraying applications. In: 5th Precis. Agric. in Australasia Symp: Information for Better Production and Envir Manag., 17-19 Jul 2001, Sydney, Australia.

Molin JP, Cerri DGP, Baio FHR, Torrezan HF, Esquerdo JCDM, Ripoli MLC (2002) Evaluation of a light bar for parallel swathing under different forward speeds. World Congress of Computers in Agr. and Natural Resources. 13 March 2002. Iguacu Falls, Brazil: ASABE.

Morgan M, Ess D (2003) The precision farming guide for agriculturists. Second edition. John Deere Publishing, Moline, Illinois, USA.

Morrow TF (2002) Evaluation of DGPS Row Guidance Systems, Analyzing Operator Feedback Methods Based on Accuracy and Operator Insights. MSc Thesis, Univ of Tennessee. 93 pp.

Mousazadeh H (2013) A technical review on navigation systems of agricultural autonomous off-road vehicles. J. Terramech. 50: 211–232.

Müller Elektronik (2018) Steering systems & GPS. Brochure. 12pp. www.mueller-elektronik.de

Norwood S, Fulton J (2009) GPS/GIS Applications for Farming Systems. Alabama Farmers Federation Commodity Organizational Meeting. 5 February 2009.

Reichhardt (2012). Auto Guidance System Brochure. Reichhardt, 12 First Street Southi Sabin, MN 56580. www.reichhardt.com.

Reid JF, Zhang Q, Noguchi N, Dickson M (2000) Agricultural automatic guidance research in North America. Comput. Electron. Agric. 25: 155–167.

Santos AF, Silva RP, Tavares TO, Ormond ATS, Rosalen DL, Assis LC (2017) Parallelism error in peanut sowing operation with auto-steer guidance. Revista Brasileira de Engenharia Agrícola e Ambiental. 21(10):731-736.

Santos AF, Correa LN, Gírio LAS, Paixao CSS, da Silva RP (2018) Position Errors in Sowing in Curved and Rectilinear Routes Using Autopilot. Eng. Agríc. 38: 568-576.

Say SM, Keskin M, Sehri M, Sekerli YE (2017) Adoption of Precision Agriculture Technologies in Developed and Developing Countries. International Science and Technology Conference, 17-19 July 2017 Berlin, Germany. pp.41-49.

Silva CB, Moraes MAF, Molin JP (2011) Adoption and use of precis. agric. tech. in the sugarcane industry of Sao Paulo state, Brazil. Precis. Agric. 12: 67–81.

Torres FP, Ribeiro Filho AC, Baio FHR (2000) Comparaçao da utilizaçao da barra de luz na agricultura de precisao em relaçao ao marcador de espuma. In: Agric. de Precisao. Viçaso: UFV. 357-364.

USDA (2015a) Agricultural Resource Management Survey: US Peanut Industry. United States Department of Agriculture (USDA) National Agric Stat Service (NASS). No 2015-1. 4 pp.

USDA (2015b) Agricultural Resource Management Survey: US Rice Industry. United States Department of Agriculture (USDA) National Agric Stat Service (NASS). No 2015-2. 4 pp.

Unal I, Topakci M (2012) Navigation Methodology and Different Navigation Systems for Agricultural Applications (In Turkish with Abstract in English). 27. National Agricultural Mechanization Congress, 5-7 September 2012, Samsun, Turkey.

Verma L (2015) China Pursues Precision Agriculture on a Grand Scale. Resource Magazine. July/August 2015. 22: 18–19.

Whelan B, Taylor J (2013) Precision agriculture for grain production systems. Csiro Publishing. 199 pp.