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Evaluation of a Low-Cost GPS Receiver for Precision Agriculture Use in Adana Province of Turkey

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Abstract: The most vital factor in the application of precision agriculture technology is the cost of the required high-technology equipment. The equipment cost is the major obstacle in adopting the precision agriculture. GPS receiver is one of the most essential tools with high initial costs in this technology. The aim of this study was to evaluate a low-cost GPS receiver in 3 different tests including static, dynamic circular area, and dynamic straight line tests. It was observed that the tested low-cost GPS receiver yielded a deviation of less than 1.50 m, 1.60 m, and 1.48 m in static, circular area, and straight line tests, respectively. It can be concluded that the low-cost GPS receiver without differential correction can be used for variable fertilizer application and soil and yield mapping since it has an appropriate accuracy values for these applications. On the other hand, it would not be suitable for some precision agriculture applications that require an accuracy of less than 1 m such as variable herbicide application and row crop planting. Instead, a GPS receiver with differential correction service should be employed for such applications. In addition, the mean percent error values were -1.3% and -0.5% in all tests in the circle area calculation. These values can be considered to be acceptable for the field area calculation studies.

Key Words: Low-cost GPS receiver, Evaluation, GIS, Precision agriculture

Düşük Maliyetli Bir GPS Alıcısının Adana İlinde Hassas Uygulamalı Tarımda Kullanılabilirliğinin Değerlendirilmesi

Özet: Hassas uygulamalı tarım teknolojisinin uygulanmasındaki en önemli faktör gerekli olan yüksek teknoloji ürünü ekipmanların masrafıdır. Ekipman masrafı, hassas uygulamalı tarım teknolojisinin uygulanabilirliğinde en önemli engeldir. GPS alıcısı, bu teknolojide yüksek yatırım maliyetine sahip en önemli araçlardan biridir. Bu çalışmanın amacı, düşük maliyetli bir GPS alıcısını; durağan, hareketli dairesel alan ve hareketli düz çizgi olmak üzere üç farklı test ile değerlendirmektir. Test edilen düşük maliyetli GPS alıcısının; durağan, hareketli dairesel alan ve hareketli düz çizgi testlerinde, sırasıyla 1.50 m, 1.60 m, ve 1.48 m'den daha az değerde sapma gösterdiği gözlemlenmiştir. Düzeltme servisi olmayan düşük maliyetli bir GPS alıcısının, göstermiş olduğu sapma değerlerine dayanarak, değişken düzeyli gübreleme ile toprak ve verim haritalamada kullanılabileceği sonucuna varılmıştır. Ancak, bu tip bir alıcı, değişken düzeyli yabancı ot ilaçlama ve sıraya ekim gibi 1 m'den daha düşük doğruluk gerektiren işlemlerde kullanıma uygun değildir. Bunun yerine, bu gibi uygulamalarda düzeltme sinyali servisine sahip alıcılar kullanılmalıdır. Ayrıca, dairesel alan hesaplamada, ortalama hata payı, küçük ve büyük daireler için sırasıyla -%1.3 ile -%0.5 arasında gerçekleşmiştir. Bu değerler alan hesaplama uygulaması için kabul edilebilir düzeydedir.

Anahtar Sözcükler: Düşük maliyetli GPS alıcısı, Değerlendirme, GIS, Hassas uygulamalı tarım

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Introduction

Global Positioning System (GPS) is a satellite-based navigation system operated by the United States government. A GPS receiver obtains signals from at least 4 GPS satellites to fix a 3-dimensional geographical position (latitude, longitude, and altitude) worldwide. GPS receivers are used in many areas such as military, transportation, tourism, forestry, hunting, etc. (Letham, 1999). Another usage is in agriculture especially in precision agriculture, which deals with determining the variability in a field and then variably applying the agricultural chemical inputs, such as fertilizers and pesticides, to reduce the use of chemical inputs and protect the environment (Morgan and Ess, 2007). A GPS receiver is used to determine the coordinate of a point on a field for applications such as soil mapping and yield mapping.

The most vital factor in the use of precision agriculture technology is the cost of the required high-technology equipment. The cost of equipment is reported as being the major obstacle in the adoption of the precision agriculture (Shannon et al., 2006). GPS receiver is one of the most essential tools with high initial costs in this technology. Its price ranges from several hundred to several tens of thousands of US dollars based on the accuracy of the receiver. Even if it is not easy to set a price limit for low-cost receivers, a researcher used the term “low-cost” for a receiver with a price of about 300 US dollars (Shannon et al., 2001) and another researcher used the value of 1000 Euro in his study (Schwieger, 2005). The low-cost receivers gained importance after the US government removed the selective availability (on-purpose error) in 2000. Shannon et al. (2001) reported that 95% of the points fell within a radius of 6.3 m without the selective availability compared to 45.0 m. This action had a great positive effect on the error budget of the low-cost GPS receivers. However, research was needed to test the accuracy of the low-cost GPS receivers for their suitability to precision agriculture applications. Many studies were conducted for this purpose in various countries and, in particular, in the US.

Shannon et al. (2001) compared a low-cost GPS receiver to a differentially-corrected GPS (DGPS) receiver for wheat and soybean yield mapping and reported a high similarity between the maps ranging from 66.4% to 79.7% and an average relative accuracy of 1.78 m between the DGPS receiver and the low-cost GPS receiver. They concluded that low-cost GPS receivers could provide the necessary accuracy needed for creating yield maps. They also discovered that better yield maps could be produced when the low-cost GPS antenna is mounted outside the combine cab. They repeated the study in larger scale in the following harvest season and obtained an average relative positioning difference of 2.97 m between the GPS receivers. They also compared the maps and reported a high similarity ($R^2 = 0.73$) (Shannon et al., 2002). Taylor et al. (2004) dynamically tested 2 GPS receivers, one with differential correction and the other without correction, on a 0.8 km length of railroad track using a small rail cart. They reported the average accuracy values of 0.171 m and 1.348 m in cross track test for the corrected and uncorrected GPS receivers, respectively. Ehsani et al. (2003) evaluated the dynamic accuracies of 5 low-cost WAAS corrected DGPS receivers while driving on a straight path based on an RTK GPS receiver system. They reported that the average absolute cross-track error was between 0.63 m and 1.37 m for all GPS receivers. Cole et al. (2004) constructed an I-beam track to assess the dynamic performance of GPS receivers for application in precision agriculture. They collected data to compare an RTK GPS system and a low-cost GPS receiver. They reported that the low-cost receiver positioning data strayed from the RTK data by as much as 1.75 m.

Although many studies were conducted on the evaluation of low-cost GPS receivers throughout the world, there are a limited number of studies in Turkey. Keskin and Say (2006) studied the effectiveness of low-cost GPS receivers for measuring ground speed. They found a very strong relationship between the average GPS speeds and the average calculated speeds ($R^2 > 0.99$) and they concluded that low-cost GPS receivers can be used confidently to measure the ground speed in agricultural machinery operations. Koc et al. (2006) developed a computer program to carry out the static and dynamic evaluation of a low-cost GPS receiver. They concluded that the precision of the GPS position was less than 3.0 m; however, the speed obtained from the receiver was about 1.25 km h^{-1} less than the true speed values. Zengin and Yesil (2006) carried out a study to compare a handheld GPS receiver and a Kinematic on the Fly (KOF) system under forest cover and reported that the results obtained by the kinematic method were more precise.

Similar feasibility studies need to be conducted in different locations and countries. The first reason for this is that the GPS satellites are not stationary and continually moves in space and this can affect the quality of its signal and the reliability of the GPS receivers. The second reason is the possible degradation or unavailability of the GPS service due to intentional or unintentional jamming signals in different countries (Iyidir and Ozkazanc, 2004). Therefore, the aim of this study was to test and evaluate a low-cost GPS receiver for precision agriculture use in Turkey.

Materials and Methods

A low-cost 12-channel GPS receiver (Magellan Meridian, Thales Navigation, San Dimas, CA, USA) costing about $350 was used without differential correction. The receiver has an update rate of 1 per second. WGS84 map datum was used in the study. A laptop computer was used to read and store the real-time GPS data. The receiver had PC interface cable to allow data transfer to the computer through the serial communication (COM) port. Since the laptop computer did not have a serial communication port, a COM-to-USB converter was used to create a virtual serial communication port (COM1).

Two computer programs written in QuickBasic programming language (Version 4.5, Microsoft Corp., Redmond, WA, USA) were used (Keskin and Say, 2006). The first program was used to simultaneously read and save raw GPS data from the receiver connected to the computer's virtual COM1 port. The program shows the raw GPS data on computer screen and at the same time, it saves the raw data into a data file. The program uses the time (hhmm) when the program gets started as the base file name. In this way, the raw GPS data from the GPS receiver are saved to the data files named in the manner of "hhmm.txt". The aim of the second program was to process the raw GPS data files to extract the location data (latitude, longitude, and altitude as a function of time) and then save the processed data to another data file (hhmm-p.txt) (Keskin and Say, 2006).

A Geographical Information System (GIS) software (ArcView, Version 8.1) was used to map GPS locations. The experiments were conducted on the Research and Experiment farm (37.04°N, 35.38°E) of the Faculty of Agriculture of Çukurova University located in Adana, Turkey.

Three different tests were conducted in the study: static test, circular dynamic and area test, and dynamic straight line test.

Static Test

The objective of this test was to determine the deviation of the measured GPS coordinates (latitude, longitude, and altitude) from the coordinate of a fixed point. A point was determined in an open field for this test. A 2 m pole with a holder for the GPS receiver on the top was erected to the point and the GPS receiver was fixed into the holder on top of the pole. The laptop computer was placed on a small table near the pole and the GPS receiver was connected to the computer. The tests were carried out 4 times on 4 different dates (Table 1). The data were collected from morning to evening for about 12 hours in every test day.

Circular Dynamic and Area Test

This test had 2 objectives. The first aim was to find out the maximum deviation of the GPS data points from the circle line in dynamic measurement. The second aim was to compare the theoretical area with the calculated areas from the GPS data. Two circles with the diameters of about 40.7 m and 70.4 m were marked in an open field. A GPS holder was fabricated and placed on top of a farm tractor's (John Deere 5210) cab. The laptop computer was placed inside the tractor's cab. When the front wheel of the tractor was at the starting point of the circle, the computer program was started and the program was stopped at the ending point. The speed of the travel was constant at about 1.5 m s^{-1} (tractor gear level was B2 and the engine rpm was 1500) during the data collection. The experiment was conducted on 2 different occasions (Table 1). Data were collected during the travel of the tractor. The data was collected on each test date at different times with 5 repetitions.

Table 1. Tests carried out in the study.

Experiment	Trial No	Date
Static Test	1	16 September 2006
	2	23 September 2006
	3	07 October 2006
	4	22 October 2006
Circular Dynamic and Area Test	1	23 March 2007
	2	30 March 2007
Straight Line Dynamic Test	1	11 November 2006
	2	25 November 2006
	3	10 February 2007

Dynamic Straight Line Test

The purpose of this test was to determine the maximum deviation of the GPS data points from the straight line. A distance of about 100 m was marked using flags on a straight stabilized farm road in the direction of southwest-northeast. Similar to the circular area test, the computer program was initiated at the starting point and the program was stopped at the end point. The measurements were carried out at 2 different speed levels of 1.5 m s^{-1} and 2.5 m s^{-1} (5.4 km h^{-1} and 9.0 km h^{-1}). The test was repeated on 3 different dates (Table 1). On each date, the GPS data were collected at different times of the day in the morning and in the afternoon by going 6 times northward and 6 times southward.

Data Processing

In each measurement, the GPS receiver was set to send the raw data according to the NMEA (National Marine Electronics Association) 0183 standard with 4800 baud rate, 8 data bits, no parity, 1 stop bit, and in ASCII format (Adamchuk, 2001; Bennett, 2003). After the data were collected, the 2 computer programs were used to extract the GPS location data from the raw data files. According to the NMEA 0183 standard, the location data are available in the data sentence beginning with the $GPGGA data format; therefore, the program extracted the location data from the data lines starting with $GPGGA. The processed data were then transferred into spreadsheet software to calculate the average latitude, longitude, and altitude for the static test. Then the average deviations for each static test were calculated. Since the coordinate of the static point was not known before the experiment, the mean of the coordinates obtained from the static test results was used in the calculations. The northing and easting distance values (X and Y values) in meter were calculated using the equations (Meridian World Data, 2007) given below:

$$x = (69.1)\,(1609)\,(Lat2 - Lat1)$$

$$y = (69.1)\,(1609)\,(Lon2 - Lon1)\cos(Lat1 / 57.3)$$

For the circular area and straight line tests, the GPS locations were mapped using GIS software. Then, the maximum deviation of the GPS data points from the straight line was calculated using the GIS software's distance function for both circular area and straight line tests. Since it was not possible to determine the center line of the straight line and the circles, the maximum deviation was determined by dividing the length of the line connecting most outside data points. Also, the area calculations were carried out for the circular area test data in the GIS software.

The means of the deviations of X and Y values and the altitude values obtained from different test days in the static test were compared using the SAS statistics software.

Results

Static Test

The results obtained from the static tests are given in Table 2. Approximately 30,000 GPS data points were collected daily from morning to evening in each static test. The general mean values for the latitude, longitude, and altitude of the static point for all 4 tests were calculated to be 37.0367124°, 35.3744617°, and 65.57 m, respectively (Table 2). The altitude ranged from 60.0 m to 71.0 m in all static trials.

The deviations of easting (X) values varied between -3.48 m and 2.77 m while the deviation of northing (Y) values varied from -1.44 to 2.04 m (Table 2). In addition, the variation of the easting and northing deviations in each static test is shown in Figure 1. It was observed that the deviations from the fixed point were relatively lower in tests 2 and 3 (between -1.25 and 0.88 m) compared to tests 1 and 4 (between -3.48 and 2.77 m) (Figure 1, Table 2). The maximum variation values were observed by local time 1500 in test 1 and by 1400 in test 4. In each static test day, the data collection was started in the morning and ended in the evening. Since the batteries to power the GPS receiver lasted for about 5 to 6 h, a battery replacement was needed right after the noon time. The batteries were replaced by 1500 hours in test 1 and by 1400 hours in test 4, which corresponds to the peak values in the X and Y deviation values; therefore, the highest deviations were observed right after battery replacement in tests 1 and 4 (Figure 1). This statement is also valid for the other 2 static tests in which the highest deviations were observed by 1300 and 1500 in tests 2 and 3, respectively. If these peak values were ignored, it can be stated that the X and Y deviation values were within approximately 1.50 m of the static point (Figure 1).

Table 2. Results of the static tests.

Test		Latitude (°)	Longitude (°)	Altitude (m)	X (m)	Y (m)	No. of Vis. Satellites	PDoP (-)
1	Mean	37.0367146	35.3744596	64.5	0.00	0.00	8.96	2.68
	St.Dev.	0.0000082	0.0000065	2.66	0.91	0.58	0.86	0.43
	Min	37.0366833	35.3744433	60.0	-3.48	-1.44	7	1.80
	Max	37.0367233	35.3744800	68.0	0.97	1.81	10	5.70
2	Mean	37.0367171	35.3744600	67.0	0.00	0.00	8.70	2.73
	St.Dev.	0.0000037	0.0000048	1.67	0.41	0.43	0.94	0.44
	Min	37.0367100	35.3744467	65.0	-0.79	-1.18	7	1.30
	Max	37.0367250	35.3744683	71.0	0.88	0.74	10	7.40
3	Mean	37.0367079	35.3744600	65.4	0.00	0.00	8.90	2.67
	St.Dev.	0.0000027	0.0000039	0.72	0.30	0.35	0.75	0.42
	Min	37.0366967	35.3744483	64.0	-1.25	-1.04	6	1.80
	Max	37.0367133	35.3744683	67.0	0.60	0.74	10	5.90
4	Mean	37.0367101	35.3744671	65.4	0.00	0.00	9.10	2.55
	St.Dev.	0.0000092	0.0000129	1.05	1.03	1.15	0.77	0.46
	Min	37.0366967	35.3744533	63.0	-1.49	-1.22	7	1.60
	Max	37.0367350	35.3744900	68.0	2.77	2.04	10	4.60
General Mean		37.0367124	35.3744617	65.57	-	-	-	-

The number of visible satellites was between 6 and 10 in all static tests (Table 2). It is a common fact that 4 satellites are enough for a GPS receiver to conduct a 3-dimensional (3D) position fix (latitude, longitude, and altitude); therefore, it can be expressed that the GPS receiver tracked more than the required number of visible satellites during each static test. Also, it was observed that the mean Position Dilution of Precision (PDoP) values, which are the unitless measurement of the geometry of satellites above the receiver's current location (Trimble, 2003), were between 2.55 and 2.73 in all static tests (Table 2). Usually, the value of PDoP should be less than 4.0 for an accurate GPS position fix (Trimble, 2003). In this study, since the mean PDoP values were less than 2.73 in all of the static tests, it can be stated that the accuracy of the GPS position fix was good enough.

Circular Dynamic and Area Test

Two different data analysis were conducted in the circular area test. Firstly, the maximum deviations of the GPS data points from the circle line were calculated using the distance feature of the GIS software and secondly, the areas of the circles created in the GIS software were calculated using the appropriate GIS functions. The maximum deviations from the circle line are given in Table 3 while the data points were depicted in Figure 2. The maximum deviation values were 1.40 and 1.30 m for the smaller circle in tests 1 and 2, respectively, while they were 1.60 and 1.55 m for the bigger circle in tests 1 and 2, respectively (Table 3). The mean deviation values were 1.350 and 1.575 m for the smaller and bigger circles, respectively. In sum, the deviation values in the circular dynamic and area test were less than 1.60 m. In addition, the calculated and measured circle areas are presented in Table 3. The calculated area for the smaller circle was 1301.0 m^2 while it was 3892.6 m^2 for the bigger circle. The mean percent error values over the 2 tests were -1.3% and -0.5% for the small and big circles, respectively.

Dynamic Straight Line Test

The maximum deviations of the GPS data points from the straight line were calculated using the distance feature of the GIS software and are presented in Table 4. Also, the GPS data points were mapped using the GIS software

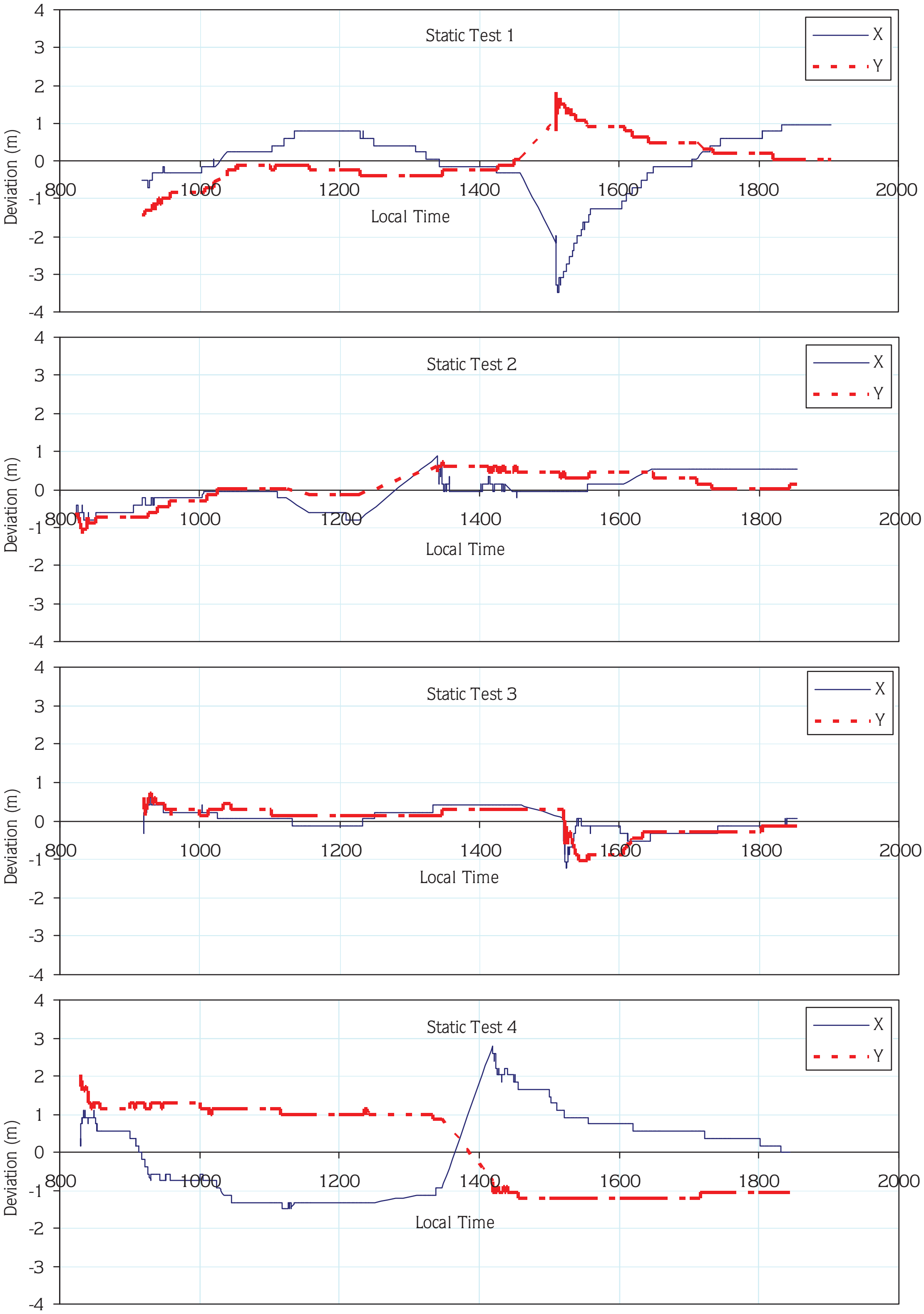

Figure 1. The variation of the easting and northing deviations in each test day.

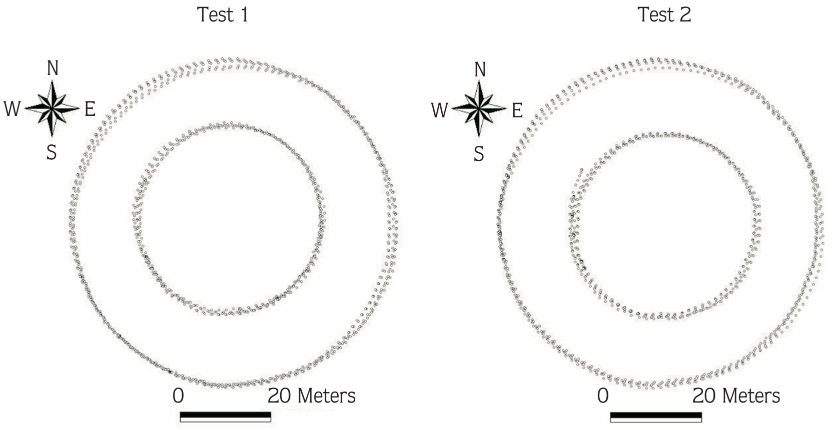

Figure 2. The GPS data points mapped using the GIS software for the circular dynamic and area test.

Table 3. Maximum deviations from the circle line, measured circle areas, and error rates in circular dynamic and area test.

Circle	Test	Maximum Deviation (m)	Average Measured Area (m^2)	Average Area Error (%)
Small	1	1.40	1310.1	0.7
D = 40.7 m	2	1.30	1257.7	-3.3
A = 1301.0 m^2	Mean	1.350	1283.9	-1.30
Big	1	1.60	3899.9	0.2
D = 70.4 m	2	1.55	3845.7	-1.2
A = 3892.6 m^2	Mean	1.575	3872.8	-0.50

Table 4. Maximum deviations from the straight line in straight line test.

Speed	Trial	Maximum Deviation From the Straight Line (m)
Low	1	1.48
	2	1.40
	3	1.30
	Mean	1.393
High	1	0.85
	2	0.95
	3	1.10
	Mean	0.967

and depicted in Figure 3. The tests were carried out at 2 different speed values. It was observed that less data points were captured at high speed levels as expected. The maximum deviation values for all 3 tests were between 1.30 and 1.48 m with the mean value of 1.393 m for low speed values (Table 4). On the other hand, the deviations varied from 0.85 to 1.10 m and the mean value was 0.967 m for high speed values. In general, the deviation values were less than 1.48 m in the dynamic straight line test.

The statistical analysis showed that the means of the deviations of X and Y values obtained from different test days in static test were not significantly different ($P > 0.05$). In addition, the means of the altitude values obtained from the static tests 1, 3, and 4 were found to be not statistically different ($P > 0.05$); however, the mean of the altitude values of the static test 2 was different from the ones of the other 3 static tests ($P < 0.05$).

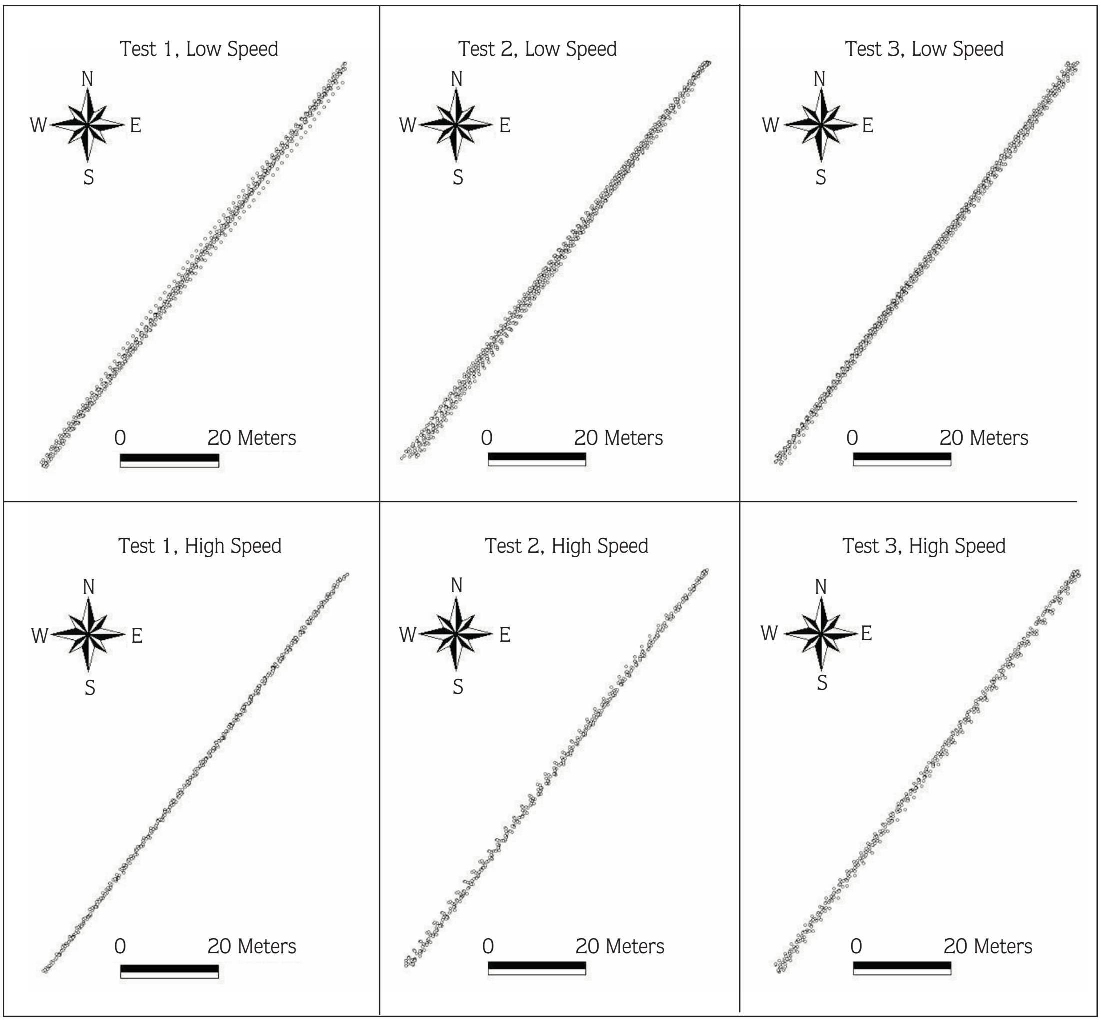

Figure 3. The GPS data points mapped using the GIS software for the straight line test.

Discussion

A low-cost GPS receiver was evaluated without differential correction in 3 different tests, which are the static, circular area, and dynamic straight line tests in this study. In the static tests, the deviations of easting (X) values varied between -3.48 m and 2.77 m while the deviation of northing (Y) values were between -1.44 and 2.04 m (Figure 1 and Table 2). Highest deviations were observed right after battery replacement in static test 1 and static test 4. If these peak values were ignored, the X and Y deviation values were within approximately 1.50 m of the static point. The reason for higher deviation rates after the battery replacement could not be determined. In the circular area tests, the mean deviation values from the circle line were found to be 1.350 and 1.575 m for the smaller and bigger circles, respectively (Figure 2 and Table 3). In the circle area calculation, the mean percent error values were -1.3% and -0.5% in all tests for small and big circles, respectively (Table 3). These values can be considered as acceptable for area calculation studies. Similarly, Stombaugh et al. (2003) tested a low-cost GPS receiver for boundary mapping and area calculation and reported an error rate of -2.14% and 0.47% in field area calculation. In the dynamic straight line test, the mean deviation values for all 3 tests were 1.293 m for low speed values while it was 0.967 m for high speed values (Figure 3 and Table 4). The position accuracy of the GPS receiver used in this study was reported to be 7 m (95% 2D RMS) (Thales Navigation, 2002). The deviation values obtained in the study was within the accuracy limits reported in the specifications of the receiver's manufacturer. In addition, the obtained results are in good agreement with the results of previous studies conducted by Shannon et al. 2001 (1.78 m), Shannon et al. 2002 (2.97 m), Taylor et al. 2004 (0.171 m - 1.348 m), Ehsani et al. 2003 (0.63 m - 1.37 m), Cole et al. 2004 (1.75 m), Koc et al. 2006 (3.0 m) even if the evaluation methods have some small differences. In static test, we observed the highest deviations right after battery replacement. No similar result on the effect of battery change on the accuracy values of the GPS was found in the literature. It would be appropriate to recommend waiting for about half an hour after battery replacement or using a continuous power source for better accuracy.

Statistical analysis showed that the means of the X and Y deviations in different static test days were not significantly different ($P > 0.05$). Also, the means of the altitude values of the static tests 1, 3, and 4 were found to be not statistically different ($P > 0.05$); however, the mean altitude value of the static test 2 was different from the ones of the other 3 static tests ($P < 0.05$). This can be attributed to the fact that in general the GPS receivers provide better accuracy in longitude and latitude measurements than the altitude measurement (Letham, 1999; Lechner and Baumann, 2000).

Precision agriculture employs different agricultural operations that need different GPS accuracy values. For instance, variable fertilizer application and yield mapping requires an accuracy of 30 m and 10 m, respectively (Stafford, 1999; Lechner and Baumann, 2000). In this study, it was observed that the tested low-cost GPS receiver provided a deviation of less than 1.50 m, 1.60 m, and 1.48 m in static, circular area, and straight line tests. Based on this result, it can be concluded that the low-cost GPS receiver can be used for variable fertilizer application and yield mapping as well as soil sampling and boundary mapping since it has an appropriate accuracy values for these applications. Shannon et al. (2001) reported a similar finding for yield mapping in a study in which they compared a low-cost GPS receiver to a differentially-corrected GPS (DGPS) receiver for wheat and soybean yield mapping and reported a high similarity between the maps ranging from 66.4% to 79.7% and an average relative accuracy of 1.78 m between the Differential GPS (DGPS) receiver and the low-cost GPS receiver.

On the other hand, some precision agriculture applications such as variable herbicide application, spray overlap avoidance, automatic guidance of tractors and combine harvesters, row crop planting, and seed bed structure requires an accuracy of less than 1 m (Stafford, 1999; Morgan and Ess, 1997; Lechner and Baumann, 2000); therefore, the low-cost GPS receiver would not be suitable for these applications. Instead, a GPS receiver with differential correction service should be employed for such applications.

The cost of the equipment for the adoption of the precision agriculture technology is particularly important for the developing countries like Turkey since the size and the investment possibilities of the farms are relatively lower compared to the bigger size of the farms of the developed countries. According to the findings of this study, it can be stated that there is no need to use an expensive and more accurate GPS receiver in soil and yield mapping applications and variable fertilizer application as well as soil sampling and boundary mapping in precision agriculture since low-cost GPS receivers provide appropriate accuracy for this type of applications.

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