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Variable Rate Fertilizer Control System for Centrifugal Fertilizer Spreaders

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Abstract: Aim of this research is to develop a variable rate controller system includes mechanical part, electronic circuit, application map software and laboratory test system apply variable rate fertilizer application due to requirement of crop instead of constant rate of application used by farmers generally. Centrifugal fertilizer spreader with two discs, stepper motors, variable rate controller, GPS and variable rate application software were used as materials in this research. Developed variable rate controller and application software were improved. In addition, a laboratory test software was developed. Laboratory tests of the new control system were realised. 15-15-15 (N-P-K), %46 Urea, 20-20-0 (N-P-K) and %33 Ammonium Nitrate chemical fertilisers widely used by farmers for field crops were used in the laboratory tests. Developed system was worked without any problem.

Keywords; centrifugal fertiliser spreader, precision farming, variable rate fertilisation

Diskli Gübre Dağıtma Makinaları İçin Değişken Oranlı Gübre Kontrol Sistemi

Öz: Bu araştırmanın amacı; çiftçinin uyguladığı alışılagelmiş homojen gübre uygulama yerine bitkinin ihtiyacına uygun belirlenmiş miktarları konuma göre dağıtan gübreleme yapan daha önce geliştirilmiş bir makine ile değişken düzeyli gübreleme yapmaktır. Araştırmada materyal olarak santrifüjlü gübre dağıtma makinesi, step motor, değişken düzeyli kontrol sistemi, GPS ve uygulama haritası programı kullanılmıştır. Araştırmada daha önce geliştirilen kontrol sistemi ve değişken düzeyli uygulama programı iyileştirilmiştir. Ayrıca laboratuar testleri için bilgisayar programı geliştirilmiştir. Yeni sistemin laboratuar denemeleri yapılmıştır. Testlerde çiftçiler tarafından ülkemizde tarla tarımında yaygın olarak kullanılan 15-15-15 (N-P-K), %46 Üre, 20-20-0 (N-P-K) ve %33 Amonyum Nitrat gübreleri için testler yapılmıştır. Sistem testler sırasında sorunsuz olarak çalışmıştır.

Anahtar Kelimeler; diskli gübre dağıtma makinası, hassas tarım, değişken düzeyli gübreleme

1. Introduction

Application of fertilizer in agricultural production is one of the most important processes. Fertilizer is traditionally applied equal regardless of variability in the soil to the whole field. Soil samples are taken separately for each sampling point, mixed and analysed as a single sample. Consequently a single fertilization rate (fixed variable rate) is generally recommended to the farmers according to the results in conventional farm management. However, spatial variability in the soil can be detected by sampling based on geographical coordinates. As a result of this kind farm management called as precision farming, variable rate fertilization can be suggested and performed (Sındır and Tekin 2002). Variable rate application (VRA) is application of information technologies such as global positioning system (GPS), geographic information system to farm management (Blackmore 1999). It is very difficult to reconstitute the natural balance that is deteriorated as a result of environmental pollution caused by the unconscious use of mineral fertilizers. Taking necessary precautions is very important to prevent excessive chemical fertilizer usage (Bellitürk 2015). The use of variable rate of nitrogen (N) in the field increases crop yield, reduces nitrate pollution of groundwater and farming costs (Kim et al. 2002). Nitrogen

fertilizer in 50.5 kg versus 101 kg per hectare it is used twice in Thrace Turkey (Bayraktar 1997). Blackmore et al. (1994) reported that fertilizer spreading machines with variable rate fertilizer control system can be successfully used in applying fertilizers as variable rate. Bongiovanni and DeBoer (2000) carried out field experiments for determining effects of the most applied nitrogen doses in corn production. In the first year the data showed that the nitrogen effect varied considerably according to the terrain and that variable rate fertilizer application technology was more profitable than nitrogen fertilizer application uniformly applied at 80 kg / ha. Godwin et al. (2002) reported that variable rate nitrogen application provided an economic gain of 22 pounds per hectare in 2000.

Türker and Güçdemir (2013) have determined whether variable rate fertilizer application will be economical at the point of meeting the savings achieved and investment cost in farmer conditions. Precision agriculture investments for 160 ha in corn production can be met in the first year. Significant savings have been achieved from variable rate phosphorus and nitrogen applications.

A study carried out by Tekin and Sındır (2013) to develop a variable rate control system that allows granular fertilizer application at varying rates, adaptation to a commercial granular fertilizer spreader and improved sitemap performance. The researchers report that the developed system can be used easily for fertilizer spreaders with some mechanical modifications. Özgüven and Türker (2010) investigated whether the application of precision agriculture technologies is economical or not for corn production in Çukurova Region by using partial budgeting method for different area sizes and amount of input in 2002-2008 period. According to the results equilibrium efficiency increase of 4.01% in corn production in Çukurova region and the precision farming cost can be met by reducing the balance at 12.02% at all costs in the combined system for 100 ha area.

Use of developed variable rate application systems may cause to reduce unnecessary fertilizer usage, reduce cost, increase yield and quality of product and reduce the negative effects of chemical fertilizers on environment. Because of the advantages of the variabl rate applications, aim of this research was to develop a variable rate fertilizer application system for fertilizer spreader machines with disc manufactured in Turkey.

2. Materials and methods

Fertilizer spreader: In the study, the double disc fertilizer spreader was used (Figure 1). Its dimensions were given in Table 1.

Figure 1. Fertiliser spreader machine with double discs

Şekil 1. *Çift Diskli Gübre Dağıtma Makinesi*

Application rate adjusting unit: The position and variable rate application map was loaded on the computer. The position was checked by using GPS to determine rate of the required fertilizer for each point. If it was required, the position of the plate located at the bottom of the centrifugal fertilzer was changed automatically to apply fertilizer due to application map. Materials used in the control system were given in Table 2.

Table 1. Technical specifications of Fertiliser spreader machine with double discs

Çizelge 1. *Çift diskli gübre dağıtma makinesinin teknik özellikleri*

Dimensions	
Width (mm)	2090
Height (mm)	1527
Length (mm)	1227
Capacity (dm^3)	1000
Working width (m)	6-24

Table 2. *Components of the electronic control system*
Çizelge 2. *Elektronik kontrol sistemi*

Material	Number
PIC24fj16	1
Socket	5
XTAL 10Mhz	1
Condensator	8
Control PCB	1
Limit switch	4

Step motors was controlled PIC18F46K22. Limit switches determine maximum and minimum working distances for backward and forward direction of the stepper motors.

CHC X91 GNSS device was used for determining of geographical positions.

Mineral fertilisers used in this research were 15-15-15 (N, P, K), 20-20-0 (N, P, K), 33% Ammonium Nitrate NH3NO4), and 46% Urea.

In this study, the variable rate controller system placed on the double disk fertilizer spreader and tested. The developed system was tested. The valve positions were checked according to the application map data. In addition, amount of the distributed fertilizers for different kind of fertilizers and scales of the machines were measured. For this, the machine is attached to the tractor, the depot was full and position of the fertilizer spreader machine was parallel to filed. The machine was worked for a certain period of time, not less than 30 seconds at 540 min^{-1} of PTO revolution before starting laboratory tests. Then the tests were carried out for 60 seconds. The amount of distributed fertilizer was weighed and fertilizer rate was calculated for each fertilization scale. Test were carried out in three replication (Anonymous 2006).

3. Results and Discussions

In this research; a variable rate controller, a laboratory test software and an application map software were developed for centrifugal fertiliser spreaders. Detailed information about the variable rate controller system and results of the laboratory tests for different fertilizers were given in this section,.

3.1. Variable rate fertilizer control system

The variable rate control system developed previously by another research project had toothed screw shaft to change amount of the active area of a whole located bottom of the centrifugal fertilizer spreader. In this research, instead a gear system that receives rotation from shaft of the stepper motor was designed and amount of the distributed fertilizer controlled by changing active area of the hole (Figure 2). The movement of the system was limited by limit switches (limiters) on both sides of the disc. Half-gear which cannot be connected to the stepper motor when approaches to the l limit switch, it is stopped by limit switcher for going further (Figure 3). The circuit diagram of the electronic control system was given in Figure 4.

(a) **(b)**

Figure 2. Old design (toothed axle) (a) and new design (with gears) (b) plate control system
Şekil 2. *Eski (dişli mil) ve yeni(dişli) değişken oranlı gübre akış kapak kontrol mekanizası*

Figure 3. Connection of the limit switch to the system

Şekil 3. *Sistemin sınırlayıcı (limit switch) bağlantısı*

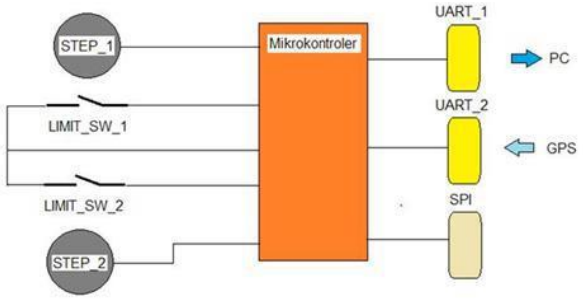

Figure 4. Block diagramme of the new designed variable rate controller

Şekil 4. *Yeni değişken oranlı gübre dağıtma sistemi blok diyagram*

The general task of the system was to send the GPS data from the UART2 port to the PC connected to the UART1 port. Then it resend UART1 port of the microcontroller to start STEP1 and STEP2 motors connected to the plates of the hole located at bottom of the centrifugal fertilizer spreader. The UART port was a short name given to the Universal Asynchronous Receiver/Transmitter port. Data such as texts and figures were transmitted via this port which enables serial communication with the PC and microcontroller. The devices (PC / Microcontroller) convert the transmitted parallel data into serial data, making them available in the communication line. The UART interface receives data as byte and carries them out of the transmission path in one bit sequentially. The system combines the bits from a second UART transmission line and re-bytes them. There were different protocols in hardware. These may be RS232, RS485, and RS482. UART1, UART2, SPI, which can be seen in the block diagram, are the modules that are in the internal structure of the microcontroller PIC18F46K22. STEP1, STEP2 stepper motors and LIMIT_SW_1, LIMIT_SW_2 were connected to the input / output port of the microcontroller.

Stepper motor: The used stepper motors were connected to the plate mechanism of the fertilizer spreader machine. Drivers located on the motors. The servo motors takes only the direction (forward-backward) and step information from the microcontroller.

LIMIT_SW: They were inductive sensors and sensitive to metals. They perceive metals in their effective area. These sensors were located in the position where the plate mechanism was closed. When send commands to the STEP1 and STEP2 for going to the closed position, the stepper motors move to the closed position and then stopped by limit switches. The stepper motors move to the closed position until they come to the closed position and they stop the movement by understanding these sensors.

UART: These modules provide asynchronous serial data communication. The RS-232 standard defines this communication. Accordingly, the communication protocol is defined. The electrical signals defined according to this protocol are provided by a separate integrated MAX232 integration.

Serial Peripheral Interface (SPI) Bus: A module establishes full duplex serial data link. Additional memory modules such as SD card, LCD indicators etc. communicate quickly through this module.

Microcontroller: PIC18F46K22 is the latest generation of Microchip's RISC-based processor and Harvard architecture. It can be reaches 16 MIPS (16 Million Instractions per Second). It has 64 Kbyte program memory, 4 Kbyte RAM memory and 1 Kbyte EEPROM memory. There are many integrated modules such as UART, SPI, ADC, DAC, and PWM. The new electronic circuit developed in this research has advanced features and more modular structure than the previously developed electronic circuit. These features make it possible to add desired enhancements and additional functions to the circuit. The processor on the electronic card had a processing capacity as 10,000,000 commands per second. The supply voltage was 12V and the

current 30mA. It is suitable to feed with battery. The new circuit has two communication ports consequently it can also communicate with the PC at the same time while communicating with the GPRS. The processor has 16 kilobytes of ROM and 8 kilobytes of RAM memory. It can provide direct connection to memory cards and save yield data in its memory. An LCD display can be connected to the other SPI port. These features will allow it to work stand-alone in later versions. The unit has additionally 8 isolated digital inputs and 4 relay outputs and 4 step open-collector transistor outputs. The microcontroller program of the electronic card was written in C programming language. In order to communicate with Programme, GPRS, and NMEA (National Marine Electronics Association) GGA (Global Positioning System Fixed Data) command set were loaded. The program sends the GPS coordinates by communicating with the PC and the program written in Visual Basic processes data with a determined protocol to send to the card and establishes opening of the plates at required amount. A test program with the Delphi programming language was also developed to test card functions and run plates manually. The stepper motor can also be calibrated by this test program, at the calibration settings associated with the valve. The communication protocol in the test program is the same as the main program in Visual Basic.

3.2. Fertilizer Spreader Machine Laboratory Test Program

A test program was developed for laboratory tests of the fertilizer spreader. Through the program, both stepper motors can be operated for each scale / step values ranging from 0-18. If necessary, tests can be performed by selecting either two or one stepper motor separately. Images from the program were given in Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9.

The commands in the menu in the interface are explained below.

GÖNDER = SEND SELECTED COMMAND TO CONTROL CARD.
SOL RESET = CLOSE LEFT PLATE
SAĞ RESET = CLOSE RIGHT PLATE
RESET = CLOSE BOTH PLATES
İleri yönde = Forward Moving
GERİ YÖNDE = Backward mowing
Sürekli Komut Gönder = Command was sent to close the plates after a determined time as seconds.

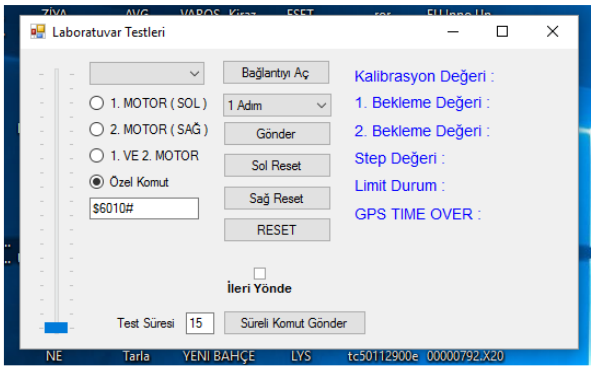

Figure 5. A general view of laboratory test software
Şekil 5. *Laboratuar test programı görünümü*

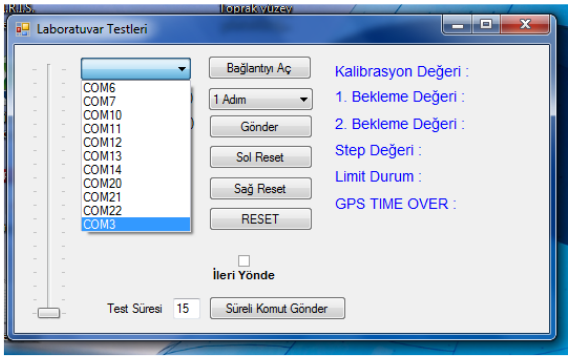

Figure 6. Determining of communication port
Şekil 6. *Haberleşme portunun seçimi*

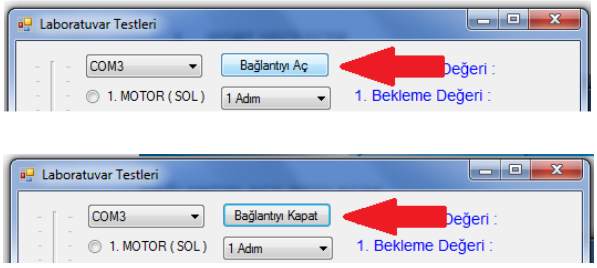

Figure 7. On and off of the communication port
Şekil 7. Haberleşmenin açılması ve kapanması

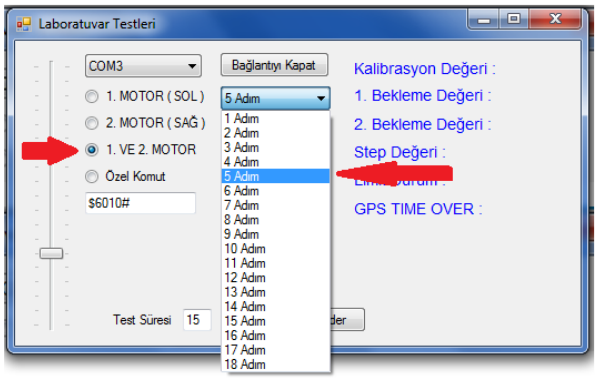

Figure 8. Determining of step of the number
Şekil 8. *Adım sayısının seçimi*

Figure 9. Determining of step of the number
Şekil 9. *Testler sırasında programın ekran görüntüsü*

3.3. Variable rate application map software

An "Variable Rate Application Map Software" which divide the field into grids at the required due to field boundaries and the working width of the machine and required fertilizer amount can be assigned to the grids has been developed, the algorithm of the program was given in Figure 10.

The differences between the variable rate application programs developed in the earlier project and in this project was given in Table 3. Some images from this program was given Figure 11.

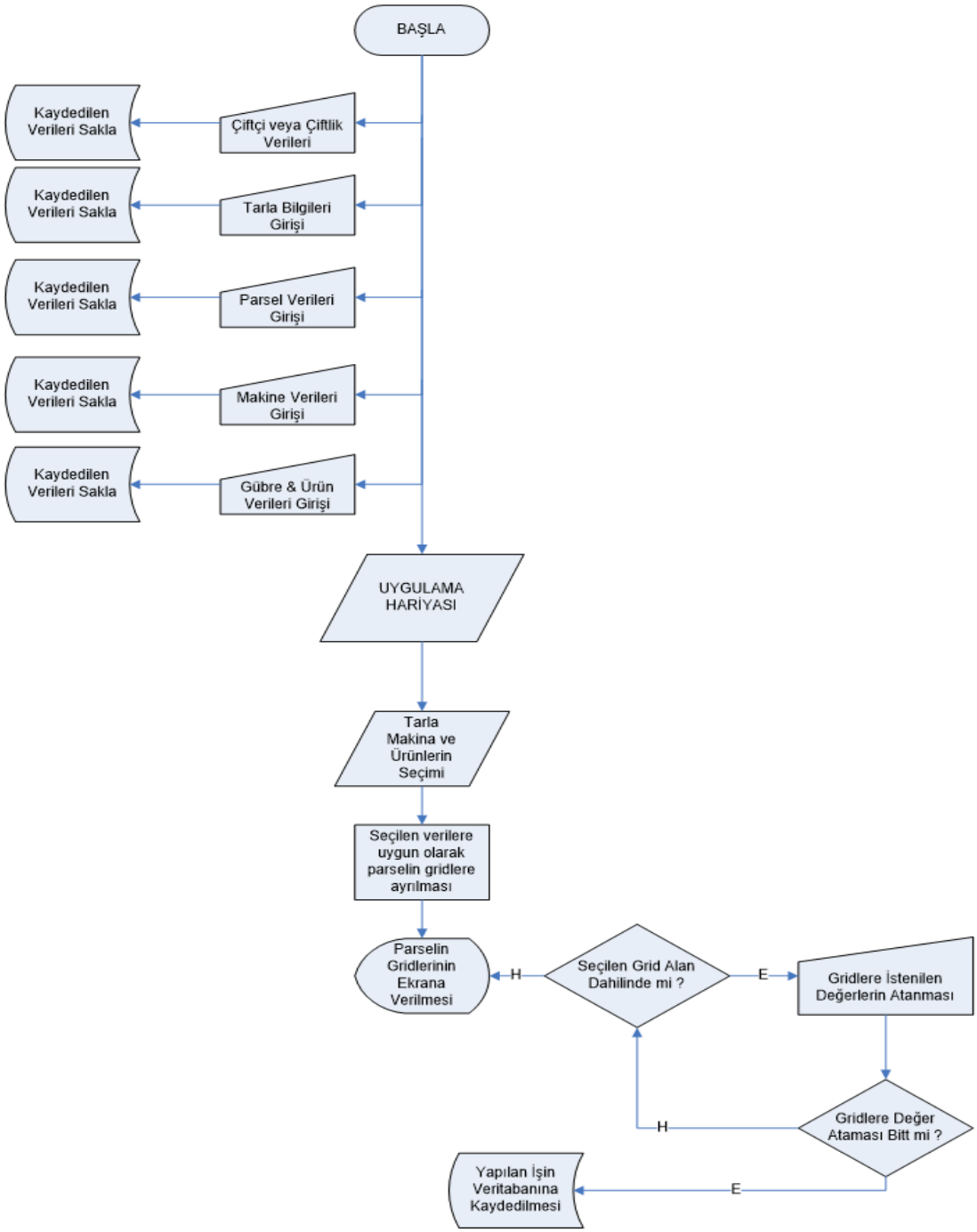

Figure 10.Algorithm of the variable rate fertilisation software
Şekil 10. *Değişken oranlı gübreleme program algoritması*

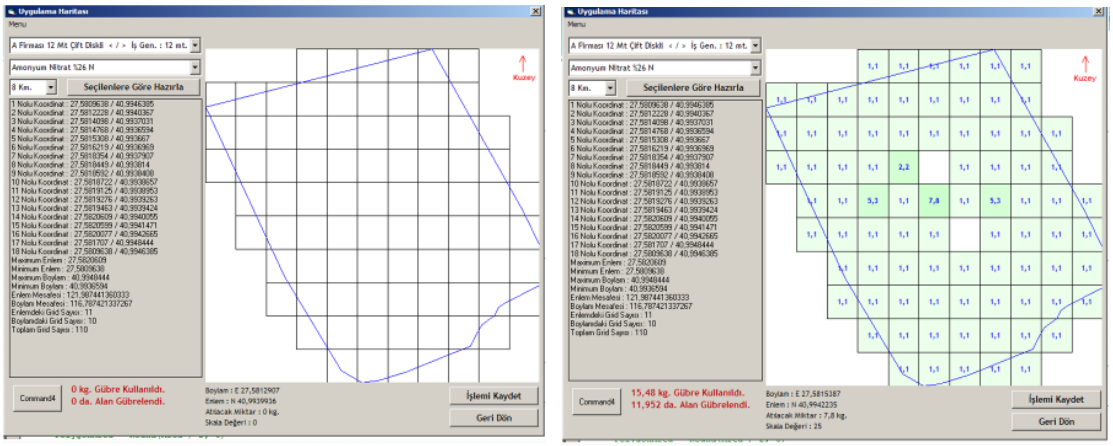

Figure 11. Screen views of the variable rate application software
Şekil 11. *Değişken miktarlı girdi uygulama programı ekran görüntüleri*

Table 3. Differences between old and new design the application software
Çizelge 3. *Eski ve yeni girdi uygulama programları arasındaki farklar*

Old software	New software
1. Visual Basic Platform	Visual Studio VB.Net (2012)
2. M.S. Access Database	XML database
	Working on an Online Real Time Map
	Turning polygons directions according to the tractor driving direction
	Overlapping polygons with field boundaries
	Divide polygons in half for dual disc fertilizer spreader machines
	Assign different values to polygons divided by two
	It can create simulations

3.4. Laboratory test results of the variable rate control system

The variable rate controller system was tested by using the developed test program for 15-15-15, 46% Urea, 20-20-0, 33% Ammonium Nitrate fertilizers for different scale values (Figure 12). Test results of 15-15-15 (N, P, K) were given in Table 4, 46% Urea in Table 5, 20-20-0 (N, P, K) in Table 6 and 33% for ammonium nitrate in Table 7.

Figure 12. Laboratory tests of the machine and control system
Şekil 12. *Makine ve kontrol sisteminin laboratuar testleri*

Table 4. Amount of the 15-15-15 (N, P, K) fertiliser for different scales
Çizelge 4. *Farklı Skala değerleri için 15-15-15 (N, P, K) gübre miktarları (kg)*

Scale	1st replications		2nd replications		3rd replications		Mean		Total
	Left	Right	Left	Right	Left	Right	Left	Right	
2	1.97	2.04	1.85	2.01	1.76	1.85	1.86	1.96	3.82
4	3.50	4.27	3.60	4.17	3.00	3.87	3.37	4.10	7.47
6	7.13	8.43	7.10	8.27	6.67	8.20	6.97	8.30	15.27
8	14.33	16.20	16.03	13.03	13.93	16.13	14.77	15.12	29.89
10	25.85	29.95	25.25	28.30	25.00	29.10	25.37	29.12	54.48
12	33.39	44.03	38.92	44.59	36.52	42.26	36.28	43.62	79.90
14	48.90	57.60	54.90	58.00	49.16	57.80	50.99	57.80	108.79
16	59.25	69.75	61.95	69.60	59.85	69.15	60.35	69.50	129.85
18	63.42	78.72	69.60	85.50	69.90	77.25	67.64	80.49	148.13

Table 5. Amount of the Urea fertiliser for different scales
Çizelge 5. *Farklı Skala değerleri için 46% Üre gübre miktarları (kg)*

Scale	1st replications		2nd replications		3rd replications		Mean		Total
	Left	Right	Left	Right	Left	Right	Left	Right	
2	1.65	2.55	2.20	2.10	2.25	2.90	2.03	2.52	4.55
4	4.65	5.85	4.75	5.70	4.95	6.00	4.78	5.85	10.63
6	8.65	1.95	9.25	11.00	9.55	11.35	9.15	8.10	17.25
8	16.80	19.55	16.85	19.50	16.80	19.05	16.82	19.37	36.18
10	29.05	34.00	26.60	33.00	29.75	34.05	28.47	33.68	62.15
12	42.60	48.50	44.20	48.20	42.50	46.30	43.10	47.67	90.77
14	57.50	63.10	58.20	63.80	54.70	64.00	56.80	63.63	120.43
16	65.55	69.30	67.80	73.95	68.10	72.30	67.15	71.85	139.00
18	72.60	77.55	75.75	80.55	70.35	81.15	72.90	79.75	152.65

Table 6. Amount of the 20-20-20 (N, P, K) fertiliser for different scales
Çizelge 6. *Farklı Skala değerleri için 20-20-20 (N, P, K) gübre miktarları (kg)*

Scale	1st replications		2nd replications		3rd replications		Mean		Total
	Left	Right	Left	Right	Left	Right	Left	Right	
2	1.45	1.55	1.45	1.70	1.40	2.90	1.43	2.05	3.48
4	3.70	2.70	3.45	3.75	3.60	6.00	3.58	4.15	7.73
6	4.55	5.60	7.40	7.50	6.70	11.35	6.22	8.15	14.37
8	12.55	14.35	13.85	11.45	10.45	19.05	12.28	14.95	27.23
10	23.60	25.30	25.00	25.80	25.20	25.90	24.60	25.67	50.27
12	39.20	41.40	39.10	41.00	40.00	41.50	39.43	41.30	80.73
14	51.60	54.00	50.55	46.05	50.55	55.95	50.90	52.00	102.90
16	60.60	68.10	66.90	65.70	66.30	71.10	64.60	68.30	132.90
18	68.25	73.05	68.70	75.75	68.40	74.40	68.45	74.40	142.85

Table 7. Amount of the 33% Ammonium Nitrate fertiliser for different scales (kg)
Çizelge 7. *Farklı skala değerleri için %33 Amonyum Nitrat gübre miktarları (kg)*

Scale	1st replications		2nd replications		3rd replications		Mean		Total
	Left	Right	Left	Right	Left	Right	Left	Right	
2	2.70	3.20	3.00	3.40	3.05	2.90	2.92	3.17	6.08
4	6.40	6.65	6.40	6.70	6.45	6.00	6.42	6.45	12.87
6	12.45	13.35	11.10	12.65	11.50	11.35	11.68	12.45	24.13
8	22.15	23.35	22.30	22.75	21.95	19.05	22.13	21.72	43.85
10	39.00	41.70	38.60	42.00	38.40	38.60	38.67	40.77	79.43
12	53.20	58.40	56.50	59.60	56.00	59.20	55.23	59.07	114.30
14	72.15	78.60	70.50	77.10	72.00	77.85	71.55	77.85	149.40
16	88.20	93.00	87.15	91.80	86.85	90.45	87.40	91.75	179.15
18	99.30	102.45	97.35	102.90	97.80	103.95	98.15	103.10	201.25

When the results were investigated; it was seen that the amount of fertilizer was increased by increasing the number of steps corresponding to the scale. This means that the stepper motors controlled plates located at the bottom of the centrifugal fertiliser spreader. If the fertilizer requirement of the grids of the field spatially varied according to the developed variable rate fertilizer application program, the required scale / step will be automatically adjusted by the variable rate controller system and applied in different rates (kg / ha) during fertilization. A double disc mineral fertiliser spreader was used in the tests and heterogeneity in fertilizers caused differences between distribution of the right and left discs. This is also valid for farmer practices because the farmer have been using the fertilizer without sorting by sieve. The difference in size of the fertilizer particles affect the fertilizer application rate during application of the fertilizer. The main objective of this study was to test the performance of the variable rate control system developed for the centrifugal fertilizer spreader manufactured in Turkey. According to the results, system performance was good enough to realize fertiliser application as variable rate.

4. Conclusions

In this study, a variable rate control system was developed for centrifugal fertilizer spreading machines. The variable rate controller system includes mechanical components, electronic control system, a laboratory test program and variable rate agricultural input application program. In the scope of the research, fertilizer distribution values were determined for different scale values by using 15-15-15 (N, P, K), 46% Urea, 20-20-0 (N, P, K) and 33% Ammonium Nitrate fertilizers commonly used for agriculture production. The system automatically applies the required amount of fertilizer according to the varieties of the field and the plant according to the position instead of throwing the same amount of fertilizer on every side of the field, variable rate application prevents the use of excess fertilizer. As it is well known that the majority of Turkish farmers are dealing with field crops. If this system adopt to the centrifugal fertiliser spreader machines, it will create big contribution to the economy.

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