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Development of a Row Type Variable Rate Fertilizer Machine and Performance Assessment

Ufuk TÜRKER[1*] Babak TALEPBOUR[1] Mehmet Metin ÖZGÜVEN[2]
[1]Ankara Üniversitesi Ziraat Fakültesi Tarım Makinaları ve Teknolojileri Mühendisliği Bölümü, Ankara
[2]Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Biyosistem Mühendisliği Bölümü, Tokat
(orcid.org/0000-0002-7527-7376); (orcid.org/0000-0002-6421-4804); (orcid.org/0000-0002-2380-8972)
*e-mail: uturker@agri.ankara.edu.tr

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Abstract: Increasing profitability associated with reduction of environmental pollution and production costs made variable rate application unavoidable. Therefore, fertilizing according to the field demand and ability to vary fertilizer rates on-the-go is regarded as one of the site-specific management tools. Variable rate application machines tend to be more complicated and thus farmers must take into account how reliable the extra components and systems. This study introduces a frugal variable rate granular fertilizer with features of and simplicity that was modified on a row fertilizer machine. Interpolation accuracy, coefficient of variation and response time as parameters to achieve a reliable variable rate fertilizing system were considered in order to evaluate the fertilizer applicator performance. According to the results, when interpolation accuracy was determined as R2, 0,94 the response times of low to high and high to low transition rate orders were estimated as 4,44s and 4,63s taking into account operation speed at 1 ms-1, respectively. Coefficient of variation of fertilizer rates ranged from 6,44 to 26,25% and 10,45 to 81,3 for application rate from 0 to 150 kg/ha. Variation of fertilizer rate among the metering units in terms of coefficient of variation (CV) resulted from 10,11 to 36,15% and 11,15 to 117,89% in increasing and decreasing transition order, respectively.

Keywords: Variable rate fertilizer application, Control system, İnterpolation, Response time.

Sıraya Gübre Atan Değişken Oranlı Makinenin Geliştirilmesi ve Performansının Belirlenmesi

Öz: Artan karlılık ve çevre kirliliğinin azaltılması, değişken oranlı uygulamayı kaçınılmaz kılmaktadır. Bu nedenle, tarla gereksinimine göre gübreleme ve hareket halindeyken gübre oranlarını değiştirme kabiliyeti sahaya özel araçlarından biri olarak kabul edilmektedir. Değişken oranlı makinalar daha karmaşık yapıda olduklarından çiftçiler, ekstra bileşenlerin ve sistemlerin ne kadar güvenilir olduğunu ve getirdiği ek maliyet ve zorlukları göz önünde bulundurmalıdır. Bu çalışma, sıraya gübre atma makinasına modifiye edilmiş değişken oranlı bir granül gübre sistemini ve performansını tanıtmaktadır. Gübre atma makinasının performansını değerlendirmek için, enterpolasyon doğruluğu ve güvenilir değişken oranlı bir gübreleme sistemi elde etmek için parametreler olarak, gübre değişkenlik katsayısı ve tepki süresi, dikkate alınmıştır. Sonuçlara göre, enterpolasyon doğruluğu 0,94 (R2) olarak belirlenmiştir. Tepki süreleri, en düşük gübre miktarından en yüksek miktara ve en yüksekden en düşük miktara geçiş oranları 1ms-1 ilerleme hızında sırasıyla 4,44 ve 4,63s olarak hesaplanmıştır. Gübre oranlarındaki değişim katsayısı, %6,44 ile %26,25 ve 10,45 ile 81,3 arasında değişmiştir. Değişken gübre atma ünitesinin gübre oranı değişkenlik katsayısının (CV) değişimi, sırasıyla geçiş sırasındaki artan ve azalan değerlerde sırasıyla %10,11 ila 36,15 ve %11,15 arasında 117,89 gerçekleşmiştir.

Anahtar Kelimeler: Değişken oranlı uygulama, Kontrol sistemi, Enterpolasyon, Tepki süresi

1. Introduction

There are many questions such as economic, agronomic and technology related questions when adopting a sitespecific management program for crop production (Ess et al., 2001). The cost of adopting, difficulties in integrating components, problems with data interpretation and agronomic solutions were also some of the issues in adopting site specific management based on spatial variability across farming zones rather than other Precision Agriculture (PA) tools such as automatic steering and yield monitoring (Jochinke et al 2007). Especially due to a high level of management information, data interpretation and decision support process requirements, implementation of variable rate application (VRA) is differed from other PA technologies. Like other innovations, relative advantage, compatibility, complexity, trialability and observability are the five key attributes that can be used to explain a high proportion of possible reasons for low/variable adoption of PA technology (Robertson et al., 2012).

The access to the technical training, meeting, oral transmission, trust on technician and believe on the technology introduced by scientist are the factors affecting in change of technology use (Chi et al., 2002). Generally, socioeconomic factors, agro-ecological factors, institutional factors, information sources, farmer perception, behavioral factors, technological factors are the main factors effecting on adoption of PA (Antolini et al., 2015). Because of usefulness and ease of use that are central aspects of technology adoption, it seems to be more effective to create a low performance tool with few "useful" characteristics in order to attain a lower purchase price (Pierpaoli, 2013).

Currently, with continuing research to variable rate fertilization technology, using map-based or sensor-based application as two basic methods of implementing site-specific management (SSM) for the VRA with its own unique benefits and limitations has been developed (Ess et al., 2001).

Previous studies on development of variable rate granular fertilizers revealed that good application performance with high accuracy and short response time are the main aspects for evaluating the performance of a granular applicator (Kim et al 2008, Talha et al., 2011, Forouzanmehr et al 2012, Akdemir et al., 2018). Most of these studies have focused on fertilizing applicator and developed a way to determine fertilizer rate based on field sampling data was neglected. Therefore, the objective of this study was to develop and evaluate the alternative method to determine fertilizer rates and its application on row granular fertilizer. In this study, low cost and ease of use as two specific features were considered.

2. Materials and Methods

2.1. Test Fertilizer and Rate Control Equipment

A six row hoeing fertilizer was used as a test machine. Generally, distributing mechanism for granular fertilizers is worked by changing the fertilizer outlet cross sectional area existing under fertilizer hopper. Plastic molded sheaves mounted on fertilizer shaft and replace by turning adjusting lever to right or left to achieve the desired flow rate. A linear actuator with position feedback was used to control adjusting lever replacement use in fertilizer norm changing (Figure 1).

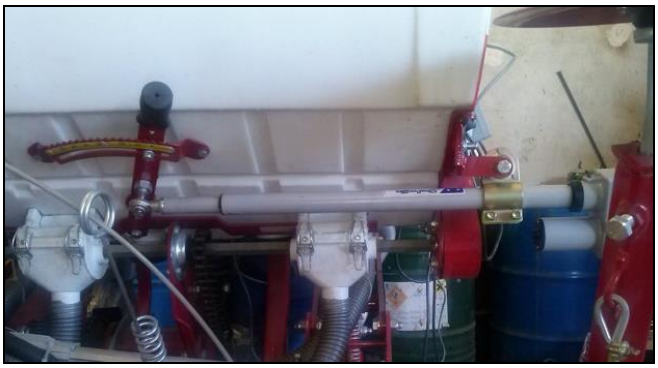

Figure 1. Flow rate control mechanism
Şekil 1. *Gübre akışı kontrol mekanizması*

2.2. Fertilizing Rate Determination

In order to obtain fertilizing rate based on predetermined field sampling Inverse Distance Weighting (IDW) interpolation method was implemented. The simplicity of underlying principle, the speed in calculation, the ease of programming, and reasonable results for many types of data are some of the advantages associated with inverse distance weighted interpolation (Hu, 1995). IDW method was used in this study which uses a mathematical function known as Shepard´s method (Shepard 1968):

$$F(x,y) = \sum_{i=1}^{n} w_i f_i \quad (1)$$

$$w_i = \frac{h_i^{-p}}{\sum_{j=1}^{n} h_i^{-p}} \quad (2)$$

where p is an arbitrary positive real number called the power parameter (typically p = 2) and hj are the distances from the dispersion points to the interpolation point, given by:

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (3)$$

where x, y are the coordinates of the interpolation point and xi, yi are the coordinates of each dispersion point. For this method the influence of a known data point is inversely related to the distance from the unknown location that is being estimated as nearby values contribute more to the interpolated values than distant observations (Azpurua et al., 2010). C++ programming language was used for writing the required programs. The accuracy of developed program was investigated by choosing 40 hypothetical points within the field. Interpolation was done based on pre-determined field sampling data and then compare with IDW interpolation values obtained from ArcMap 10 software as referenced program.

2.3. Variable Rate Application Control System

The system used for control fertilizer application rate was developed in two different forms; manual and automatic forms. In both systems, linear actuator arm mounted on the fertilizer outlet lever was provided by using driving circuit comprising of ATMEGA328 based Arduino Uno board and relay circuit. Feedback signals from linear actuator were perceived by Arduino Uno in order to determine actuator position. Then a program load on board combined two interpolation value and feedback signals and send out an essential command to relay circuit to perform required fertilizer rate.

In the manual system, the desired fertilizer rate was determined by pressing on relative button. Five embedded buttons use on control unit was in the number and color of anticipated classification in interpolation program. Time of pressing on buttons can also be determined by using a prescription map. System integrated with a GPS via tablet computer. As the GPS location on each color of prescription map was considered as corresponding color on the buttons. So, the required fertilizer rate was applied when relative colored button pressed (Figure 2).

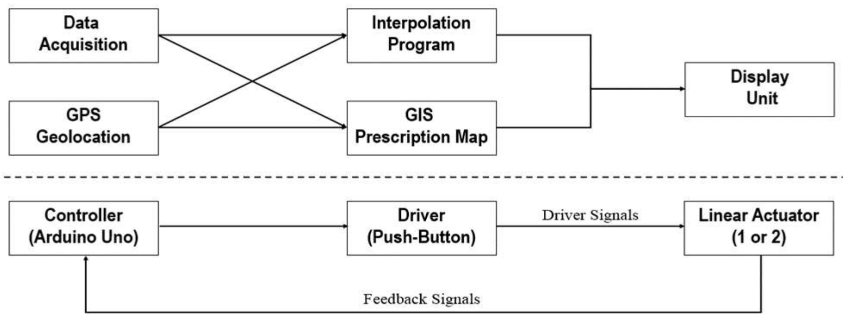

Figure 2. Block design of manual type variable rate fertilizer
***Şekil 2**. Manuel tip değişken oranlı gübrelemenin blok diagramı*

In the automatic system, the same process was done with the exception that no operator intervention is required to apply fertilizer rates. By using this system without the need to mapping software, predicted fertilizer rates was determined by interpolation program at GPS position were sent to control unit to provide linear actuator movement at the desired level (Figure 3).

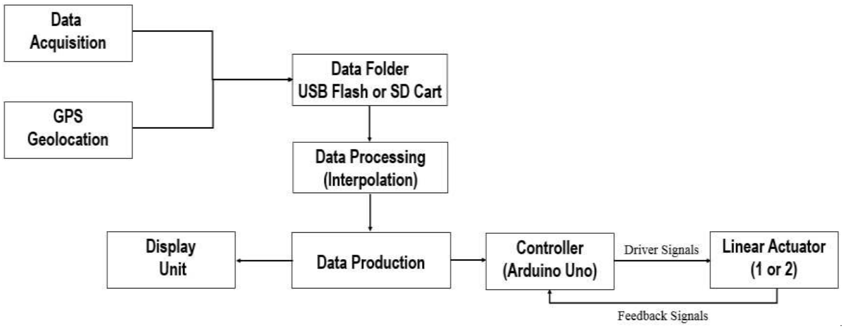

Figure 3. Block design of automatic type variable rate fertilizer
Şekil 3. *Otomatik tip değişken oranlı gübrelemenin blok diagramı*

A C++ software program was developed in order to integrate the function of the system component.

2.4. System Performance Evaluation

Performance evaluation of the developed system was carried out under different target fertilizer rate (0, 60, 90, 120, 150 kgN/ha) and 1 m/s as operation speed. Urea (46% N) was used as selected granular fertilizer and foam rubber surface was placed in order to determine the fertilizer performance for the different rate setting and for the transition from one rate to another. The calibration of fertilizer was done before installing the system component. A simulated field test was conducted to collect granular fertilizer from metering units for short intervals of travel to define the transition performance. 10 plots with 3.3 m2 square for each grid dimensions comply with machine working width were created along 20 m distance. Two lines of collecting surface were used and fertilizer from each three metering unit was collected into each line. Change of fertilizer rate was initiated at the first plot of experiment line, and then samples collected from each plot were weighted to determine the application rate for each line. Test procedure to determine response time for different fertilizer rate was conducted at low to high transition order (increasing form) and high to low transition order (decreasing form). Considering 1 m/s as operation speed, where the application rate actually starts to change can be translated into time.

Sigmoid equation (Han et al, 1995) was used to fit the data from experiment in order to determine response time for both increasing and decreasing form of fertilizer rate changing. A four-parameter logistic model estimated sigmoidal behavior of the variable rate system response as follows (Motulsky, 2004):

$$Y = d + \frac{a - d}{1 + \left(\frac{X}{c}\right)^{b}}$$

Where, Y=application rate, a=minimum rate, c=inflection point, d=maximum rate and X=distance.

Microsoft Excel based XLSTAT extension procedure was used to determine model parameter estimates. The extracted sigmoid pattern of the model used to interpret the application rate behavior.

3. Results and Discussion

3.1. Interpolation Accuracy

Hypothetical points selected from a field were used to investigate developed interpolation program. The value of pre-determined field sampling data was interpolated using IDW interpolation of spatial analyst tool box as an ArcMap 10.2.2 software function. Figure 4 shows the best fit line relating the interpolated values from developing program to ArcMap 10.2.2 software values. The result of linear regression was revealed a high coefficient of determination (R2=0.94) between two variants that demonstrated the accuracy of interpolation program.

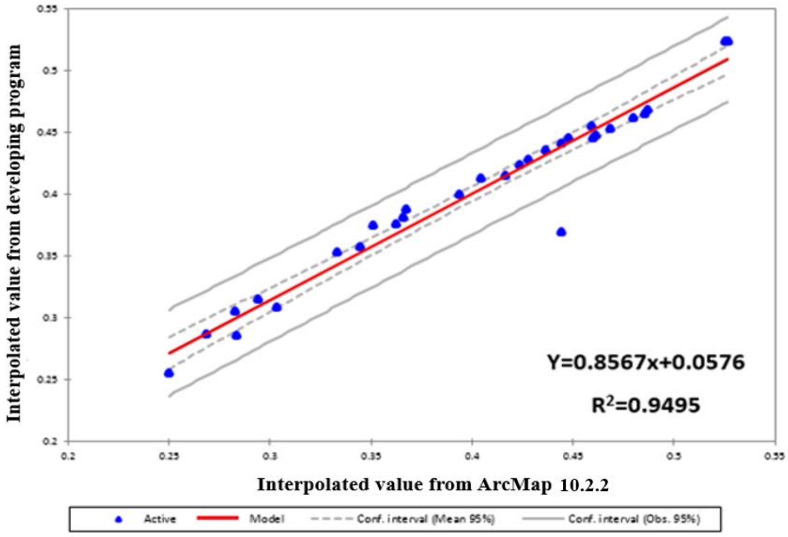

Figure 4. Linear regression relating the interpolated values from developing program to ArcMap 10.2.2 software values

Şekil 4. *Geliştirme programından ArcMap 10.2.2 yazılım değerlerine kadar enterpolasyon değerleri ile ilgili doğrusal regresyon*

3.2. Application Performance

Increasing and decreasing rate changing order as two transition order were applied in order to evaluate application performance. The variability of the fertilizer delivered by each metering unit in terms of down-the-row and among metering units is summarized in Table 1. Statistical data in this table represent application data of test procedure from 10 plots with 1,65*2 m dimension.

Table 1. Descriptive statistic of fertilizer rate at different rate setting

Çizelge 1. *Farklı gübre oranlarında tanımlayıcı istatistik*

Transition order	rates, kg/ha	Mean, kg/ha	Percentage deviation, %	Down-the-row		Among metering units	
				STDEV, kg/ha	CV, %	STDEV, kg/ha	CV, %
Increasing rate (low to high)	0-60	52.25	-12.92	13.71	26.25	18.89	36.15
	60-90	87.39	-2.9	7.3	8.35	10.63	12.17
	90-120	112.93	-5.89	7.68	6.8	13.27	11.75
	120-150	144.54	-3.64	9.31	6.44	14.61	10.11
Decreasing rate (high to low)	150-120	123.68	+3.06	17.65	14.27	17.31	13.99
	120-90	99.46	+10.51	10.39	10.45	11.09	11.15
	90-60	69.15	+15.25	7.97	11.53	12.08	17.48
	60-0	18.99	+18.99	15.43	81.3	23.35	117.78

Variation of fertilizer rates down-the-row for two series of pilots with 2 m length resulted in coefficient of variation (CV), ranging from 6,44 to 26,25% and 10,45 to 81,3 for application rate from 0 to 150 kg/ha and 150 to 0 kg/ha as increasing and decreasing transition order, respectively. Variation of fertilizer rate among the metering units in terms of CV resulted from 10,11 to 36,15% and 11,15 to 117,89% in increasing and decreasing transition order, respectively. It seems that the system has better performance on increasing transition order in both down-the-row and among metering units in terms of CV. During the process of fertilization rate changing in the form of increasing to decreasing order, the calculated value related to CV were high at the beginning and end of shifts compared with other midrates. Accumulation of fertilizer on downfall wickets at startup and incomplete wickets closure due to granules resistance at the end of rate changing was observed as the reason of CV percentage.

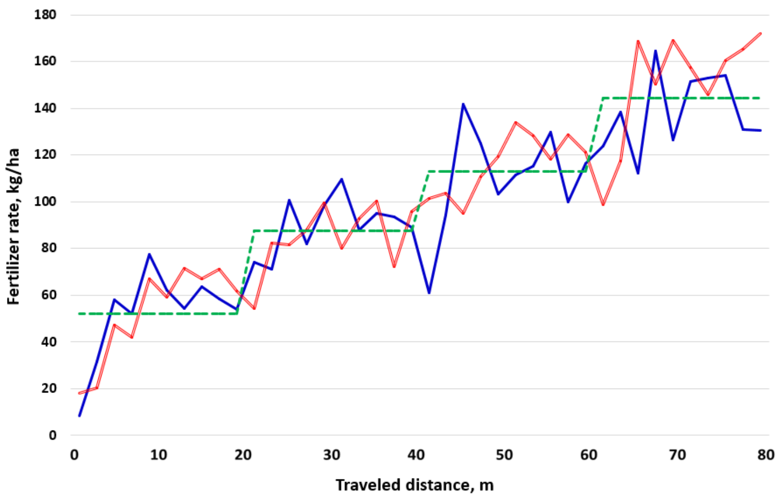

Figure 5. Variation in fertilizer rate with traveled distance at increasing transition order (collected from right hopper and collected from left hopper represents observed data and dashed line represent mean value for each fertilizer rate).
Şekil 5. *Artan oranlarda geçiş sırasındaki hareket mesafesi ile gübre oranındaki değişim*

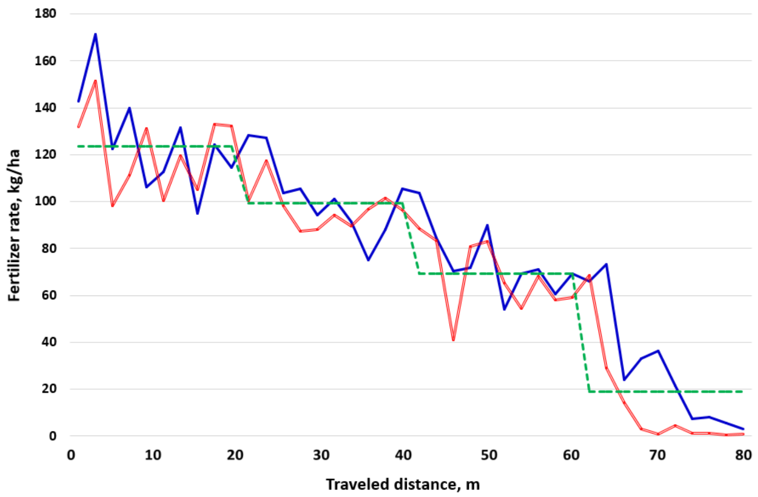

Figure 6. Variation in fertilizer rate with traveled distance at decreasing transition order (collected from right hopper and collected from left hopper represents observed data and dashed line represent mean value for each fertilizer rate)
Şekil 6. *Azalan oranlarda geçiş sırasındaki hareket mesafesi ile gübre oranındaki değişim*

Figures 5 and 6 present variation in fertilizer rate with distance for increasing and decreasing transition order, respectively. Mean values related to the different fertilizer rate setting were demonstrated on each figure.

3.3. Time Response

As a result of a simulated field test, all data from different fertilizer rate exchanging were used to investigate the sigmoidal behavior of the variable rate system. Generally, changes in fertilizer rate can be observed as an S-shaped diagram. So, in order to test the control system ability to change the applied rate on-the-go, sigmoidal parameter estimation, R-squared values and distance values at 95% confidence interval were determined (Table 2).

Table 2. Sigmoidal model parameters estimation, R-square and time response values for different fertilizer rate at two transition order

Çizelge 2. *Sigmoidal model parametreleri kestirimi, iki geçiş sırasındaki farklı gübre normları için R-kare ve zaman tepki değerleri*

Transition Order	Exchange rate	Model Parameters a	b	c	d	R^2	X*	Time Response*
	kg/ha	Estimate	Estimate	Estimate	Estimate		metre	second
Low to High	**0 - 60**	66.81	1.59	4.11	22.79	0.67	9.01	9.01
	60 - 90	94.19	4.01	4.17	62.65	0.60	5.30	5.30
	90 -120	118.67	11.47	4.04	81.27	0.47	4.78	4.78
	120 -150	152.45	4.59	4.41	110.51	0.42	3.19	3.19
High to Low	**150 - 120**	117.28	364.24	4.54	149.26	0.46	4.53	4.53
	120 - 90	93.89	22.142	5.76	118.22	0.57	5.37	5.37
	90 - 60	62.38	4.62	4.60	96.51	0.82	3.91	3.91
	60 - 0	-6.14	0.94	0.06	1874.42	0.88	9.44	9.44

* 95% confidence Interval

Table 2 shows the summary results for sigmoidal model parameters estimation and time response values at increasing (low to high) and decreasing (high to low) transition order. As the results show, even though the signal of the fertilizer rate change applied at the beginning of the first pilot (0 m), the rate changed after few meters travelled. The travelled distance needs to apply desired rate represents the time needed for the actuator to overcome mechanical friction of the system. The distance travelled before the complete change occurred at increasing rate order were about 9.01, 5.30, 4,78, 3,19 m for 0-60, 60-90, 90-120, 120-150 kg/ha rates, respectively. As the same, distance values determined for decreasing rate order were 4,53, 5,37, 3,91 and 9,44 m for 150-120, 120-90, 90-60, 60-0 kg/ha rates, respectively. Considering 1 m/s as operating speed, the values determined for distance were corresponded to a system response time. It should be noted that because of increasing of fertilizer rate from 0 to 60 kg/ha and decreasing rate from 60 to 0 kg/ha were doubled, determine response time for first/last 30 kg will be possible by halving response time values obtained from above mentioned fertilizer rates (0-60 and 60-0 kg/ha). The average values of response time were also determined as 4,44 and 4,63 s for increasing and decreasing transition orders, respectively.

Figures 7 shows graphically the relationship between the predicted fertilizer rate and the observed fertilizer rates using a logistic model (y), (x). The simple linear regression model was established to evaluate comparing the predicted and the observed data during the test procedure. The parameters of the regression analysis showed that the model was able to satisfactorily predict the fertilizer rate in each transition order. As the results of regression analysis, CV was found as 0,89 and 0,94 for increasing and decreasing fertilizer rate, respectively. The results showed that the established model can be a suitable tool to investigate response time in proffered system.

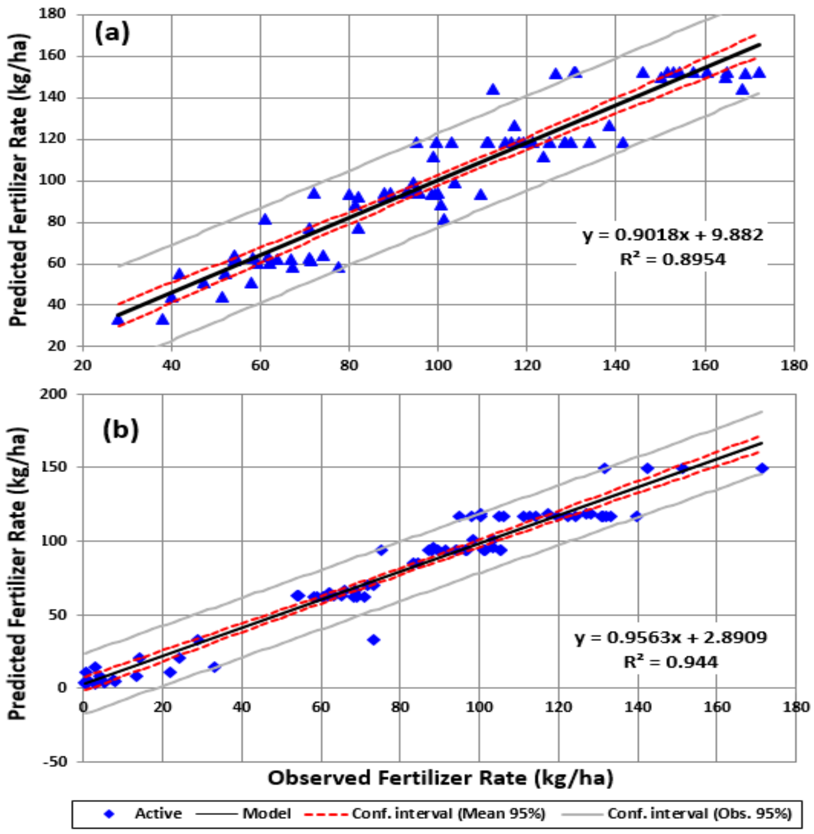

Figure 7. Relation between predicted and observed fertilizer rates during test procedure for increasing transition order (a) and decreasing transition order (b). The total number (n) of samples in each plot is 80

Şekil *7. Artan gübre normları için testler sırasında öngörülen ve gözlemlenen değerler arasındaki ilişki*

4. Conclusions

In this study, a cheap and simple solution to variable rate granular fertilizing based on field sampling data was introduced. For this purpose, the system consisted of interpolation, control and applicator adjustment systems with the beneficiary of geographic information system (GIS) implementation. Developed system was modified for a six row hoeing fertilizer in order to change fertilizer rate on-the-go in both manual and automatic types. The manual type system allowed operator to change the required fertilizing rate either from prescription map or developed interpolation software. The automatic system was used field sampling data document to apply a desired fertilizer rate properly at the right time of progress without any operator interference.

A test procedure was carried out to evaluate the accuracy of interpolation software and the performance of the variable rate system across the field in terms of response time. Compared with professional software's used for variable rate applications such as Arcmap, the accuracy of developed software by the Inverse Distance Weighting method was proved with high coefficient of determination (0.94) from a linear regression model.

During a simulated field test, changing in fertilizer rates was followed by increasing and decreasing rates as transition orders in 20 m length distance with two series of 10 plots. In order to determine system response time, fertilizer rates were changed at the beginning of predetermined distance to set a distance for acquirable fertilizer rate. Taking into account operation speed at 1 m/s, the average values of response time were determined as 4,44 and 4,63 s for increasing and decreasing transition orders, respectively.

Developed system is not only used for the row fertilizer machine, but also it can be beneficial in all variable rate applicators such as seeders, centrifugal fertilizer distribution machines and spreaders with changing in their distributor driving systems. Replacement of linear actuator with high speed and highpower type and optimization of the opening and closing mechanism to overcome granular fertilizer particles in front of the wickets, are recommended to improve variable rate system quality use in row hoeing fertilizer machines.

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