

# Performance Assessment of VRT-based Granular Fertilizers Broadcasting Systems

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## Abstract

Due to environmental concerns in addition to economical considerations, Variable Rate Treatment concept is widely applied in the agricultural arena. Granular fertilizers' broadcasting is one of the most growing applications employing VRT and GPS guidance technologies. Although such systems are commercially produced, standards for performance assessment yet to be developed. ASAE S431.2 provides a standard procedure for testing broadcasters performance. However, this standard does not cover the testing of broadcast spreaders with VRT. Three different testing methodologies are presented in this paper to lay the basics of any testing procedures to be developed. The suggested procedure is widely applicable assessment process and not specifically designed to evaluate a specific system. A semi-automatic rotary variable rate broadcaster equipped with GPS real time guidance was designed and built locally. Evaluation procedures focused on differences between the prescribed and the actually applied amounts; between nutrient ( $P_2O_5$ ) levels before and after treatment and between targeted and actual nutrient levels after treatment in GPS identified points in the field.

## Objectives

The objective of this study is to develop a rational procedure to assess the overall performance of a typical GPS guided, VRT based broadcasting system based on the comparison between the measured values and the targeted ones.

## Review of Literature

Testing procedures of the over all VRT broadcasting systems are rarely mentioned in the literature where most of the research work focused on partially testing or waiting for yield to judge system performance. Fulton *et al* (2001) mentioned that application accuracy is an important property to quantify when assessing variable-rate spinner spreaders. The coefficient of variation (CV) is typically used to characterize the quality of spread distribution. Lower CVs tend to be indicative of more uniform distribution patterns. Typically, the CV varies from 5% to 10% for spinner spreader patterns. They added that, many factors affect fertilizer distribution and application accuracy, such as systematic errors associated with machine calibration and metering efficiency. However, Sogaard and Kierkegaard (1994) reported that CVs could be more in the range of 15% to 20% under field-testing. These higher CVs are probably

due to rougher surfaces experienced under field conditions. Where Parish (1991) reported CVs in the upper 20's to the lower 30's in some test cases with these high variations resulting from terrain irregularities. They added that, ASAE standard S341.2, Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders (ASAE S431.2, 1997), provides a uniform procedure for testing, assessing the performance, and reporting the results of broadcast spreaders. It specifies test setup, collection devices, test procedures, effective swath width, and determination of the proper testing application rates. When using the outlined procedure, the results provide a quantification of application accuracy and possible spread pattern deviations. Since standard deviation refers to the mean as a reference value, it may be used to quantify the variability of soil fertility as stated by Jin and Jiang (2002), on the other hand using it to assess VRT-based system performance would not be realistic.

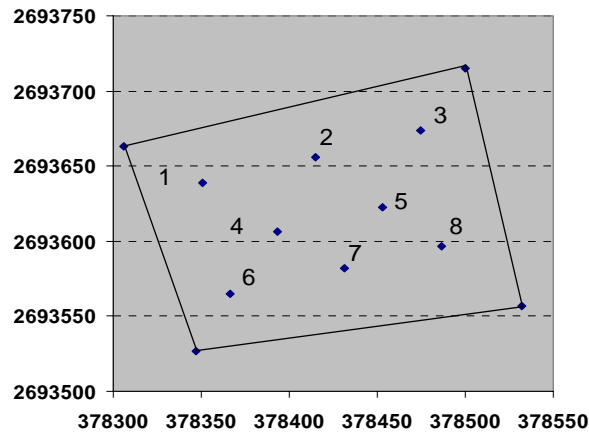
It may be concluded that, referring to the mean value to evaluate system performance is not accurate enough to provide comparable results due to its floating reference point. System assessment requires the referred value to be the targeted nutrient level or targeted application rate to produce robust results.

## **Materials and Methods**

As stated by El-Mowafy and Fadel (2002), Different real-time GPS positioning techniques that can be utilized for the task in hand were examined and compared, including the Real Time Kinematic method (RTK), the Differential GPS (DGPS), and the phase-smoothed DGPS. The RMS and maximum and minimum values of standard deviations ( $\sigma$ ) of the East, North and Elevation coordinates of the trajectory points were calculated for the former two methods, respectively. The plane coordinates were computed from the GPS derived WGS-84 Cartesian coordinates by transforming them to the local ellipsoid, computation of the geographic coordinates, and projecting them on the local system which adopt a Universal Transverse Mercator projection. The RTK technique gave a superior positioning accuracy of 1-4 cm on the average, which was optimal for tractor guidance and topographic mapping. On a lower level, the DGPS technique gave mean accuracies of 0.2-0.65 m, which are suitable for positioning and guidance purposes, but which are not sufficient for accurate topographic mapping needed for application control.

## **GRID SOIL SAMPLING**

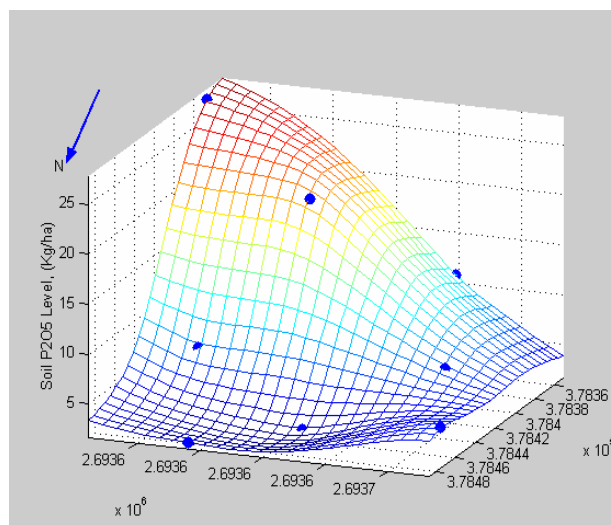
Grid soil sampling is a commonly used method for assessing variability in soil fertility and provides the basis for variable rate fertilizer recommendations. In order to estimate soil requirements, the field was gridded in 50-meter mesh and soil samples were collected from eight GPS defined locations. Soil analysis results were mapped and studied to find out the needed amount of Calcium Super Phosphate to be added per hectare. In order to evaluate system performance and its feasibility, soil chemical analysis of the same GPS defined locations, were carried out no later than two hours after applying the fertilizers using the designed system under.



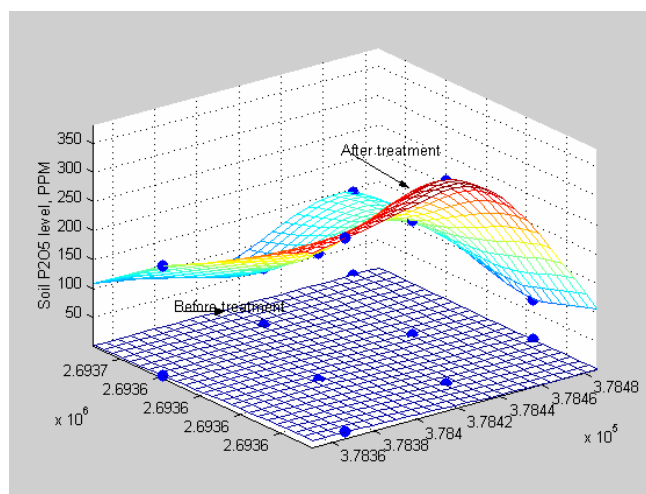
**Figure 1** Distribution of Soil Samples

### Evaluation procedures

Different evaluation parameters for the overall performance of the variable rate application system are presented in this paper. Statistical representation of the variation of the studied element (in this research is  $P_2O_5$ ) is the main concern and should be the reference judging point for any evaluation procedure in the future. Most of the previous literature used the standard deviation to assess system performance and its ability to distribute fertilizers uniformly. Standard deviation compares samples values to their mean, which does not help judging the ability of the system to satisfy field requirements stated as targeted prescribed application rates hence, nutrient level.



**Figure 2**  $P_2O_5$  Application Rates



**Figure 3 Soil  $P_2O_5$  Levels Before and After Treatment**

A system must be capable to distribute uniformly; then it must be capable to vary the application rate to satisfy different soil requirements in different points.

Any VRT-based performance evaluation test should answer the following questions:

- Does the system applied the prescribed quantity in the exact location fed by the GPS system? and how close?
- Does the system changed field uniformity, in which direction?
- How to compare the system under investigation with other tested systems?

To answer the previous questions field-testing and statistical analysis should be carried out. There are different statistical methods to analyze system performance. Inferences about the differences between two population means for paired samples are used to judge performance statistically. Mann (1995) .

In this paper different methodologies will be presented in order to assess system performance.

### **Methodology I**

This methodology focused on the differences between field conditions before and after applying the fertilizer using the system under investigation in specific locations. This methodology was applied practically in Al-Oha farm, UAE University. (El-Mowafy and Fadel (2002))

The following steps were taken as testing procedure:

1. field mapping using GPS tools .
2. eight locations were randomly selected to collect soil samples and  $P_2O_5$  levels were determined . Those points were GPS-identified.

3. field was divided to presumably three homogeneous zones according to the determined  $P_2O_5$  levels.
4. A prescription table was developed according to the recommended  $P_2O_5$  levels in the area for Rhodes forage.
5. system was run and the prescribed amounts of fertilizers were added according to the prescription table.
6. soil samples were collected from the same GPS identified locations and  $P_2O_5$  levels were determined as shown in Table1.
7. the following statistics formulae were used to calculate the standard deviation of the paired differences for the sample.

**Table 1  $P_2O_5$  level before and after treatment at GPS identified points**

Point #	$P_2O_5$ level before treatment, ppm	$P_2O_5$ level after treatment, ppm
1	2.51	72.33
2	2.95	50.28
3	4.81	91.98
4	11.97	172.90
5	3.23	177.25
6	1	35.00
7	0.96	98.78
8	9.05	113.46

$$\bar{d} = \frac{\sum d_{(i,j)}}{n} \dots\dots\dots 1$$

$$S_d = \sqrt{\frac{\sum d^2 - \frac{(\sum d_{(i,j)})^2}{n}}{n-1}} \dots\dots\dots 2$$

$$S_d^- = \frac{S_d}{\sqrt{n}} \dots\dots\dots 3$$

Where

$d$  the difference between  $P_2O_5$  level in a location before and after treatment. ( $d_{(i,j)}$   
 $= P_2O_5$  level before treatment, ppm -  $P_2O_5$  level after treatment, ppm)

$\bar{d}$  the mean of the paired differences of the sample

$S_d$  the standard deviation of the paired differences for the sample (before and after treatment)

$S_d^-$  estimated standard deviation of paired differences

$n$  the number of locations

Mann (1995)

results were as follows:

$$S_d = 49.78$$

$$S_d^- = 17.6$$

## Methodology II

This second methodology depends on investigating the differences between the targeted  $P_2O_5$  level (in this case it is 51ppm) and the after treatment level in each GPS-identified point. To achieve this goal the following steps should be taken:

1. field mapping using GPS tools
2. collect soil samples and determine nutrition levels in the GPS identified points
3. A prescription table to be developed according to the recommended levels.
4. system to be run to apply the prescribed amounts of granular fertilizer
5. soil samples to be collected from the GPS-identified points and  $P_2O_5$  level to be determined in samples (Table 2).
6. to evaluate differences between targeted and  $P_2O_5$  level in the field , standard deviation of the paired differences ( $S_d$ )(equation 2) and estimated standard deviation of paired differences ( $S_d^-$ )(equation 3) should be calculated as mentioned above.

Applying equation1 where  $d(i,j)$  = targeted  $P_2O_5$  level , ppm –  $P_2O_5$  level after treatment, ppm.

**Table 2 Targeted and actually  $P_2O_5$  levels after treatment**

Point #	$P_2O_5$ level (Targeted) ppm	$P_2O_5$ level (After treatment), ppm
1	51	72.33
2	51	50.28
3	51	91.98
4	51	172.90
5	51	177.25
6	51	35.00
7	51	98.78
8	51	113.46

results were as follows:

$$S_d = 52.1$$

$$S_d^- = 18.4$$

### Methodology III

The third method depends on evaluating field conditions before treatment by collecting soil samples from different GPS-identified locations to be used in preparing the prescription map. Theoretically, prescribed quantities should be delivered to the corresponding locations. The actually delivered quantities should be determined by running the system and collecting the delivered fertilizers in a standard collecting trays (ASAE S431.3, 1999) put in the GPS-identified points. A comparison between the prescribed and the delivered amounts should be carried out to assess system's ability of delivering the right amount in the right site.

The following steps may be taken as testing procedure:

1. field mapping using GPS tools
2. collect soil samples and determine nutrition levels in the GPS identified points
3. A prescription table to be developed according to the recommended levels.
4. standard collecting trays to be located in the GPS identified sites and marked with the GPS coordinate
5. system to be run to apply the prescribed amounts of granular fertilizer
6. collecting trays contents to be weighed (Table 3)
7. to evaluate differences between prescribed and actually delivered amounts , standard deviation of the paired differences ( $S_d$ ) (equation 2) and estimated standard deviation of paired differences ( $S_d^-$ ) (equation 3) should be calculated as mentioned above. Applying equation 1 where  $d(i,j)$  = prescribed  $P_2O_5$ , kg/ha – actually delivered  $P_2O_5$  level, kg/ha.

**Table 3 Prescribed and actually added  $P_2O_5$  levels**

Point #	$P_2O_5$ level (Prescribed) kg/ha	$P_2O_5$ level (Actually added), kg/ha
1	109.37	158.68
2	108.39	107.56
3	104.22	198.11
4	88.16	365.74
5	107.76	395.49
6	112.76	77.27
7	112.85	222.32
8	94.71	237.30

results were as follows:

$$S_d = 118.24$$

$$S_d^- = 41.8$$

## Results and Discussion

The different presented methodologies in this research may be used separately to judge system performance from various prospective.

### Methodology I

This method depends on the comparison between field condition before and after treatment. This method does not indicate if the system added what it supposed to add in specific location or not. On the other hand, system's influence on field uniformity could be concluded specially if regular CV is calculated for both cases before and after treatment as mentioned in (ASAE 1999).

$$Mean = X = \sum \left( \frac{X_i}{N} \right) \dots\dots\dots 4$$

$$StandardDeviation = SD = \sqrt{\frac{\sum (X - X_i)^2}{(N-1)}} \dots\dots\dots 5$$

$$CV = \frac{SD \times 100}{X} \dots\dots\dots 6$$

where:

$X$  is arithmetic mean

$X_i$  is nutrient ( $P_2O_5$ ) level in a GPS-identified location, ppm

$N$  is number of GPS-identified locations.

For this specific research,  $CV$  values for  $P_2O_5$  levels in the field before and after treatment were 86.66 and 51.29 respectively. That means, regardless the targeted level satisfaction, the system improved uniformity of  $P_2O_5$  levels in the field by 60%.

### Methodology II

This method contrasts  $P_2O_5$  levels after treatment to the targeted level in the field. It judges system's capabilities of applying the prescribed amount in the right site. More differences between the two levels, mean worse system performance and higher  $S_d$  and  $S_d^-$  values. Other factors may be involved in this procedure such as rain and soil properties where chemical fertilizer may be converted into different compound.



### ***Methodology III***

differences between the prescribed and the collected samples from standard collecting trays are investigated. This method is more reliable than the other two methods where some of the nutrient may be lost in sampling or in the analysis process. This method could be a good foundation for a standard testing procedure.

### **Conclusion**

The overall performance of VRT-based, GPS-guided, granular fertilizers broadcasting system is evaluated in this research via three different procedures. The aim of adopting method I is to judge the effect of using the tested system on uniformity of nutrient level in the field. On the other hand results of method II explain if the system could help changing nutrient level in the field to meet the targeted level and how close. Method III quantify the ability of the system to add the prescribed amount of fertilizer in the right location.

Taking in consideration that overall system performance may be affected by one or more of the following factors:

#### ***Surrounding environment:***

Wind speed and direction drifts broadcasted granules before touching down the field.

Field surface roughness and slope are major factors affecting positioning accuracy in addition to its effect on distribution pattern.

#### ***GPS system:***

Position information accuracy depends on GPS system technology, it may result applying the right application rate in the wrong location.

Prescription table is based on the collected data about field condition. Inaccuracies of sampling and/or analysis produces a faulty prescription table.

#### ***Spreader:***

Broadcaster calibration represent a major factor of the overall system accuracy. Some machines are difficult in calibration and their rate may change not only according to spinner disk speed but to the amount of fertilizer left in the tank as well.

Broadcasting pattern should be investigated in the calibration process and be considered in the design of the machine path way accompanied with the prescription table.

#### ***Control system:***

Time of response depends on control system technologies. Generally speaking, electronics have faster response than other components of the systems such as hydraulics where oil compression take place when hydraulic valves are energized to change spinner disk RPM. Capacitance of hydraulic hoses may increase time delay between electronic command and mechanical change in RPM. To reduce this factor, steel pipes are recommended.

The methodologies presented in this paper may evaluate different system performance parameters. The third method may be acceptable to lay the foundation for a standard testing procedures for the GPS-guided, VRT-based granular fertilizers broadcasting systems.

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