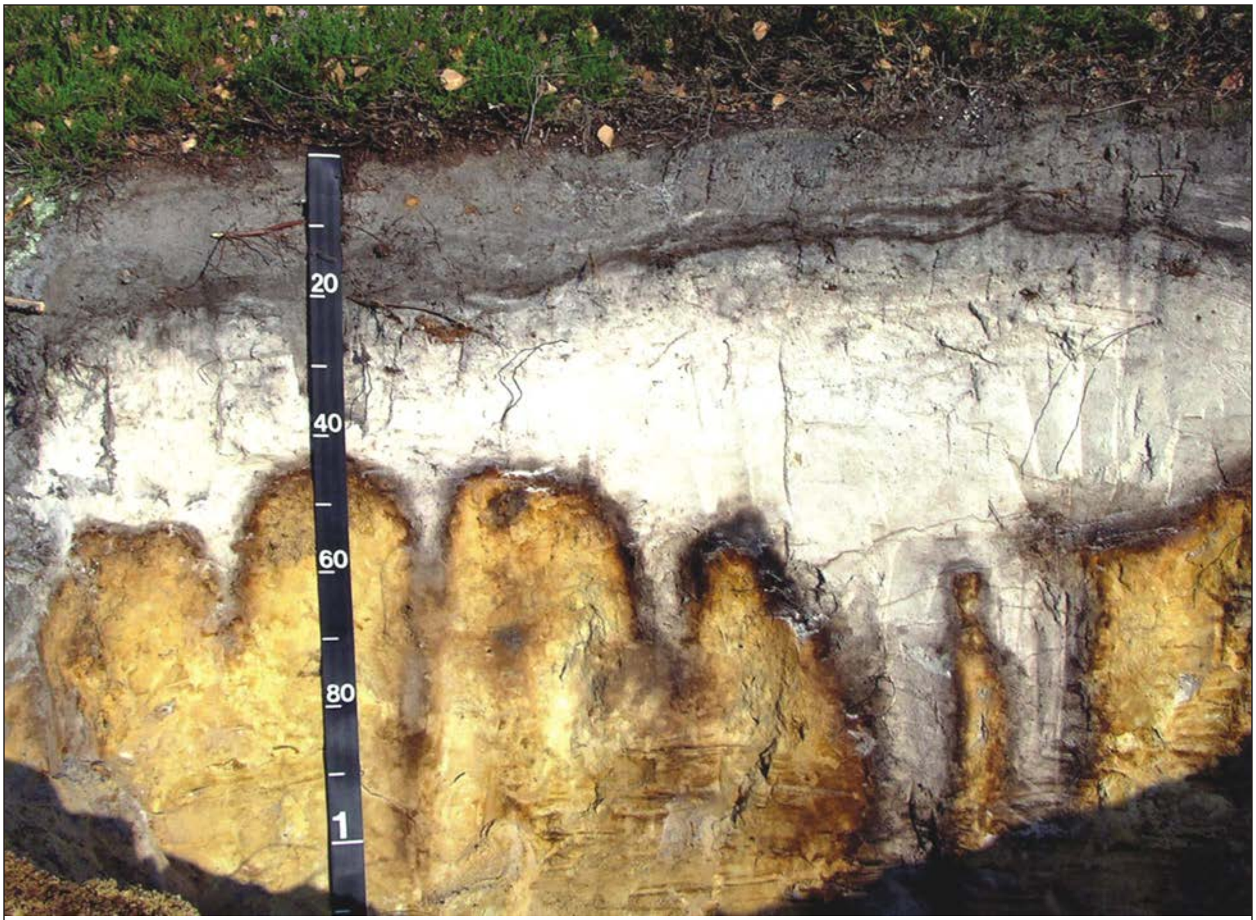

International Journal of

Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 5 (4): 206-215, 2010
ISSN 1816-4978
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Impact of Sprinkler Irrigation Uniformity on the Variability of Sugar Beet Leaf N Content

[1]H. Nouri, [1]M.S.M. Amin, [2]S.J. Razavi, [3]A.R. Anuar, [1]W. Aimrun and [4]S.C. Borujeni
[1]Smart Farming Technology Laboratory, Institute of Advanced Technology,
Universiti Puta Malaysia, Serdang 43400, Selangor, Malaysia
[2]Department of Agricultural Machinery Engineering,
Isfahan University of Technology, Isfahan, 84156-83111, Iran
[3]Department of Land Management, Faculty of Agriculture,
University Putra Malaysia, Serdang 43400, Selangor, Malaysia
[4]Soil Conservation and Watershed Research Center of Iran,
Department of Environmental Science, Faculty of Environmental Studies,
University Putra Malaysia, Serdang 43400, Selangor, Malaysia

Abstract: The main objective of this study was to determine spatial variability of sugar beet leaf N content affected by distribution pattern of urea fertigation. This study was conducted in Fesaran village, Isfahan Province of Iran and limited to sugar beet (monogerm seed) which is the fourth commercial crop in Isfahan Province. Urea applied through sprinkler irrigation (solid set system-removable sprinklers). Soil and sugar beet leaves samples were obtained to specify soil total N as well leaf N content. Results of soil and crop analysis were used to produce spatial variability maps through GS^+ and ArcGIS 9.2 software. Semivariogram results were used to perform an ordinary kriging to obtain interpolated values of selected variables from the sample points through and across the study area. It was found that there was a low variability of soil total N 4 days after fertigation as well as low variability in sugar beet leaf N content which indicates that the soil has a homogenous total N through and across the field and urea fertigated uniformly on sugar beet leaves. The results of urea fertigation through sprinklers indicate uniform fertigation makes low spatial variability of sugar beet leaf N content.

Key words: Fertigation, sugar beet, spatial variability, sprinkler irrigation, leaf N content

INTRODUCTION

Water application uniformity is essential for an efficient agriculture especially in regions where water resources are limited and precipitation is not main source to respond water demand. In these areas usually fertilizers, pesticides and other soluble chemical production mixture is added into the irrigation system for watering and responding other crop needs. Accordingly, distribution pattern of fertilizer application by fertigation is important because of its influence on crop performance. On the other hand, it is difficult to determine when and how fertilizer should be applied through an irrigation system (fertigation). Plant response is the common tool for farmers to decide but this may be too late to be useful. Hassanli *et al.*

Corresponding Author: H. Nouri, Smart Farming Technology Laboratory,
Institute of Advanced Technology, Universiti Puta Malaysia,
Serdang 43400, Selangor, Malaysia

(2010) indicated that irrigation methods has key role in efficient use of water but still there is limited information on their application on sugar beet performance in arid countries such as Iran. Spatial variability maps of soil and crop properties would be appropriate tools to make a precise management strategy. Solid set sprinkler or trickle systems provide sufficient distribution of water and N when appropriately designed and operated. These systems do not generally require constant N rate injection so some granular sources may be dissolved in water and batch loaded with a venturi injector or a mixing tank (Wright *et al*., 2002). Li *et al*. (2005) claimed that for sprinkler fertigation, one of the factors that can affect on nitrate leaching is irrigation uniformity. The effects of non uniformity fertigation on leaching of nitrate should be considered in determining the target uniformity of sprinkler system design. The higher uniformity can decrease nitrate leaching but possibly will limit the use of sprinkler systems because the initial costs of these systems increase with increasing application uniformity. Mantovani *et al*. (1995) simulated crop yield which was affected by sprinkler irrigation whereas there is uniformity in sprinkler water distribution and linear function in crop waer production. Jiusheng (1998) programmed a model to simulate yield relationship and evapotranspiration deficits at special growth stages to evaluate the impacts of sprinkler uniformity on crop yield. Models showed crop yield enhancement regarding to sprinkler uniformity, despite the result of an experimental research which was conducted by Mateos *et al*. (1997) and Li and Rao (2000). This study asserted that sprinkler uniformity has minor effect on crop yield. Pang *et al*. (1997) studied the effects of irrigation amount, uniformity and N amount and timing of split nitrogen application on crop yield and nitrate leaching. The result showed Christiansen Uniformity Coefficient (CU) reduction from 100 to 75% increased nitrate leaching and yield reduction significantly. Leung *et al*. (2001) deliberated role of nitrate leaching and soil nitrate content distribution on irrigation uniformity in a carrot field and concluded that irrigation depth and uniformity had slight impact on spatial distribution and nitrate leaching while uniformity was larger than 80%. Also, Home *et al*. (2002) made a comparison among sprinkler, furrow and basin irrigation through field experiments conducted on a coarse textured soil of Okra in water and N use efficiencies. The result of the field experiment represented the deepest percolation in furrow irrigation while the least one happens in sprinkler irrigation system. The research on the effect of fertigation distribution pattern and layout of sprinkler irrigation system (solid set with removable sprinklers) on the variability of sugar beet performance is a technique to explain the crop response to sprinkler fertigation. Therefore, this study was to determine spatial variability of sugar beet leaf N content affected by urea fertigation distribution.

MATERIALS AND METHODS

Study Area, Sampling Design and Laboratory Test

Soil and crop sampling was performed in a sugar beet field of 3.1 ha, located at Fesaran village, Esfahan in central part of Iran. Soil type was clay loam and loam. Water source for irrigation system was mixture of open channel which was feeding from Zayandeh-Rood River and deep well in the farm. Water analysis was driven from water sample of pool which holds mixture of water from the river and well. Water EC of well and open channel was about 5.08 and less than 1 dS m^{-1}, respectively. Sugar beet (*Beta vulgaris*) was planted with the spacing of 20×50 cm on 9th July 2007. Sugar beet field was fertigated by sprinkler irrigation system (solid set with removable sprinklers) applied Urea (46% N) with the rate of 200 kg ha^{-1} (recommended rate by sugar factory researchers who observed this field for several years) on 30th August 2007. Pest and diseases control followed the standard practices in this area.

Experimental units were assigned using geostatistical sampling design with concern of systematic sampling for accurate interpolation by kriging to produce spatial map. A total of 10 laterals of sprinkler irrigation system cover the study area. Research area composed of 27 plots, typical plot size is 23×23 m whereas sprinklers mounted on the 120 cm height and risers were installed at the corners of each plot. Three different points were selected as the observed points in each plot. Their locations were recorded by Differential Global Positioning System (DGPS) and flagged for the different stages of soil and crop sampling.

Soil samples were collected to analyze soil fertility information (Julius Ayodele and Solomon Olusegun, 2008) in 81 point at 30 cm depth (effective root zone for sugar beet). Soil samples were air dried, grinded and then sieved through 2mm sieve. Soil status was studied in total N before fertigation on 4th July 2007 and after fertigation on 3th September 2007 to create spatial and temporal variability maps. Leaf samples were harvested on 9th November 2007. To determine the total N in soil samples, Salicylic acid-thiosulfate of Kjeldahl method was selected (Page *et al*., 1982). Leaves samples were collected from recently matured leaves, one that has just reached full size while there are 4-5 of such leaves in the crop. These leaves are located about midway between the young center leaves and the oldest leaves whorl. Total N auto analyzer Kjeltec 1030 have been used to determine leaf N content.

The normal distribution was estimated by P-P plot. Descriptive statistics including mean, median, standard deviation, coefficient of variation, variance, minimum and maximum of soil and crop properties were analyzed using SAS (Park, 2006). To determine the correlation between plant properties to soil characteristics, Pearson-two tail test was employed.

The commonly used measurement tool to determine the uniformity of sprinkler systems is catch can test (Li *et al*., 2005). Once the data are collected by catch cans, a number of different calculations can be performed. A common measurement of variability in water application includes coefficient of uniformity proposed by Christiansen (1941) and distribution uniformity.

$$CU = \left(1 - \frac{\sum_{i=1}^{n} |X_i - \bar{X}|}{N_{\bar{x}}}\right) \times 100$$

where, CU is Christiansen uniformity coefficient, X_i is water application depth, $\sum_{i=1}^{n} |X_i - \bar{X}|$ is sum of the absolute deviation from the mean x of all N observations and $N_{\bar{x}}$ is Number of observations.

The distributional function was used to evaluate the distribution uniformity (DU) (Merriam and Keller, 1978).

$$DU = \frac{\text{Average low quarter depth}}{\text{Overall average depth}} \times 100\%$$

The uniformity of sprinkler irrigation which is the central design goal (Keller and Bliesner, 2000) was measured in the sugar beet field watered by solid set sprinklers. As it can be shown in Fig. 1a-c, pool and pump station were located in the Southern part of the field. Total of 10 laterals were derived from main pipe in Western border of the field by 23×23 m distance of laterals and sprinklers. Full circle sprinklers namely AMBO (Italy) sprinkled 2.08 L sec^{-1} of water at 4 bar pressure by 10 mm nozzle with 21 m effective wetted radius.

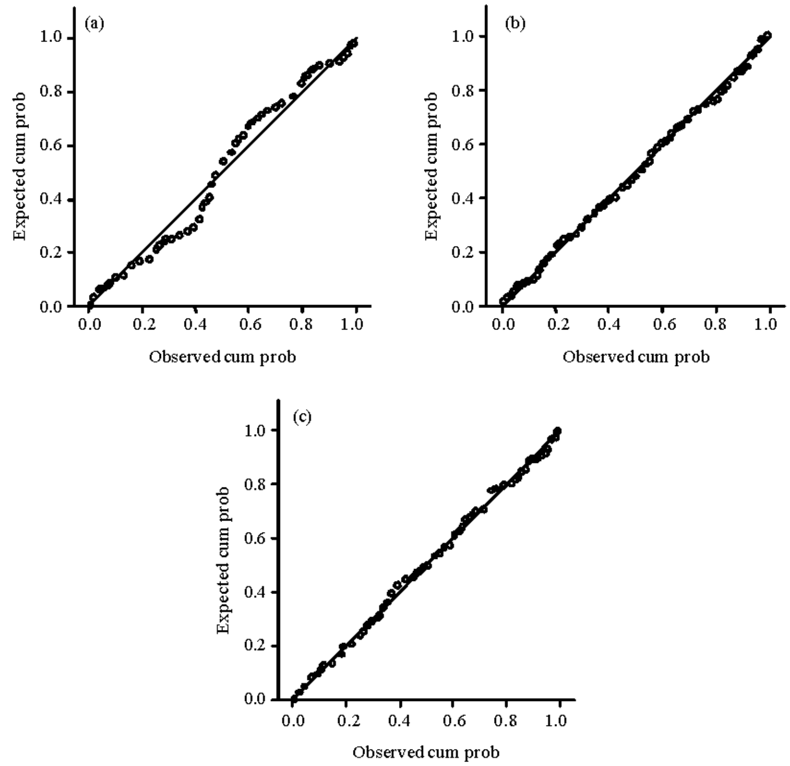

Fig. 1: Normality test by P-P plot (a) soil total N-before fertigation, (b) soil total N-after fertigation and (c) leaf N content

Fertilizer was applied through sprinklers 30 min after irrigation starting time and finished 1 h before finishing irrigation. It should be noted that the irrigation by plain water after fertigation is essential to avoid remaining fertilizers residual on the leaves. A plot of 46×46 m observed area was divided in grids of 3×3 m subplot to apply catch can test. To measure water distribution pattern below the canopy, 240 catch cans of 250 mm height and 120 mm diameter were placed at the corner of each subplot on the ground surface and collected water for 1 h.

Spatial Structure and Map Creation

To produce variability maps of soil total N and leaf N content, kriging method (Krige, 1984) was used. In brief, the kriging is an advanced interpolation procedure generating estimated surfaces via semivariograms, which represent and characterize the spatial variation set against the distance (lag) (Isaaks and Srivastava, 1989).

The spatial structure of each variable has been defined from semivariogram components included fitted model type, nugget (C_0), sill ($C+C_0$), range (A_0), partial sill (C) and Reduced Sum of Square (RSS) were calculated by geostatistical analysis software through GS^+ (Geostatistics for the Environmental Sciences, Gamma Design Software, 2004, Version 7, LLC Plainwell, Michigan).

Nugget is the variance at distance zero and represents the experimental error; sill is the semivariance value at which the semivariogram reaches the upper bound after its initial increase. It is the maximum variance for this kind of semivariograms and represents the total (a priori) semivariance of the study area; range is the value (x-axis) at which one variable becomes spatially independent, that is the lag-distance at which the semivariogram flattens. The nugget to sill ratio quantifies the importance of the random component and provides a quantitative estimation of the spatial dependence (Di Virgilio *et al*., 2007). According to Cambardella *et al*. (1994), Reduced Sum of square (RSS) provides an exact measure of how well the model fits the variogram data; the lower the reduced sums of squares, the better the model fits. Choice of the best fitting model for this study was based on the lowest RSS in lag-distance of 23 m.

In order to create spatial variability maps, it is necessary to interpolate sampled data to estimate un-sampled data (Balasundram *et al*., 2006). Interpolation is the estimation of values for points in an area not actually sampled. There are different interpolation techniques, ranging from simple linear techniques that average the values of nearby sampled points, to more complex techniques like kriging that use base weights on distance to nearby sample points and the degree of autocorrelation for those distances. ArcGIS enables the creation of maps to geographically represent and analyze variation of soils and crops (Hache, 2003; Darwish and El-Kader, 2008). Ordinary kriging have been applied to extrapolate the values of unsampled field parts (Balasundram *et al*., 2008). To build kriged surface maps ArcGIS 9.2 was used (Blackmore, 1999; Aimrun *et al*., 2007). Thylen and Murphy (1996) and Blackmore and Marshall (1996) applied this technique in crop properties mapping.

RESULTS

Descriptive statistic is shown in Table 1. Basing on P-P plot (Fig. 1) and comparing mean and median, all variables were normally distributed. Mean of soil total N increased from 0.19 to 0.25% which is related to urea application. Coefficient of variation of all selected variables showed dispersion of data from mean. Pearson's two tail correlation test (Fig. 2a, b) showed a significant positive correlation of soil total N to leaf N content at 95% confidence.

Total of 10 laterals of solid-set (removable sprinklers) system were collected to test sprinkler irrigation uniformity (Fig. 3). The collected water in 240 catch cans was measured after 1 h operation time. Field evaluations were conducted adopting the methodology of Merriam and Keller (1978). Spatial variability of each sprinkler (Fig. 4) indicates that the closer to sprinkler the more volume water received but it should be noted that overlapping will cover places with low and medium irrigation depth to have required uniformity. Application uniformity as a major parameter of sprinkler irrigation efficiency was analyzed using quantitative measures of uniformity. The distribution of sprinkler irrigation was determined by calculation of CU and DU which are 80.32 and 69.57%. DU>65% and CU>75% assumed as an acceptable performance level for economical design. Also claimed that CU>70% conform a normal distribution of sprinkler irrigation system.

Table 1: Descriptive analysis of soil and crop properties

Descriptive statistics	Soil N-BF (%)	Soil - AF (%)	Leaf N content (%)
Mean	0.190	0.250	3.20
Median	0.190	0.240	3.20
SD	0.023	0.036	0.37
Coefficient of variation	12.440	14.700	10.30
Variance	0.001	0.001	0.13
Minimum	0.130	0.170	2.16
Maximum	0.240	0.370	4.30

BF: Before fetrigation, AF: After fertigation

(a)

		N	Correlation	Sig.
Pair 1	N-b4 and N-aft	81	0.351	0.001

(b)

	Paired differnce				t	df	Sig. (2-tailed)	
	Mean	Std. Deviation	Std. error Mean	95% CI of the difference	Mean	Std. Deviation	Std. error Mean	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
N-BF and AF	-0.0583	0.0356	0.004	-0.066	-0.050	-14.72	80	0.00

Fig. 2: Results of pair-wise test, (a) paired sample correlations and (b) paired sample test

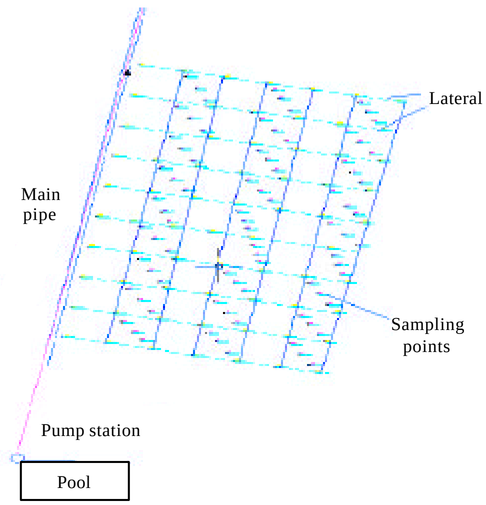

Fig. 3: Sprinkler system layout

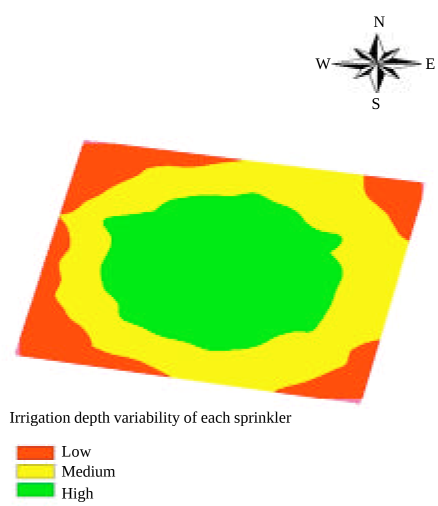

Fig. 4: Sprinkler irrigation distribution pattern

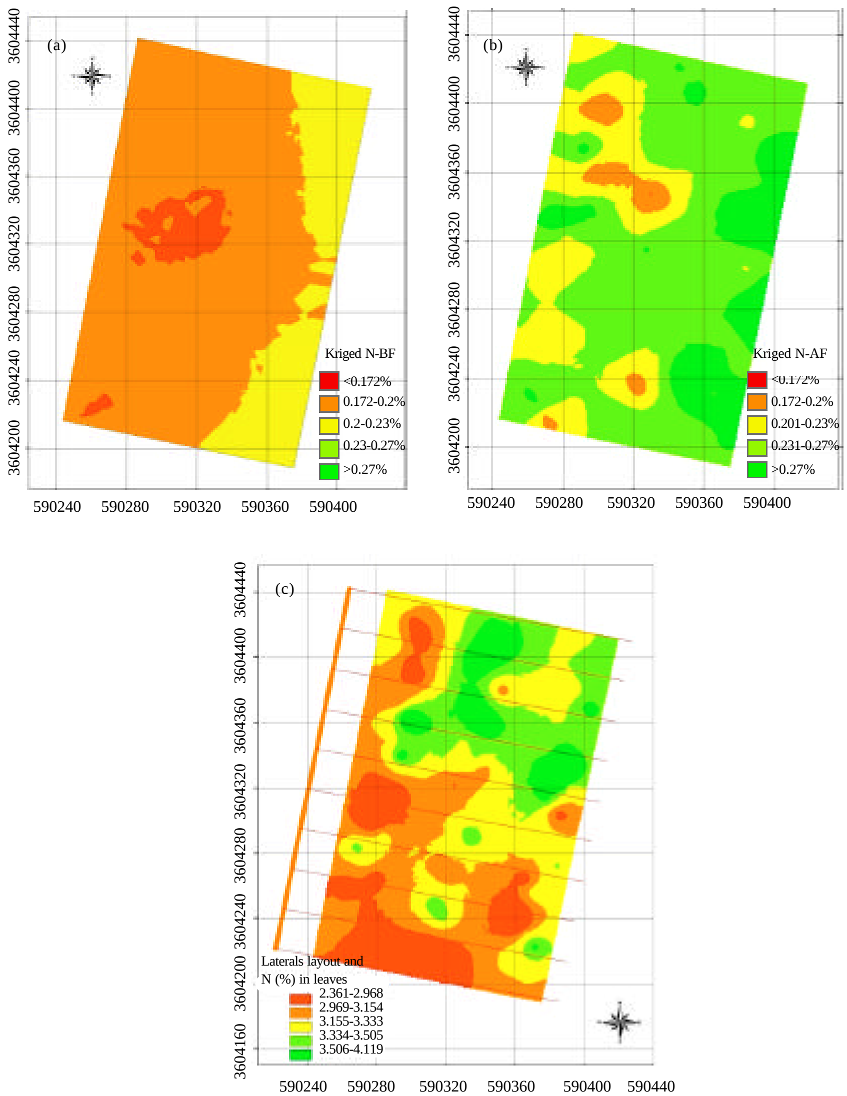

Fig. 5: Spatial Variability Maps of Soil Nutrients, (a) N-before fertigation, (b) N-After fertigation and (c) leaf N content

Semivariograms were prepared for soil total N and sugar beet leaf N content by GS+ software. They were calculated from 81 samples. Semivariograms results (Table 2) indicated that there is moderate spatial variability in soil total N before fertigation whereas strong spatial variability was seen in soil total N after fertigation and leaf N content (Cambardella *et al*., 1994). The best fitted models in semivariograms for soil total N- before and after fertigation were Spherical while for leaf N content was Exponential. Based on semivariogram results, spatial variability maps of soil total N before and after fertigation and leaf N content were mapped through ArcGIS 9.2 (Fig. 5). To visualize the variability of 5 zones, they were defined as very low (red), low (orange), moderate (yellow), high (light

Table 2: Geostatistical description of soil and crop properties

ID	N(%) - BF	N(%) - AF	Leaf N content (%)
Model type	Spherical	Spherical	Exponential
Nugget	0.0003	0.000094	0.023
Sill	0.0006	0.001378	0.141
Range	141.8	38.9	42.6
Partial Sill	0.0003	0.00128	0.14
RSS	5.36×10^{-9}	2.1×10^{-7}	1.2×10^{-3}
R^2	0.944	0.569	0.38
Nugget/Sill	0.5	0.068	0.16

BF: Before fetrigation, AF: After fertigation

green) and very high (dark green) application. Figure 5 shows changes of soil total N from very low to moderate zone before fertigation (Fig. 5a) into moderate to very high after fertigation (Fig. 5b). It is apparent from Fig. 5c that leaf N content in the northern part of the field is higher than that in the Southern part.

DISCUSSION

Due to water scarcity in the study area, sugar beet cultivation relies on irrigation especially sprinkler irrigation. Therefore, efficient irrigation system should be developed to apply farming inputs precisely. Sprinkler irrigation uniformity can influence fertigation distribution pattern (Li *et al*., 2006) accordingly sugar beet performance (tuber sugar content and yield) (Nouri *et al*., 2009). Sprinkler system applied water and fertilizers on leaves consequently leaf N content is a proper indicator to analyze fertigation uniformity and crop performance. This research studied urea fertigation distribution pattern through sprinkler irrigation uniformity. It provided evidence that leaf N content was affected by fertigation uniformity. Arafa *et al*. (2009) confirmed that there is positive trend between fertilization use efficiency and crop growth. Variability map of sugar beet leaf N content demonstrated the less leaf N in Southern part of the study area where laterals were closer to pump station. It can be concluded that proper uniform distribution of sprinkler irrigation made uniform leaf N content. It should be noted that the initial distribution of nutrients in the soil might also affect the plant nitrogen uptake (Li and Rao, 2003) hence uniform soil total N can have a positive influence on uniform leaf N content and consequently, yield. Mateos *et al*. (1997) found out response of crop performance to sprinkler uniformity. Although, Warrick and Gradner (1983) claimed that irrigation distribution does not affect results greatly crop yield.

Although, results showed low variability of leaf N content of sugar beet resulted by uniform irrigation, precision fertigation by variable rate application equipment can apply required amount of fertilizer on the right area.

ACKNOWLEDGMENTS

The researchers are grateful of support by Institute of Advanced Technology (ITMA) and Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia and Department of Agricultural Machinery Engineering, Isfahan University of Technology, Isfahan, 84156-83111, Iran.

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