USING A TOPOGRAPHIC FACTOR TO EXPLAIN SOIL AND COTTON LINT VARIABILITY IN THE LANDSCAPE

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Abstract

A landscape-scale study conducted in a center pivot irrigated field in Lamesa on the southern High Plains of Texas showed that site elevation affected the spatial pattern of soil water content (SWC), soil NO_3-N, total N uptake, and lint yield of cotton (*Gossypium hirsutum* L.), irrigated with 50% and 75% cotton potential evapotranspiration (ET). In this study, soil and cotton crop variables were measured on a 15-m interval along a 710 m (50% ET) and 820 m (75% ET) transect across the field. Geostatistical methods (autocorrelation and crosscorrelation analysis), and multivariate autoregressive state-space analysis were used to quantify and describe the spatial association of soil water, sand, N uptake, and lint yield with site elevation. Here we use a topographic factor, determined from neighboring site slopes, to explain variability of SWC, cotton N uptake, and lint yield measured in this landscape-scale study. The coefficient of determination (R^2) increased when the topographic factor was included in the regression of lint yield vs. N uptake. This simple method gives insights on the association of soil water and N use with site elevation and slope in a large field.

Introduction

The greatest hazard affecting water and N use of cotton production in the semiarid southern Texas High Plains is wind erosion. It has been shown that topographic features characterize the landscape-scale patterns of soil water (Simmons et al., 1989; Halvorson and Doll, 1991; Li et al., 2000), higher N_2O fluxes (Corre et al., 1996), N contribution of pea residue (Stevenson et al., 1997), soil organic matter, P, K, Ca and Mg contents, and other properties (Brubaker et al., 1993; Timlin et al., 1998; Kravchenko and Bullock, 2000), N uptake (Escamilla et al., 1991; Li et al., 2000), and crop yield (Stone et al., 1985; Halvorson and Doll, 1991; Timlin et al., 1998; Li et al., 2000). In landscapes with topographic influences, differences in corn grain yield between landscape positions were much more consistent than yield differences between erosion classes (Stone et al., 1985). Water redistribution in a complex landscape had significant effect on spring wheat grain yield and water use (Halvorson and Doll, 1991). Surface elevation and curvature contributed to spatial and temporal variability of maize yield on a hillslope in New York state (Timlin et al., 1998). Soil NO_3-N sampled at 0-0.3 m depth in the spring was autocorrelated within a distance of 60 m, and the crosscorrelation distances between soil water content, N uptake, cotton lint yield, and elevation varied between 60 and 80 m (Li et al., 2000).

Elevation and slope are usually considered as the most important parameters of topographic features. Soil surface curvature factor, calculated from the elevation of neighboring points on a grid pattern of the field, was highly correlated to the soil moisture (Sinai et al., 1981). Slope position was found to be related to winter wheat yield (Ciha, 1984; Halvorson and Doll, 1991). A topographic factor, calculated from neighboring point slopes, measured 3, 6, 15, and 30 m apart, was developed to provide a quantitative method to determine elevation effects on plant water use and spring wheat yield in four different fields (Halvorson and Doll, 1991). This factor was highly correlated to soil moisture (Sinai et al., 1981) and plant water use and spring wheat yield in the landscape (Halvorson and Doll, 1991).

As most large fields on the semiarid southern Texas High Plains are characterized by an undulating surface, we hypothesized that soil water and N runon and runoff should occurr in the landscape and contribute to the variability in N uptake and crop yield. The autocorrelation and crosscorrelation distances between soil and cotton crop variables and elevation have been determined using the ARIMA procedure, and the underlying processes of lint yield, soil water, NO_3-N, and elevation has been described using the state-space analysis (Li et al., 2000). Here our objectives were to determine (i) a topographic factor calculated from neighboring point slope measured 15 m apart along two transects, and (ii) relationships between SWC, cotton N uptake and lint yield, and elevation and slope using the topographic factor. Information gained should be useful to quantify and explain the variability between soil physical and chemical properties, and cotton crop production at the landscape level.

Materials and Methods

Landscape Experiment and Measurements

The study was conducted at the Lamesa Agricultural Research Farm ($32^0$46'N, $101^0$56'W) of Texas A&M University on the southern High Plains of Texas in 1999. The 50 ha field was characterized by an undulating surface. The experimental area was 96 m wide and 840 m long, and situated in the eastern part of the center pivot. The soil was an Amarillo sandy loam (mixed, superactive, thermic aridic Paleustalf, Alfisols). In the spring (mid-March), soil NO_3-N was sampled in a 16 x 20 m grid size across the experimental area. Along the two transects, west-transect (T-W) and east-transect (T-E), 64 m apart (Fig. 1), soil NO_3-N to a depth of 1.2 m in 0.3-m increments was on average 49.7, 56.4, 53.6 and 66.2 kg ha^{-1} on the T-W, and 31.8, 43.2, 39.5 and 37.3 kg ha^{-1} on the T-E, respectively. Other soil physical and chemical characteristics of this soil have been described in Li et al. (2000).

Experimental treatments were irrigation at 50% and 75% calculated cotton potential ET levels using a LEPA (Low Energy Precision Application) irrigation system (Lyle and Bordovsky, 1981). The T-W and T-E received 50% and 75% ET irrigation water, respectively (Fig. 1). Both transects, following the circular pivot pattern used for planting, were instrumented with aluminum neutron access tubes (5 cm diameter and 2 m long) spaced 15 m apart across the field. There were 47 and 53 soil, water, and crop monitoring sites on the T-W and T-E, respectively. Cotton (cv. 'Roundup® Ready HS-26') was seeded at a rate of 16.8 kg ha^{-1} on 10 May 1999. The SWC was determined by neutron probe in 0.3-m increments to 1.8 m depth at each monitoring point on an approximately 15-day interval during the growing season. The total irrigation water applied was 190 and 286 mm for the T-W and T-E, respectively. Information about irrigation, SWC measurement and calculations, soil and plant sampling and analysis as well as cotton lint harvest for this study is given by Li et al. (2000).

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:585-588 (2001)
National Cotton Council, Memphis TN

Calculations

A topographical factor for each site along the two transects was related to the site's slope, which was calculated from the site's elevation, measured by a Satloc SL 2001/3001 L-Band Receiver, and a 15 m distance between two neighboring sites. The Satloc GPS readings were calibrated with the USDA-Natural Resources Conservation Service's altitude survey data, measured across the whole field using a Trimble Survey Grade GPS Model 4700 Dual Channel RTK system in 1998. The topographical factor (TF) was estimated as suggested by Halvorson and Doll (1991) as follows:

$$TF = -\text{Slope} = -\frac{\text{Elevation (A-B)}}{\text{Distance A-B}} \quad [1]$$

Where A and B are two neighboring sites along transects, and the TF is for site B.

Cotton lint yields were regressed against total N uptake. The TF was then used to adjust the total N uptake for topographic effects using Eq.[2] as follows:

$$ANU = NU\,[(TF \times CH) + 1] + b \quad [2]$$

Where ANU is the adjusted N uptake in kg ha^{-1}, NU is N uptake in kg ha^{-1}, CH is the percentage change in N uptake imparted by a TF of ± 1 at a given site divided by 100. The CH that gave the highest R^2 value was used to for the calculation of the adjusted value, as indicated by Halvorson and Doll (1991).

Autocorrelation functions of the soil NO_3-N, and crosscorrelation functions and distances between SWC, clay, sand, total N uptake, and lint yield, and elevation were determined using the ARIMA procedure of SAS Institute, and results are given in Li et al. (2000).

Results

Elevation, Slope, and Topographic Factor

Altitude at the experimental area ranges between 889.8 and 892.8 m (Table 1), which is gently rolling from south to north (slope 0.3-6.3%), and declines from west to east (slope 0.3-5.2%). The site slope variation was smaller on the T-E than on the T-W, and positions on the T-W are on average 1 m higher than on the T-E (Table 2). There are the alternative concave and convex positions across the transects with lower positions in the middle. As compared to the T-E, the northern summit is higher and slopes extend further on the T-W (Fig. 1).

Slope, defined as the relief degree of a site related to the elevation of its neighbor site at a separation distance of 15 m, decreased from the southern downslope starting point to the central lower area and then increased to the northern side (Table 1). As a result, TF's calculated with Eq. [1], varied with the slopes along transects (Table 1). If a slope was downward toward a site, the TF was positive. Conversely, if the site was upward toward the site, the TF was negative. As a result, TF's were positive in concave positions in the landscape, where a net increase in soil water and nutrients can be expected due to runon water and nutrient from upslope positions. Topographic factors were negative in convex positions, where a net loss of water and nutrient should occur from downslope runoff (Table 1).

Spatial Patterns of Elevation, Soil Water, Clay, and Lint Yield

The means and standards errors of the measured landscape variables varied with elevation and irrigation (Table 2). Clay and soil NO_3-N were higher on the higher-elevation T-W. Sand, soil pH, SWC, N uptake, and lint yield and lint quality parameters (micronaire index, uniformity, and elongation) were higher on the T-E, where site positions were on average 1 m lower with 75% ET irrigation (Table 2). According to the standard errors lint yield varied more on the T-W and clay, and sand and N uptake varied more on the T-E (Table 2). These landscape variables (SWC, sand content, N uptake, lint yield, and elevation) were crosscorrelated (SWC vs. lint yield, SWC vs. elevation, lint yield vs. elevation, etc) at a distance varying between 60 and 80 m in the landscape, shown in Li et al. (2000).

The SWC at different soil layers varied with irrigation level, soil depth, site elevation, and slope length across the field (Li et al., 2000). As shown in Fig. 2, the spatial patterns of clay (Fig. 2a), SWC in the whole rooting zone (0-0.9 m) and lint yield (Fig. 2b) showed a dependence on site elevation and slope length on the T-W (Fig. 2a). The SWC, N uptake and lint yield were higher on the south-center lower position areas on the T-W (Fig. 2), and the spatial pattern of these variables showed a similar trend on the T-E (Li et al., 2000).

Relations Between Landscape Variables and Topographic Factor

All the measured soil properties and cotton response variables were negatively correlated to elevation in the landscape. The correlation between elevation and SWC (r = - 0.67), NO_3-N (r = - 0.34), clay content (r = - 0.31), cotton lint yield (r = - 0.54), and total N uptake (r = - 0.40) were significant ($P > 0.05$), and lint yield was negatively correlated to clay content (r = - 0.46). Cotton lint yield and total N uptake were linearly correlated to SWC (Fig. 3) in the rooting zone (0-0.9 m). Soil water explained 56% and 47% of the lint yield variation, and 24 and 16% of the N uptake variation on the T-W and T-E, respectively. The spatial association between cotton lint yield, soil water, NO_3-N, and elevation, described by the multivariate autoregressive state-space analysis (Li et al, 2000), showed that lint yield at position i was positively weighted on SWC at previous position i-1 (state-space equation coefficients of 0.656 and 0.452 on the T-W and T-E, respectively). All measured lint yield values are within the 95% confidence limits of lint yield forecasts given by the state-space model (Li et al., 2000).

The regression of lint yield vs. total N uptake gave a small coefficient of determination (R^2 = 0.12). When the TF was added to the regression with Eq. [2], the R^2 increased to 0.27, which was significant. This difference indicated that the TF included in the regression model changed the relation between total N uptake and lint yield, and quantified the impact of the topographic features on N uptake and lint yield.

Discussion

Topographical factors can be used to explain why higher cotton lint yields were measured on lower landscape positions. These areas likely received runoff water from higher elevations. The positive values of TF (0.3-2.9 on the T-W, and 0.4-3.3 on the T-E) for the flat and footslope area (Table 1) indicated runon water and NO_3-N from upslope positions. Similar positive and negative TF's in the flat area indicated a slight gain or loss of water and nutrient, resulting in a similar lint yield value in this area. Inversely, water and nutrient could be lost due to runoff from upslope and summit elevations (negative TF, Table 1), where lint yield (Fig. 2) was lower. There is a 3.2 m drop from the northern plateau to the footslope area. Correspondingly, high SWC and lint yield (above the mean) were measured on the footslope areas (Fig. 2b), where soils contained more water within the rooting zone (Fig. 2b). Lint yields declined in northern upslope areas, especially on the T-W where the slope was extended (Fig. 2) and the TF was highly negative (Table 1).

Higher lint yield would be expected on relatively lower positions, which were within 2 m elevation related to the lowest position in the area (Li et al., 2000). A positive TF means water and nutrient runon, and a negative TF represents a loss. Halvorson and Doll (1991) reported that TF measured at 15 m distance gave the highest coefficient of determination (R^2) to the regression of wheat yield vs. total water use. Slope and TF's seemed to be

useful parameters to describe gain and loss of water and nutrient from a site in the landscape.

Conclusions

Elevation and slope were the key factors causing variability in soil water, texture, lint yield and N uptake in a large field. A simple topographic factor quantitatively explained runon and runoff effects of soil water and nutrient on N uptake and cotton lint yield in the landscape. The topographic factor relates the influence of elevation and slope to crop yield and N uptake in the landscape.

Acknowledgments

We thank the Texas State Support Cotton Committee, the Idaho National Engineering Laboratory (INEEL), and Texas Agricultural Experiment Station (TAES) for the financial support.

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Table 1. Landscape assessments (ranges) of site geographic positions and topographic factors.

Land positions	Distance (m)	Altitude (m)	Slope[x] (%)	Topographic Factor[y]
	T-W Transect			
Southern starting point	10	892.6		
Flat areas - Footslopes	40 - 385	890.2 - 891.3	0.3 - 2.9	0.3 to - 2.9
Northern Summit - Shoulder	475 - 700	891.6 - 892.8	3.9 - 6.3	- 3.9 to - 6.3
	T-E Transect			
Southern starting point	10	892.2		
Flat areas - Footslopes	300 - 550	889.6 - 891.2	0.4 - 2.3	0.4 to - 2.3
Northern Summit - Shoulder	700 - 760	891.4 - 892.0	2.7 - 4.7	- 2.7 to - 4.7

[x] Slope is the decline degree related to the previous site 15-m apart

[y] Negative topographic factor for summit and shoulder positions

Table 2. Means and standard deviations (SD) of measured landscape variables.

	T-W (50% ET)		T-E (75% ET)	
Landscape variables	Mean	SD	Mean	SD
Elevation (m)	892	1.1	891	1.0
Clay content (g kg^{-1})	255	38	230	54
Sand content (g kg^{-1})	708	43	734	64
Soil pH	7.5	0.04	7.7	0.04
Soil water content (m^3 m^{-3})	0.11	0.05	0.13	0.06
Soil NO_3-N (kg ha^{-1})	159	20	143	18
Total N uptake (kg ha^{-1})	109	18	125	23
Lint yield (kg ha^{-1})	819	157	1092	94
Lint micronaire	4.48	0.02	4.55	0.03
Lint uniformity	82.3	0.14	82.9	0.08
Lint strength	28.8	0.16	28.7	0.17
Lint elongation	6.63	0.03	6.77	0.03

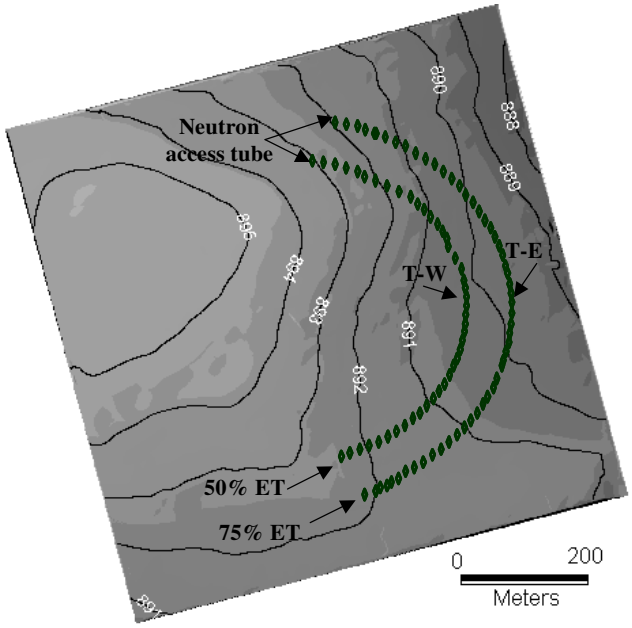

Figure 1. Elevation (m) of the experimental field showing the positions of the irrigation levels, neutron access tubes, and west-transect (T-W), and east-transect (T-E).

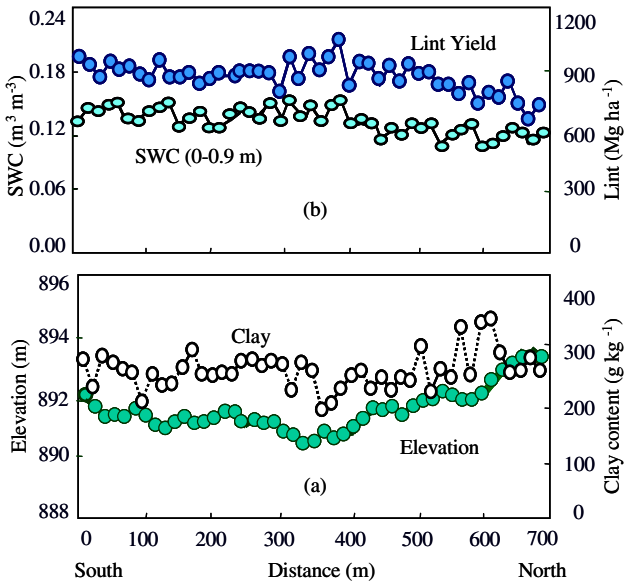

Figure 2. Spatial patterns of elevation and clay (a), and soil water content (SWC) in the rooting zone (0-0.9 m) on 9 Aug. and cotton lint yield at harvest on 5 Oct. 1999 (b) on the west transect (T-W).

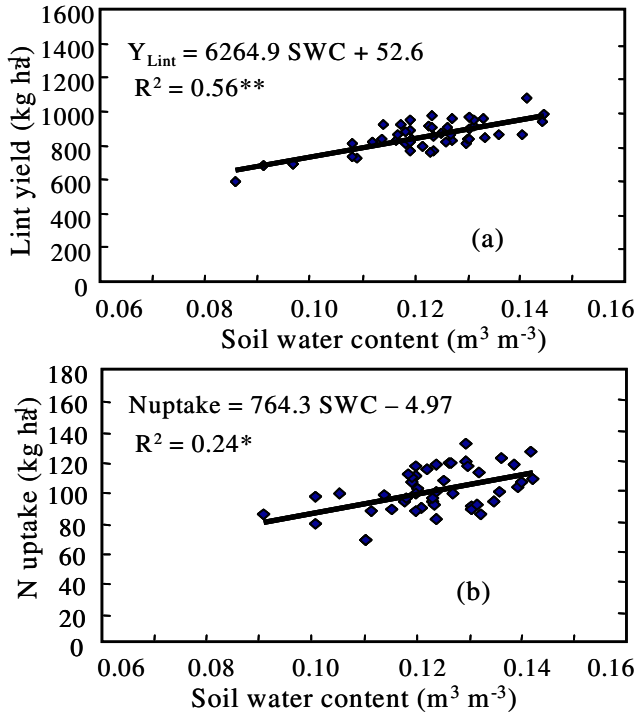

Figure 3. Relations between soil water content (SWC, 0-0.9 m, measured on 9 Aug. 1999) and cotton lint yield at harvest (a), and total N uptake (b) measured on 15 Sep. 1999 the T-W.