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IRRIGATED COTTON LINT YIELDS AS AFFECTED BY PHOSPHORUS FERTILIZER AND LANDSCAPE POSITION

K. F. Bronson,[1,*] A. B. Onken,[1] J. D. Booker,[1] R. J. Lascano,[1] T. L. Provin,[2] and H. A. Torbert[3]

[1]Texas A&M University, Texas Agricultural Experiment Station, Lubbock, TX 79401
[2]Texas A&M University, Texas Agricultural Extension Service, College Station, TX 77843
[3]USDA-ARS, Grassland Soil & Water Research Laboratory, Temple, TX 76502

ABSTRACT

Phosphorus (P) is the second most limiting nutrient in cotton (*Gossypium hirsutum* L.) production after nitrogen. Response to P fertilizer, however, is often hard to predict in the Southern High Plains, even with soil test-based applications. Landscape position has a strong influence on yields and perhaps on fertilizer response as well. The objective of this 5-year study (1994–1998) was to determine P fertilizer response in irrigated cotton in different landscape positions. We used an 825-m transect of end to end 15-m plots across a broad swale in an Amarillo fine sandy loam in Lamesa, TX that included three landscape positions, sideslope, bottomslope and drainageway. A randomized complete block design was used with 11 replicates and 5 P rates (0, 22.4, 33.6,

*Corresponding author.

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44.8, and 56 kg P ha^{-1}). Analysis of variance showed a linear or quadratic response to P fertilizer in 3 of 5 years, and an effect of landscape position in 4 of 5 years. Four-year lint yield averages, excluding 1997, were 1355 kg ha^{-1} in the bottomslope position in the landscape, and 1210 and 1226 kg ha^{-1} on the sideslopes and in the narrow drainageway, respectively. Cross-correlation using the 55 plots as a transect revealed few effects of soil properties on lint yield, but negative correlation between yield and elevation. In 1997, the one year without a landscape effect on yield, more rain fell during the growing season than in the other 4 years. This suggests that yield potential is higher in lower landscape positions because of more favorable soil water relations. Cotton lint response to P fertilizer was evident only in the bottomslopes and in the drainageway, and was absent in the sideslopes, meaning that variable rate fertilizer applications could be linked to management zones based on landscape position.

INTRODUCTION

Phosphorus fertilizer response is often hard to predict, even on low soil test P soils (1, 2). In the Southern High Plains, water and nitrogen are the main constraints to cotton production, and these factors can preclude P fertilizer responses (3).

Landscape position is a strong controlling factor in yields and fertilizer response of crops like wheat (*Triticum aestivum* L.) (4–6), but has not received much attention in cotton. Soil properties, including nutrient status and water relations are known to vary strongly by landscape position (4, 7, 8). Lower lying landscapes often produce greater crop yields due to water redistribution and or higher soil nutrient levels (4, 8). Furthermore, landscape positions have been tested as the basis for variable rate or site-specific N fertilization in wheat in Saskatchewan (9), and were shown to enhance fertilizer N use efficiency.

On the research and demonstration farm of Texas A&M University–Texas Agricultural Experiment Station in Lamesa, TX, it has been observed that crop yields are often greatest in the low-lying center of a broad swale on the east side of the farm. It has been assumed that this was due to redistribution of water in the swale. This type of landscape is typical of topography in the southern High Plains, where the slopes rarely exceed 3%. We conducted a P fertilizer rate study with end to end plots and a large number of replicates that would cover the width of the swale. Our objective was to measure P fertilizer response and the influence of landscape position on irrigated cotton lint yields.

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Table 1. Initial Soil Properties by Landscape Position, Lamesa, TX, 1994

	Drainageway (n = 5)	Bottomslopes (n = 17)	Sideslopes (n = 33)	C.V. (%)
P ($mg\,kg^{-1}$)	12.8 a[1]	10.9 a	7.8 b	37.6
Ca ($mg\,kg^{-1}$)	1108 a	785 b	1060 a	29.6
Zn ($mg\,kg^{-1}$)	0.18 a	0.19 a	0.16 a	23.3
Soil organic C ($g\,kg^{-1}$)	2.4 a	2.1 a	2.3 a	20.2
Clay ($g\,kg^{-1}$)	90.0 a	97.1 a	113.6 a	27.7
Sand ($g\,kg^{-1}$)	804.0 a	825.3 a	805.8 a	3.6
Relative elevation (m)	85.6 b	86.7 b	90.4 a	2.0

[1] Means in a row followed by the same letter are not significantly different by Duncan's Multiple Range Test at the 0.05 probability level.

MATERIALS AND METHODS

The study site was in Lamesa, TX, 32° 46′ N, 101° 56′W. We established an 825-m transect of end to end 15-m plots in 1994 across a broad swale in an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalf) that included the landscape positions sideslope, bottomslope, and drainageway. Initial acidified ammonium acetate-EDTA-extractable-P (10) in the 0- to 15-cm surface layer ranged from 8 $mg\,kg^{-1}$ in the sideslopes to 13 $mg\,kg^{-1}$ in the drainageway (Table 1). Phosphorus fertilizer rate plots (15-m-long, four 1-m-rows wide) were randomized within each of 11 replicates. Five P fertilizer rates of 0, 22.4, 33.6, 44.8, and 56 kg P ha^{-1} were applied as a 15% H_3PO_4-P solution. Phosphorus was chiseled-in 7.5 cm deep, 10 cm from both sides of each row a few days before cotton seeding in April of each year. Cotton variety 'Paymaster HS26' was used in 1994 to 1996 and 'Paymaster 2326 Roundup Ready' was planted in 1997 and 1998. Planting was in 1-m rows, which were in a circle. A blanket N fertilizer (as urea ammonium nitrate) rate of 180 kg ha^{-1} was applied to all plots. Thirty kg urea ammonium nitrate-N (32-0-0) ha^{-1} was applied pre-plant through sprinkler nozzles on the center pivot irrigation system. In-season, five applications of 30 kg N (32-0-0) ha^{-1} were applied though the irrigation system through ground-length hoses. Center-pivot irrigation was at 75% estimated ET replacement through ground-length hoses in 2-m centers on a 3.5-day schedule (11). Rain received and irrigation applied during the growing seasons are shown in Table 2. Two center rows of each 15-m plot were stripper-harvested in October of each year. Seed cotton was ginned and yields are reported as lint (kg ha^{-1}).

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Table 2. Irrigation Applied and In-Season Rainfall Received, Lamesa, TX, 1994–1998

	Irrigation	In-Season Rain	June-July-August Rain	June-July-August- 44-Year Average Rain
			cm	
1994	37	32	6	16
1995	24	36	13	16
1996	26	20	15	16
1997	18	30	20	16
1998	32	8	10	16

In spring of 1994, five soil samples were taken at 0- to 15-cm depth in every plot and analyzed for routine soil properties. Samples were taken in a diagonal line across the plot, separated by 2 m down the rows and 25 cm across the rows. Samples within each plot were composited and analyzed for P (acidified ammonium acetate-EDTA-extractable), NO_3 (KCl-extractable), Zn (DTPA-extractable), pH (water), soil texture, and soil organic C. Elevation was determined on 15-m intervals on the center of the four rows of the plots with a Trimble Survey Grade Geographical Positioning System, Model 4700 Dual

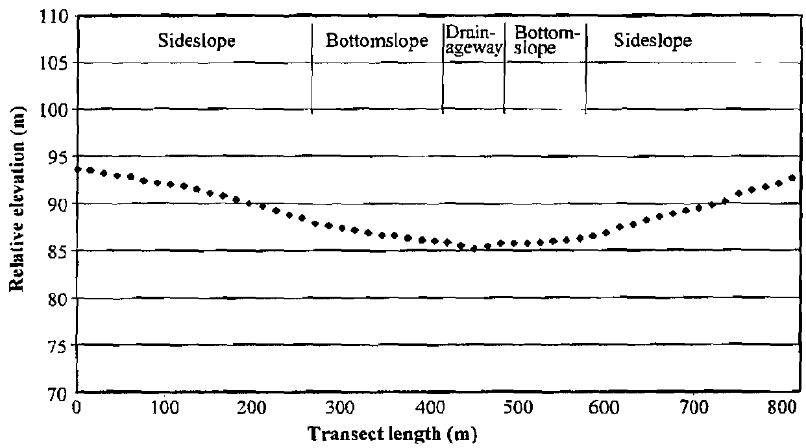

Figure 1. Elevation along the transect of the study and landscape positions, Lamesa, TX.

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Table 3. Effect of P Fertilizer, Landscape Position, Elevation, and Soil Texture on Cotton Lint Yields, Lamesa, TX, 1994–1998

	Replicate[1]	P Rate[1]	Landscape[1]	Elevation[2]	Sand[2]	Silt[2]	Clay[2]
1994	ns	*	**	ns	0.32*	−0.29*	−0.29*
1995	*	*	**	ns	0.23*	ns	ns
1996	ns	**	**	−0.26*	ns	ns	ns
1997	ns	ns	ns	ns	ns	ns	ns
1998	*	ns	*	−0.57**	ns	ns	ns

[1] ANOVA.
[2] Correlation (zero-lag).
ns, *, ** not significant, significant at the 0.01 and 0.05 probability levels, respectively.

Channel Real-Time Kinematic System (Trimble Navigation Ltd, Overland Park, KS), and the landscape positions sideslope, bottomslope and drainageway were defined from this data (Figure 1).

Various statistical analyzes were performed on lint yield, soil property and elevation data for each of the five years of the study. Analysis of variance [PROC GLM (12)] was used to determine statistical differences between replicates (blocks), P fertilizer rate, and landscape positions in cotton lint yield and soil properties. PROC CORR (12) was used to do simple correlation between lint yield, soil properties, and elevation. Bi-variate cross-correlation was done up to ten, 15-m lags between yield, soil properties and elevation using PROC ARIMA (12). Auto-regressive, moving average, state-space models of lint yield data with soil properties and elevation state variables were tested with PROC STATESPACE (12, 13). PROC FACTOR (12) was used to look for underlying common factors that related to soil properties and elevation (14).

RESULTS AND DISCUSSION

Cotton lint yields responded positively to P fertilizer in 1994 to 1996, but not in 1997 or 1998 (Table 3). Landscape position had a strong effect on yields in all years except 1997. Bottomslopes had greater lint yields than the sideslopes in these years. Drainageway yields were similar to sideslope yields. Elevation had a negative correlation with yield in 1996 and 1998 (Table 3). Cross-correlation revealed negative relationships between lint yield and elevation in 1994 and 1995, but at lags greater than zero (data not shown).

The 1997 growing season was the only year that above average rainfall was received in June, July, and August (Table 2). This suggests that moisture was

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limiting on the sideslopes in all, but the wet 1997 year, and that soil water redistribution resulted in more optimal water contents in the bottomslopes. Li et al. (15) reported that volumetric soil water content increased with decreasing elevation across the same swale used in our study. Lower yields on the upper slopes may also have been associated with greater susceptibility to wind and water erosion and heat.

One of the soil nutrients measured, DTPA-Zn, was negatively correlated with elevation, suggesting some downslope movement ($r = -0.45$, $p < 0.01$). However, there was no cross-correlation between any soil nutrients (besides soil P) and lint yield, which limits the landscape effects mainly to water relations. Some relationships between soil particle size and lint yield were observed in 1994 and 1995, but these may have been due to correlation with elevation (Table 3).

Unlike cooler regions with more drastic topography changes, such as the Palouse region of eastern Washington (16), soil organic C was relatively uniform across landscape positions (Table 2). Lint yield was not related to soil organic C in any of the years (Table 3). This is in contrast again to the Palouse region, where high soil organic matter contents of the footslopes resulted in greater wheat yields than the lower organic matter backslopes and topslopes (16). Clay and soil organic C were both positively correlated with elevation at our site, probably due to erosion of the sandy loam topsoil on the upper slopes ($r = 0.31$, and 0.31, respectively, $p < 0.05$). The absence of greater soil organic C and clay contents

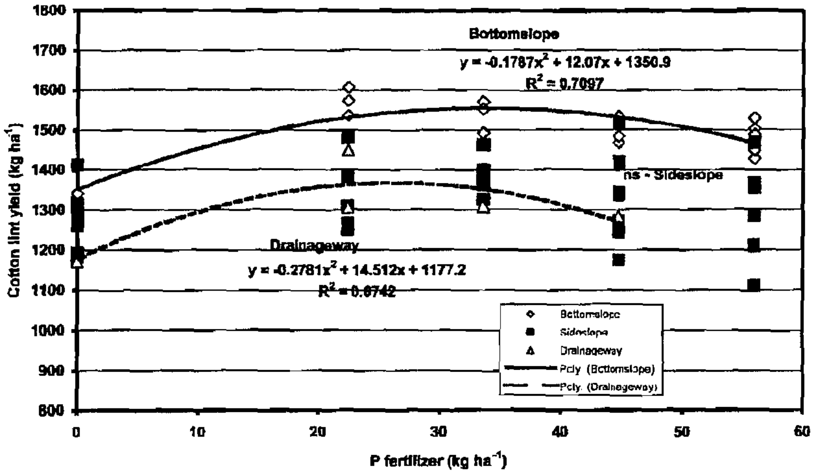

Figure 2. Average phosphorus fertilizer response (1994 to 1996) by landscape position, Lamesa, TX.

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in the bottomslopes than on the sideslopes suggests that water redistribution to this landscape position, and not differences in water-holding capacity, is what positively affected yields.

We examined P fertilizer response by landscape position for 1994 to 1996, the years with significant response. Figure 2 reveals that no response to P fertilizer was observed on sideslopes. Phosphorus response was quadratic in both bottomslopes and in the drainageway. Maximum agronomic response was at 34 and 26 kg P ha^{-1} in bottomslopes and drainageway, respectively. Lack of P response in the sideslopes occurred despite lower initial soil P than the lower lying landscapes (Table 2). Similar to eastern Colorado (5), initial soil P in our study was negatively related to soil Ca ($r = -0.48$, $n = 55$), probably due to increasing insoluble Ca phosphates with higher soil Ca. Ortega et al. (5), however, did not observe consistent P fertilizer responses in wheat between landscape positions. Their multivariate principal component analysis, that included several soil properties and soil moisture measurements, explained yield response to P. Results of factor analysis of our soil property and elevation data, however, did not reveal any underlying factors that relate to more than one of the soil properties or elevation.

Our results with P fertilizer response in cotton are in contrast to the N fertilizer response results with wheat in eastern Washington (17). They reported higher N response in backslopes than in footslopes, possibly due to greater soil organic matter and N mineralization in the footslopes. We could not assess the effect of aspect as did Fiez et al. (4, 17), due to the circular rows in our study.

State-space procedures are auto-regressive, moving average models that can relate yields in a transect to soil properties (13). We tested state-space models for every year of our study. In every year but the wet 1997 year, elevation was the most important variable in these models. Texture remained in the models in 1994 and 1995 only. State-space models have the advantage over empirical regression models of predicting yields at specific locations. Their usefulness in predicting P fertilizer response, however, was not evident in this study.

These results suggest that future variable-rate or site-specific P fertilizer applications could be linked to management zones based on landscape position. In Texas, P fertilizer rates are based on soil test P as well as on yield goal. Landscape-based P management should therefore consider both higher yield goals in the bottomslopes and greater responsiveness to P fertilizer at similar soil test P values.

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