Factors affecting spatial variation in two crop rotations

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Abstract

An experiment was initiated at two 4-ha sites with hummocky to undulating terrain, to examine the spatial variation rotation benefits of wheat grown after pea compared to wheat grown after wheat. In the second year of the rotations, N and non-N effects related to rotational differences — soil water content, root and leaf disease, weed density, growing season N availability — were used to assess spatial variation of wheat seed yield in the two crop rotations. ANOVA and state-space modeling and landform complex approaches were used to quantify spatial variation. Yield was 10% greater in the footslopes of both rotations at St. Louis, and 10% lower in the footslopes of only the wheat-wheat rotation at Birch Hills, when compared with yield in the shoulders. The lower yield in the footslopes of the wheat-wheat rotation at Birch Hills partly was associated with higher weed density. The landform effect at St. Louis could not be explained with ANOVA. State-space analysis showed that the factors responsible for the spatial variation of seed yield differed between sites. Furthermore, local variation for soil water and N availability in the pea-wheat rotation, and lower leaf disease severity, mainly explained wheat yield at given locations in space at St. Louis. At Birch Hills, local variation for common root rot incidence in both rotations explained wheat yield at given locations in space. Preliminary results from this study reflect the spatial variation can be rotation specific, depending on the site.

Introduction

Researchers and farmers alike have become interested in the benefits of precision agriculture, otherwise known as site-specific management, prescription farming, variable rate application technology (VRAT), farming by the foot, or satellite farming. The basic concept behind site-specific management is that a field should be managed according to the spatial variability of potential crop productivity. Crop rotation is perhaps the most common used and important management tool to control crop productivity. For example, sowing wheat on pea and canola stubble, rather than on wheat stubble, can increase wheat seed yields by 10%, and in good years by as much as 60% (Bourgeois and Entz 1996; Stevenson and Van Kessel 1996ab). Management practices like crop rotation, also can impact on the spatial variation of crop yield (Stevenson and Van Kessel 1996b; Beckie and Brandt 1997). Stevenson and Van Kessel (1996b) found that wheat seed yield was about 400 kg ha^{-1} lower in the high-catchment footslopes as compared to the low-catchment footslopes and shoulders in the second phase of pea-wheat and wheat-wheat rotations. The landform effect on seed yield in the pea-wheat rotation was related to greater soil water and N content in the high-catchment footslopes. Increased grassy weed infestation in the high-catchment areas of the wheat-wheat rotation was related to lower seed yields in this same area. Beckie and Brandt (1997), in a similar region of the Canadian prairies, found that the yield advantage of growing wheat on pea rather than flax stubble was negligible in the mid- to upper-slope positions, but ranged from 10 to 24% in the lower slope positions.

Crop rotation studies conducted at the landscape-scale could provide information necessary to implement variable rate strategies for different prairie cropping systems by quantifying the effect of spatial variation. Therefore, a study was conducted to identify factors linked or associated with the spatial variation of seed yield in different crop rotations. Identification of these factors, as well as identifying and eliminating those factors not taking part in the processes, will provide additional avenues of inquiry regarding the quantification of processes controlling seed yield. Such diagnosis, and subsequent understanding, will allow optimal management of soil resources and crop yield in different crop rotations.

Materials and Methods

Site description and research design

Research sites were established in 1996 near St. Louis, and Birch Hills, Saskatchewan. The sites had terrain that varied from hummocky to undulating, and soils developed on a Chemozemic silty-textured lacustrine parent material with sone occurrences of Gleysolic and Regosolic soils. Pea-wheat-barley and wheat-wheat-barley rotations were established in a randomized complete block design. Plots were 30-m by 80-m and allocated to five blocks (Fig. 1). A systematic grid with 10-m spacing was superimposed across all rotations at each study site. A topographic survey was conducted at each grid point, a digital elevation model generated, and slope variables calculated. The slope variables were then used to identify distinct management units (shoulder, footslope, and level landform elements complexes) within each site (Fig. 1). Levels with an above-average elevation were reclassified as shoulders and those points with a below-average elevation were reclassified as footslopes.

Measurements were made at 10 sampling points in each plot (Fig. 1) in the second yr wheat crop following pea or wheat. Soil water content (O-30 cm) was determined prior to sowing wheat. Individual weed species were counted in four 0.25-m by 0.25-m quadrats after postemergence herbicide application. Wild oat (predominant species) density at St. Louis, and total weed density at Birch Hills, were considered for further analysis. Common root rot incidence also was assessed between anthesis and maturity in the same rotation phase using a 0 to 4 scale. Tan spot and septoria leaf blotch lesions on the flag and upper leaves were rated near anthesis using a 0 to 11 scale. Growing season N availability (atom % ^{15}N excess) was estimated using ^{15}N isotope dilution. A 1-m^2 area was harvested at each sampling point to determine wheat seed yield. These covariables were chosen because of their expected importance as factors determining crop productivity in the different crop rotations.

An ANOVA was conducted to determine those variables responding to the main effect of landform complex and specific interactions between crop rotation and landorm complex. Significant landform complex effects, and interactions with crop rotation, for wheat seed yield were investigated further by including covariables responding to the same effects or interactions. Weed density data were transformed (natural logarithm) prior to all analyses to reduce the influence of non-normal data distributions. The median of the untransformed data was used to demonstrate central tendency and semi-interquartile range was used to demonstrate variability about each median.

A state-space analysis was conducted to provide further detail on the spatial variation of wheat seed yield in each crop rotations. State-space analysis is a special autoregressive technique adopted from applied time series analysis. Unlike regression analysis or ANOVA which can only describe the average response across a field site and assumes common variance, it uses a deterministic relationship between variables that accounts for the state of a system in the local neighborhood. Therefore, state-space analysis is sensitive to response functions of different spatial subunits or 'hot spots' in a field — More detail on state-space analysis can be obtained from Shumway (1988) and Wendroth et al. (1992). Significant cross-correlation for each of the covariables with seed yield was desired for a covariable to be included in the state-space model (results not shown). The state-space analysis provided a model describing the state of wheat seed yield at a given location in space that was related to the state of the covariables at neighboring locations. The relative size of the state coefficients, as well as the fiducial limits of uncertainty, were used to appraise whether the factors responsible for the spatial variation of wheat seed yield were captured. State coefficients approaching zero indicated variables not related to variation for seed yield. A relatively wide fiducial limit indicated that the chosen covariables did not accurately describe the spatial patterns for seed yield. The data were arranged into a linear transect for each rotation, and normalized to remove differences in scale among the variables, prior to the state-space analysis.

Results and Discussion

Differences between landform complexes

Seed yield, soil water content, root disease, and weed infestations at St. Louis was greater in the footslopes compared with the shoulders for all rotations (Fig. 2). It was illogical to explain higher yields in the footslopes when higher disease and weed incidence were highest in the same areas, so these variables were not included in the covariance ANOVA Covariance ANOVA showed that the landform effect for soil water did not explain the higher seed yield in the footslopes of both rotations.

Seed yield at Birch Hills was moderately (P = 0.08) greater in the shoulders compared with the footslopes for the wheat-wheat rotation, and did not differ between landform complexes for the other rotation (Fig. 2). A number of weed species including Canada thistle, cleavers, and predominantly wild oat, were more abundant in the footslopes of the pea-wheat and wheat-wheat rotations. Covariance ANOVA showed that total weed density partly (covariable $P =$ 0.11) explained the landform effect for seed yield.

Spatial interpolation

State-space analysis showed that localized variation for seed yield at St. Louis was explained mainly by soil water content and atom % ^{15}N excess at neighboring locations in the pea-wheat rotations, and leaf disease severity at neighboring locations in the wheat-wheat rotation (Fig. 3). Localized variation for seed yield at Birch Hills was explained mainly by common root rot incidence in both rotations, and to a lesser extent soil water content and leaf disease severity, at neighboring locations (Fig. 4).

Concluding remarks

A few inconsistent threads emerged from the results of the two analyses. Spatial variation associated with differences in seed yield between landorm complexes was not entirely explained, and did not indicate any correspondence with the results of the state-space analysis. It is quite feasible that the factors controlling the spatial variation of seed yield in the different rotations varied across the field — each distinct high- or low-yielding area may be controlled a unique set of factors. For example, weed (particularly wild oat) density at Birch Hills appeared to have a predominant influence on seed yield at only a couple of sampling points (Fig. 5). Analysis of variance is based on mean responses across a field and the assumption of constant variance across the field. These restrictions mean that ANOVA would not be able to properly consider the influence of weeds at only a few sampling points. Localized variation also would increase error variation and reduce the sensitivity of ANOVA. State-space analysis, on the other hand, showed that the factors responsible for the spatial variation of seed yield in the two rotations contrasted at one site and were similar at the other site. Greater point-to-point variation for state-space predictions occurred for seed yield in the wheat-wheat rotation (Figs. 3 and 4). Additional points outside the fiducial limits and a relatively higher state-space coefficient occurred in the pea-wheat rotation. These contrasting results indicate that the spatial variation of wheat yield in the wheat-wheat rotation was more adequately explained by chosen covariables than in the pea-wheat rotation. Future investigation might consider additional factors (e.g., soil P availability) when diagnosing spatial variation of seed yield in the pea-wheat rotation.

It would seem that crop rotation potentially could influence site-specific management in different cropping systems at certain sites. It would be ideal if the results of the state-space analysis could be targeted directed towards the different landform complexes or elevation. Such a correspondence might mean that the higher yield in the footslopes at St. Louis mainly was due to greater soil water and N availability in the pea-wheat rotation and lower leaf disease severity for the footslopes in the wheat-wheat rotation. It is difficult to say whether such a strategy would be feasible, however, further investigation is necessary to confirm this possibility.

Acknowledgments

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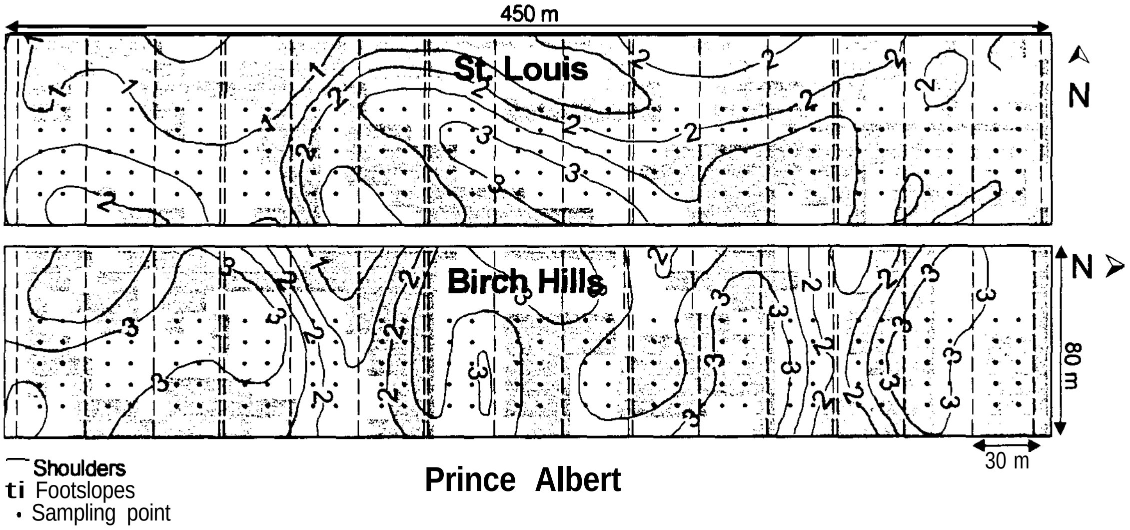

Fig. 1. Landform complex/sampling point maps of the two study sites in the Black soil zone of SK.

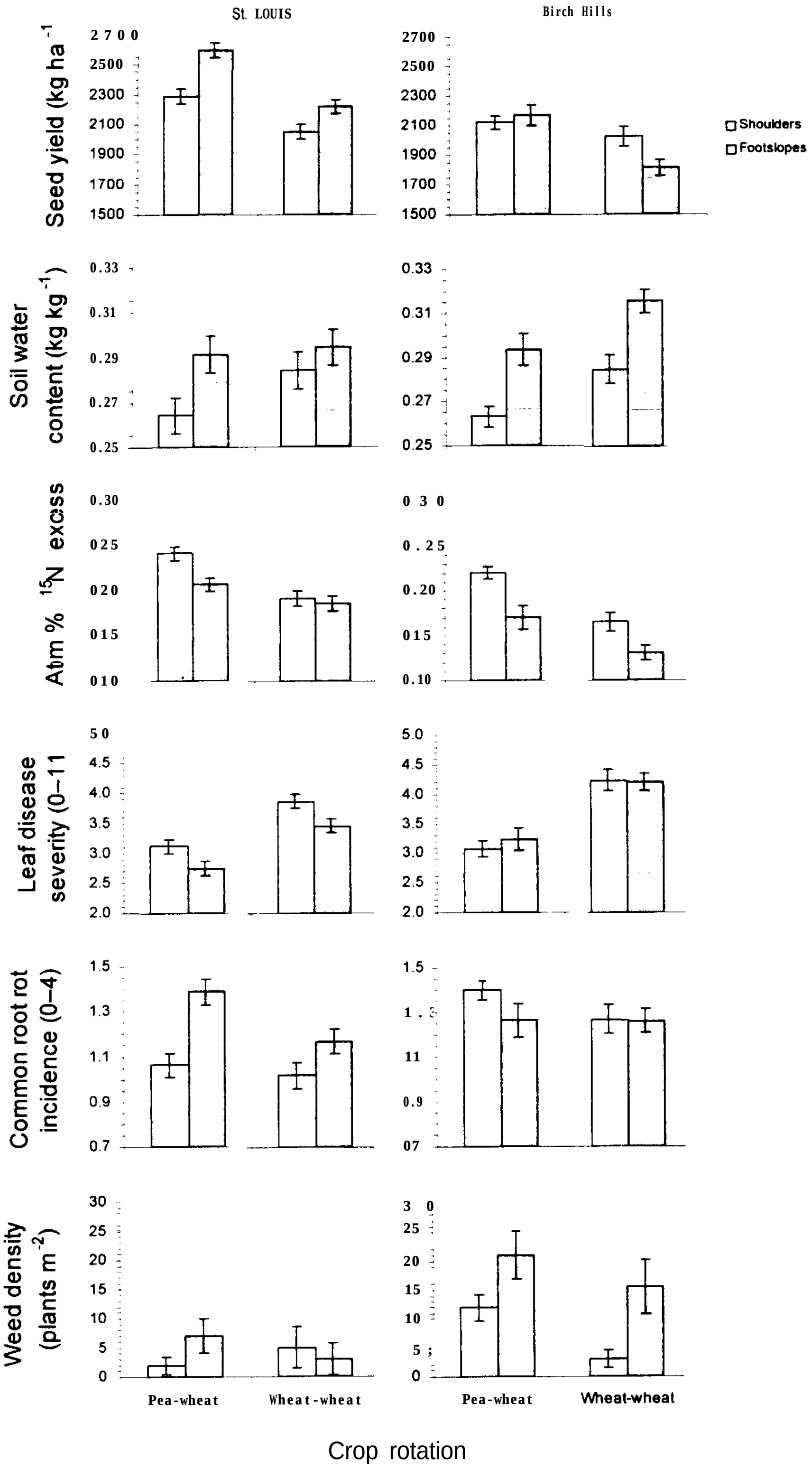

Fig. 2. The average landform effect in the second phase of two crop rotations at two locations. Standard error bars are given for each mean. Medians and semi-interquartile ranges were used to demonstrate averages and measures of variation for weed density.

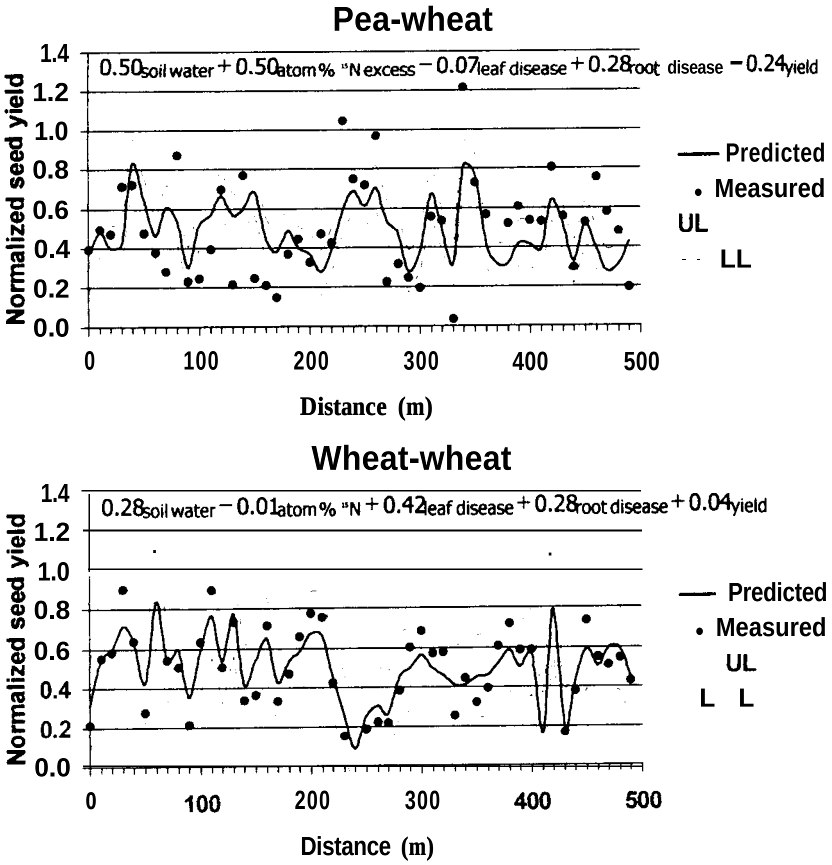

Fig. 3. State-space models for two rotations at St. Louis, SK. Solid line represents the state-space predictions, dots represent actual normalized seed yield data, and UL and LL represent the upper and lower fiducial limits.

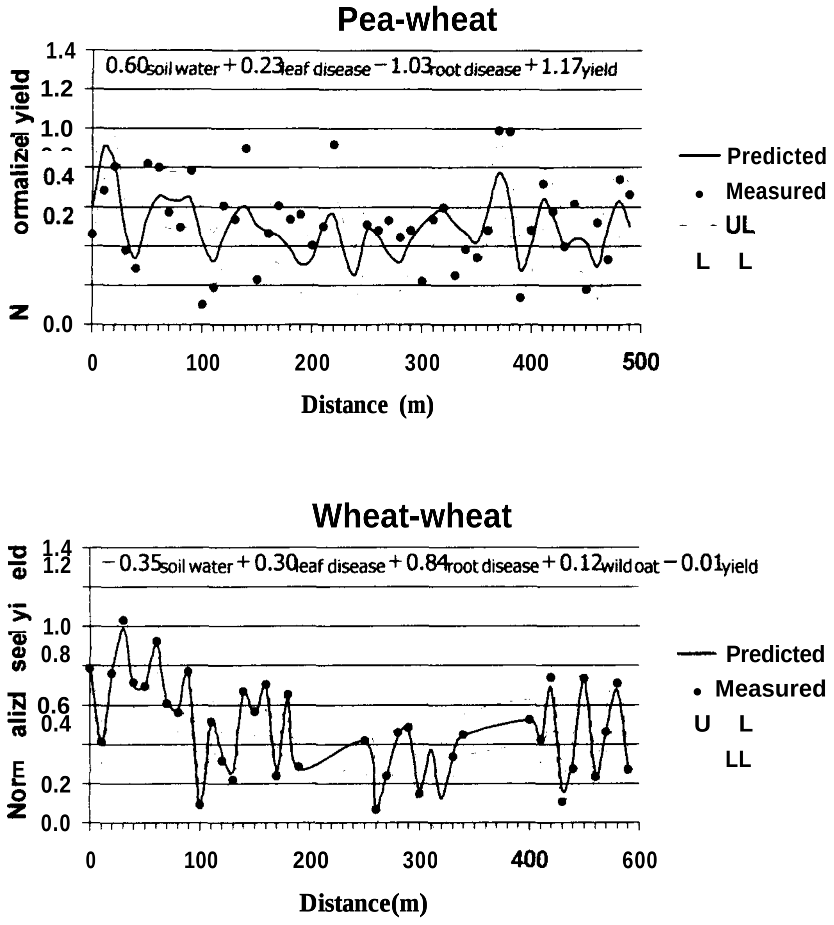

Fig. 4. State-space models for two rotations at Birch Hills, SK. Solid line represents the state-space predictions, dots represent actual normalized seed yield data, and UL and LL represent the upper and lower fiducial limits.

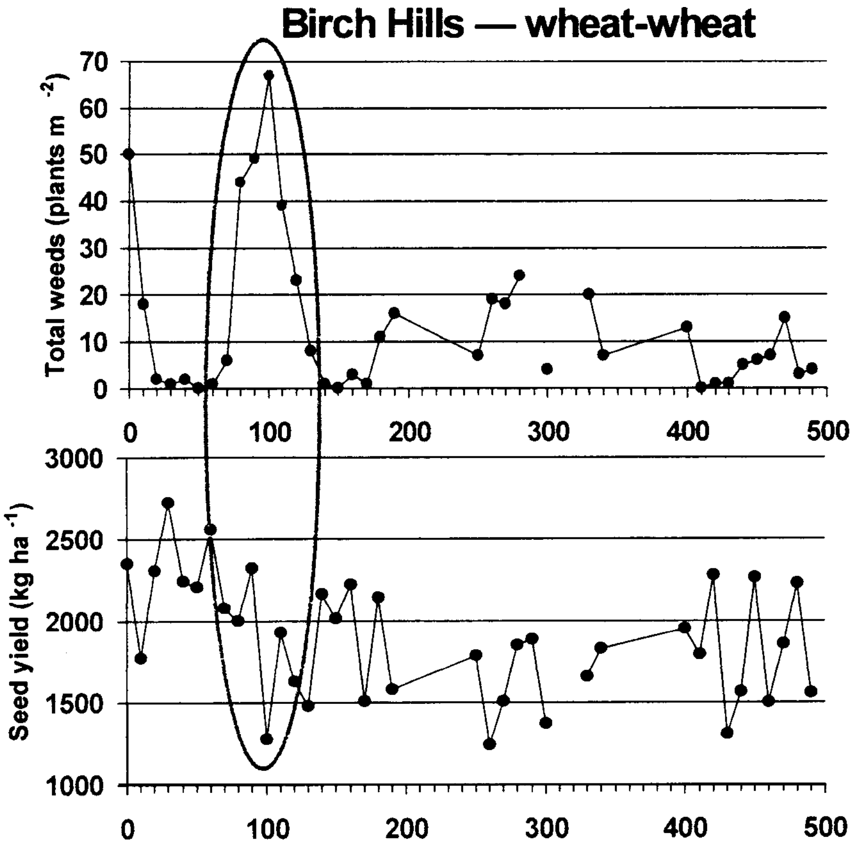

Fig. 5. Variation for total weed density and wheat seed yield along the transect in the second phase of the wheat-wheat rotation at Birch Hills, SK. Highlighted area indicates possible footslope positions where high weed density resulted in lower seed yield.