Pattern and factor analyses of diverse **plant a**nd yield attributes' responses **to alternative crop rotations and management practices**

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Abstract

Research is needed to identify cropping systems that simultaneously improve economic viability of farms and decrease reliance on external inputs while improving the natural resource base. The objective of this research was to map initial soil and crop yield variability and quantify patterns of spatial yield variability in response to increased crop diversity and contrasting management practices. All phases of 2- and a 4-yr crop rotation were established in 2002 on 192 geo-referenced plots. Three factors (F1, F2 and F3) explained 49.2% of total variation in 42 soil variables. Total yield in 2002 and 2003 were negatively correlated (r=-0.37) and yield variance in 2003 was 79% of its initial value in 2002. In 2003 system x tillage accounted for 52% of total variance in corn yield, system x tillage x fertility accounted for 33% of total variance in soybean yield and fertility accounted for 40% of variance in wheat yield. Crop-specific three latent variables were found among system, tillage, fertility, EC_a, D, F1, F2 and F3 and accounted for 69.0, 63.0 and 66.0% of total variance in corn, soybeans and wheat, respectively. When grain yield was regressed on these latent variables, the R^2 were 0.84, 0.68 and 0.47 for corn, soybean and wheat, respectively. Multiple regression analysis indicated that 2-3 sub-samplings and growth monitoring, especially past the 200 Julian date, and a final sub-sample at harvest generated adequate data (R^2=0.75-0.83) to create a detailed spatio-temporal map of the experimental site, plant development and crop yield in a single cropping season.

Media summary

Multivariate analyses of geo-referenced sub-sampled soil, plant and crop attributes will help identify agronomically improved and economically viable alternative cropping systems and environmentally-friendly management practices.

Key words

Sub-sampling, spatial variability, crop rotations, alternative management, yield.

Introduction

A greater reliance on the corn-soybean crop rotation in the upper Midwestern USA during the last 50 years was brought about by the development of more efficient management practices, effective external inputs, governmental policies and favorable economics (Porter et al., 2003). However, environmental concerns and the economic and social ramifications of increased reliance on government subsidies have triggered an interest in developing alternatives to the present agricultural system (Smolik and Dobbs 1991).

Research is needed to identify systems that simultaneously improve the economic and social viability of farms and rural communities in the upper Midwest while protecting the environment and improving or maintaining the natural resource base (Johnson et al. 2003). It is postulated (Smolik and Dobbs 1991) that systems which increase crop diversity, reduce tillage and reduce the use of external inputs potentially will improve economic, social and environmental sustainability. Long-term experiments are needed to determine yield trends, estimate nutrient dynamics and balances, understand changes in yield, predict soil carrying capacity and assess system sustainability (Regmi et al. 2002). The objective of this research was to map initial soil and crop yield variability, quantify patterns of spatial yield variability in response to increased crop diversity and contrasting management practices and determine optimum levels of spatio-temporal sub-sampling of plant, crop, soil and environmental variables.

Methods

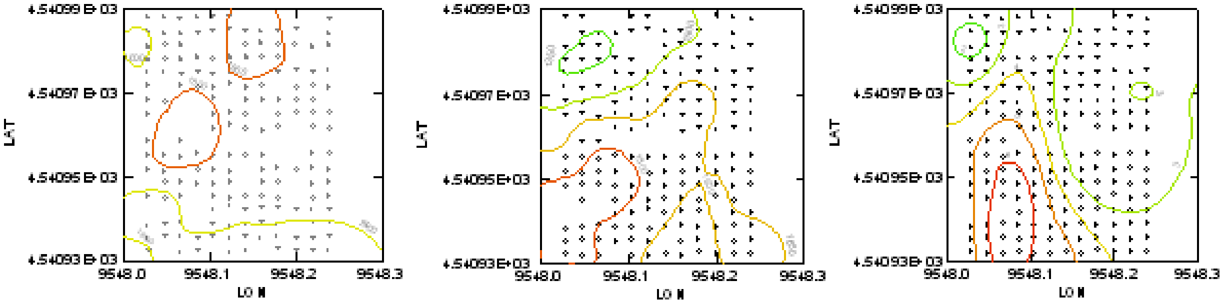
All phases and four replicates of a 2-yr (corn-soybean) and a 4-yr (corn-soybean-wheat-alfalfa-alfalfa) crop sequence, were established in 2002 on 192 geo-referenced plots (6 x 12 m, each) in a randomized complete block design. Organic and inorganic systems, conventional and strip tillage with or without the recommended nitrogen fertilizer rates for each crop were randomized and their individual and combined effects on crop yield and yield components were quantified. Apparent electrical conductivity (EC_a) and 42 soil physical, chemical and biological variables were measured in soil samples from each of the 192 main plots. Two geo-referenced sub-sampling plots (1 m^2, each) representing all factors in the experiment were established in each of 64 main plots. Yield data was collected in 2002 and 2003 from all plots and was based on a 15 m^2 harvested area. In 2003 data was collected 7 to 9 times from the sub-sampling plots between Julian dates 122 and 223 on foliage development as percent green area (GA) of surface area until 100% soil cover was reached, plant height (PH), number of plants/unit area (NP), and at harvest, number of seed (NS) and seed weight (SW)/unit area. The difference (D) between infrared thermometer readings taken at key phenological stages on plants and bare soil in the 64 sub-sampling plots and at physiological maturity on all 192 main plots was calculated. Multivariate and geo-statistical analyses procedures, singly and in combinations, were utilized to detect spatio-temporal variability (Mallarino et al., 1999), quantify plant and crop responses to inputs and management practices (Joernsgaard and Halmoe, 2003) and build a database for long-term monitoring and planning purposes. Soil-related factors (F1, F2, F3), EC_a and D were used as covariates in the multivariate analyses of crop yield.

Results

The experimental plots represent typical corn-soybean fields in the upper Midwest of the US. Factor analysis of 42 soil physical, chemical and biological variables resulted in extracting three factors (F1, F2, and F3) that accounted for 49.2% of total variation in the original variables. F1 accounted for 23.7% of total variance and was dominated by variables related to soil carbon and soil pH. F2 accounted for 13.4% of total variance and was dominated by variables related to soil phosphorus, potassium, microbial biomass and soil physical properties (sand and silt). F3 accounted for the remaining 12.1% of variation and was dominated by variables related to soil nitrogen. A negative and strong relationship was found between EC_a (mean=3.8 and variance=16.7) and each of F2 ($r=-0.63$, $P<0.01$) and F3 ($r=-0.34$, $P<0.05$).

When adjusted for spatial variability (using yield in 2002 and EC_a as covariates, Fig 1), mean grain yield in 2002 and 2003 were negatively correlated ($r=-0.37$, $P<0.05$) and yield variance in 2003 was 79% of its initial value in 2002. Total crop yield in 2003 was not associated with EC_a, F1, F2 or F3, however, corn, soybean and wheat grain yields displayed different associations with EC_a. Whole plot and sub-sampled soybean yield and yield components were positively correlated with EC_a (r ranged from 0.24, n.s. to 0.36, $P<0.05$); respective values for corn ($r=-0.39$ to -0.77, $P<0.05$) and wheat ($r=-0.26$, n.s., to -0.41, $P<0.05$) were negative.

The exponential model in the anisotropic semivariogram analysis, using yield in 2002 as a covariate, and two spherical models using D and Ec_a as covariates, resulted in r^2 values of 0.69, 0.63 and 0.46, respectively. Respective r^2 values using F1, F2 and F3 were 0.14, 0.47 and 0.13. Consequently, the first two models, with yield in 2002 and D as covariates, fit the variogram data better than the remaining models.



(a) (b) (c)

Fig. 1. Two dimensional plots of yield in 2002 (a), yield in 2003 (b) and EC$_a$ in 2003 (c) as reproduced by ordinary kriging.

Variance components of all 2- and 3-way interactions among levels of main factors (i.e., system, tillage and fertility) were significant ($P<0.05$) in 2003, however, in 2002 significant interactions were limited to tillage x fertility and system x fertility. In 2003, tillage and system x tillage accounted for 37.5% ($P<0.05$) and 52% ($P<0.05$), respectively, of total variance in corn yield. Fertility and system x tillage x fertility accounted for 27% ($P<0.05$) and 33.0% ($P<0.05$) of total variance in soybean yield, respectively, whereas tillage, fertility and system x tillage accounted for 19.5% ($P<0.05$), 17.5% ($P<0.05$) and 40% ($P<0.05$) of variance in wheat yield, respectively. Average corn yield was exceeded by 31.5% when corn was managed under a conventional system, conventional tillage and received the recommended nitrogen fertilizer rate. A modest (11.0%) yield increase over the overall mean was achieved by soybean under the same management practices as for corn, however, without nitrogen fertilizer. Wheat was the only crop to respond to organic system, strip tillage, in addition to nitrogen fertilizer, and produced 23.8% more grain yield than average.

Crop-specific three latent variables were identified among: system, tillage, fertility, EC$_a$, D, F1, F2 and F3 and accounted for 69.0, 63.0 and 66.0% of total variance in corn, soybeans and wheat, respectively (Table 1). Loadings, associations and direction (negative or positive) of all eight components of the three latent variables differed widely among crops. The first latent variable had high loadings for tillage, EC$_a$, D and F2 in corn; EC$_a$, F2 and F3 in soybean; and tillage, D and F3 in wheat. The second latent variable had high loadings for system, F1 and F3 in corn; tillage and D in soybean; and system and Ec$_a$ in wheat. The third latent variable was dominated by fertility in corn, and by fertility and F2 in soybean and wheat. Multiple regression models relating grain yield of corn, soybean and wheat with the three latent variables resulted in R^2 values of 0.84 ($P<0.001$), 0.68.0 ($P<0.01$) and 0.47 ($P<0.08$), respectively.

Stepwise multiple regression analysis was employed to predict grain yield in main plots as a function of repeated measures (GA, NP, NS, SW, PH and D, see methods for abbreviations) in sub-plots. The first regression model explained 75% of total variation in grain yield of main plots, involved three repeated measures of GA, PH, and D, and included the following variables as predictors (followed by the Julian date when the reading was recorded): GA(128) + GA(136) + GA(170) + PH(153) + PH(170) + PH(181) + D(164) + D(188) + D(196). A second model explained 83% of total variation in grain yield of main plots, involved two repeated measures of GA, PH and D, in addition to NP, NS and SW in sub-plots at harvest, and included the following variables as predictors: GA(212) + GA(223) + PH(206) + PH(223) + D(212) + D(251) + NP + NS + SW.

Table 1. Loadings of 8 factors on 3 latent variables (and percent variation accounted for by each latent variable) for corn, soybean and wheat (highest loadings are in bold).

Crop	Latent variable	System	Tillage	Fertility	ECa	D	F1	F2	F3
Corn	1 (0.29)	0.08	**0.69**	0.07	**-0.93**	-0.53	0.15	**0.79**	0.14
	2 (0.24)	**0.79**	0.09	0.08	-0.10	0.02	**-0.78**	-0.32	**0.72**
	3 (0.16)	0.27	-0.18	**0.73**	-0.02	**0.62**	-0.09	0.36	-0.34
Total variation	0.69								
Soybean	1 (0.25)	**-0.49**	-0.24	0.11	**0.89**	0.40	0.02	-0.51	**-0.69**
	2 (0.18)	0.03	**-0.83**	0.19	0.24	**-0.74**	-0.04	-0.25	0.11
	3 (0.20)	0.04	0.13	**0.74**	-0.03	-0.22	**0.61**	**0.73**	-0.10
Total variation	0.63								
Wheat	1 (0.27)	0.30	**0.79**	-0.03	-0.19	**-0.90**	0.31	0.04	**0.70**
	2 (0.20)	**-0.71**	0.01	-0.11	**-0.81**	-0.03	**0.45**	0.49	0.17
	3 (0.19)	0.14	0.03	**0.77**	-0.06	-0.06	0.39	**0.67**	-0.57
Total variation	0.66								

Conclusion

We developed an initial map of soil, crop and plant variables, and measured the impact of soil characteristics and management practices on plant growth, crop yield and yield components. The study aims at developing more diverse crop rotation and environment-friendly management practices and included corn, soybean, wheat and alfalfa in two crop rotations. Three to four samplings of plant growth, yield and yield components were adequate to account for a large part (75-83%) of the variation in whole plot yield. A database was established to measure and predict the impact of soil variables, management factors, and crop sequences on crop yields and economic viability of new cropping systems. This research will increase understanding of alternative cropping systems. It will also produce a less costly, more rapid, and more accurate method for identifying sustainable cropping systems.

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