IRRIGATED PRECISION FARMING FOR CORN PRODUCTION∗

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ABSTRACT

Precision farming is being practiced in the mid-west under non-irrigated conditions but little explanation exists regarding the practical application under irrigated conditions in our semi-arid environment. A USDA-ARS and CSU interdisciplinary research team is developing a scientific understanding of the causes of yield variability of corn. Two years of data are analyzed for two commercial center pivot irrigated fields (72 and 52 ha). Variability in water application, field elevation, soil texture, western bean cutworm, ammonium, organic matter, phosphorus, potassium and soil electrical conductivity were significant in explaining the yield variability. The transfer of this knowledge to the cooperating farmers is as important as gaining the knowledge itself. First year data showing over-irrigation resulted in the farmers reducing their excess irrigation by 70 percent. Farmers are also beginning to experiment with reduced fertilizer and pesticides. The risk can be minimized with a better understanding of the variables contributing to crop production.

1.0 INTRODUCTION

Precision farming (PF) or site specific management is currently promoted by several sectors of agribusiness. The concept of precision farming is to apply the right amount of inputs at the right time on the right area. Farmers are using combines with GPS and grain yield monitors to generate maps of spatial yield variability within fields. Many fertilizer dealers offer variable application of fertilizers and chemicals using specialized equipment. Precision farming is not just the use of high-tech equipment, but the acquisition and wise use of information obtained from that technology (Vanden Heuvel, 1996). The long term thrust of our research effort is to evaluate the impacts of PF on water quality and the economic feasibility of PF under irrigated conditions. The objectives are to quantify the causes of yield variability and the economic feasibility and environmental benefits of precision farming (Fleming, *et al*., 1998). The farmer's willingness to change their management strategy based on the scientific evidence that they can decrease input costs but not significantly increase risk is an important consideration.

Sampling strategies and analysis techniques are needed for integration into a decision support system that determines the appropriate scale for implementing variable rate technology. A multidisciplinary team including soil fertility scientists, crop scientists, weed scientists, entomologists, plant pathologists, systems engineers, remote sensing scientists, GIS experts, irrigation engineers, agricultural economists, and statisticians

∗ Presented at the Second International on Geospatial Information in Agriculture and Forestry Forestry Conference, Lake Buena Vista, Florida, 10-12 January 2000.

is working together to systematically gain a better understanding of precision farming. Buchleiter *et al., (*1997) presented the details of the project organization and site selection. The specific objective of this paper is to evaluate the factors affecting yield variability under the existing farm management and the potential for use of PF. Two cooperating farmers using high levels of inputs to obtain maximum yields are managing their own corn production and providing us with the yield data from two center pivot irrigated fields. We will also observe how their management strategies are influenced by the results of our data collection and analysis.

2.0 MATERIALS AND METH0DS

Aerial photographs of the two center pivots obtained by the USDA Farm Service Agency in 1992-1995 and the USDA-Natural Resource Conservation Service (NRCS) soils maps were used to select fields that exhibited significant crop and soil variability. Topography maps with 30 cm contour interval were made with the assistance of the NRCS. Field data were collected by the scientists from each discipline, sampling their respective parameters at the same 76 x 76 m grid.

2.1 SOILS DATA

The soils were sampled for fertility at randomly selected sites within each of the grid cells in April 1997 and March 1998. The surface 20 cm was analyzed for NO_3-N, NH_4-N, P, K, Zn, pH, organic matter and texture. Subsoil samples for 0.3-0.6, 0.6-0.9 and 0.9-1.2 m increments were analyzed for NO_3-N and NH_4-N. A Geonics Limited EM38[1] conductivity sensor was used to generate an electromagnetic conductivity map in the spring of 1997 for both fields. Electrical conductivity data were also collected in the spring of 1998 using the Veris[1] soil mapping system.

2.2 WEED DATA

The weed seedling population was sampled after post emergence spraying to estimate the weed population that competed with the crop (Wyse-Pester, *et al.*,1998*)*. Seedlings were identified and counted by species in a 0.15m band over 1.52 m of crop row. Seedlings were sampled at the center of each grid cell and at a randomly selected site between adjacent center points within a row. Major species were pigweed (*Amaranthus retroflexus* L.), nightshade (*Solanum sarrachoides* Sendtner), lambsquarter (*Chenopodium album L*.), and field sandbur (*Chenchrus incertus* M.A. Curtis). Since weed species differ in the ability to compete with maize, the total competitive load (Coble, 1986) was calculated for each quadrate.

2.3 INSECT DATA

Adult activity of locally important pest insects was measured. Pheromone traps were monitored weekly during the flight periods of European corn borer, *Ostrinia nubilalis* (Hübner), and western bean cutworm, *Richia albicosta* (Smith). Western corn rootworm, *Diabrotica virgifera virgifera* LeConte, adults were also monitored with traps containing the attractant 4-methoxycinnamaldehyde. One trap was located in each grid cell and more intense sampling was done in at least one quarter of each field. A total of 375 trap locations was employed over the two study fields.

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[1] Mention of trademark, proprietary product , or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

2.4 CLIMATIC AND IRRIGATION DATA

Center pivot irrigation systems with low pressure applicators and a big gun on the outer end of the lateral to irrigate the corners were used on both fields. A weather station was located adjacent to each field to measure solar radiation, temperature, vapor pressure, wind run, and precipitation. The data were used to calculate daily evapotranspiration (ET) for soil water budgeting purposes. Six recording raingages were placed around the periphery and one at the center of each field to assess spatial variability of rainfall. Records of the irrigation timing and amount of water applied were maintained throughout the irrigation season.

Since it is unfeasible to physically collect irrigation depths across the fields for all irrigations, computed depths from a simulation program that had been verified by field catch can data were used to map total water application (Jordan *et al.,* 1998). The average, maximum, minimum, and standard deviation of seasonal water applied in each grid cell were calculated. The water budget was calculated at each grid point to determine locations of excess and deficit irrigation throughout the season (Morton *et al.*, 1998).

2.5 YIELD DATA

The cooperators harvested both fields with combines equipped with yield monitors and GPS units. A base GPS unit was installed in the area that broadcast differential signals to increase the spatial accuracy. Yield data were processed and mapped with Farmers' Software Harvest Mapping System on a Map Info platform. The 1997 average maize yields were 10.9 and 13.0 t/ha for fields 1 and 2, respectively. In 1998 the average maize yields were 8.8 and 12.2 t/ha for fields 1 and 2, respectively.

3.0 DATA LAYERS FOR STATISTICAL ANALYSIS

The average yield data were summarized from the individual yield monitor observations within each grid cell. In 1997 a total of 58,474 and 42,338 data points was collected in 120 and 84 cells on field 1 and 2, respectively. In 1998, 44,737 and 40,788 data points was collected in 116 and 75 cells on field 1 and 2, respectively.

All variables included in the analysis are summarized in Table 1 and Table 2. Included are the minimum and maximum for each of the variables observed in the cells. The range for the data for most variables is quite similar. The yield for Field 1 was significantly lower for 1998 because of hail damage. The soil texture and elevation obviously did not change and the soil electrical conductivity data were collected only in 1997.

4.0 MODEL RESULTS

The primary goal of the analysis was to determine which predictors produced the best estimates of yield. We modeled yield as a function of the variables summarized in Table 1 and 2. We used an autoregressive spatial model (Upton and Fingleton, 1985) which is similar to a linear regression model, but it corrects for the spatial relationship between the observations. We fit separate models for each year and each field. An extensive model selection effort was undertaken using the Akaike information criterion (AIC). The autoregressive model and detailed results for 1997 are presented by Heermann, *et al.,* 1999.

The best predictors of 1997 yield were average electromagnetic conductivity, ammonium, organic matter, phosphorous, and the standard deviation of the water application for field 1. The model explained 73% of the

Table 1. Description and range of yield, water, insect and weed variable for each cell used in statistical model.

Variable	Units	Year	Field min	1 max	Field min	2 max
Yield – Average	t/ha	1997	8.42	12.14	10.04	13.97
		1998	5.98	10.11	9.03	14.84
- Minimum	t/ha	1997	2.20	9.67	2.21	11.37
		1998	2.20	7.89	2.20	13.18
- Maximum	t/ha	1997	11.70	18.73	13.48	17.85
		1998	9.28	17.50	12.16	18.59
-Standard deviation	t/ha	1997	2.20	9.67	0.52	3.45
		1998	0.61	2.51	0.62	2.98
Maize population	ha^{-1}	1997	60,000	100,000	75,000	100,000
		1998	34,000	95,000	52,000	100,000
Water application – average	mm	1997	549	982	427	1338
		1998	422	649	393	531
-Minimum	mm	1997	163	568	156	731
		1998	162	508	38	505
-Maximum	mm	1997	610	2,294	608	2,687
		1998	436	1,924	457	619
- Standard deviation	mm	1997	22	487	8	657
		1998	7	457	8	122
Total Competitive Weed Load	(ND)	1997	0.0	22.9	0.0	1.0
		1998	0.0	7.3	0.4	0.4
European corn borer-average	count	1997	0.0	5.0	0.1	4.4
		1998	0.0	14.0	0.0	11.0
Western bean cutworm – total	count	1997	0	326	0	89
		1998	4.0	163	0.0	97
Western corn rootworm – total	count	1997	0	4	0	5
		1998	0.0	6.0	0.0	6.0

variability in the yield (R^2=0.73) with 45% of the variability in yield explained by the spatial correlation between the observations and an additional 28% of the variability in yield explained by the predictors. For field 2, the best predictors of 1997 yield were average shallow conductivity, ammonium, and minimum water application for the season. The model explained 66% of the variability in yield with 26% explained by spatial correlation. The elevation measurements were not available when the 1997 analyses were carried out.

For field 1 in 1998, the average of water application per cell, minimum elevation, percent silt and average deep conductivity were the best predictors of yield. The model explained 72% of the variability in the response (R^2=0.72) with 40% of the variability in yield explained by the spatial correlation between the observations and an additional 32% of the variability in yield explained by the predictors. For field 2 in 1998, the predictors included in the top model were maximum elevation within the field, percent clay, average western bean cutworm, average deep conductivity, and potassium. The model explained 87% of the variability in yield with 61% of the variability in yield explained by spatial correlation. Note that R^2 increases as the number of predictors in a model increases.

TABLE 2. Description and range of soil variables for each cell used in statistical model. The soil parameters are from the top 20 cm of the soil profile.

Variable	Units	Year	Field min	1 max	Field min	2 max
Soil Texture – sand	%	Both	71.6	93.6	68.0	91.6
- silt	%	Both	0.4	10.8	2.4	18.8
- clay	%	Both	4.0	20.4	5.0	16.0
Phosphorous	mg kg^{-1}	1997	4	54	5	23
		1998	5	103	4	42
Potassium	mg kg^{-1}	1997	93	417	125	291
		1998	87	314	108	338
Nitrate Nitrogen	mg kg^{-1}	1997	4	59	4	25
		1998	1	28	4	30
Zinc	mg kg^{-1}	1997	2.2	8.1	1.3	3.5
		1998	2.3	7.5	1.2	7.3
Ammonium nitrogen	mg kg^{-1}	1997	2	9	1	5
		1998	3	10	3.3	7.2
Organic Matter	%	1997	0.6	1.7	0.7	1.4
		1998	0.5	1.6	0.7	1.4
pH	(ND)	1997	6.8	8.1	7.1	8.0
		1998	6.9	7.9	7.2	8.1
Elevation – Mean	m	Both	1354.9	1357.1	1341.8	1349.1
- Minimum	m	Both	1353.5	1356.8	1341.2	1348.5
- Maximum	m	Both	1354.1	1357.4	1342.4	1349.4
-Standard deviation	m	Both	0.04	0.56	0.02	1.00
Soil electromagnetic (EM) conductivity	ms/m^2	1997	15.5	58.5	9.8	35.5
Shallow soil electrical conductivity	ms/m^2	1998	7.8	20.9	5.7	13.8
Deep soil electrical conductivity	ms/m^2	1998	10.8	42.9	11.5	28.7

4.1 IMPLICATIONS OF MODEL FOR SITE SPECIFIC APPLICATION

The water terms for each of the fields in 1997 and for field 1 in 1998 were significant in explaining yield variability. The lower yields were on the periphery of the field where lower applications and larger variations of water occurred. In 1997 both fields were generally overirrigated, and water would be assumed to not limit yield.

Ammonium, phosphorous and potassium were negatively correlated with yield, which indicates that they are not limiting. EM (soil electromagnetic conductivity) and deep Veris soil electrical conductivity were positively correlated with yield while for field 2 in 1997 the shallow Veris soil electrical conductivity was negatively correlated with yield. Evidently the conductivity data are a surrogate for soil parameters that impact crop growth. Current research is directed at identifying these soil factors and quantifying soil/conductivity relationships. The elevation parameter was significant in showing a relationship to yield in 1998. We assume that the elevation is also a surrogate for factors affecting yield. Organic matter in field 1 has a positive correlation with yield that would probably result from greater dry matter production in areas of consistently higher yield.

The nitrogen variables were based on preseason soil tests and not on the total available for plant growth. The average total nitrogen applied during the season was 360 and 320 kg/ha for fields 1 and 2, respectively. Of this total, 200 and 150 kg/ha were applied by fertigation with the center pivot sprinkler system. Since approximately one half of the total nitrogen was applied with the water, the water uniformity significantly influences the nitrogen uniformity. The variability of water would result in similar variability in nitrogen and contribute to the correlation with yield.

The current producer management has applied inputs of water, fertilizer, and pest control chemicals at levels that they believe remove the factors as yield limiting. The significance of minimum and standard deviation of water for field 1 in 1997 indicates that there is a potential management strategy to increase the uniformity of application with the irrigation system to reduce yield variability. Even though excess water was applied, much of it came from natural precipitation that cannot be controlled. Since approximately one-half the nitrogen was applied in the irrigation water, it also could contribute to the yield variability. The challenge is to encourage producers to experiment with reduced inputs and not significantly increase their risk. The reduction in inputs and their costs must not reduce their net return for the enterprise.

The irrigation system design and operation are obvious areas to investigate whether changes would reduce the standard deviation and increase minimum application, thereby reducing yield variability. The spatial uniformity of water application could be improved through redesign of the sprinkler packages and operation criteria. The intermittent operation of the big gun on the end of the system introduces non-uniformity in the water distribution caused by the pressure changes. The speed of sprinkler rotation (travel speed) could be programmed to change as the big gun is turned on and off. The system should be slowed down while the big gun is on to allow the rest of the sprinklers to apply the same depth of water as on the area where the big gun is off. Topographical differences in elevation also could cause different operating pressures and thus different application depths. This could be compensated by changing the speed of rotation, with slower speeds on the high elevation areas where the pressures are lower. Another design option is to add pressure regulators to maintain constant pressure, independent of topography or operation of the big gun. However, this will significantly increase the pumping costs when the pump is supplying water at pressures higher than needed for much of circle being irrigated. An economic analysis needs to be done before pressure regulators are recommended.

The temporal variability of water application is also an important consideration for improving crop production. The significance of the minimum depth of water in our analyses could indicate that certain areas received less water than required at some crop growth stages. Adoption of more scientific irrigation scheduling is an avenue that will be explored to determine if this would decrease the variability in yield.

4.2 FARMER MANAGEMENT STRATEGY

The two farmer cooperators were selected because of their commitment to explore precision agriculture technology. Both farmers were using grain monitors on a combine and provided us yield data. We asked the farmers to continue to manage their operation as they had in the past. We did ask them not to apply fertilizer with a variable rate applicator. One of the farmers did apply fertilizer variably based on soil samples on a one ha grid on other fields. He was not satisfied with the application maps generated with this large grid sampling. He, with the assistance of his fertilizer dealer, became interested in developing management zones for variable application of fertilizer (Fleming, et al., 1998, Fleming, et. al., 1999). High, medium, and low yielding areas were delineated based on bare soil color from aerial photographs and modified with the farmer experience of yield within the field. Strips of variable rate preplant nitrogen application were studied in 1998. The yield differences did not correlate with the preseason nitrogen treatments because the additional nitrogen applied by chemigation plus nitrogen in the profile was sufficient for maximum production. These results have led to additional studies in 1999 to determine the best nitrogen management strategy.

The 1997 observation that water exceeded the seasonal evapotranspiration by approximately 250 cm, caused both farmers to reconsider their irrigation management. Consequently, they did significantly change their irrigation management and their excess irrigation to ET was reduced from approximately 250 mm to 75 mm in 1998. Even though the cooperating farmers manage to minimize risk, they do reduce inputs when then feel comfortable doing so. The key lesson from this example is the need to develop decision support tools that will provide producers with additional information and let them analyze the situation and change their own management strategies. Plans are being made to put on new sprinkler packages to improve the uniformity in an attempt to reduce the yield variability. This is another example of the farmer analyzing the data being collected and making a decision to take positive action to correct the identified cause of yield reduction.

Both farmers are cooperating on reduced nitrogen studies on our two study fields after concluding that nitrogen is being applied in excess of crop requirements. The center pivot system with a computer controlled panel makes an excellent tool for variably applying nitrogen through chemigation by sector control of the injection system. Producers are concerned about the negative impacts of chemicals on the environment and are looking at ways to match crop needs without increasing their risk beyond a manageable level and applying more chemicals than needed.

5.0 CONCLUSION

The potential to reduce yield variability in this semi-arid area appears to be by increasing the uniformity of irrigation. An increase in the uniformity of water will also increase the uniformity of fertilizer and other chemicals where they are applied by chemigation. The potential benefit of increased site-specific inputs of fertility and pest management chemicals is small where the farmers' management tolerance for risk is low and inputs are high in an attempt to obtain maximum yields. The greatest potential of PF is in reducing the cost of inputs. However, PF could increase financial risk. The environmental benefits of decreased chemical inputs are an important part of management that is minimally factored into many farmer decisions and will likely be increasingly important in the future.

The farmers have demonstrated the value of additional scientific information by changing their management strategy towards irrigation and fertilizer applications. PF provides the opportunities to decrease input costs and potentially increase net income. An important aspect of future PF research is to establish sampling strategies, analysis techniques and decision aids that can be used by producers. The current project has demonstrated the value of data collection and interpretation for each field. Farmers are moving into the information age and will be doing much of the applied research on each individual field and in management zones within a field.

6.0 ACKNOWLEDGEMENTS

The authors thank Newell Kitchen and Clyde Fraisse, Cropping Systems and Water Quality Research Unit, ARS, Columbia, MO and Farmers Software, Fort Collins, CO for collecting and analyzing the EM38 soil electromagnetic conductivity and Veris soil electrical conductivity data, respectively.

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