USING PRECISION AGRICULTURE TO DEVELOP PRODUCTION FUNCTIONS TARGETING LANDSCAPE POSITIONS IN HIGH AND LOW FERTILITY SOILS

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Precision agriculture or site-specific agriculture offers a promising avenue to harness the potential of soil productivity by managing plant nutrition management as well as pest and disease management to a small unit within field. In the past, nutrition application and disease management was done on a large-scale or over many acres of field(s). Current technological development allows for a more micromanagement of crops. Crop yields vary across fields and between years within the same agricultural field due to the complex interaction between multiple factors including topography, soil properties, weather, and management practices. Spatial differences in fields including topographic position, terrain attributes, erosion and drainage classes are some of the important factors that have been identified to impact crop yields [1,2]. Kravchenko and Bullock [2] reported that topographic features explained 20% of yield variability, whereas soil properties explained 30% of yield variability. Another study conducted by Jiang and Thelen [3] in Michigan found that soil and topography contributed to 28 to 58% of the variability in crop yields. Within topographic features, the elevation has the most dominant effect on crop yields and resulted in higher yields at lower topographic positions [2,3]. However, curvature, slope and flow accumulation effects on yields varies depending upon the topographic locations and precipitation. da Silva and Silva [4] reported that yield was significantly related to the flow accumulation lines in the irrigated fields. A study by Green and Erskine [5] reported that topographic wetness index explained 38 to 48% spatial variability in wheat yield in Colorado. Topography affects soil physical and chemical properties by influencing erosion or deposition of soil particles, organic matter and soil nutrients as well as it also influences soil water availability by impacting vertical and horizontal water redistribution [2]. Anselin*, et al.* [6]

found that nitrogen response varies by landscape position and suggested that site-specific N applications might be profitable under such landscape with topographic variations. A study by Thelemann*, et al.* [7] reported lower corn grain and stover yields in depositional and flat areas due to higher moisture retention for longer time periods, whereas yields were highest on well-drained summit positions. Although, effects of topography on crop yields can be found from microscales to watershed scale, but topographical influence becomes more complex on larger scales due to increase in variability of soil properties, precipitation, temperature and other climatic factors [2].

In addition to spatial variability, temporal differences in crop yields can be largely attributed to weather conditions including precipitation, temperature, and total growing degree days during crop season [8,9]. Based on 104 years of data on corn yields and weather, Hu and Buyanovsky [10] reported that effects of climate on corn yields in Missouri can be explained by in-season variations in temperature and rainfall. Hu and Buyanovsky [10] found that the weather in the high-yielding years was characterized by low rainfall and warmer temperature during the planting and ripening period (September-October), more rainfall and warmer temperatures during the germination and emergence, more rainfall and less than average temperature during the anthesis and kernel filling periods (June to August). The relationship between the topographic attributes and crop yields can vary depending on the weather conditions [11]. Bao-Liang, Cheng-Si, Walley, and Yates [11] found that the correlation between crop yields and topographic attributes during the wet year was not as strong as during the dry year in a rolling landscape. The upslope length was the best yield indicator during the dry years, whereas no such interaction was obtained between topographic attributes and yield in wet years [11]. Kumhálová*, et al.* [12] also found a weak correlation between flow accumulation and yield during the wet years and strong correlation for the dry years. In a six-year study, Kaspar*, et al.* [13] found that corn yield was negatively correlated with elevation, slope and soil curvature in four years with less than average rainfall, whereas the yields were positively related with those topographic attributed in two years with abundant rainfall.

Spatiotemporal variability in crop yields can be managed using precision agriculture [6,9]. The geo-referenced yield data obtained from yield monitors allows detailed characterization of spatial-temporal variability in yield [14]. The high-resolution LIDAR data and yield maps can be combined together for site-specific management of crops. LiDAR is an active remote sensing application in which laser pulses from a satellite or aircraft is sent to the ground and then receives that light back providing a range depending on the time for the pulse to return and this dataset can be used to make high-resolution digital elevation models (DEM) [15]. The high-resolution topographic attributes from DEM can be related to spatial yield variability at compatible scales [14,16]. The DEM can be used in the delineation of management zones within fields [17]. The most commonly used topographic attributes in the topography and yield correlation studies were elevation, slope, aspect, curvature, flow length, upslope contributing area, flow direction, flow accumulation, distance to flow accumulation lines, wetness index, stream power index and sediment transport index [14]. Many previous studies have utilized precision agriculture techniques for understanding the spatial-temporal variation in crop yields [6,9,18]. For example, Parent, Bélanger, Parent, Santerre, Viau, Anctil, Bolinder and Tremblay [17] reported that two soil management units were formed by locating landscape positions of clay accumulation, waterlogging and soil compaction through the use of DEM and clay/OM ratio distribution maps.

The overall objective of this study was to investigate how conservation tillage impact yield at six different topographic positions in low and high fertility soils of Illinois. Specific objectives were to: (1) compare spatial and temporal patterns of corn-soybean and soybean-corn yield during wet and dry years; and (2) identify multiple factors which can explain yield variability at the field scale and develop production function of these factors.

MATERIALS AND METHODS

This section describes materials and methods as well as data used in this study. Among other aspects, this section also describes how micro-field data were obtained. This study uses soil parameters from a small 8X8 square meter grids within 302 hectares in Southern and Central Illinois. The number of grids comes up to more than 30,000.

Site Description

The research sites in southern and central Illinois were located in Jackson County and Macon County, Illinois, respectively (Figure 1). Three fields (field no. 9, 13 and 25) with eight year of yield data (2008-2015) from southern Illinois located near Carbondale, Illinois and two fields (fields Brk-A North and McDonald-320 west) with four years of yield data (2011-2014) from central Illinois located near Decatur Illinois were selected for spatial-temporal analysis of the yield data. The fields 9, 13 and 25 in southern Illinois had an area of 21, 30, and 24 ha, respectively. The field Brk-A north and McDonald-320 west had an area of 79 ha and 100 ha, respectively. The dominant soil series of three fields of southern Illinois were Hosmer silt loam (Fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs) occupying greater than 50% of the field area, Stoy silt loam (Fine-silty, mixed, superactive, mesic Fragiaquic Hapludalfs) with about

35% of the field area, and Bonnie silt loam (Fine-silty, mixed, active, acid, mesic Typic Fluvaquents) occupying 11% of the field area. The Hosmer silt loam is characterized by slope ranging between 1-20% and are moderately well-drained soil that is formed from loess found on the hillsides. The Stoy silt loam has a slope ranging between 2-5% and is classified as somewhat poorly drained soils that are formed from loess on uplands. The Bonnie silt loam is characterized by 0-2% slope and is poorly drained soils that are formed by silty alluvium on floodplains. Dominant soil series for Brk-A North field was Flanagan silt loam Fine (smectitic, mesic Aquic Argiudolls) occupying 58% of the field area and Drummer silt loam (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) occupying 15% of the field area whereas McDonald-320 west had Flanagan silt loam on 45% area and Drummer silt loam on 55% area of the field. Both soil series have slope ranging between 0-2% and classified as somewhat poorly drained to poorly drained that are formed from loess or other silty material having an underlying loamy calcareous till or underlying loamy stratified outwash. Daily precipitation and air temperature data were obtained from nearest weather station and were used to calculate monthly total precipitation and average monthly temperature. The 20-year total monthly precipitation and average air temperature from 1987-2007 for Carbondale, IL and from 1990-2010 for Decatur, IL were also obtained.

Agronomic Management

All selected fields were under no-tillage practice with corn-soybean or soybean-corn rotation and were non-irrigated. During the study period in southern Illinois, corn was planted for four years in fields 9 and 13 (2008, 2010, 2012 and 2014) and in field 25 (2009, 2011, 2013, and 2015). In central Illinois, corn was planted in years 2011 and 2013 in Brk-A North field and in years 2012 and 2014 in Mcdonald-320 West field. The crop and fertilizer application rate during each year for all fields is provided in table 1. The nitrogen (N) was applied as anhydrous ammonia during spring in fields located in southern Illinois and during fall in fields located in central Illinois. Phosphorus (P) and potassium (K) were applied as diammonium phosphate and Muriate of potash. The seeding rate for corn averaged around 86450 seeds ha^{-1} with row spacing of 76.2 cm and for soybean averaged around 407550 seeds ha^{-1} with row spacing of 20 cm.

Derivation of Topographic Positions and other Attributes

Topographic position index (TPI) tool in GIS was used to identify topographic positions. Digital elevation model (DEM) with a raster resolution of 1.25x1.25 m generated from LIDAR data available on geospatial database for state of Illinois was used for identifying these positions. The model used for delineating topographic positions is a direct adaption of the Slope Position Classification model by Evans et al. 2016. The Slope Position Classification model developed by Evans et al. 2016 delineates six topographic positions (e.g., convergent shoulder, divergent shoulder, convergent backslope, divergent backslope, convergent footslope and divergent footslope). The TPI in the slope position classification model is the difference of a cell elevation (e) in a DEM from the mean elevation (*m*e) of a user-specified area surrounding e. Details of classifying topographic position is provided in Singh et al 2016. A radius of 125 m was used to determine the TPI in each field individually and a TPI raster was outputted from the DEM. A larger radius of 125 m was chosen so that microscale topographic variation within each field could be omitted. Additionally, other terrain and soil attributes like soil series, drainage class, k factor, slope percent, elevation were also derived either from digital elevation model of LIDAR or by overlaying soil series data provided by web soil survey of Natural Resources Conservation Service.

Grain Yield

Corn and soybean were harvested after they reached physiological maturity during late September to late November. Grain yield moisture was adjusted to 15.5 and 13% for corn and soybean, respectively. A yield monitor equipped combine was used to collect yield at 1-sec interval across the fields. Coordinates including latitude and longitude for yield data points were recorded simultaneously by a GPS receiver of the combine. Unrealistic yield data points that were likely caused by significant positional errors or operating errors such as abrupt changes of speed, partial swath entering the combine, and combine stops and starts-were removed from the data set before the statistical analyses. Yield editor software was used to remove outliers from the yield data according to Sudduth and Drummond (2007). After removing outlier developed yield data sets having latitude and longitude were imported to ArcGIS (10.2.2) for extraction of topographic positions and land-use features that matched each yield point collected by the combine. A vector data set was developed by overlaying yield data points on topographic position raster and soil series raster of each field.

Analytical methods

The data is collected over time and hence yield within a grid may not vary a lot given the stability in soil characteristics within a short span of over 8 years. We, however, account for correlation in yield data collected from the same grids over different seasons using grid-level fixed effects.

Econometric models, panel data methods in particular, are used to understand the influence of topographical positions on yield. Given that the soil characteristics do not change year to year in any significant way, we put more confidence in the fixed effects model as it accounts for correlation within grids over time.

Soil parameters used in this study have different characteristics within a single parameter (e.g., topography) but could overlap across parameters (e.g. slope percent, elevation, or aspect). Therefore, we run different models with different sets of controls to ascertain the validity of the estimates.

RESULTS AND DISCUSSION

Data reveals interesting variation across important weather and soil parameters, especially topographic positions. The average yield range across the six topographic positions was between 0.478 and 23.835 Mg ha^{-1} with a mean of 8.13 Mg ha^{-1}. Within a field (#13) of 42 hectares, there is considerable variation in yield. In this 42-hectare field (#13) located in Southern Illinois, the yield (per hectare) ranges from less than half a metric ton to about 16 metric tons per hectare.

We find that, relative to the lowest topographic position, the upper-level positions within a grid show higher yield. The yield difference in the regression model shows to be more than a metric ton per hectare. This translates to 39 bushels per acre. This difference between low and higher topographic positions decrease in a pooled OLS model and random effects model.

Given the magnitude of changes in weather, this technology would help farmers adapt production practices to obtain higher yields. For example, an important production decision facing farmer is if the fertilizer application strategy is any different during a drought year. Our data period includes a drought year, the year 2012. Once we control for the drought year, the coefficients of topographic positions are slightly different. The upper elevations show a bit higher yield. This could be due to water settling down on lower positions.

Table 1. Crops rotation and NPK application rate for each field in southern and central Illinois.

Location	Field	Year	Crop	N	P	K
				--------------kg ha^{-1}--------------		
Southern Illinois	9	2008	Corn	198	34	139
	13		Corn	198	34	139
	25		Soybean	59	34	84
	9	2009	Soybean	20	23	140
	13		Soybean	-	-	139
	25		Corn	209	34	112
	9	2010	Corn	215	45	112
	13		Corn	190	34	84
	25		Soybean	30	23	111
	9	2011	Soybean	37	41	135
	13		Soybean	8	9	67
	25		Corn	217	41	174
	9	2012	Corn	237	36	122
	13		Corn	209	34	112
	25		Soybean	30	34	140
	9	2013	Soybean	26	29	166
	13		Soybean	30	33	164
	25		Corn	209	19	150
	9	2014	Corn	237	36	122
	13		Corn	239	36	133
	25		Soybean	15	17	144
	9	2015	Soybean	31	35	120
	13		Soybean	30	34	112
	25		Corn	222	17	56

Table 1 continued…

Location	Field	Year	Crop	N	P	K
				--------------kg ha^{-1}--------------		
Central Illinois	Mcdonald-320 West	2011	Soybean	-	-	105
	Brk-A North		Corn	190	72	-
	Mcdonald-320 West	2012	Corn	147	8	
	Brk-A North		Soybean	-	-	111
	Mcdonald-320 West	2013	Soybean	-	-	6
	Brk-A North		Corn	218	61	-
	Mcdonald-320 West	2014	Corn	157	8	
	Brk-A North		Soybean	-	-	101

Table 2. Summary statistics of elevation and slope of all fields in southern and central Illinois.

Field	Variable	Mean	Min	Max	SD	p50
9	Slope (%)	4.14	0.11	19.83	1.77	3.88
	Elevation (m)	133.21	125.93	141.90	3.25	132.49
13	Slope (%)	3.66	0.37	10.45	1.54	3.55
	Elevation (m)	128.42	124.79	132.33	1.61	128.57
25	Slope (%)	5.05	0.05	17.01	2.77	4.64
	Elevation (m)	131.97	127.55	138.18	2.37	131.90
Brk-A North	Slope (%)					
	Elevation (m)					
Mcdonald-320 West	Slope (%)					
	Elevation (m)					

Table 3: Fixed effects regression estimates of soil parameters on yield

Variables	Model-1	Model-2	Model-3	Model-4
Slope Percent	0.253***	0.173***	0.074***	0.037**
	(0.01)	(0.01)	(0.01)	(0.01)
Soil Aspect	0.00	0.00	-0.001*	-0.001***
	0.00	0.00	0.00	0.00
Soil Elevation	-0.040***	0.00	(0.00)	0.024***
	(0.00)	(0.00)	(0.00)	(0.00)
Topo=11	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
Topo=12	0.624***	0.541***	0.528***	0.508***
	(0.16)	(0.14)	(0.16)	(0.14)
Topo=21	0.330***	0.608***	1.038***	1.145***
	(0.09)	(0.08)	(0.09)	(0.08)
Topo=22	0.191*	0.475***	0.933***	1.046***
	(0.09)	(0.08)	(0.10)	(0.08)
Topo=31	1.722***	1.698***	2.040***	1.957***
	(0.17)	(0.15)	(0.18)	(0.15)
Topo=32	1.948***	1.831***	2.223***	2.054***
	(0.10)	(0.09)	(0.11)	(0.09)

Note: * p<0.05, ** p<0.01, *** p<0.001

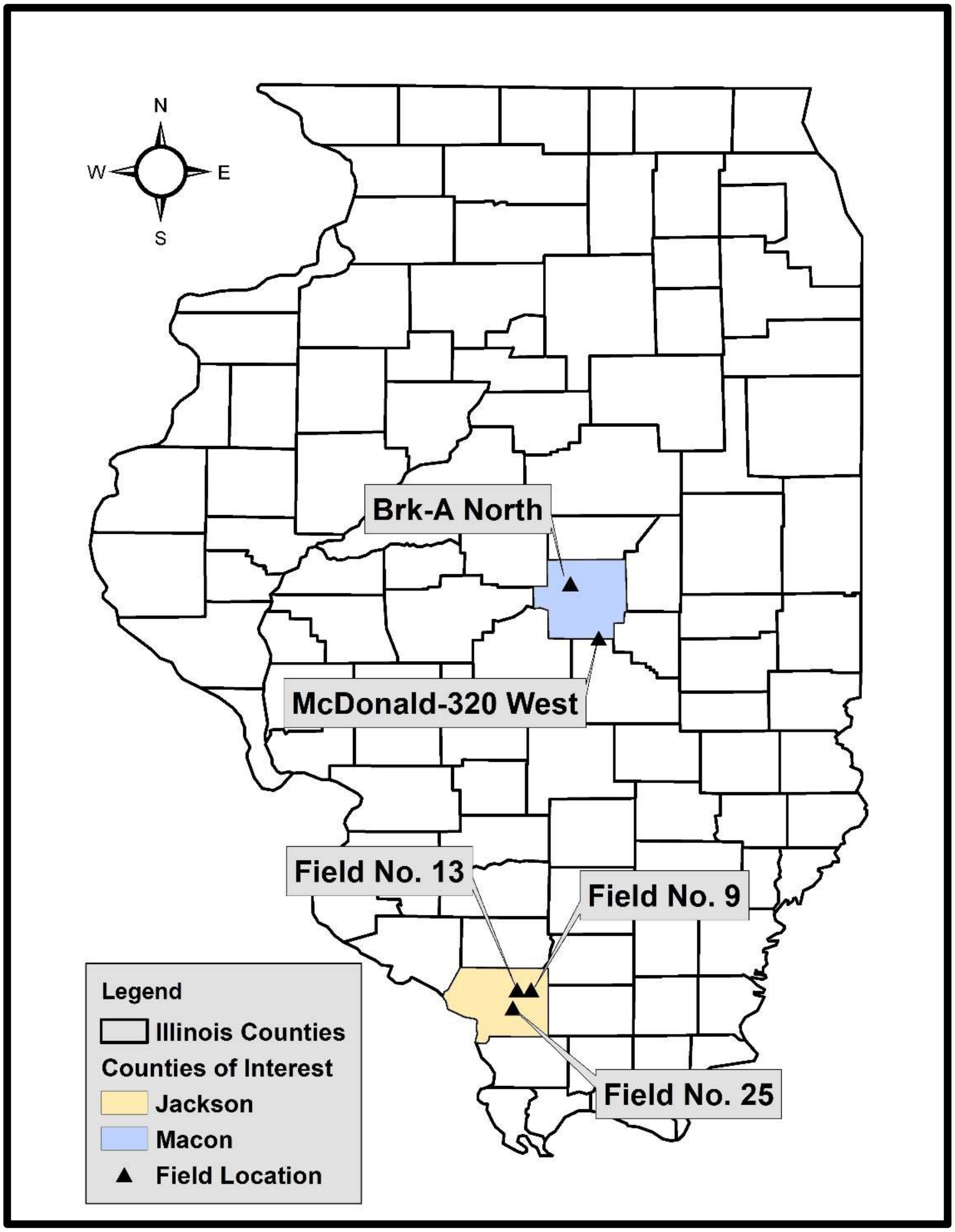

Figure 1. Study locations of all fields in southern and central Illinois, USA.

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