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Impacts of Terrain Attributes on Economics (including variable rate nitrogen) and the Environment: Costs of Reducing Potential Nitrogen Pollution in Wheat Production

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Market Report	Year Ago	4 Wks Ago	3-20-17
Livestock and Products, Weekly Average			
Nebraska Slaughter Steers, 35-65% Choice, Live Weight.	132.00	119.55	129.50
Nebraska Feeder Steers, Med. & Large Frame, 550-600 lb.	198.24	162.03	164.77
Nebraska Feeder Steers, Med. & Large Frame 750-800 lb.	165.76	133.83	137.92
Choice Boxed Beef, 600-750 lb. Carcass.	226.24	188.93	221.56
Western Corn Belt Base Hog Price Carcass, Negotiated	51.55	74.09	66.71
Pork Carcass Cutout, 185 lb. Carcass 51-52% Lean.	69.65	84.57	81.26
Slaughter Lambs, wooled and shorn, 135-165 lb. National.	143.71	142.38	139.73
National Carcass Lamb Cutout FOB.	359.79	341.73	326.26
Crops, Daily Spot Prices			
Wheat, No. 1, H.W. Imperial, bu.	3.93	3.19	3.10
Corn, No. 2, Yellow **Columbus**, bu.	3.33	3.22	3.22
Soybeans, No. 1, Yellow **Columbus,** bu.	8.21	9.36	9.00
Grain Sorghum, No.2, Yellow Dorchester, cwt.	5.48	5.06	4.97
Oats, No. 2, Heavy Minneapolis, Mn, bu.	2.66	3.01	2.86
Feed			
Alfalfa, Large Square Bales, Good to Premium, RFV 160-185 Northeast Nebraska, ton.	250.00	NA	133.75
Alfalfa, Large Rounds, Good Platte Valley, ton.	82.50	65.00	67.50
Grass Hay, Large Rounds, Good Nebraska, ton.	85.00	65.00	65.00
Dried Distillers Grains, 10% Moisture Nebraska Average.	134.50	111.50	96.00
Wet Distillers Grains, 65-70% Moisture Nebraska Average.	51.50	43.75	40.77
*** No Market**			

Photo by Ray Brown, Columbia County Washington

Understanding the influence of variable rate nitrogen technology in other areas can help inform Nebraska producers.

The economic cost of achieving desired environmental outcomes from uniform and variable rate fertilizer application technologies depends both on market forces and agronomic properties. Using spatial econometric methods, we analyze the impact of nitrogen fertilizer supply by terrain attribute on the yield and protein content of hard red spring wheat grown in Eastern Washington as well as the impact on residual nitrogen. We find significant association with all three. The economic impact of nitrogen restrictions depends critically on both prices and level of the restriction. Uniform application of nitrogen was found to economically outperform variable rate application, but variable rate application provided positive environmental benefits due to less residual nitrogen.

Market forces, such as prices, have been demonstrated to be among the important factors that drive individual decisions. Physical and biological processes that affect the interface between agricultural production and the environment are primarily agronomic. As a result, both market forces and agronomic relationships must be understood in order to influence agricultural production decisions in environmentally positive ways. The motivation behind this research is to incorporate detailed consideration of market forces and agronomic properties in an analysis of producers' economic costs of achieving desired environmental outcomes. We focus specifically on potential nitrogen pollution from production of hard red spring wheat (HRSW) on the rolling terrain in Eastern Washington. The rolling terrain in Eastern Washington provides a robust grain production environment to evaluate the influence of production technology stemming from site-specific technology (variable rate nitrogen application). Results can be very insightful to grain and oilseed producers in Nebraska who are considering adopting variable rate nitrogen application. Of course, producers considering adopting variable rate nitrogen application must take into account their own set of agronomic conditions. Nevertheless, variable rate nitrogen application should shine in production conditions like those found in Eastern Washington, thereby, giving producers in other locations knowledge of the kind of production environment needed for variable rate nitrogen application to be profitable.

Effective nitrogen management is critical for the economic production of crops and the long-term protection of the environment (Lopez-Bellido *et al*., 2006). Agricultural producers apply nitrogen to increase yields which, in wheat production, also increases protein content. However, removal rates of applied nitrogen in harvested cereal grain are estimated to average only 33 percent, leaving the remainder potentially subject to loss from the intended agricultural production system (Raun and Johnson, 1999)[1]. Much of the remaining nitrogen is immobilized (i.e., changed from an inorganic to an organic form) and may be recovered in the future through mineralization (changed from organic to inorganic form). Nevertheless, losses of available nitrogen supplies to the environment (i.e., pollution) can also be very large, as high as 35 percent (Kumar and Goh, 2000).

Empirical evidence documents that one of the most important motivations that translates market forces and agronomic rules into individual production choices is the goal of maximizing profit. Management of risk and environmental stewardship goals may also be important factors in a farmer's preference hierarchy and may temper actions aimed at profit maximization. In each case, input and output prices are primary signals of market forces. For example, consider the low profit scenario where wheat price is low and nitrogen fertilizer price is high. In this scenario, producers typically respond by applying less nitrogen, thereby lowering the probability of nitrogen pollution. The opposite can also be true; high wheat price and low nitrogen price would incentivize higher nitrogen application rates, thereby increasing the probability of nitrogen pollution. Fertilizer (input) and wheat (output) prices matter in determining both the level of environmental quality and the economic impact on producers from maintaining or improving environmental quality.

Technology, particularly site specific management, may play a large role in maintaining or improving environmental quality while minimizing adverse economic impact on producers. Agricultural producers typically apply nitrogen to their fields at a uniform rate. But, fields are seldom uniform in their nitrogen requirements. For fields with different intra-field nitrogen needs, a uniform application of nitrogen results in over application for some areas and under-application for other areas Fiez, Pan, and Miller, 1995; Pan *et al*., 1997; Mamo *et al*., 2003). Under-application reduces yield, revenue, and profit. In addition to adversely affecting profit, over-application can result in pollution when excess available nitrogen impacts ecosystems by contaminating groundwater, streams, lakes, and oceans. Hence, determination of the intra-field variables that affect potential nitrogen pollution and the resulting economics of reducing nitrogen pollution would be a valuable contribution to achieving desired environmental outcomes from agricultural production and possibly even enhancing profit.

Terrain attributes (i.e., topographic properties) have previously been used to help explain spatial variability of crop yields (Green and Erskine, 2004). Terrain attributes may be linked to differences in yields through a variety of mechanisms. They include both the spatial and topographical features like slope and aspect (direction to which a slope faces). They also include underlying soil properties through their systematic spatial distribution – e.g., adjoining plots can be expected to have similar soil properties, other things equal, and hilltops often have "thinner" soil than bottom lands. Terrain attributes may also help explain potential nitrogen pollution. Therefore, identifying terrain attributes that can lead to higher amounts of nitrogen pollution could be a valuable step toward reducing nitrogen pollution.

We seek to fill an important gap in the literature by evaluating the economic effect on wheat growers from reducing residual nitrogen through use of variable rate technology on fields with multiple terrain attributes. With regard to the effects of nitrogen application, residual nitrogen is treated as a proxy for potential nitrogen pollution. Due to complex soil and landscape-scale processes, it is difficult to measure the actual level of nitrogen pollution. To circumvent this problem, we measure the amount of nitrogen that has the highest probability of becoming pollution and label it residual nitrogen. Residual nitrogen represents the amount of nitrogen not accounted for by crop production and soil measurements.

We examine the effect of nitrogen supply and terrain attributes on yield and protein content of HRSW production as well as residual nitrogen levels at a research site in Eastern Washington with rolling terrain. We identify important terrain attributes and determine whether an innovative spatial weights matrix that accounts for elevation results in greater statistical efficiency in parameter estimation. We also assess the economics of uniform and variable rate nitrogen application methods under alternative prices and nitrogen regulations.

We analyze 10 terrain attributes that fully characterize the highly variable terrain in the experiment: global irradiation, planform curvature, profile curvature, tangential curvature, flow direction, specific catchment area, wetness index, slope, elevation, and aspect. Global irradiation measures the amount of annual solar energy a surface receives based on the geometry of the sun, earth, and field; consequently, a north-facing slope would have a smaller irradiation measure than a south-facing slope· Planform (or plan) curvature measures the rate of slope change along the contour (horizontal plane) (Kimberling *et al.*, 2012); it describes whether the flow is converging (concave, negative values) or diverging (convex, positive values) from a point. Profile curvature measures the rate of slope change along the direction of the slope; it describes whether the flow is accelerating (convex, negative value) or decelerating (concave, positive values). Tangential curvature measures the inclined plane perpendicular to the slope. Flow direction measures the direction of steepest decent from a point. Specific catchment area measures the size of the contributing area. Wetness index measures the hydrological process at a point by taking into account the size of the upslope contributing area and slope. Slope measures the angle (steepness) of the surface. Elevation measures the vertical height. Aspect measures the direction to which the slope is facing, assigning values in degrees from north.

DATA

Data for this analysis came from a field-level experiment at the Washington State University Cook Agronomy Farm located in the rolling Palouse hills north of Pullman, Washington, in a 21-inch rainfall zone. The Cook Agronomy Farm includes 151 acres of irregularly oriented hills and ridges separated by U-shaped draws. The experiment used 92 acres of the 151 acres available at the Cook Agronomy Farm. Each year HRSW and hard red winter wheat (HRWW) were grown on approximately 30-acre parcels. Unlike many nitrogen studies where data come from a small number of experimental plots, these data were obtained by sampling multiple global positioning system (GPS) referenced sites from field experiments, resulting in 369 individual sites. With 92 acres in the experiment there are approximately 4 individual sites per acre. Individual sites were set up in a non-aligned grid with points randomly assigned to the ¼ acre square. Yield, protein, and residual nitrogen data were collected at each individual site. Terrain attribute data were derived from the use of a survey grade GPS system using 30,440 point readings. Terrain attribute data were then interpolated to 10 meter square grid cells using local polynomial interpolation. A 6-year field experiment began in fall 2000. The experiment used a rolling three-year rotation that consisted of HRWW in Year 1, six alternative crops (we use the term previous crops) in Year 2, and HRSW in Year 3[1]. Each alternative crop in Year 2 was grown on 1/6 of a parcel (approximately five acres). The six alternative crops were spring peas, winter peas, spring canola, winter canola, spring barley, and winter barley. All previous crops were grown every year, and each crop was grown twice on the same land during the six years. The Cook Agronomy Farm uses no-till, direct-seed technology (i.e., seeds are planted directly into standing stubble), full size machinery, and field-sized plots to represent commercial farming operations. For additional details about the experimental design and operational procedures, see Ibrahim and Huggins (2011).

RESULTS

With the spatial model controlling for local soil and topographic spatial dependence, we identified statistically significant impacts of nitrogen supply by terrain attribute on yield, protein, and residual nitrogen. We found that yield response to nitrogen supply was the greatest with high slope and high profile curvature (i.e., accelerating slope) and small planform curvature (converging flow). We also found that residual nitrogen response to nitrogen supply was greatest under the opposite extreme in slope, planform curvature,

[1] With a three-year rotation over a six-year study period, HRSW was produced twice at each location and resulted in 738 data observations, of which 704 observations were usable. Data from 34 points are missing because of data collection issues. The economics of the six rotations are not directly relevant to the economics and environmental impacts of nitrogen application for HRSW since we have measurements of available nitrogen before planting and after harvest. With these nitrogen measurements, we are able focus on HRSW while accounting for the impact of the previously grown crop.

and profile curvature. Consequently, to reduce residual nitrogen and have the least impact on yield, greater attention should be paid to reducing nitrogen supply in the flatter areas. In these areas, nitrogen has a higher probability of becoming pollution since the only way to exit the field is into plants, surface or ground water, or the atmosphere and not by passing the nitrogen to lower elevations.

The economic effect on producer profit from restricting residual nitrogen was examined by simulating 12 price scenarios with a constrained optimization, mixed integer nonlinear programming model. The results of these simulations suggest ways that policymakers might induce producers to reduce residual nitrogen. If required to minimize residual nitrogen, producers could lose up to $44 per acre at high grain/nitrogen and high protein/nitrogen price ratios but only $5-6 per acre at average price ratios. Yet the reduction of residual nitrogen would be more than half as great at average price ratios as at high price ratios. Thus, inducement to reduce residual nitrogen and consequently applied nitrogen could be accomplished with trivial cost to the farmer at average grain and protein relative to nitrogen price ratios, but the same standard could impose substantial costs at high price ratios. The economic burden of environmental policy associated with nitrogen fertilizer could thus be greatly reduced by implementing a price-dependent partial restriction policy.

Despite the significant effect of terrain attributes on yield and protein content of wheat and on residual nitrogen, uniform application of nitrogen was found to economically outperform variable rate application because of the higher cost of variable rate application. However, variable rate application provided positive environmental benefits over uniform application by leaving less residual nitrogen. Nevertheless, while incentivizing producers to adopt variable rate application is a goal policymakers concerned with environmental quality might consider, it does not exhibit the same impact potential as a price-dependent partial restriction policy.

The complete article can be found at: http://onlinelibrary.wiley.com/doi/10.1111/agec.12321/full or by requesting a copy to Cory Walters at cwalters7@unl.edu

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