Characterization of spatial variation in wheat yield and protein using soil and plant sensors

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Summary
Successful production of irrigated durum wheat in semi-arid regions like Central Arizona require achieving a balance between the crop's nutritional needs and the amounts of applied fertility inputs, Nitrogen in particular. Unfortunately, some conditions that favor high yields are also associated with low protein contents that compromise grain quality. This project is improving our understanding of the factors that interact at the field-level to determine grain yield and quality characteristics. Two commercial fields in Sacaton AZ were grid-sampled to characterize soil texture and apparent electrical conductivity; three times during the growing season we collected information on soil/plant Nitrates, and the spectral response of the canopy using optical sensors. Yield and protein content maps were generated with a yield monitor. Results suggest grain protein concentration is associated with the rate of soil N uptake. Optical and displacement sensors can potentially detect in-field variation in plant size to enable sensor-based N management.

Introduction
Research funded by the AGRPC in 2010 yielded meaningful results in the spatial analysis of yield variability, in terms of both quantity and quality. A particular strength of this research was the focus on field-level analysis in fields under conventional management by a grower cooperator in the Sacaton AZ area. The results showed the strong influence of soil properties associated with soil water-holding capacity, as characterized with bulk EC measurements, on the final protein levels in the field. Canopy reflectance data characterized the amount of plant biomass at tillering but showed weak association with yield components at the end of the season. Our work in 2010 provided meaningful information because never before had been generated information on the spatial distribution of key soil/plant variables at the field scale in wheat production in Arizona. This type and quality of information is crucial to develop recommendations with a solid basis for improved fertility management under a site-specific, variable-rate approach. Other areas of management that can be improved with this line of work include irrigation management and seeding operations. In 2011 we proposed to build upon the foundation of the previous season and make a stronger case for improved management of wheat. Our work continued to be oriented towards developing recommendations on how to improve yield and grain quality through site-specific management, and timely application of production inputs. As we will see in the methods section, we increased significantly the sampling of Nitrates in both soil and plant. The analysis of timing and amounts is expected to yield important information to help the fertility management of durum wheat.

Experimental Work
In 2011 we continued to use the approach of working with grower collaborators to monitor actual field conditions created with their conventional management schemes as well as by the natural variability of soil in their fields. In agreement with Mr. Karl Button, manager of Ramona Farms in Sacaton AZ, we selected two fields. One in Sacaton AZ (111.731302 deg W,

33.111317deg N) and the other in Casa Blanca AZ (111.915868 deg W, 33.142297deg N). Both fields had 15 acres of Westmorland durum wheat dry planted the first week of December 2010 with water followed soon after.

An improved scheme of field-level research was followed during the growing season with particular attention to capturing the dynamics of soil/plant Nitrogen. This was achieved with soil/plant sampling for laboratory analysis of N status at tillering, jointing-booting, and flowering; along with spectral measurements of the crop using hand-held instruments. We chose to use the CropCircle ACS-470 3-band active spectral sensors (Holland Scientific; Lincoln, NE) that provided information on the canopy reflectance at 670, 720, and 820 nm. These quantities were combined to compute the normalized difference vegetation index (NDVI) which is an indicator of vegetation status. On-the-go soil electrical conductivity surveys were conducted at tillering using the Soil EC 3100 sensor manufactured by Veris Technologies (Salina, KS). In order to geo-reference all the data generated in this project we used a differential correction GPS model AgGPS232 manufactured by Trimble (Sunnyvale, CA). All electronic signals from soil/plant and yield sensors were collected with the use of a data logger model CR-3000 manufactured by Campbell Scientific (Logan, UT). The variability in soil physical/chemical characteristics in these two fields is illustrated with the differences seen in colors in the apparent soil electrical conductivity (EC_a) maps shown in figure one below.

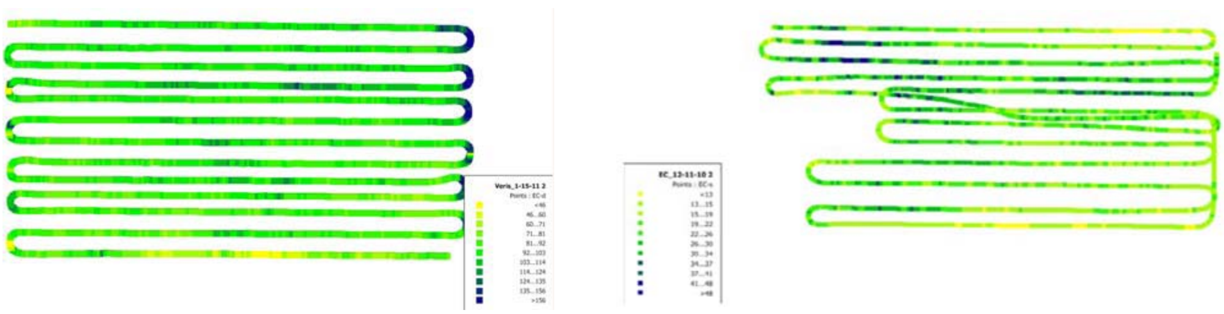

Figure 1. Soil apparent electrical conductivity maps of top soil layer (o-12 in) in Sacaton (left) and Casa Blanca (right) at the time of tillering (January 2011).

Soil and plant samples were taken following a square grid of 220 x 220 ft that translates to one sample per acre. These samples were collected following the guidelines recommended by Ottman M, “Fertilizing Small Grains in Arizona”, 2006 (Extension bulletin AZ1346) and were sent to a commercial laboratory for Nitrate Nitrogen quantification. These point samples were collected just hours before the timing of fertilizer applications which happened three times during the growing season: January 17, March 17, and April 6, 2011 (Sacaton), and January 26, March 17, and April 14, 2011 (Casa Blanca). In addition to soil-plant sampling, on those same dates we deployed optical sensors to measure canopy light reflectance of the crop. Figure 2 shows the timing of these measurements and Figure 3 shows an example of field deployment of optical sensors.

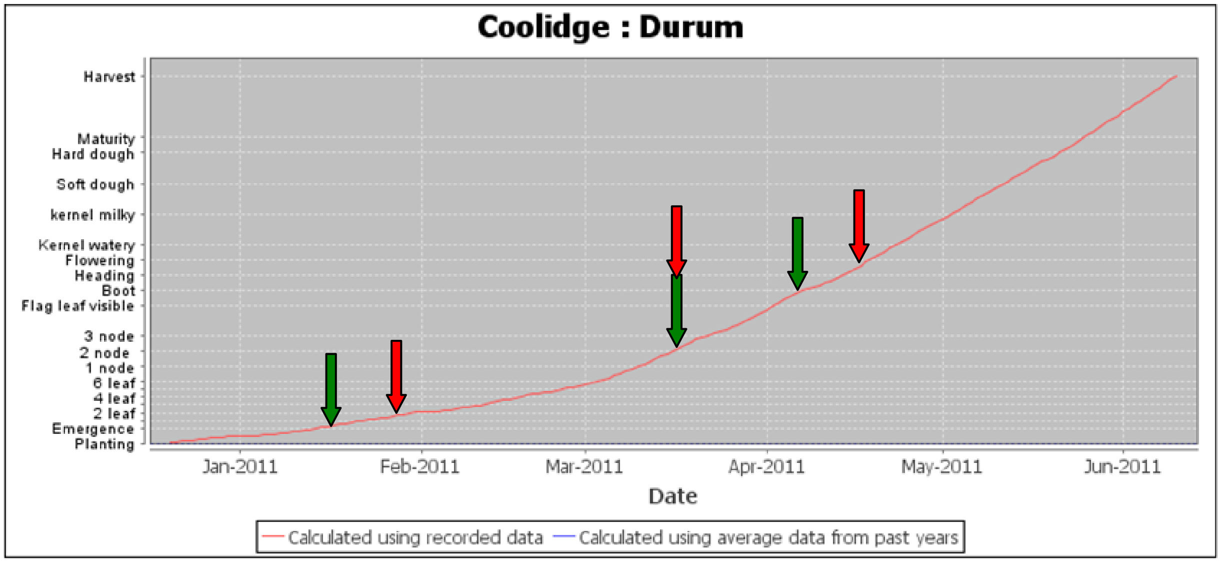

Figure 2. Timing of plant measurements of soil/tissue N and the crop spectral response. Green and red arrows correspond to Sacaton and Casa Blanca locations respectively.

Figure 3. Plant canopy reflectance measurements in Sacaton AZ on March 17, 2011.

Harvest of these two experimental sites was carried out in early June with a Case-IH combine instrumented with a yield monitor system sponsored by the AGRPC in 2010. At the time of harvesting, we collected 4 geo-referenced grain samples per acre for quality determination in the laboratory.

Results
The data collected throughout the growing season and at harvest were aggregated around the points in the field grid. Statistical analysis was based on computing the correlation values of the following variables: a) soil apparent electrical conductivity (mS/m); b) canopy reflectance in the form of normalized difference vegetation index (NDVI); c) canopy reflectance (%) in the form of three individual wavelengths (670, 720, and 820 nm); d) soil Nitrates (ppm); e) plant Nitrates (ppm); f) yield (ton/a); and g) grain protein (%). Soil apparent electrical conductivity was found to be associated to yield in a positive relationship and inversely related to protein content. This can be explained by the predominant response of the EC sensor to water holding capacity of the soil. Overall the results of these correlation analyses show moderate relationships between the yield components (quantity and quality) and the soil/plant variables measured throughout the season. The correlations matrices for these two fields are presented in the appendix of this report.

Visual inspection of the spatial distribution of plant/soil Nitrates and yield components lead to the observation that areas of the field with the highest protein levels followed a dynamic pattern characterized by a significantly large uptake of soil N early in the season and depletion of the resource by the end of the growing season. Therefore areas of high protein (around 14%) were associated with a more efficient utilization of soil Nitrates (top graph in Figure 4). In contrast, the areas of lower protein (bottom graph in Figure 4) with values in the low 13% showed that more soil N was left un-used and the levels of N in the plant were lower as compared to the case of higher protein.

The above relationships need to be validated with more research, which is being planned for the 2011-12 season. Plant height sensors will be deployed in an effort to capture information related to plant density.

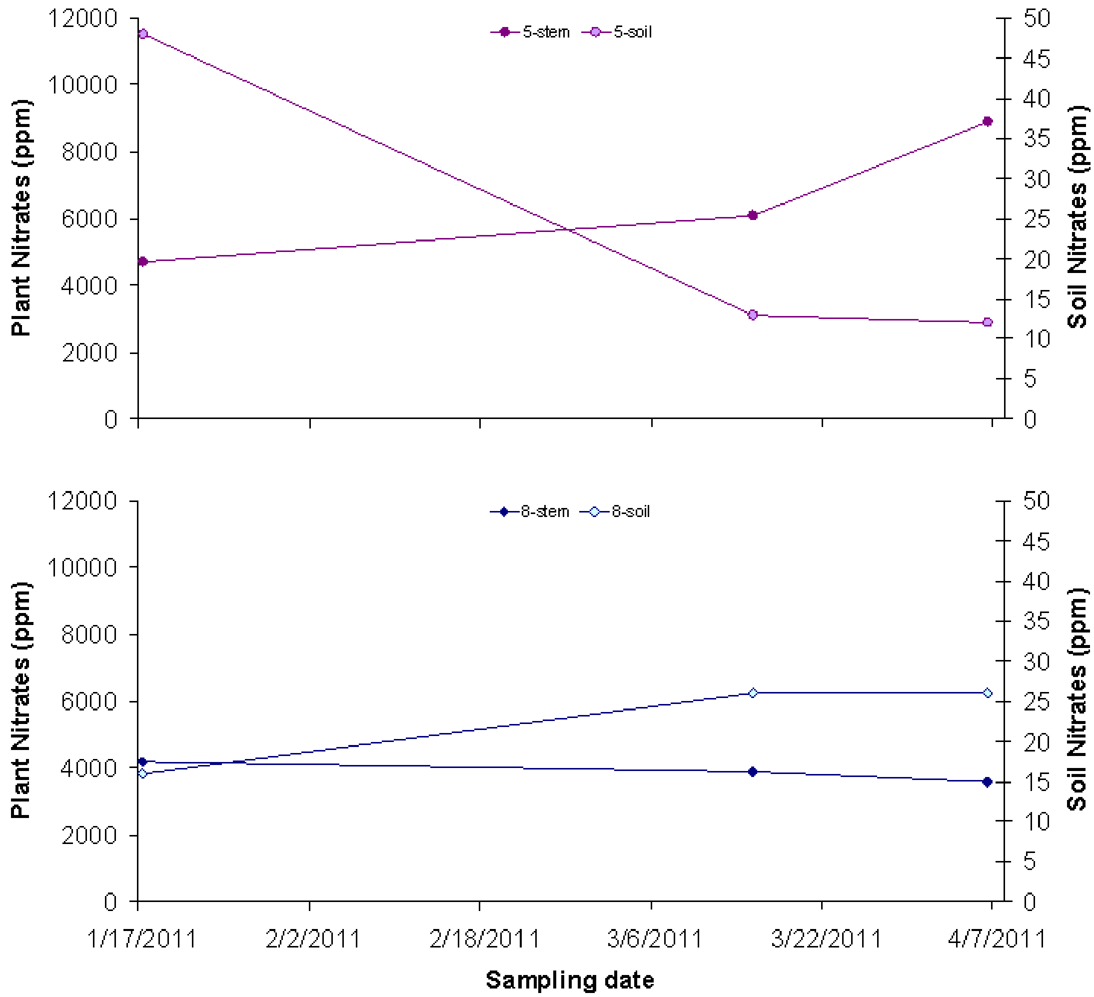

Figure 4. Dynamic behavior of soil and plant Nitrates during the growing season. Top and bottom graphs correspond to points of high and low protein content respectively. Data from the study site in Sacaton AZ.

Appendix 1. Correlation matrices of all variables under study in Sacaton (top chart) and Casa Blanca (bottom chart) sites.

	Sand (%)	Silt (%)	Clay (%)	shallow_1-	deep_1-1	plant_1-1	soil_1-17	DVI_1-17-1	LR_1-17-1	0nm_1-17-	0nm_1-17-	0nm_1-17-	plant_3-1	soil_3-15	DVI_3-15-1	LR_3-15-1	0nm_3-15-	0nm_3-15-	0nm_3-15-	plant_4-6	soil_4-6-	DVI_4-6-1	LR_4-6-1	70nm_4-6-1	20nm_4-6-1	20nm_4-6-1	Yield (lb/ac	Protein (%)
Sand (%)	1																											
Silt (%)	-0.53	1																										
Clay (%)	-0.56	-0.41	1																									
Eca_shallow_1-17	0.20	0.24	-0.45	1																								
Eca_deep_1-17	0.09	0.08	-0.18	0.76	1																							
NO3_plant_1-17	-0.37	0.37	0.04	-0.07	-0.36	1																						
NO3_soil_1-17	-0.32	0.52	-0.17	0.07	-0.30	0.79	1																					
NDVI_1-17	0.47	-0.61	0.08	0.26	0.58	-0.55	-0.69	1																				
CLR_1-17	0.49	-0.59	0.05	0.34	0.62	-0.54	-0.67	0.99	1																			
670nm_1-17	-0.27	0.57	-0.26	-0.35	-0.55	0.42	0.52	-0.88	-0.89	1																		
820nm_1-17	0.31	0.04	-0.37	-0.24	-0.01	-0.20	-0.27	0.10	0.05	0.39	1																	
720nm_1-17	-0.17	0.48	-0.29	-0.42	-0.51	0.31	0.39	-0.74	-0.77	0.97	0.59	1																
NO3_plant_3-15	-0.22	0.46	-0.21	0.06	-0.33	0.66	0.84	-0.66	-0.66	0.54	-0.17	0.44	1															
NO3_soil_3-15	-0.08	0.13	-0.04	0.29	0.16	0.39	0.16	-0.13	-0.12	0.24	0.22	0.25	0.44	1														
NDVI_3-15	0.11	-0.15	0.02	-0.28	-0.46	0.51	0.51	-0.27	-0.30	0.14	-0.25	0.10	0.56	0.04	1													
CLR_3-15	0.07	-0.10	0.02	-0.33	-0.49	0.47	0.52	-0.36	-0.40	0.25	-0.19	0.21	0.59	0.06	0.98	1												
670nm_3-15	-0.02	0.03	-0.01	0.21	0.50	-0.60	-0.66	0.48	0.49	-0.29	0.34	-0.20	-0.68	-0.09	-0.94	-0.95	1											
820nm_3-15	0.14	-0.29	0.14	-0.38	-0.37	0.35	0.25	-0.01	-0.07	-0.03	-0.10	0.00	0.32	0.01	0.92	0.90	-0.76	1										
720nm_3-15	0.21	-0.44	0.20	-0.20	0.15	-0.15	-0.46	0.71	0.65	-0.57	0.20	-0.43	-0.44	-0.12	0.12	0.02	0.19	0.46	1									
NO3_plant_4-6	-0.07	0.45	-0.36	0.19	-0.23	0.58	0.88	-0.50	-0.50	0.39	-0.16	0.31	0.77	0.10	0.52	0.55	-0.60	0.33	-0.31	1								
NO3_soil_4-6	0.04	-0.31	0.26	0.13	0.44	-0.30	-0.45	0.38	0.40	-0.39	-0.09	-0.38	-0.38	0.08	-0.42	-0.39	0.39	-0.34	-0.03	-0.55	1							
NDVI_4-6	0.29	-0.06	-0.25	-0.14	-0.62	0.35	0.33	-0.32	-0.32	0.21	-0.19	0.15	0.45	0.06	0.69	0.65	-0.64	0.56	-0.01	0.47	-0.56	1						
CLR_4-6	0.16	0.18	-0.35	-0.09	-0.58	0.52	0.59	-0.51	-0.51	0.43	-0.10	0.36	0.64	0.18	0.65	0.65	-0.67	0.48	-0.20	0.72	-0.56	0.90	1					
670nm_4-6	-0.14	-0.16	0.31	-0.15	0.15	0.00	0.09	0.18	0.14	-0.32	-0.30	-0.31	0.01	-0.26	0.43	0.37	-0.35	0.47	0.30	0.00	-0.11	-0.17	-0.21	1				
820nm_4-6	0.18	-0.14	-0.06	-0.23	-0.52	0.34	0.38	-0.23	-0.25	0.05	-0.35	-0.01	0.44	-0.09	0.88	0.82	-0.81	0.78	0.12	0.47	-0.59	0.85	0.75	0.37	1			
720nm_4-6	0.12	-0.38	0.24	-0.25	-0.23	0.00	-0.01	0.14	0.11	-0.33	-0.41	-0.36	0.04	-0.32	0.69	0.60	-0.56	0.70	0.38	-0.01	-0.35	0.41	0.16	0.74	0.77	1		
Yield (lb/ac)	-0.05	0.28	-0.22	-0.06	-0.27	-0.17	-0.12	-0.10	-0.10	0.24	0.32	0.28	-0.08	-0.09	-0.43	-0.44	0.45	-0.41	0.00	0.02	-0.46	0.18	0.14	-0.58	-0.14	-0.33	1	
Protein (%)	0.01	-0.33	0.31	-0.32	-0.37	0.33	0.21	-0.02	-0.08	-0.10	-0.23	-0.09	0.38	0.12	0.78	0.78	-0.71	0.83	0.30	0.31	-0.26	0.45	0.38	0.45	0.67	0.63	-0.36	1

	Sand	Silt	Clay	EC_shallow	EC_deep	plant_1-2	soil_1-26	DVI_1-26-1	LR_1-26-1	0nm_1-26-	0nm_1-26-	0nm_1-26-	plant_3-1	soil_3-15	DVI_3-15-1	LR_3-15-1	0nm_3-15-	0nm_3-15-	0nm_3-15-	plant_4-1	soil_4-15	DVI_4-15-1	LR_4-15-1	0nm_4-15-	0nm_4-15-	0nm_4-15-	Yield	Protein
Sand	1																											
Silt	-0.79	1																										
Clay	-0.42	-0.22	1																									
EC_shallow	-0.20	-0.07	0.43	1																								
EC_deep	-0.19	0.16	0.05	0.77	1																							
NO3_plant_1-26-	0.08	0.10	-0.28	0.02	0.06	1																						
NO3_soil_1-26-1	0.06	0.27	-0.49	0.01	0.07	0.81	1																					
NDVI_1-26-11	0.18	-0.43	0.35	0.04	-0.22	0.07	0.01	1																				
CLR_1-26-11	-0.07	-0.24	0.47	0.17	-0.06	0.11	0.01	0.92	1																			
670nm_1-26-11	0.16	0.19	-0.53	-0.75	-0.45	-0.15	-0.15	-0.56	-0.64	1																		
820nm_1-26-11	0.32	-0.08	-0.40	-0.87	-0.69	-0.14	-0.17	0.02	-0.14	0.82	1																	
720nm_1-26-11	0.30	0.03	-0.53	-0.82	-0.58	-0.17	-0.16	-0.35	-0.52	0.96	0.92	1																
NO3_plant_3-15-	-0.15	0.39	-0.34	0.27	0.33	0.57	0.76	-0.12	-0.11	-0.38	-0.54	-0.43	1															
NO3_soil_3-15-1	-0.22	0.39	-0.22	0.15	0.34	0.26	0.17	-0.32	-0.17	-0.14	-0.39	-0.28	0.57	1														
NDVI_3-15-11	-0.01	-0.02	0.03	0.39	0.49	0.51	0.53	0.13	0.29	-0.53	-0.55	-0.59	0.58	0.20	1													
CLR_3-15-11	0.06	0.00	-0.10	0.13	0.29	0.50	0.50	0.05	0.19	-0.29	-0.32	-0.36	0.55	0.27	0.94	1												
670nm_3-15-11	0.05	-0.07	0.03	-0.43	-0.58	-0.50	-0.50	0.03	-0.16	0.47	0.59	0.57	-0.61	-0.31	-0.98	-0.92	1											
820nm_3-15-11	0.13	-0.23	0.14	0.08	0.05	0.50	0.47	0.45	0.49	-0.44	-0.21	-0.38	0.39	0.01	0.79	0.81	-0.65	1										
720nm_3-15-11	0.01	-0.18	0.26	-0.20	-0.46	-0.28	-0.31	0.36	0.17	0.12	0.40	0.27	-0.52	-0.45	-0.76	-0.81	0.86	-0.32	1									
NO3_plant_4-15-	-0.26	0.54	-0.38	0.15	0.52	0.59	0.62	-0.19	0.01	-0.21	-0.38	-0.34	0.66	0.55	0.62	0.57	-0.69	0.28	-0.64	1								
NO3_soil_4-15-1	-0.25	0.38	-0.16	0.22	0.63	0.43	0.39	-0.10	-0.02	-0.21	-0.33	-0.28	0.55	0.32	0.56	0.50	-0.61	0.25	-0.53	0.70	1							
NDVI_4-15-11	-0.34	0.19	0.26	0.41	0.35	0.68	0.58	0.09	0.25	-0.56	-0.62	-0.64	0.58	0.20	0.70	0.59	-0.70	0.51	-0.44	0.61	0.58	1						
CLR_4-15-11	-0.30	0.27	0.09	0.25	0.32	0.74	0.63	-0.04	0.14	-0.41	-0.52	-0.51	0.65	0.29	0.79	0.73	-0.80	0.58	-0.60	0.72	0.63	0.94	1					
670nm_4-15-11	0.33	-0.36	0.01	-0.40	-0.66	-0.24	-0.21	0.33	0.19	0.19	0.45	0.32	-0.39	-0.30	-0.39	-0.33	0.51	0.04	0.54	-0.59	-0.80	-0.61	-0.55	1				
820nm_4-15-11	-0.20	0.00	0.31	0.20	-0.05	0.70	0.59	0.31	0.41	-0.54	-0.44	-0.55	0.49	0.07	0.62	0.54	-0.53	0.71	-0.19	0.35	0.18	0.82	0.81	-0.06	1			
720nm_4-15-11	0.01	-0.30	0.43	0.08	-0.42	0.33	0.28	0.59	0.55	-0.46	-0.15	-0.35	0.08	-0.24	0.14	0.06	0.02	0.51	0.39	-0.23	-0.40	0.31	0.22	0.52	0.75	1		
Yield	-0.52	0.40	0.24	0.64	0.60	0.35	0.35	0.18	0.40	-0.71	-0.73	-0.79	0.48	0.40	0.43	0.22	-0.45	0.19	-0.19	0.66	0.45	0.68	0.56	-0.52	0.45	0.14	1	
Protein	0.24	0.17	-0.64	-0.58	-0.13	0.33	0.27	-0.33	-0.42	0.45	0.31	0.44	0.39	0.47	0.12	0.33	-0.17	0.11	-0.41	0.37	0.39	-0.05	0.20	-0.09	-0.06	-0.37	-0.33	1