Precision Nitrogen Management Based on Nitrogen Removal in Rainfed Wheat

D. J. Bonfil[1], I. Mufradi[1], S. Asido[1] and D.S. Long[2]

1. *Field Crops and Natural Resources Department*
    Agricultural Research Organization
    Gilat Research Center, MP Negev 85280, Israel

2. *Columbia Plateau Conservation Research Center*
    USDA-Agricultural Research Service, PO Box 370
    Pendleton, OR 97810, USA

ABSTRACT

Growers of hard red spring wheat may capture price premiums for maximizing the protein concentration of their grain. Nitrogen (N) nutrition adequacy is crucial to achieving high grain protein concentration. The objective of this study was to determine the usefulness of N removal maps by comparing grain protein, yields, and dollar returns obtained from this precision N management approach with that from conventional uniform N management. Strip plot experiments were designed to compare spatially variable versus uniform N application in seven dryland fields in Israel. Spatially variable N management was based on continuously valued N removal maps derived from grain protein and yield monitor data: N removal = N removed in grain (N_{grain}) + N removed in straw (N_{straw}) where N_{grain} = previous season's grain yield (kg ha^{-1}) × grain protein (%) / 570, and N_{straw} = grain yield × 0.01. Uniform N management was based on soil tests and yield goals to establish the N recommendation for base application at planting. Spatially variable management increased grain yield from 128 to 665 kg ha^{-1} over that of uniform management in six of seven fields. Similarly, gross return from spatially variable placement increased from \$21 to \$135 ha^{-1} over that from uniform N management in these fields. Variable rate base N application appears to increase grain quality, grain yield, and profitability under semiarid conditions.

Keywords: Crop monitoring, On-the-go, Site specific management, Variable rate application, Wheat, Zeltex AccuHarvest.

INTRODUCTION

Hard wheat (*Triticum aestivum* L.), is an important dryland cereal crop in which it is important to maximize the protein concentration for milling and baking purposes. Mediterranean areas are well suited for production of high-quality hard wheat, but consistently achieving high wheat quality necessitates addressing the spatial variability of quality traits. In semiarid environments, many factors lead to within-field variation in wheat quality and include plant available water, nitrogen (N) supply, topography, and soil type (Long et al., 2000).

Historically, growers have relied upon the conventional practice of applying the fertilizer required for crop needs uniformly across the field. Natural and acquired variability in production capacity within a field will cause the applied N to be excessive in some parts of a field and inadequate in others (Larson and Robert, 1991). From an agronomic standpoint, over application of N may lead to excessively high grain protein levels whereas under application may lead to N deficiency resulting in reduced grain protein and grain yield.

Grain N removal maps derived from site-specific yield and protein measurements have been proposed for improving the uniformity of grain quality within farm fields (Long et al., 2000; Taylor et al., 2005). This method may ease the need for costly soil sample-based N recommendations. The underlying assumption is that plant status at harvest expresses an integrated response to the conditions that prevailed during the growing season, with soil moisture and N fertility being the most critical limiting resources to crop productivity (Engel et al., 1999). Use of grain protein content as a diagnostic tool for evaluating fertility status was first proposed by (Goos et al., 1982). Ability to apply this information across entire fields has become a reality with the advent of operational on-combine grain quality analyzers (Long and Rosenthal, 2005; Long et al., 2008).

The objective of this study was to determine the usefulness of N removal maps by comparing grain protein, yields, and dollar returns obtained from this precision N management approach with that from conventional uniform N management. We also propose how N removal maps may be combined with a Decision Support System to decide whether more N is needed in-season to ensure high grain quality.

MATERIALS AND METHODS

The precision N management strategy employed in the present study was based on the method first proposed by R. Engel, D. Long, G. Carlson, and C. Meier (1999) that uses previous season's information on site-specific grain yield and grain protein concentration. Grain yield and protein data were collected during harvest of seven commercial spring wheat fields in kibbutz Saad, Israel from the 2004 (Fields 35E and 37), 2005 (Field 44E), and 2006 (Fields 18E, 30S, 34S and 46E) growing seasons. These data were obtained with a JD 9660 combine harvester equipped with a GPS receiver, AgLeader YF3000 yield monitor, and Zeltex AccuHarvest Grain Quality Monitor. In 2004, prior to acquiring the Zeltex sensor, protein data were derived from laboratory near infrared analysis of 800-g grain samples that had been manually collected from the combine's grain bin filling auger.
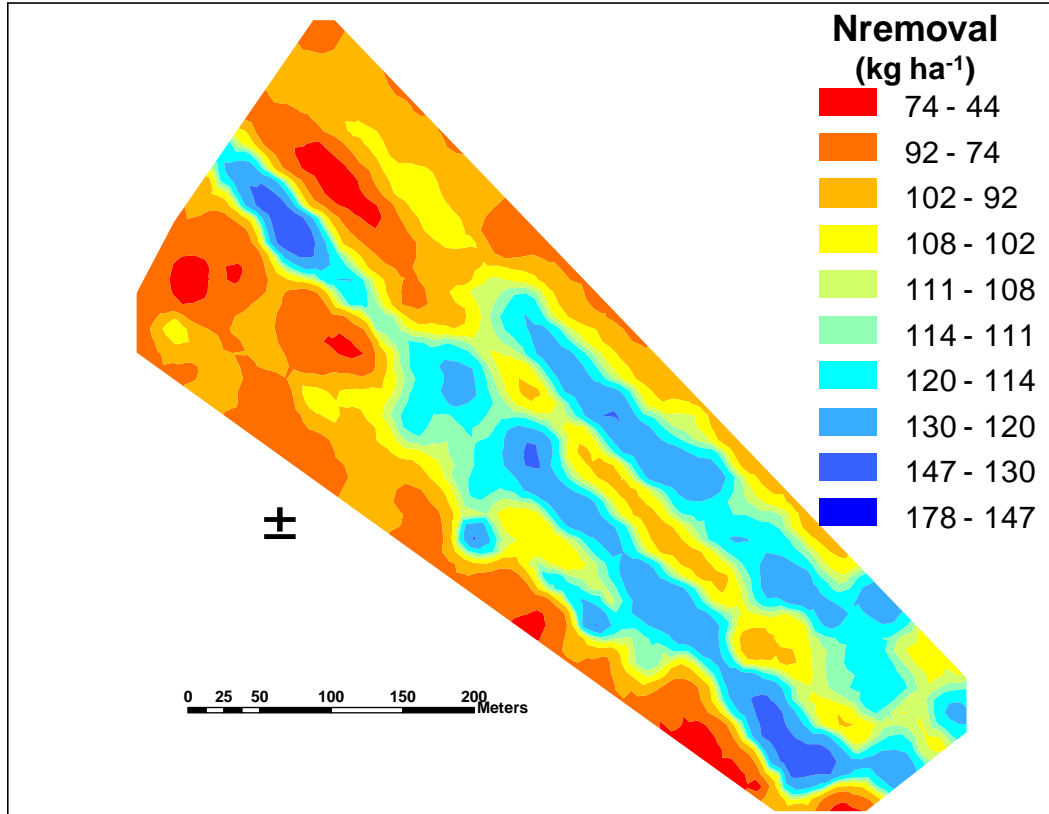
Figure 1. Map of N removal calculated from mapped values of grain yield and grain protein (Field 34S).

Computation of Nitrogen Removal

Yield and protein data were imported into the Geostatistical Analyst extension of the ArcGIS software, which provides for computation of variograms and interpolation by kriging. Best fitting spherical variograms were computed and used as a basis for ordinary kriging of the yield and protein data to a common 10-m estimation grid. Using ArcGIS, continuously valued N removal maps were then derived from the kriged values of grain protein and grain yield maps (Fig. 1).

Nitrogen removal ($N_{removal}$) of the previous season's crop is computed:

$$N_{removal} = N_{grain} + N_{straw} \qquad \text{Eq. 1}$$

as the sum of the N removed in grain (N_{grain}) and the N removed in straw (N_{straw}). The first step is computing the N removed in grain (N_{grain}) using the equation:

$$N_{grain} = \text{grain yield (kg ha}^{-1}) \times \text{grain protein (\%) / 570} \qquad \text{Eq. 2}$$

where the product of the mapped values of grain yield in kg ha^{-1} and grain protein in percent are divided by 570 (theoretical content of N in grain). In Israel, straw is often removed from the field and used as a feed for livestock. Therefore, the second step is computing N removed in straw (N_{straw}) by means of the equation:

$$N_{straw} = \text{grain yield (kg ha}^{-1}) \times 0.01 \qquad \text{Eq. 3}$$

where grain yield in kg ha^{-1} is multiplied by the N content of the straw. The N content of 1% for straw was based on extensive laboratory testing and is assumed to be a reasonable estimate. Furthermore, this value is based on a harvest index of 33% and post-harvest incorporation of 50% of the straw into the soil.

The resulting N removal maps were exported as text files, and imported into the Ag Leader SMS Advanced software for creation of a variable-rate task map. Variable rate N application was implemented by means of the Ag Leader Insight system with linkage to a Raven 570 flow rate controller. The steps in calculating N$_{removal}$ and developing a variable-rate prescription map for a following wheat crop are illustrated in Figure 2.
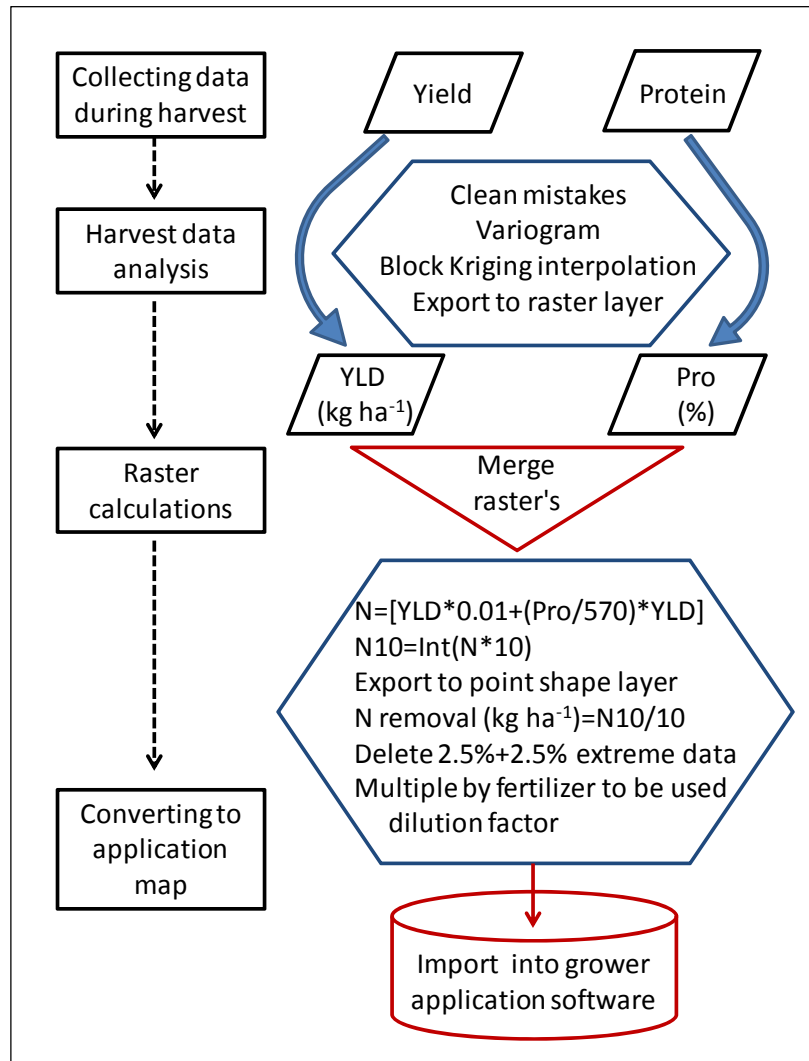

Figure 2. Flowchart of the steps involved in developing a fertilization map for variable-rate N application.

Field Experiments

Strip plot experiments were designed to compare spatially variable versus uniform N application in the same seven fields (35E and 37 in 2005; 44E in 2006; 18E, 30S, 34S and 46E in 2007). Spatially variable N management was based on continuously valued N removal maps. Conventional uniform N management was based on soil tests and yield goals to establish the N recommendation for base application at planting. Nitrogen in each treatment was applied as liquid fertilizer (urea + ammonium nitrate solution, 32% N). Each variable-rate and uniform treatment strip pair was 12-m wide and extended the length of an entire field (700 to 800-m). Treatment pairs were randomly placed and replicated four to six times.

Each treatment strip was harvested using the same combine and sensors. In addition, up to 90 grain samples (800-g) were hand sampled from the combine's grain bin filling auger during harvest for laboratory determination of test weight. Spatially patterns of yield and yield quality data were tested and determined with the spatial analyst (ArcView). The calculated variogram coefficients (type, partial sill, range and nugget) were used in the SAS code. Spatially variable and uniform treatments were analyzed for significant differences in grain protein, yield, and test weight using Proc Mixed of SAS (SAS Inst., Cary, NC) (Schabenberger and Pierce, 2002).

RESULTS AND DISCUSSION

Validation experiments

Rainfall plus supplemental irrigation (applied after sowing) exceeded the long-term average (390 mm) in each site-year (Table 1). Thus, average grain yields equaled, or exceeded, a yield goal of 450 kg ha^{-1} in all fields. The exception was Field 44E where cereal cyst nematode caused severe damage and reduced yields, and has been a recurring problem from year to year (Bonfil et al. 2004a).

Grain yield from spatially variable N placement was significantly greater (≤665 kg ha^{-1}) than that from uniform N placement in six of the seven fields (Table 1). Test weight was not influenced by N treatment. Grain protein concentration significantly increased by as much as 0.8% in four of seven fields resulting from spatially variable N management.

More N was applied in the spatially variable treatment versus the conventional uniform treatment (Table 2). For instance, in Field 30S, spatially variable placement provided 127 kg more N ha^{-1} than the uniform treatment. Therefore, the increase in grain yield and protein content favoring spatially variable placement is likely attributable to the greater amount of N applied. However, gross return from spatially variable was large enough to more than offset the greater N costs in most fields. That spatially variable management increased both grain yield and protein content suggests that the N recommendation from uniform management was inadequate for yield. It is possible that under-fertilization from uniform management was the result of smaller areas with large soil N test values, which biased the average value for the field upwards. We have observed over-fertilization from uniform N management to promote excessive vegetative growth and reduced grain yields. Consequently, growers are discouraged from applying excess N. Spatially variable management allows above average N rates in field portions where more fertilizer is needed to meet a greater yield potential.
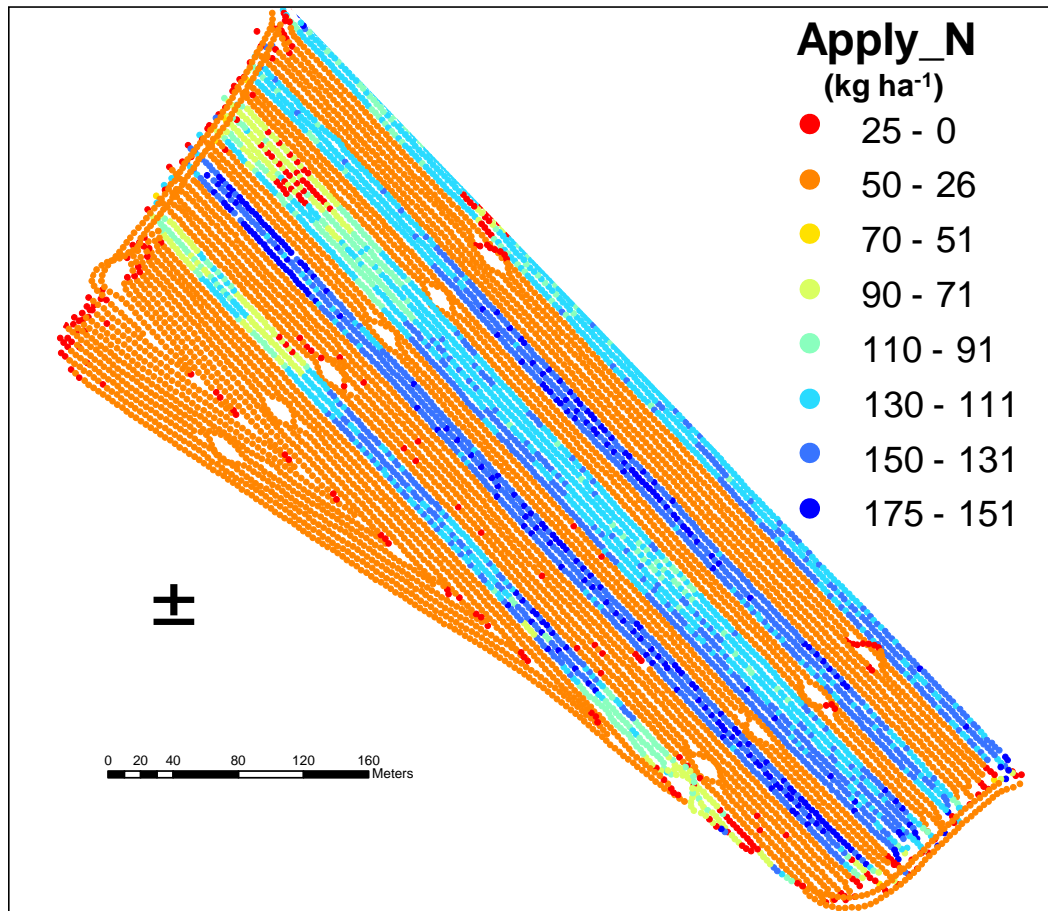
Figure 3. N application (kg ha^{-1}) calculated from the N$_{removal}$ map (field 34S) for strip plot experiment, two treatments 12 m wide and 6 replications.

Table 1. Grain yield, test weight, and grain protein concentration from uniform N placement (A) versus spatially variable placement (B) by field.

Field	Rain + irrigation	Yield		Test weight		Protein	
	mm	(kg ha^{-1})		(kg 100l^{-1})		(%)	
		A†	B	A	B	A	B
35E	410	4500c	5170a	82.4a	82.1a	9.9c	10.3b
37	410	4830b	5220a	82.9a	82.8a	11.4a	11.5a
44E	325	3530a	3530a	78.3a	76.1a	13.6a	14.0a
18E	500	5830c	6360a	82.1a	81.8a	11.1a	11.5a
30S	500	6110b	6640a	81.5a	81.7a	11.9b	12.2a
34S	440	5010b	5560a	81.7a	79.8b	12.3b	13.1a
46E	440	5400b	5530a	81.7a	80.8c	11.4c	11.7a

† Within a row, means followed by the same letter are not significantly different at the 5% probability level.
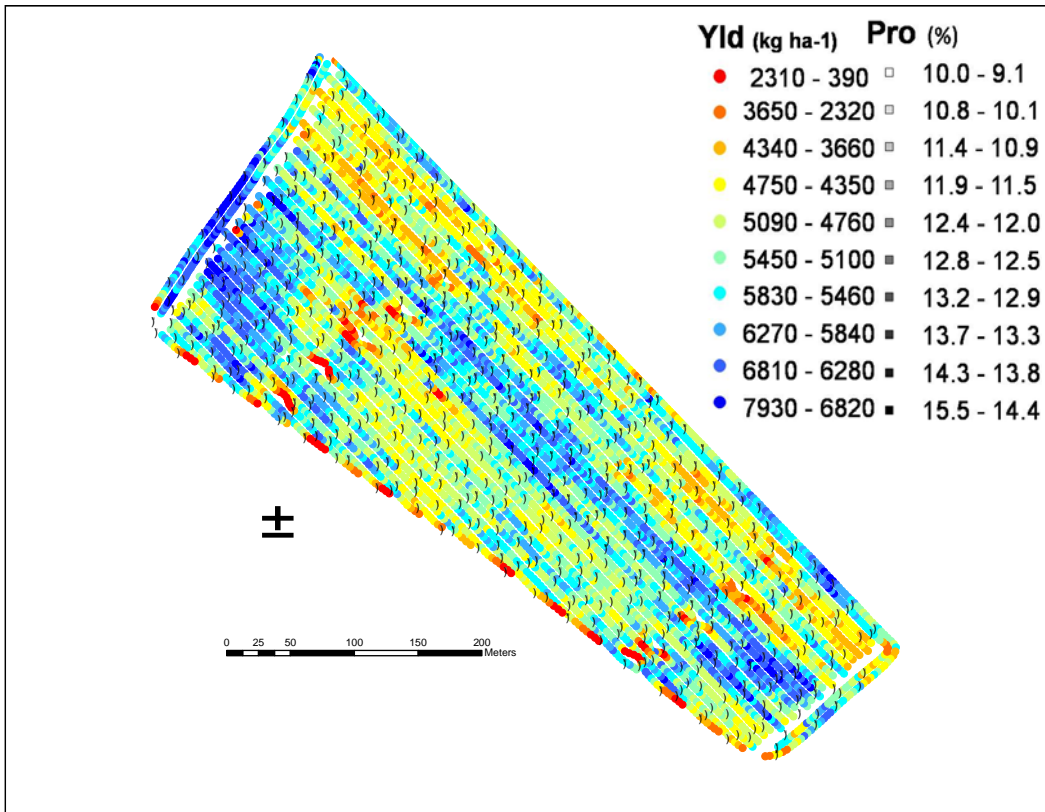
Figure 4. Grain yield (Yld: kg ha^{-1}) and grain protein content (Pro: %) in a strip plot experiment, two treatments 12 m wide and 6 replications (field 34S).

Gross returns from spatially variable placement were up to $135 ha^{-1} over that from uniform N placement in these fields (Table 2), except for 44E that was infested with cereal cyst nematode. The N removal procedure led to greater fertilizer N input costs that were as much as $102 ha^{-1} more than those associated with the uniform procedure. Nevertheless, net returns from spatially variable placement varied from a loss $92 to a gain of $75 ha^{-1} over that from uniform N management. Ignoring Field 44E, where yields were negatively impacted by nematode damage, the fertilizer management based on N removal did lead to a profit loss only in Field 46E. Prices for soil sampling/testing vary between regions and growers may already own variable-rate application equipment (i.e. yield monitor, GPS receiver, and flow rate controller). Consequently, our findings do not consider these costs.

Table 2. Gross return from uniform and variable rate management; difference in gross return, N applied, and N cost; and difference in net return by adopting $N_{removal}$ (B) vs. uniform conventional (A) base N application management in Saad's fields.

Field	Gross return			N applied	N cost[†]	Net return
	Uniform	Variable	Difference (Variable-Uniform)			
	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	kg ha^{-1}	$ ha^{-1}	$ ha^{-1}
35E	764	899	135	78	74	62
37	882	954	72	51	49	23
44E	824	803	-21	75	72	-92
18E	1367	1488	121	108	102	19
30S	1427	1554	127	54	52	75
34S	1173	1287	114	92	88	26
46E	1262	1283	21	58	55	-34

[†]N cost based on $0.95 kg^{-1}. Equipment and soil sampling costs were not considered.

The N removal method relies upon previous season's yield variability. As crop variation can differ between successive seasons, the method could be augmented with in-season N applications that allow growers to react to rainfall events and apply N at appropriate times for plant uptake. Late season applications of a small amount of foliar N may be effective in increasing both N use efficiency and grain quality of an entire field (Bonfil et al., 2004c). Application can be done in real-time by means of optical sensors that measure crop N status from canopy reflectance measurements. Examples of device for N topdressing application include the Hydro-N-Sensor system (http://www.hydro.com) and the Green-Seeker (http://www.greenseeker.com).

Recently, a Decision Support System (DSS) for local Israeli conditions (Heading-DSS) was developed for fertilization and agronomic management of wheat grown under semi-arid conditions (Bonfil et al., 2004b; Bonfil et al., 2004c). Heading-DSS uses measurements of crop water and N status to identify dryland fields that are in need of late-season N topdressing to improve grain protein concentration. Decisions to apply topdressing of 25 kg of N ha^{-1} have increased grain value by as much as $100 ha^{-1} in some instances. The next step is to determine whether remotely sensed estimates of crop canopy water (Eitel et al., 2006; Pimstein et al., 2007) and N status (Eitel et al., 2007; Flowers et al., 2001) could be used to provide spatially distributed inputs for the Heading-DSS. We envision that a combination of N removal maps at planting and in-season Heading-DSS recommendations would improve N use efficiency, grain quality, and economic returns.

CONCLUSIONS

The results of the present study are sufficiently promising to suggest that precision N management based on N removal can potentially improve agronomic and economic returns from dryland wheat production systems. Grain yield monitors and grain quality sensors are commercially available for its implementation. However, the results are relevant to dryland wheat regions receiving <450 mm of growing season precipitation and growers who already own variable-rate equipment.

REFERENCES

Bonfil D.J., B. Doldgin, I. Mufradi, and S. Asido. 2004a. Bioassay to forecast cereal cyst nematode damage to wheat in fields. Precis. Agric. 5:329-344.

Bonfil, D.J., A. Karnieli, M. Raz, I. Mufradi, S. Asido, H. Egozi, A. Hoffman, and Z. Schmilovitch. 2004b. Decision support system for improving wheat grain quality in the Mediterranean area of Israel. Field Crop. Res. 89:153-163.

Bonfil, D.J., I. Mufradi, and S. Asido. 2004c. Decision support system for improving wheat quality in semi-arid regions, pp. CD-ROM 7th International Conference on Precision Agriculture and Other Precision Resources Management. ASA-CSSA-SSSA, Madison, WI.

Eitel, J.U.H., P.E. Gessler, A.M.S. Smith, and R. Robberecht. 2006. Suitability of existing and novel spectral indices to remotely detect water stress in Populus spp. Forest Ecol. Manag. 229:170-182.

Eitel, J.U.H., D.S. Long, P.E. Gessler, and A.M.S. Smith. 2007. Using in-situ measurements to evaluate the new RapidEye satellite series for prediction of wheat nitrogen status. Int. J. Remote Sens. 28:4183-4190.

Engel, R.E., D.S. Long, G.R. Carlson, and C. Meier. 1999. Method for precision nitrogen management in spring wheat: I. Fundamental relationships. Precis. Agric. 1 :327–338.

Flowers, M., R. Weisz, and R. Heiniger. 2001. Remote sensing of winter wheat tiller density for early nitrogen application decisions. Agron. J. 93:783-789.

Goos, R.J., D.G. Westfall, A.E. Ludwick, and J.E. Goris. 1982. Grain Protein Content as an Indicator of N Sufficiency for Winter Wheat. Agron. J. 74:130-133.

Larson, W.E., and P.C. Robert. 1991. Farming by soil. pp. 103-112. In R. Lal and F.J. Pierce (ed.) Soil Management for Sustainability. Soil and Water Conservation Society of America, Ankeny, IA.

Long, D.S., R.E. Engel, and G.R. Carlson. 2000. Method for Precision Nitrogen Management in Spring Wheat: II. Implementation. Precis. Agric. 2:25-38.

Long, D.S., and T. Rosenthal. 2005. Evaluation of an on-combine wheat protein analyzer on Montana hard red spring wheat. p. 385–392. In J. Stafford et al (ed.) Proc. 5th European Conf. Prec. Agric., Uppsala, Sweden. 9–12 June. Wageningen Academic Publ., Wageningen.

Long, D.S., R.E. Engel, and M.C. Siemens. 2008. Measuring grain protein concentration with in-line near infrared spectroscopy. Agron. J. 100:247-252.

Pimstein, A., A. Karnieli, and D.J. Bonfil. 2007. Monitoring of wheat and maize crops based on ground spectral measurements and multivariate data analysis. J. Appl. Remote Sens. 1:013530 (16 pages).

Schabenberger, O., and F.J. Pierce. 2002. Statistical Models for Spatial Data, p. 561-701 Contemporary Statistical Models for Plant and Soil Sciences. CRC PRESS

Taylor, J., B. Whelan, and L. Thylén, M. Gilbertsson, and J. Hassall. 2005. Monitoring wheat protein content on-harvester-Australian experiences. p. 369–376. In J. Stafford et al (ed.) Proc. 5th European Conf. Prec. Agric., 9–12 June. Uppsala, Sweden. Wageningen Academic Publ., Wageningen.