VARIABLE SOURCE N FERTILIZER APPLICATIONS TO OPTIMIZE CROP N USE EFFICIENCY

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Summary:
Research was conducted in 2005 and 2006 to determine methods to delineate and map areas in fields which are more vulnerable to N loss due to wet conditions, to examine the use of a *variable-source* strategy to optimize crop N fertilizer use efficiency and, to calculate the cost-effectiveness of using this *variable-source* strategy compared to uniform applications of conventional or other N fertilizer sources.

Among the findings of this study were:

- The 2005 cropping year had relatively lower rainfall than observed in 2006 and was characterized by a long period of drought after the middle of June. This lack of rainfall may have reduced possible crop N response in 2005 and accounted for the generally lower yields observed in 2005.

- Evaluation of the distribution of surface soil water content prior to planting in 2005 at the Greenley site in Northeast Missouri suggests that elevation alone may be a good predictor of spatial patterns of surface soil water content at this site.

- Visual symptoms of plant N deficiency were observed both in control plots and in low-lying areas, possibly due to water collecting in those areas from spring and early summer rainfall during both the 2005 and 2006 seasons.

- Significantly higher yields due to addition of N fertilizer were observed at the summit and low-lying landscape positions in Greenley in 2005 and at all landscape positions in 2006. The greater yield response to application of N in 2006 was probably due to higher rainfall during that year.

- Application of anhydrous ammonia or polymer-coated urea (PCU) resulted in significantly higher yields than application of urea at the low-lying landscape position in both 2005 and 2006 at the Greenley site. The PCU application had a consistent 24 to 29 bu/acre increase in corn yields in 2005 and 2006, respectively, compared to conventional urea applications in low-lying areas of the field. Similarly, anhydrous ammonia application resulted in a 24 and 26 bu/acre increase in yields in 2005 and 2006, respectively, compared to urea in the low-lying area. These differences in performance

of the N fertilizer sources at different landscape positions was possibly due to the relatively wetter conditions in the low-lying area affecting the fate of the applied N. At the Centralia site in 2006, the PCU application had a 19 bu/acre increase over the urea application only in the footslope landscape position in a no-till cropping system with a corn-soybean-wheat rotation.

- Measurements of surface nitrous oxide (N_2O) flux at the Greenley site in 2005 did not show consistent differences in N_2O gas losses between urea and PCU fertilizer applications, although the N_2O flux in the control treatment was generally higher in the low-lying area compared to the summit and sideslope landscape positions in the field.

- Based on calculations assuming a corn price of \$3/acre, a urea price of \$0.40/lb N, a PCU price of \$0.50/lb N, an average increase of 26.5 bu/acre with use of PCU over urea, and an application cost of \$5/acre for both urea and PCU, the extra profit obtained with applying PCU instead of urea in the low-lying areas of the experimental site in Northeast Missouri was approximately \$64/acre. In addition, assuming an anhydrous price of \$0.31/lb N and the same application cost as the other N sources and an average increase of 25 bu/acre with application of anhydrous compared to urea, the extra profit with applying anhydrous ammonia instead of urea in the low-lying areas was \$88/acre.

Methods:
Two field trials were initiated in 2005 at the MU Greenley Experiment Station (Fig. 1) and in a farmer's field in Centralia. In 2006, the Centralia site was switched from the farmer's field to a long-term experimental site (i.e. Agricultural Systems for Environmental Quality or ASEQ) in Centralia supervised by the U.S. Agricultural Research Service. This site was considered preferable because it contained plots which contained different landscape positions which were similar to the Greenley site in addition to allowing for a comparison of different cropping and tillage systems. All of the sites were mapped for elevation and apparent electrical conductivity (EC_a) using a EM-38 sensor (Fig. 1). Measurement of soil EC_a gives an indication of relative depth to the claypan subsoil layer (Kitchen et al., 1999). Soil gravimetric water content was determined on 6 in depth soil samples collected in a 10 by 25 ft grid over the Greenley site on March 31st in order to compare the effects of spatial distribution of elevation and EC_a on the distribution of soil water content.

At the Greenley site, N fertilizer treatments included a control and 150 lb N/acre of either urea, polymer-coated urea (PCU; ESN, Agrium, Inc.), a 50% urea/50% polymer-coated urea mixture, or anhydrous ammonia were injected or broadcast-applied and incorporated in 10 m by 1500 ft strips across three landscape positions representing shallow, deep and low-lying areas (Fig. 1A). At the Centralia ASEQ site, N fertilizer treatments of 150 lb N/acre of either urea or PCU were broadcast surface-applied in 10 by 25 ft strips within cropping/tillage systems (i.e., minimum tillage with a corn-soybean rotation, no-till with a corn-soybean rotation and no-till with a corn-soybean-wheat (legume) rotation and at different landscape positions representing the summit, sideslope and footslope positions in the field.

Corn (*Zea mays.* L.) silage and grain yields were determined at each site. Site harvest locations for the Greenley site are shown in Fig. 1. Total aboveground biomass tissue samples at harvest and periodically during the growing season were taken and are currently being analyzed for total N content in order to determine fertilizer N use efficiency. The rate of soil N_2O gas loss or efflux was also measured periodically over the 2005 and 2006 growing season at the Greenley site for each N fertilizer treatment and landscape position. Soil N_2O gas was collected using small sealed chambers fitted with rubber septa inserted into PVC collars in the soil. The head space gas was collected from the chambers in the different treatments and analyzed by gas chromatography (GC).

Results:
Rainfall at the Greenley site during the 2005 cropping year was relatively low compared to the 2006 season (Fig. 2 A&B). However, early season rains shortly after application of N fertilizer and planting which caused temporary saturation of the low-lying area were observed in both years.

Measurement of the spatial distribution of soil water content in the top 6 in depth at the Greenley site was undertaken prior to planting in 2005 to evaluate whether measurements of elevation and EC_a would assist in predicting spatial differences in soil water content that might affect the fate of applied N fertilizer. Initial evaluation of the distribution of surface soil water content (Fig. 3), suggests that elevation may be a better predictor of spatial patterns of surface soil water content. However, this analysis did not take into account the possible effect of differences in soil water availability deeper in the soil profile on the fate of applied N fertilizer. In claypan soils, the amount of available water in the soil profile is probably affected by the depth to the claypan layer which is a property related to soil EC_a.

At the Greenley site, visual symptoms of plant N deficiency were observed both in control plots and in low-lying areas in 2005 and 2006, possibly due to water collecting in those areas from spring and early summer rainfall. However, lack of sufficient water for crop growth after the middle of June in 2005 also affected corn growth response to added N fertilizer in 2005. Grain yields at Greenley increased 20 to 46 bu/acre with added N fertilizer at the summit (shallow) and low-lying landscape positions (Table 1). In 2006, grain yield response to added N fertilizer was observed at all landscape positions and ranged from 47 to 105 bu/acre (Table 1). Application of anhydrous ammonia or polymer-coated urea (PCU) resulted in significantly higher yields than application of urea at the low-lying landscape position in both 2005 and 2006 at the Greenley site. The PCU application had a consistent 24 to 29 bu/acre increase in corn yields in 2005 and 2006, respectively, compared to conventional urea applications in low-lying areas of the field. Similarly, anhydrous ammonia application resulted in a 24 and 26 bu/acre increase in yields in 2005 and 2006, respectively, compared to urea in the low-lying area (Table 1).

At the ASEQ site in Centralia in 2006, poor corn stand establishment in the cropping system with minimum tillage resulted in no significant grain yield differences among the N fertilizer treatments at the different landscape positions (Table 2). The greatest grain yield response to N fertilizer application was observed at the footslope position of the no-till cropping system and at all landscape positions with the no-till cropping system with wheat in the rotation (Table 2). The PCU application had a 19 bu/acre grain yield increase over the urea application only at the footslope landscape position in the no-till cropping system with a corn-soybean-wheat rotation.

Measurements of surface nitrous oxide (N_2O) flux at the Greenley site in 2005 are shown in Table 3 for the early part of the growing season since the highest losses of N_2O gas are generally observed shortly after N fertilizer application. A total of 10 sampling times for N_2O flux was taken over the 2005 growing season and a total of 9 sampling times was taken in 2006. Emissions of this greenhouse and ozone-depleting gas were measured to determine the relative magnitude of this N loss under the soil and climatic conditions experienced in Missouri and to assess possible environmental benefits of the different N fertilizer sources evaluated in this study. In general, the 2005 results do not show consistent differences in N_2O gas losses between urea, anhydrous ammonia and PCU fertilizer applications, although the N_2O flux in the control treatment is generally higher in the low-lying area compared to the summit and sideslope landscape positions in the field (Table 3). Data for the 2006 surface N_2O flux measurements are still being processed. Further information will also be available from this study on the relative N fertilizer efficiency of the different N fertilizer sources at different landscape positions, but the N analysis of the harvested silage tissue has still not been completed.

Assessment of the economic costs and benefits of using the different N fertilizer sources suggests an economic advantage of using anhydrous ammonia and PCU over urea in low-lying areas of the field. Based on calculations assuming a corn price of $3/acre, a urea price of $0.40/lb N, a PCU price of $0.50/lb N, an average increase of 26.5 bu/acre with use of PCU over urea, and an application cost of $5/acre for both urea and PCU, the extra profit obtained with applying PCU instead of urea in the low-lying areas of the experimental site in Northeast Missouri was approximately $64/acre. In addition, assuming an anhydrous price of $0.31/lb N and the same application cost as the other N sources and an average increase of 25 bu/acre with application of anhydrous ammonia compared to urea, the extra profit with applying anhydrous ammonia instead of urea in the low-lying areas was $88/acre.

The results of this study suggest that a variable source approach to applying N fertilizer sources based on identifying areas in a field which are periodically wet due to their lower landscape position, may improve crop production and increase economic returns. However, further research is required under different soil types and climatic conditions at a farm scale to determine if this approach has a wider application. Our current research is identifying procedures which would allow for delineation and mapping of areas of higher risk for N loss in a field and for export of that information to a fertilizer spreader that has a capacity to selectively spread different N fertilizer sources based on the mapped information.

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Table 1. Effects of N fertilizer source and landscape position on corn grain yields at the Greenley site in 2005 and 2006.

N fertilizer treatment	Landscape Position: Summit	Sideslope	Low-lying	$LSD_{(0.05)}$ *
		2005		
	---------- bu/acre ----------			
Control	73.6	72.3	71.0	NS**
Urea	93.5	79.1	92.8	NS
PCU	94.0	73.9	117.2	29.5
PCU/Urea	95.1	77.2	104.2	NS
Anhydrous	100.6	88.7	116.3	24.1
$LSD_{(0.05)}$	8.7	NS	19.6	
		2006		
Control	97.1	92.1	129.4	30.9
Urea	190.6	176.2	176.0	NS
PCU	199.4	187.3	204.9	NS
PCU/Urea	201.3	190.4	189.1	NS
Anhydrous	201.9	186.2	202.5	NS
$LSD_{(0.05)}$	15.8	12.7	16.8	

* Fisher's (protected) least significant difference at $p < 0.05$
** NS = not significant

Table 2. Effects of cropping system, N fertilizer source and landscape position on corn grain yields at the ASEQ site at Centralia in 2006.

N fertilizer treatment	Minimum tillage*				No-till**				No-till with rotation***			
	Summit	Sideslope	Footslope	$LSD_{(0.05)}$ [†]	Summit	Sideslope	Footslope	$LSD_{(0.05)}$	Summit	Sideslope	Footslope	$LSD_{(0.05)}$
	bu/acre											
Control	65.1	46.0	65.0	NS	45.2	30.1	61.7	30.4	72.1	75.7	103.4	NS
Urea	69.4	49.1	95.8	NS	104.3	66.8	142.4	59.4	110.7	109.9	113.1	NS
PCU	78.4	63.4	96.2	NS	89.0	67.9	141.3	25.2	107.7	102.3	132.1	17.9
$LSD_{(0.05)}$	NS[††]	NS	NS		37.2	NS	51.8		33.5	23.4	15.0	

*Minimum tillage with a corn-soybean rotation

**No-till with a corn-soybean rotation

***No-till with a corn-soybean-wheat (legume) rotation.

[†] Fisher's (protected) least significant difference at $p < 0.05$.

[††] NS = not significant

Table 3. Effects of N fertilizer source and landscape position on nitrous oxide flux on four selected dates after application of N fertilizer treatments at the Greenley site in 2005.

N fertilizer treatment	Landscape Position			$LSD_{(0.05)}$*
	Summit	Sideslope	Low-lying	
		8 DAA		
		mg N_2O-N/m^2/day		
Control	0.506	0.271	1.363	0.423
Urea	1.284	0.599	2.500	NS
PCU	0.312	1.203	0.683	NS
PCU/Urea	1.199	1.148	0.517	NS
Anhydrous	1.211	0.542	1.442	NS
$LSD_{(0.05)}$	0.880	0.923	1.848	
		22 DAA		
Control	0.413	0.935	1.622	0.911
Urea	2.285	0.805	3.263	NS
PCU	2.251	4.067	2.244	NS
PCU/Urea	2.005	2.232	2.027	NS
Anhydrous	1.624	1.190	0.700	NS
$LSD_{(0.05)}$	NS	2.452	2.016	
		30 DAA		
Control	1.423	0.823	5.946	NS
Urea	1.562	1.229	1.345	NS
PCU	2.665	2.389	5.316	NS
PCU/Urea	1.196	6.706	1.578	NS
Anhydrous	7.640	2.660	0.929	NS
$LSD_{(0.05)}$	5.247	NS	NS	
		35 DAA		
Control	0.513	1.941	2.177	NS
Urea	0.758	1.324	1.458	NS
PCU	0.719	5.471	1.371	NS
PCU/Urea	0.350	0.777	1.703	NS
Anhydrous	1.333	0.928	2.494	NS
$LSD_{(0.05)}$	NS	NS	NS	

* Fisher's (protected) least significant difference at $p < 0.05$

** NS = not significant

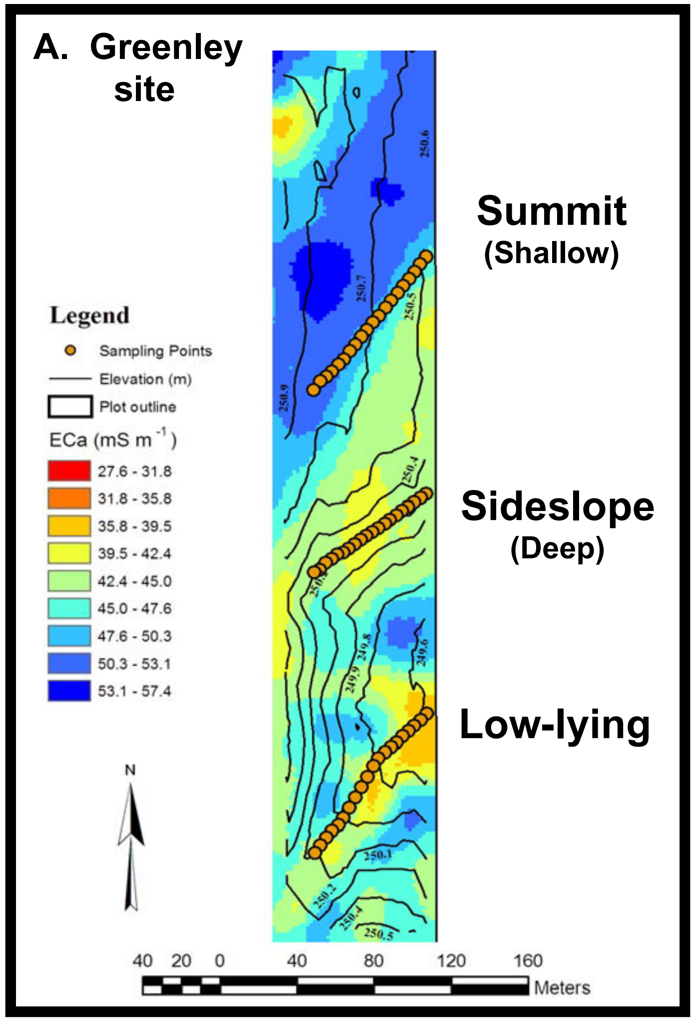

Fig. 1 . Map showing the spatial distribution of elevation and EC_a at the Greenley site. Circles in the Greenley site map show the location of the sampling collars for soil N_2O gas loss and the approximate location for the grain and silage harvests.

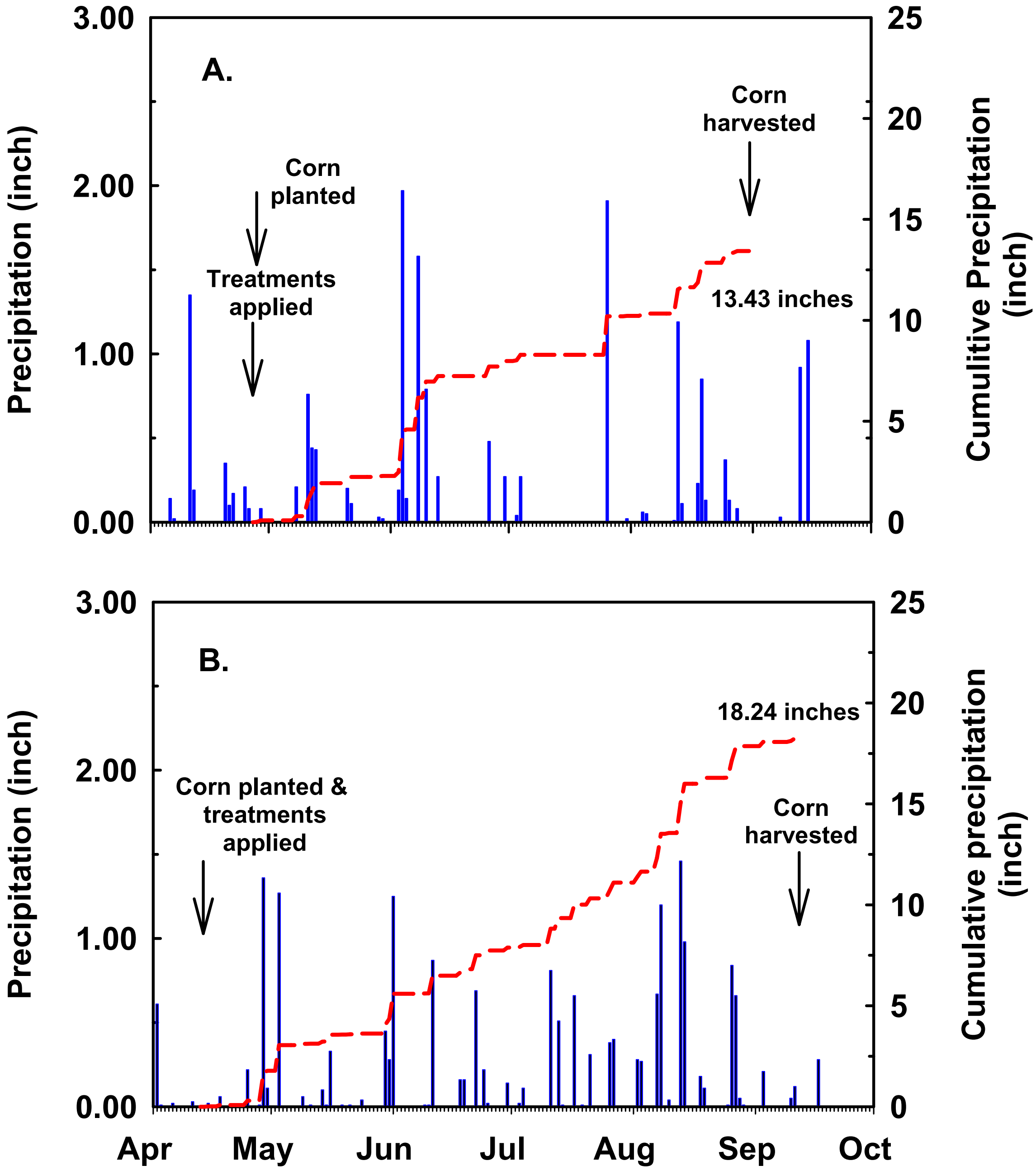

Fig. 2 A & B. Daily and cumulative precipitation at the Greenley site in A) 2005 and B) 2006. Figures also show the times of important cropping events in relation to rainfall.

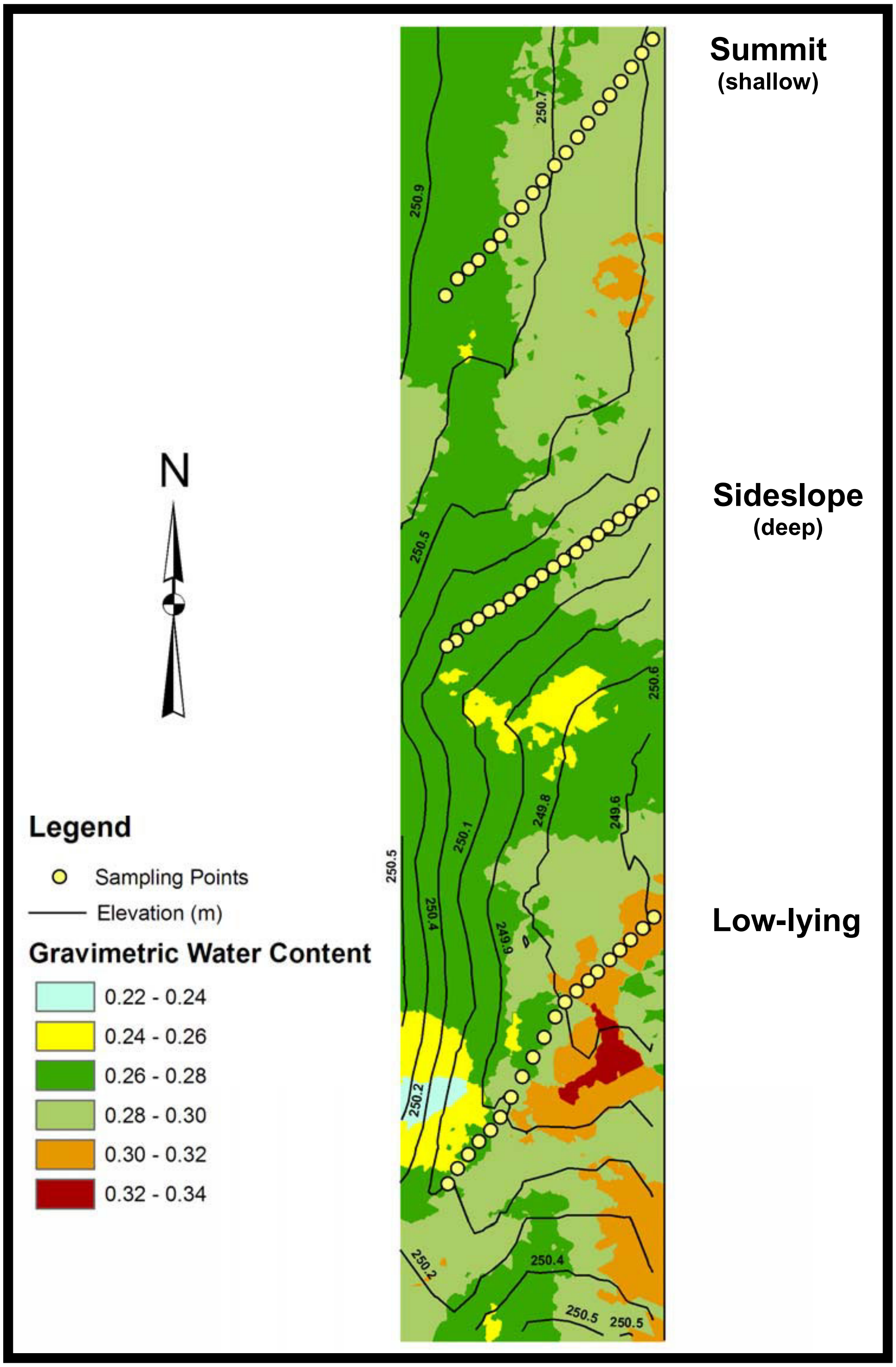

Fig. 3. Spatial distribution of soil gravimetric water content at the Greenley site on April 1st, 2005.