Sulfur deficiency detection and yield prediction using optical sensors

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- Ammonium sulfate accounts for 60–70% fertilizer in Maine's acidic soils.
- The yield of the crop is protein-dependent output because protein makes up the plant enzymes, DNA, RNA, and most important chlorophyll, which directly related to the photosynthesis.
- The S have strong interaction with Nitrogen. N and share common amino acids cysteine, cystine, and methionine.
- when N is deficient, it moves from lower to higher leaves and carries S with it, thus showing less or no S deficiency symptoms because S is immobile in plants. In contrast, when N is sufficient, no movement of N to the upper, young leaves results in more S deficiency.
- This results in unique interaction, where S deficiency becomes more severe with high N rates (Franzen et al., 2016).
- Plants with deficiency of N, P, K, S, and Mg absorb less light and reflect more light in the visible spectrum (400–700 nm) compared to normal plants.

Could sensors detect S deficiencies in potatoes?

Methods

- The two research sites and randomized complete block design with four replications was used in 2016; Aroostook Research Station (ARF), S-deficient site, and a farmer field in Easton (Easton site). The ARF was used to determine sensor ability to detect S deficiencies.
- Readings were collected at the V8 growth stage.
- The LAI was estimated using proprietor proxy LAI (PPLAI) program on the basis of NDVI measured by the HCCACS-430 sensor.
- Trimble GreenSeeker® (TGS) and Holland Scientific Crop Circle™ ACS-430 (HCCACS-430) sensor were used for this study.

Results

$NDVI = (NIR - Red)/(NIR + Red)$ -----equation 1

$Red\ Edge\ NDVI = (NIR - Red\ Edge)/(NIR + Red\ Edge)$ -----equation 2

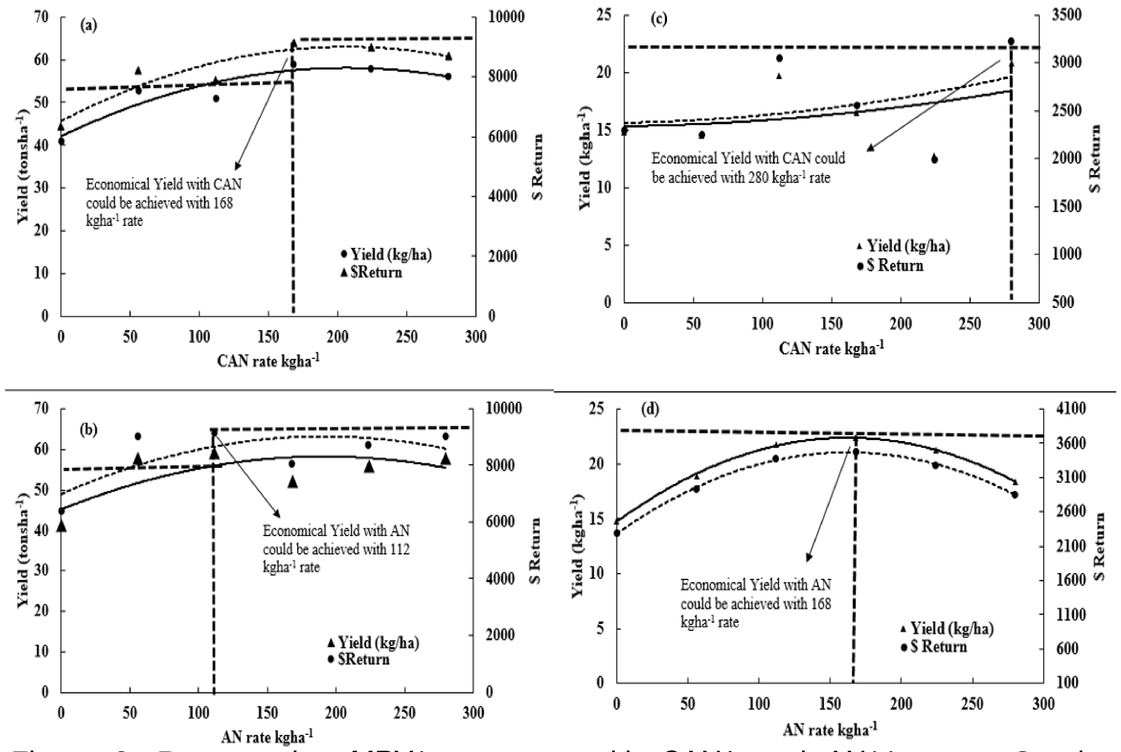

Figure 2: Representing MPY† response with CAN‡ and AN†† rates. On the secondary axis, dollar return represents the economic output with increasing yield. On the left side (a) and (b) figures are from Easton site. Right side (c) and (d) are from ARF site. † Marketable potato yield, ‡Calcium ammonium nitrate, ††Ammonium nitrate.

Table 1. Regression analysis between MPY † and NDVI ‡ from TGS †† and HCCACS-430 ‡‡ at Easton site. The coefficient of determination from the exponential relationship was used to measure the strength of the relationship between MPY and NDVI. Another relationship was developed using sensor PPLAI multiplied with sensor NDVI and then develop a relationship with MPY. The strength of PPLAI †‡ and sensor readings was also determined using regression analysis.

N source	ST	WL	NDVI and Yield	(NDVI x LAI) and Yield	NDVI and LAI
CAN+AN	HCC ACS-430	Red edge	$y = 13.377e^{5.1926x}$ $R^2 = 0.57$***	$y = 29.925e^{1.9611x}$ $R^2 = 0.58$***	$y = 22.741e^{0.7791x}$
		Red	$y = 10.941e^{1.9033x}$ $R^2 = 0.48$***	$y = 28.285e^{0.6897x}$ $R^2 = 0.58$***	$R^2 = 0.58$***
	TGS	Red	$y = 4.9323e^{2.6857x}$ $R^2 = 0.48$***	$y = 25.828e^{0.7424x}$ $R^2 = 0.60$***	
CAN	HCC ACS-430	Red edge	$y = 243.9x - 11.495$ $R^2 = 0.59$***	$y = 95.468x + 25.323$ $R^2 = 0.62$***	$y = -1.1685x + 83.7$ $R^2 =$
		Red	$y = 84.432x - 17.199$ $R^2=0.46$***	$y = 32.49x + 23.473$ $R^2 = 0.59$***	0.42***
	TGS	Red	$y = 5.3235e^{2.5815x}$ $R^2 = 0.59$***	$y = 26.218e^{0.7183x}$ $R^2 = 0.69$***	
AN	HCC ACS-430	Red edge	$y = 257.03x - 14.109$ $R^2=0.62$***	$y = 99.959x + 24.831$ $R^2=0.64$***	$y = -1.6606x + 99.059$
		Red	$y = 104.65x - 32.411$ $R^2=0.64$***	$y = 35.318x + 21.984R^2=0.66$***	$R^2=0.64$***
	TGS	Red	$y = 4.6811e^{2.7571x}$ $R^2 = 0.60$***	$y = 26.153e^{0.7399x}$ $R^2 = 0.70$***	

Table 3. Regression analysis between MPY † and NDVI ‡ from TGS †† and HCCACS-430 ‡‡ at ARF site. The coefficient of determination from the polynomial relationship was used to measure the strength of the relationship between MPY and NDVI. Another relationship was developed using sensor PPLAI multiplied with sensor NDVI and then develop a relationship with MPY. The strength of PPLAI †‡ and sensor readings was also determined using regression analysis.

N source	Sensor type	WL	NDVI and Yield	(NDVI x LAI) and Yield	NDVI and LAI
CAN+AN	HCC ACS-430	Red edge	$y = -93.851x^2 - 65.368x + 29.592$ $R^2 = 0.44$***	$y = 263.34x^2 - 133.38x + 25.403$ $R^2 = 0.44$***	$y = 3.6912x^2 - 27.691x +$
		Red	$y = 2.7838x^2 - 21.484x + 29.259$ $R^2 = 0.40$***	$y = 14.275x^2 - 30.907x + 24.835$ $R^2 = 0.43$***	29.076 $R^2 = 0.44$***
	TGS	Red	$y = 136.23x^2 - 228.73x + 113.74$ $R^2 = 0.13$*	$y = 13.803x^2 - 35.707x + 28.8$ $R^2 = 0.43$***	
CAN	HCC ACS-430	Red edge	$y = 924.38x^2 - 414.15x + 59.023$ $R^2 = 0.53$***	$y = 1039x^2 - 277.72x + 31.693$ $R^2 = 0.50$***	$y = 0.1235x^2 - 7.1541x +$
		Red	$y = 60.696x^2 - 100.34x + 55.745$ $R^2 = 0.44$***	$y = 64.08x^2 - 67.932x + 31.369$ $R^2 = 0.48$***	117.81 $R^2 = 0.49$***
	TGS	Red	$y = 168.64x^2 - 278.12x + 130.41$ $R^2 = 0.35$**	$y = 59.946x^2 - 76.598x + 37.495$ $R^2 = 0.52$***	
AN	HCC ACS-430	Red edge	$y = 163.38x^2 - 123.64x + 32.407$ $R^2 = 0.35$**	$y = 487.19x^2 - 152.39x + 25.469$ $R^2 = 0.34$**	$y = -0.0048x^2 + .8875x -$
		Red	$y = 17.743x^2 - 34.495x + 31.499$ $R^2 = 0.34$**	$y = 34.634x^2 - 38.558x + 25.071$ $R^2 = 0.34$**	6.7679 $R^2 = 0.26$**
	TGS	Red	$y = 153.57x^2 - 253.26x + 123.46$ $R^2 = 0.03$	$y = 7.0663x^2 - 28.936x + 27.383$ $R^2 = 0.32$**	

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