

# **ON-THE-GO SENSORS FOR VARIABLE RATE NUTRIENT MANAGEMENT: DETERMINING SOIL K STATUS WITH A FLAT-SURFACE ION-SELECTIVE ELECTRODE**

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## **Abstract**

Traditional soil sampling approaches are frequently not sufficiently spatially dense to characterize within field variability in soil fertility. Recent technology advances have demonstrated the feasibility of using automated soil sampling systems and tractor mounted sensors to create nutrient availability maps from more continuous measurements. Our objective was to determine if a flat-surface ion selective K electrode could measure soil K status at field moisture content. Twenty-four agricultural soils from across Indiana were collected. Standard laboratory extraction methods were used to quantify soil solution phase and exchangeable K levels. Electrode output was well correlated with all measures of solution phase K but less well correlated with exchangeable K as measured by ammonium acetate extraction. Ion selective electrodes can rapidly determine relative K intensity (solution phase K) in soil but current fertilizer recommendations are based on measurements of soil K quantity (typically commercially assessed by ammonium acetate or Mehlich III extraction). In the future, K intensity measurements may be used to make variable rate K recommendations but soil K quantity will still have to be periodically assessed in order to characterize the soil's ability to replenish or "buffer" solution phase K during crop growth.

## **Introduction**

Accurately and precisely characterizing the spatial variability of soil nutrient supplying power is an essential precondition to understanding if within field variability in soil fertility is costing a farmer potential productivity. Soil sampling at discrete point locations within a field can be effective if soil samples are collected in a sufficiently intense array to capture within field variability. However, this traditional approach to soil fertility assessment is labor-intensive and the number of soil samples required to identify the spatial structure of plant-available nutrients such as K is often too costly.

Recent technological advances have demonstrated the feasibility of using on-the-go sensing to create nutrient availability maps from more continuous soil measurements. A prototype, automated soil sampling system has been developed for use with a flat-surface pH electrode to measure soil pH on-the-go in field moist soil (Adamchuk, 1998, 2000). Ion-selective electrodes similar to the flat-surface pH electrodes are commercially available for K. Ion-selective K (IS-K) electrodes have been used in laboratory studies to rapidly measure kinetics of K fixation and release and to characterize quantity/intensity relationships and potential buffer capacity of K in soils (Nair and Talibudeen, 1973; Farrell and Scott, 1987; Wang et al., 1988; Wang and Huang, 1990.). These studies have demonstrated that IS-K electrodes offer a simple and rapid method of exploring K movement between soil K pools in the laboratory. To date, however, IS-K

electrodes have not been evaluated for in-field use nor have they been evaluated for measuring the spatial heterogeneity of plant-available K at field moisture content with the objective of making a K fertility recommendation.

The objective of this research was to determine if a flat-surface IS-K electrode could be used to measure soil solution-phase K or *K intensity* in a range of agricultural soils.

### Materials and Methods

Twenty-four agricultural soils were collected from across Indiana. Many of the soils were collected from fields at the regional Purdue Agricultural Centers where long-term studies on bioavailable K in corn/soybean production systems are currently ongoing (1997 - present). Soils were selected to represent a range of textures and K fertility levels as assessed by the recommended soil test procedure for the North Central Region (Warncke and Brown, 1998). This extraction procedure measures the *quantity* of K extracted by 1 M ammonium acetate and is an index of the K that is considered to be "plant-available" to a crop throughout the growing season.

In the laboratory soils were also analyzed for soil solution phase K by three different procedures: miscible displacement (modified from Adams, 1974), saturated paste extraction and 1:1 extraction (aqueous methods modified from Rhoades, 1982). These three measurements characterize the K concentration or *intensity* in the soil water encountered by a growing root. Miscible displacement involves the piston-displacement of soil water from a soil sample at field capacity soil moisture levels and thus is a direct measurement of equilibrium soil solution K concentration. The saturated paste and 1:1 extraction procedures involve equilibrium measurements of K at soil moisture contents greater than field capacity and thus quantify an "extended" soil solution measurement. In these procedures soil is separated from the extended soil solution by centrifugation. While the extended solution measurements involve dilution of the true soil solution resulting in the movement of some exchange complex K into solution, they are somewhat easier techniques to perform in the laboratory than miscible displacement, which is a very time-, labor- and skill-intensive technique. A 0.01 M CaCl<sub>2</sub> extraction procedure was also used (Cassman et al., 1990). The extracting ion concentrations in this procedure are thought to be dilute enough that the concentrations of analyte (K) measured are expected to be more representative of K intensity than K quantity. This last technique is relatively easy to perform routinely in the laboratory. All extractions were analyzed for K concentration by atomic absorption spectrometer.

A flat-surface IS-K electrode (IS-K001502, LAZAR Research Laboratories, Inc., Los Angeles, CA) was selected for this study. The electrode was calibrated with 1, 10, 100, 1000 ppm K<sup>+</sup> standard solutions in 5M NaCl to ensure a constant background ionic strength. Electrode output (mV) is a linear function of the log of the activity of K<sup>+</sup> (Figure 1). The effect of soil moisture content on electrode reading was addressed using four soils from the Purdue Fertility Lab reference soil bank. Reference soils J-2, E-1, Q-2, and ON-1 have NH<sub>4</sub>-OAc-ext. K concentrations of 48, 78, 108, and 198 ppm, respectively. Electrode measurements were made on 10g samples equilibrated at 20, 35, 50, 100, and 200% gravimetric soil moisture content. The

K concentration in the 24 collected, agricultural soils were measured in 10g soil samples equilibrated with distilled water 1:1 and 0.2:1 wt./vol ratios.

## Results and Discussion

Selected soils ranged in extractable quantities of K from a low of 61 ppm in a Glynwood soil to a high of 506 ppm in a Toronto soil (Table 1, NH<sub>4</sub>OAc. Ext.). True soil solution K concentrations as measured by miscible displacement technique ranged from a low of 5 ppm in a Chalmer soil to a high of 169 ppm in the Zanesville soil. Concentrations in saturated paste and 1:1 wt/vol extractions were highly correlated with miscible displacement values indicating that the relatively easier lab techniques are sufficient to determine relative soil solution K concentrations for quantity/intensity studies (Table 2). The quantity of K in soil as measured by NH<sub>4</sub>OAc. extraction were also significantly correlated with measures of solution phase K but the relationships were not as strong. This is expected as different soils have different potentials to replenish solution K levels from exchangeable or fixed K reserves (e.g. differing quantity/intensity relationships or potential buffering capacities). Figure 2 shows the relationship between intensity assessed by miscible displacement and quantity and demonstrates that the significance of the relationship is largely the result of the two soils, Zanesville and Toronto with very high quantity and intensity values. Removal of these two samples from the data set reduces the R<sup>2</sup> value for the regression equation to 0.17 (0.10 > P > 0.05). The CaCl<sub>2</sub> extractable K levels were highly correlated with both quantity (NH<sub>4</sub>OAc. ext.) and intensity measurements, reflecting the intermediate nature of this measurement.

The electrode output is influenced by soil moisture content (Figure 3). On average, voltage output decreased 18 and 25 mV when measurements were made in soil at 100 and 200% gravimetric soil moisture content, respectively, as compared to measurements made at 20% soil moisture content. For each reference soils, the relationship between electrode output and soil moisture content can be well characterized by a log function. When the effect of soil moisture on electrode output was evaluated in the 24 agricultural soils, results were similar. Measurements made in soils equilibrated at a 1:1 wt/vol ratio were 16 mV lower when compared to readings made in field moist soil (approximately 20% gravimetric soil moisture content)(Figure 4). The high R<sup>2</sup> value and a regression coefficient not significantly different than 1, indicate that the relationship holds across soil types.

In the twenty-four agricultural soils, intensity measurements (log transformed) were highly correlated with electrode output from measurements made in both field moist soil (Figure 5) and in soil equilibrated at a 1:1 wt/vol ratio with distilled water (data not shown). Statistical comparisons of correlation coefficients found no significant differences between regression relationships for the different soil K intensity measurements. Regression equation intercepts did vary significantly reflecting the different soil solution dilutions of the "extended" measurements of K intensity.

While significant, correlations between soil K quantity (NH<sub>4</sub>OAc. extractable K) and electrode output contain more scatter and are again highly biased by the two samples with high soil K supplying power. When the Zanesville and Toronto soils are removed from the data set, there is still a significant relationship but the R<sup>2</sup> value declines to 0.18 with a regression coefficient of

29.4 ( $P=0.05$ ). This lack of a strong relationship is expected as the IS-K electrode measures K activity in soil solution and does not assess the quantity of exchangeable K. The relationship between electrode output and 0.01 M  $\text{CaCl}_2$  extractable K (log transformed) is stronger ( $R^2=0.88$ ,  $P=0.000$ ; data not shown). Again this result is anticipated as this extraction gives a better estimate of K intensity (Table 2).

### Preliminary Conclusions

Flat-surface IS-K electrodes that are suited for use with a prototype automated soil sampler for in-field on-the-go sensing of soil properties can be used to characterize differences in soil solution phase K availability across a range of agricultural soils. Further testing is needed to characterize electrode performance as influenced by fertility level and variability in ionic strength within and across agricultural soils. Electrode response time and in-field performance across well-characterized spatial changes in plant-available soil K needs to be evaluated. Ultimately, for on-the-go sensing of soil K to be incorporated into fertility management programs, the conceptual approach to recommendations will have to shift from the "static" indexing of soil K quantity to the assessment of intensity coupled with an assessment of potential buffer capacity.

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Table 1. Soil K quantity and intensity in 24 agricultural soils from across Indiana.

Soil	NH <sub>4</sub> -OAc. Ext. mg kg <sup>-1</sup>	Miscible Disp. mg L <sup>-1</sup>	Saturated Paste Ext.	1:1 wt./vol. Ext.	0.01 M CaCl <sub>2</sub> Ext. mg kg <sup>-1</sup>
1 Avonberg	79	29	18	9	4
2 Bloomfield	88	58	38	17	6
3 Blount (1)	323	50	31	17	11
4 Blount (2)	123	35	33	17	6
5 Chalmer (1)	107	11	9	7	4
6 Chalmer (2)	121	5	6	3	3
7 Cincinnati	87	17	12	8	4
8 Cincinnati-Rossmoyne	124	9	10	9	5
9 Clermont	107	38	19	11	6
10 Fincastle	191	20	25	13	9
11 Glynwood (1)	78	9	5	4	2
12 Glynwood (2)	61	15	7	5	2
13 Milford	248	8	7	6	6
14 Morley	121	13	11	7	4
15 Parke	291	40	34	21	14
16 Pewamo	271	44	27	18	11
17 Raub	134	9	10	6	4
18 Rockfield	255	45	45	21	13
19 Rossmoyne	158	31	29	15	8
20 Toronto	506	110	83	46	22
21 Toronto-Millbrook	173	29	19	12	6
22 Tracy	127	59	41	21	7
23 Zanesville	427	169	98	55	24
24 Zipp	66	6	4	3	2

Table 2. Pearson correlation coefficients for correlations between various measurements of soil quantity and intensity in 24 agricultural soils from Indiana.

	NH <sub>4</sub> OAc. Ext.	Saturated Paste	1:1 wt/vol Ext.	Miscible Disp.	0.01 M CaCl <sub>2</sub>
NH <sub>4</sub> OAc. Ext.	1.00				
Saturated Paste	0.71***	1.00			
1:1 wt/vol Ext.	0.74***	0.98***	1.00		
Miscible Disp.	0.60**	0.95***	0.95***	1.00	
0.01 M CaCl <sub>2</sub>	0.87***	0.94***	0.94***	0.86***	1.00

\*\*\*, \*\* P-values less than 0.001 and 0.01, respectively.

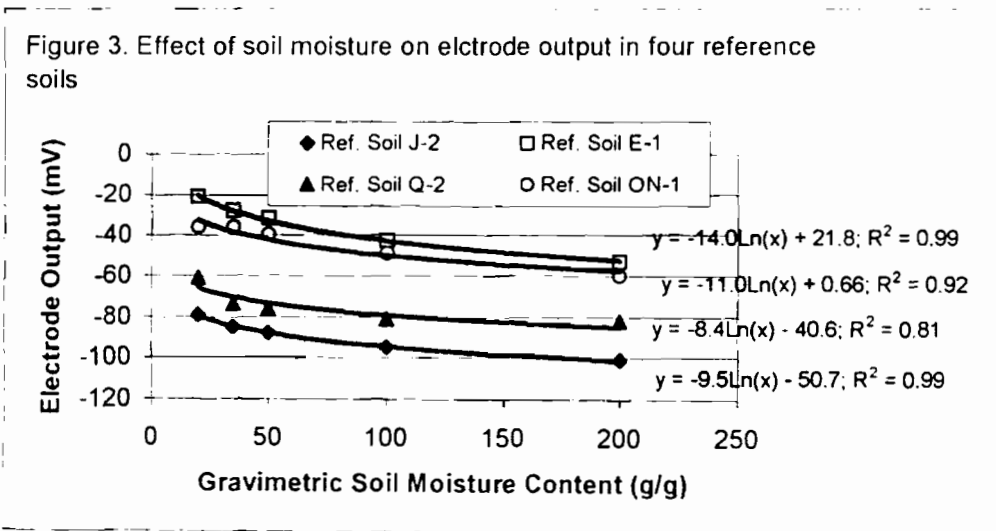
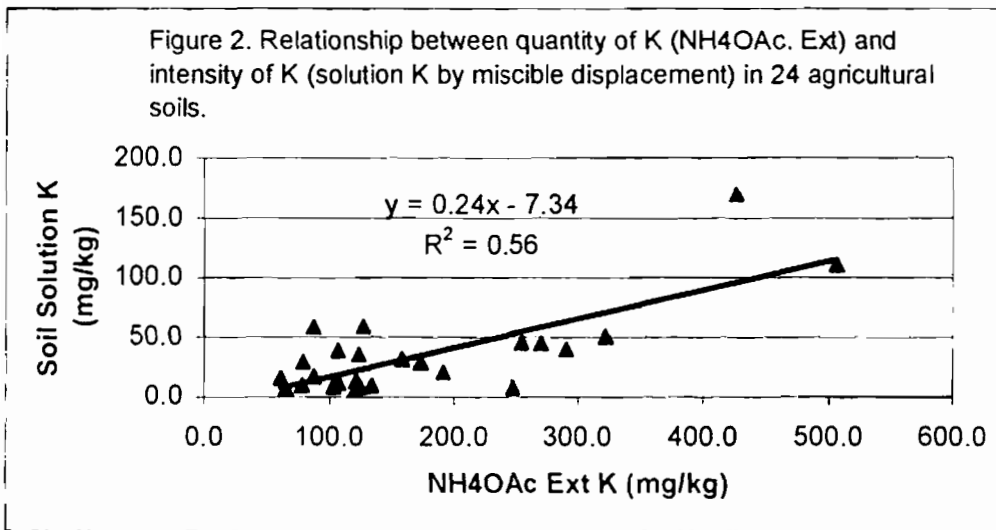
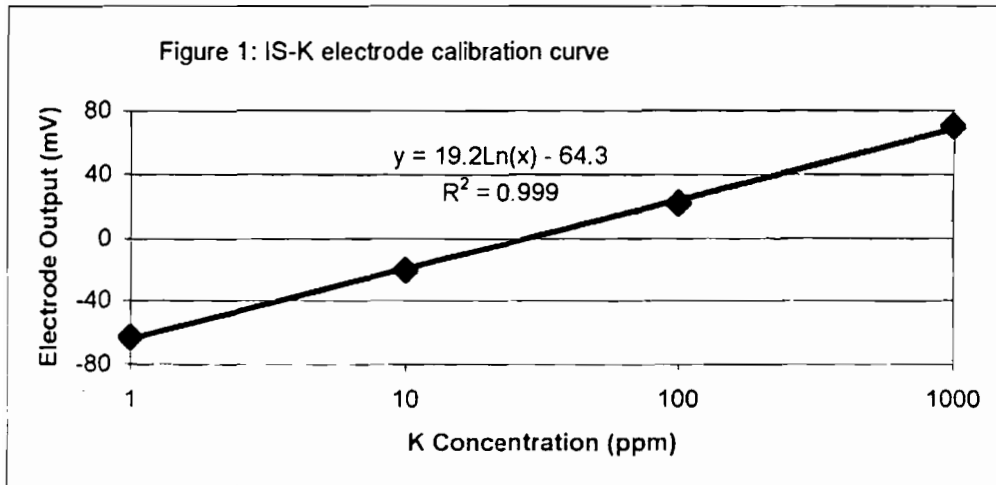


Figure 4: Effect of sample moisture on electrode output in 24 agricultural soils

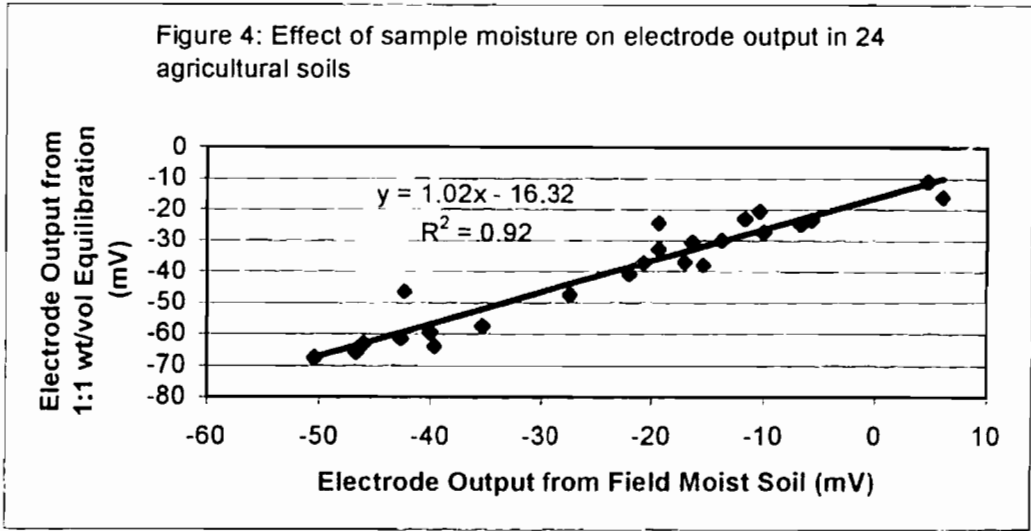


Figure 5: Relationship between electrode output and K intensity measurements in 24 agricultural soils.

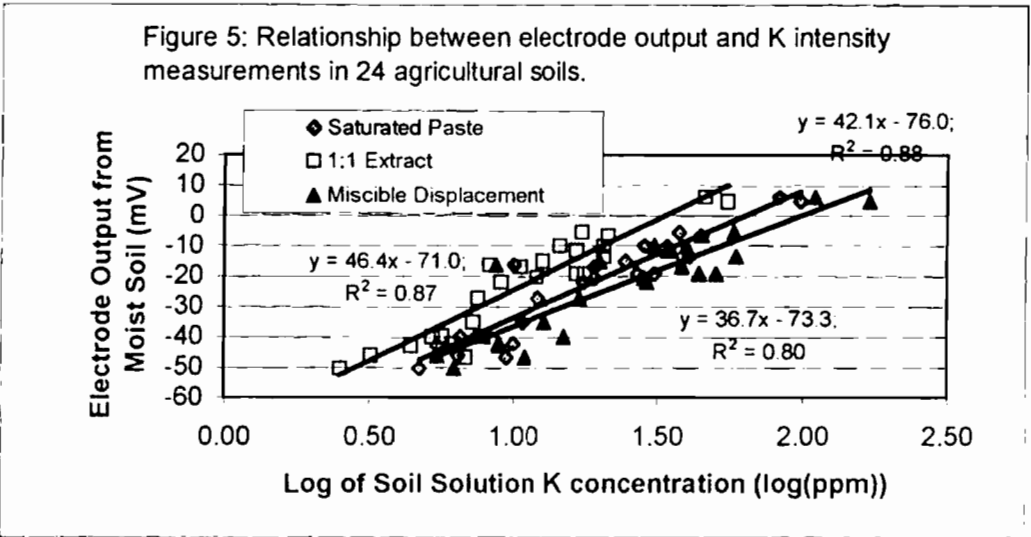
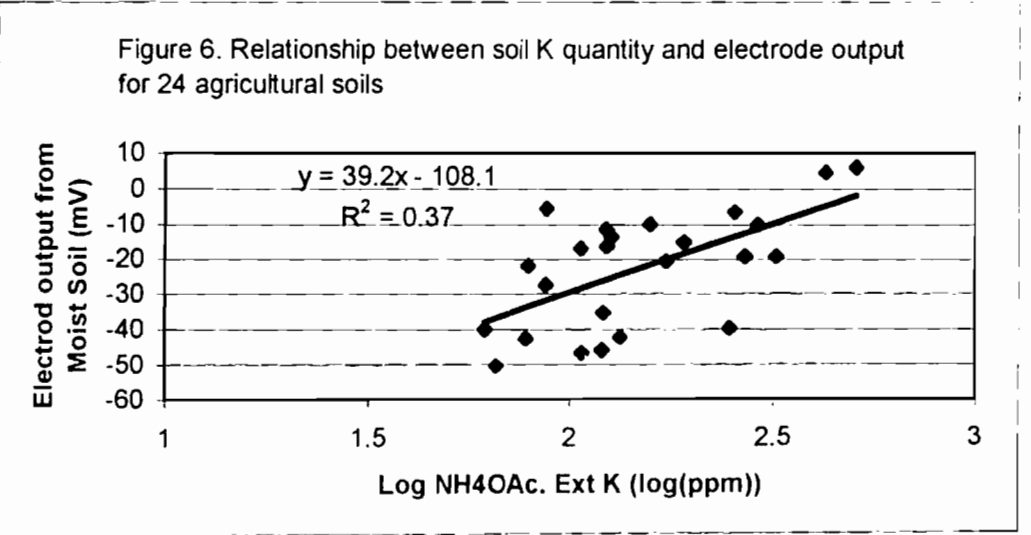


Figure 6. Relationship between soil K quantity and electrode output for 24 agricultural soils





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