Exchangeable Cation Uptake by Irrigated and Rainfed Soybeans

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Introduction and Objectives

Although Ca, Mg, and K are all exchangeable nutrients that are considered plant available, soil chemistry and plant root interactions result in different uptake and bioavailability. In particular, K and Mg have antagonistic relationships in both corn and soybeans, with over application of either nutrient suppressing uptake of the other. Within the soil, Ca and Mg can move with soil water or by diffusion, while the lower K concentrations do not readily move with soil water. This results in differences in uptake for soils with adequate moisture versus those under drought stress. Understanding how concentrations of each nutrient, the soil CEC, and soil moisture content interact is important for giving future nutrient recommendations.

The objectives of this study were to sample center pivots in their dry corners and irrigated regions and compare soil nutrient levels and nutrient uptake in the leaf tissue for potential

Methods

Ten different soybean fields with center pivot irrigation were sampled in Sussex and Kent County Delaware. In each field, two locations which received irrigation and two locations without irrigation were be sampled for both soil nutrient and soybean tissue in August 2021, at approximately R2-R3 growth stages. A total of 40 soil and 40 tissue samples were taken for analyses. All fields were full season soybeans.

Samples were dried and sent to the University of Delaware for analyses. Soils were analyzed for the total nutrient suite (macro and micronutrients, but not N), as well as pH and organic matter content. Plant tissues were analyzed for all macronutrients, selected micronutrients, Al and Na. Total nutrient uptake of Ca, Mg, and K will be compared among rainfed and irrigated samples to observe differences in soil nutrient vs soil moisture effects on uptake.

Cumulative rainfall was obtained from the Delaware Environmental Observing System (DEOS) for Georgetown, DE (Sussex County), Dover SFS (Kent County), the Newark Ag Farm (New Castle County) to represent county averages. They will not capture locally variable rainfall, but are representative of statewide trends. Rainfall in the region varied throughout the state, with lower accumulation over the summer in northern Delaware (Figure 1). Rainfall where most of the fields were sampled (Sussex and Kent) was similar throughout the season, and only really lacking at planting (April and May). A drought period occurred mid-July through early August, just prior to leaf tissue sampling. Hurricanes and larger storm events typically happen August through the fall, and cumulative rainfall continues after the short dry period in late July. Due to this, rainfed conditions may be similar to irrigated fields, as many farms did not turn on irrigation frequently in June and early July (personal communication, local soybean producers).

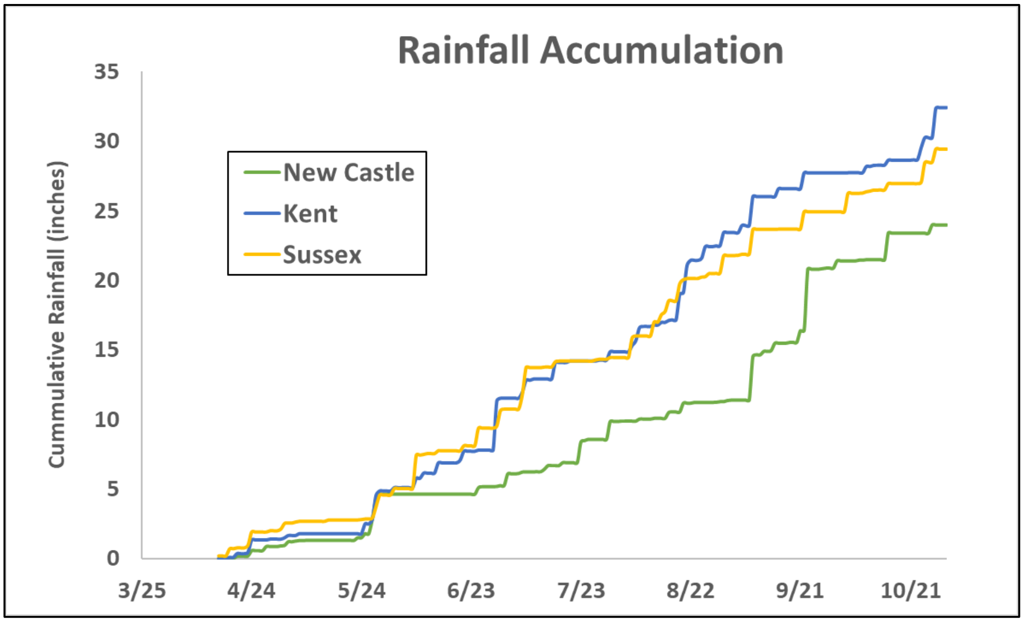

Figure 1: Cumulative rainfall in northern (New Castle), central (Kent), and southern (Sussex) Delaware from mid-April until October 31st.

Results and Discussion

Soil Characteristics and Nutrient Concentrations

Among the ten fields sampled, there was no difference in CEC or soil pH between rainfed and irrigated portions of the fields (Table 1). For a study observing uptake of nutrient based on soil moisture, we do not want differences in CEC or soil pH and would not expect irrigation to alter CEC in any meaningful way. It is possible for pH to shift overtime in these fields where irrigation is present, either due to leaching, increasing yields and nutrient uptake, or some other mechanism, but that is not the case in this study.

Although soil P concentrations are much higher under irrigation, the variation across the fields is large enough there is no statistical difference (Table 1). We also observed no differences in the macronutrients K, Ca, or Mg in the soils. Other nutrients (data not presented) also had no differenced between rainfed and irrigated portions of the field, including Zn, Cu, Fe, Mn, S, and B. The only element in soils that had any difference was Na, which was higher in irrigated (11.3 ppm) vs rainfed (7.26 ppm) parts of the field (Table 1). Irrigation water can contain dissolved salts, including Ca, NO_3, and Na, and is probably the source of additional Na in the irrigated soils. In a previous survey of Delaware soybean fields, we have observed higher yields tied to leaf tissue Na concentrations and attributed that to the effects of irrigation on both yields and leaf tissue Na (Miller and Shober, 2020).

Table 1: Soil Characteristics in Irrigated and Rainfed Portions of Each Field (α=0.1).

	CEC (meq/100g)	Soil pH	Soil P (ppm)	Soil K (ppm)	Soil Ca (ppm)	Soil Mg (ppm)	Soil Na (ppm)
Irrigated	6.48	5.69	227.62	110.23	632.78	98.70	7.26 b
Rainfed	6.30	5.62	189.90	124.71	634.62	101.45	11.30 a
p-value	*0.8041*	*0.5998*	*0.3549*	*0.2985*	*0.9869*	*0.8312*	*0.0439*

Soybean Leaf Tissue Nutrient Concentrations by Irrigated vs Rainfed Conditions

Macronutrient concentrations in the upper leaves of irrigated field regions had higher N and P concentrations compared to rainfed portions of the field, while no other macronutrients were significantly different (Table 2). Potassium was higher in irrigated regions by 0.1% with a p-value of 0.1018 (α=0.1), so while it was not considered significant, the potential for less K uptake in rainfed portions of the field is possible. In a study observing the differences between rainfed and irrigated fields, K uptake fluctuated in rainfed fields with water availability (Karlen et al., 1982). Based on summer rainfall across Delaware (Figure 1), soil moisture was only reduced in late July, so that limitations on K uptake may have been minimized relative to droughty years. Fernandez et al. (2008) noted that greater water recharge and K availability in the upper 5 cm of the soil with intermittent rainfall provided the greatest K uptake.

Table 2: Soybean leaf tissue *macronutrient* concentrations (%) at the R2/R3 growth stage (Fishers LSD, α=0.1).

	N	P	K	Ca	Mg	S
	----------	----------	---------- %	----------	----------	----------
Irrigated	5.7 a	0.41 a	2.0	0.76	0.28	0.26
Rainfed	5.0 b	0.33 b	1.9	0.77	0.30	0.25
p-value	*0.0011*	*0.0191*	*0.1018*	*0.8337*	*0.4380*	*0.1441*
Sufficiency Ranges*	*3.25-5.0*	0.3-0.6	1.5-2.25	0.8-1.4	0.25-0.70	0.25-0.6

Phosphorus availability is limited by its sorption to soil surfaces, so greater moisture provided by irrigation may allow for transport to the root, as well as root interception closer to colloid surfaces. The increased N uptake may be a product of reduced stress on the rhizobia bacteria or additions of NO_3 from the irrigation system. Although limited uptake of N, P, K and Ca have been reported in the seeds of water stressed soybeans (Wijewardana at al., 2019), there were no differences in Ca within these fields. In these fields, the lack of differences in Ca, Mg, and S between irrigated and rainfed fields is positive, meaning management across the field can be the same, a very dry year may change these results. As S and N are often dissolved in irrigation water and can have correlated uptake within the plant, it is not apparent what mechanism kept S similar between rainfed and irrigated soybeans.

Soybean leaf tissue micronutrient concentrations did not see differences for Mn, Zn, Cu, and B, but were higher for Fe in irrigated portions of the field (Table 3). All of these nutrients were in their sufficiency ranges for both irrigated and rainfed regions of the fields, and most were in the uppermost portions of these ranges. Soils on Delmarva are not lacking in Fe, and yet it appears that additional soil moisture (or Fe within irrigation waters) helps with uptake into the plant tissue. While Cu was not significantly different (p=0.1043), it was close enough we may consider that under drier conditions, Cu uptake may have been more limited in rainfed parts of the field. This may lead to Cu deficiencies, particularly if the pH was above 6.5 in these fields.

Table 3: Soybean leaf tissue *micronutrient* concentrations (%) at the R2/R3 growth stage (Fishers LSD, α=0.1).

	Mn	**Zn**	**Cu**	**Fe**	**B**
	---------------------------- ppm ----------------------------------				
Irrigated	56.4	56.1	7.9	104.8 a	51.2
Rainfed	77.7	63.6	7.4	86.8 b	56.3
p-value	*0.1589*	*0.5070*	*0.1043*	*0.0809*	*0.6778*
Sufficiency Ranges*	*17-100*	*21-80*	*4-30*	*25-300*	*20-60*

While not essential nutrients, both Na and Al were different based on irrigation status, with Na being higher in irrigated leaf tissue and Al higher in rainfed leaf tissue (Table 4). Sodium in the soil was already observed to be greater (Table 1), probably due to additions from irrigation water. The higher Na in these plants could be due to soil uptake, foliar uptake of irrigation water, or salts precipitated on the leaf surfaces.

Table 4: Soybean leaf tissue *Na and Al* concentrations (%) at the R2/R3 growth stage (Fishers LSD, α=0.1).

	Na	**Al**
	------------- ppm ---------------	
Irrigated	27.2 a	17.9 b
Rainfed	10.6 b	29.3 a
p-value	*0.0360*	*0.0533*
Sufficiency Ranges*	*Not applicable*	*Not applicable*

The greater concentrations of Al in the rain fed soybeans (approximately doubled) may indicate that stress during drought allows for more Al uptake (Table 4), particularly where there is decreased access to other nutrients. However, as a metal Fe is also plentiful in soils, and greater concentrations were observed in irrigated soybean leaves (Table 3), it is not clear what caused increased Al uptake in rainfed fields. Free aluminum can cause issues with plant growth due to reactions with roots, so additional Al in leaves could be a concern for yield in rainfed portions of the field. In this case, pH could be raised in dry corners, however, that may also cause limitations in the uptake of Cu and other micronutrient metals.

Correlations for Rainfed and Irrigated Leaf Tissue Nutrients

Correlations of soil pH and CEC to leaf tissue nutrients are in Table 5 split by rainfed and irrigated regions of the fields. Soil pH was below 6 averaged across both rainfed and irrigated fields (Table 1), so its not surprising that minimal relationships exist. In this study, tissue Mn had a negative relationship with soil pH in rainfed fields, and has been a consistent problem across Delaware soybean fields. In this case, it appears that pH becomes a bigger issue with Mn uptake when fields are irrigated, where in rainfed fields limited uptake reduces any potential relationship with pH.

Soil CEC also had minimal relationships with tissue nutrients, but in both rainfed and irrigated samples, tissue Mg was limited by higher CEC (Table 5). Although Mg concentrations were sufficient averaged across tissue samples (Table 2), fields may still be under-fertilized relative to Ca, so that CEC becomes a proxy for this issue. When a nutrient on the CEC is in lower concentration, reduced release or availability from the CEC may occur.

Table 5: Correlations of soil pH, CEC, and tissue nutrients (positive and negative relationships) versus all soil tissue nutrients measured (α=0.1).

	Rainfed		**Irrigated**	
	(+)	**(-)**	**(+)**	**(-)**
Soil pH	ns	ns	ns	Mn
Soil CEC	ns	Mg	ns	Mg, Mn
Tissue N	P, K, S, Cu	Ca, Mg, Al	P, Mg, S, Zn, Cu	ns
Tissue P	N, K	Ca, Mn, Zn, Fe, B, Al	N, K, Mg, Cu, Na	Fe, B, Al
Tissue K	N, P	Ca, Al	P	Ca, Mn, B, Al
Tissue Fe	Ca, S, Mg, Zn, B, Na, Al	P	B	P
Tissue Na	Fe	ns	P	Al
Tissue Al	Ca, Mg, S, Mn, Zn, Fe, B	N, P, K	ns	P, K, Mg, Na

Tissue N had some interesting correlations, where irrigated fields had no negative relationships with any other tissue nutrients (Table 5). Under rainfed conditions, greater N uptake was tied to higher tissue P, K, S, and Cu, while irrigated fields had an additional relationship with Mg and Zn, but not K. What is more important are the negative relationships between tissue N, Ca, Mg, and Al

in rainfed soils (Table 5). The uptake of more Ca, Mg, and Al relative to N in rainfed soils may show that under stress, elements with higher concentrations are taken up in place of N.
Tissue P only had two positive relationships in rainfed soils (tissue N and K), but many more under irrigated conditions (Table 5). Proper K fertilization and inoculation could increase P uptake under rainfed conditions, while stress may have allowed for greater uptake of Ca and many micronutrients. For irrigated soils, only tissue Fe, B, and Al had negative relationships with tissue P.

While K did not vary by water source in the soybean tissue, it was still tied to the uptake of N and P under rainfed conditions, but only P under irrigated. Similar to P, proper fertilization may assist with the uptake of K in dry corners. Aluminum had a negative relationship with K regardless of soil moisture status.

Tissue Fe, Na, and Al are also listed in Table 5 since they all had differences in concentration between rainfed and irrigated conditions. While tissue Fe was higher under irrigation (Table 3), it only had a positive relationship with tissue B and a negative relationship with P. The same negative relationship with P was observed in rainfed soils, so that this relationship may be ubiquitous regardless of moisture status. Under more stressed rainfed conditions, higher tissue Fe was tied to greater Ca, Mg, S, Zn, B, Na and Al (Table 5), even thought it had a lower concentration overall compared to irrigated fields (Table 3).

Previously we hypothesized that the higher concentrations of Na in irrigated leaf tissue samples indicates Na in the irrigation water, possibly precipitated on the leaf surface (Table 4). Correlations of Na to other nutrient were minimal, which supports the idea that Na is added by irrigation water. Under rainfed conditions, Na only had a positive relationship with Fe and no negative relationships, mostly because uptake is probably passive and not intentional. For irrigated soils, higher Na was associated with greater tissue P but less tissue Al (Table 5). The Al relationship may indicate that although irrigation increases yields and Na contents, stress that allows more Al uptake reduces Na uptake as well.

Aluminum is another element that is not needed by the soybean plant but is taken up when soil levels are high and soil pH is lower. Under rainfed conditions, Al had positive relationships with many macro and micronutrients (Table 5), and also had higher overall tissue concentrations compared to irrigated leaves (Table 4). Alternatively, greater tissue N, P, and K also tied to lower Al contents, indicating that where plants could take up the necessary macronutrients, they were less stressed and limited Al uptake, as compared to nutrients like Ca, Mg, and S. This is further supported when irrigated tissue samples are examined and Al has no positive relationships with any elements measured, but has negative relationships with P, K, Mg and Na (Table 5). Under the stress of limited soil moisture, soybean plants may allow more uptake of Al, resulting in the greater concentrations observed in Table 4.

Conclusions

Irrigated soybeans had higher concentrations of N, P, Fe, and Na in the upper leaf tissue, with K and Cu being slightly higher, but not statistically significant. This is not necessarily an issue for yield, as all measured leaf tissue nutrients were within their sufficiency ranges, except Ca which was just below the 0.8% threshold in both rainfed and irrigated soybeans.

The three primary macronutrients (N, P, and K) were all positively correlated to each other in rainfed tissue samples, but not in irrigated, which may indicate that stressed soybeans rely on the uptake of all three macronutrients. Nitrogen also had no significant *negative* correlations in irrigated fields, with concentrations above threshold values (5.7%), so its possible N was not limited in these scenarios and would not produce negative correlations with other elements. Rainfed soils saw limited uptake of N when Ca, Mg, and Al increased in the tissue, and vice versa, which may be a stress response when moisture is limited. The higher uptake of P in irrigated soybeans is probably related to moisture content giving greater access to P

Greater Na concentrations in both irrigated soil and tissue samples was most likely related to salts in irrigation water, with Na having very few relationships to other elements in leaf tissue samples. Iron was also higher in irrigated tissue samples but had more correlations to tissue nutrients in rainfed samples. This may mean that Fe uptake occurred with higher soil moisture but was not related to any other nutrient uptake. Alternatively, Al uptake in rainfed beans may also reflect excess uptake, but under stressed conditions, where it positively correlated with many other tissue nutrients, but had no positive correlations with irrigated soybeans.

All these relationships are based on 2021 rainfall, which was sufficient for most of the early summer in Delaware, and not deficient until late July. It is certainly possible to have different relationships in doughtier years, which includes greater differences (lower N, P, and K in rainfed) between regions or fields with different moisture contents.

References

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