Evaluation of in-furrow starter fertilizer sources for corn

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Introduction

Use of starter fertilizer is a practice that some corn producers are adopting as a way to achieve greater seedling vigor. Past research has shown that a small amount of nutrients, in most cases phosphorus, can have a positive impact on plant growth regardless of soil test P level. Cool and wet soils in the spring can limit root growth and significantly limit phosphorus uptake. Fertilizers contain both salt and nitrogen. The nitrogen can be detrimental to the seed if the fertilizer gives off ammonia which is toxic to living tissues. Most farmers who choose to use starter only do so if they can place it with the seed because of the simplicity of the application. This placement generally increases risk for stand loss which can significantly impact yield. The concept of the salt index was developed as a tool to assess the safety of fertilizers when placed with the seed. Salt index produces a number by which to assess the relative impact of various fertilizers and has no bearing on rate that can be safely applied. The past recommendation for seed placement for most fertilizers has been no more than 10 lbs of N + K2O in the seed furrow at any time. However, various materials manufactured with differing K sources can decrease the risk for seed placement. While this has been a good standard in the past, better data should be available to producers when they are selecting fertilizer sources for seed placement.

Recent work in Minnesota has called into question the use of the salt index as a tool for predicting what form of fertilizer to use. This work compared three sources, 10-34-0, 4-10-10, and 3-18-18 applied at two rates. In terms of the salt index the 3-18-18 contained to lowest values while the 4-10-10 was the greatest. Clay loam and sandy loam soils were compared and it was found that the fertilizer that applied the highest N rates caused the most damage and that this damage was related to the water holding capacity of the soil. Even in sand it was found that 10-34-0 had the highest damage potential when averaged across years. This data, along with research from South Dakota, indicate that ammonia generating potential may be a key factor in deciding what fertilizer to use.

The proposed study is to:

1. Evaluate corn emergence in differing soils following fertilizer applied directly on the seed based on nitrogen or potassium rates
2. Determine optimum fertilizer rates for promoting top growth and nutrient uptake.
3. Develop models for predicting seed safe fertilizer rates for corn.
4. Develop a new extension publication on fertilizer banded with the seed for corn

Methods

This proposal covers final data analysis for a study that began spring 2009 and ended fall 2011. The study utilized greenhouse work to assess the effects of seed placed fertilizer on corn in three soil types Le Sueur clay loam, Kenyon silt loam, and Zimmerman fine sand. Single experimental runs were made for individual fertilizer sources, only running one source at a time. Corn was equally spaced in 21" by 21" square flats with soil packed to an equal density. Three rows of corn with 7 seeds per row were planted in each flat. Fertilizer was applied to each row based in five rates, including a control, encompassing rates above and below what would be that of a rate expected to be safe for seed placement. Soil moisture content was monitored and controlled at around 80% available water holding capacity. This was chosen to ensure that there would be adequate water for optimal crop growth. This was also to prevent over watering and potential leaching of nutrients out of the root zone to ensure conditions for maximum potential damage. When the first plants emerged at least 1 cm above the soil emergence counts were taken from all flats each day for 14 days. At the end of the trial period the total plants emerged were summed and data was analyzed based on total emergence averaged across three replications and emergence as percentage of the control.

At the termination of each experimental run, the above ground portion of the plants and roots were collected from each flat. Each flat was designed such that roots can be carefully separated from the soil. This was done by putting a layer of landscape fabric under the soil so it can be lifted out of the flat and sifted through at the end of the experiment. All collected roots and biomass were weighed and corn tops were ground and analyzed by ICP for nutrient concentration to determine uptake. This is important for the understanding of optimal rates that promote both plant growth and nutrient uptake. Corn growers typically apply starters to promote growth and to increase yield through growth and increases in nutrient uptake. Examining different sources would provide information to determine if different starter sources can potentially influence growth and what rate to use to increase corn production.

The study included the following 11 fertilizer sources

- Di-ammonium phosphate (DAP) 18-46-0
- Mono-ammonium phosphate (MAP) 11-52-0
- Potash (KCL) 0-0-60
- Ammonium sulfate (AMS) 21-0-0-24s
- Urea 46-0-0
- Ammonium thiosulfate (ATS) 12-0-0-26s
- Ammonium polyphosphate (APP) 10-34-0
- Potassium thiosulfate (KTS) 0-0-25-17s
- 28% UAN
- 7-21-7
- 9-18-9

Pictures of individual roots have been taken from one replication to document corn top and root growth. This data will be used in a new publication on seed placed fertilizer for corn. Trials were completed previously by Rehm and Lamb in the field. This trial will study closely the effects of nitrogen on crop emergence. The data from Rehm and Lamb indicate that nitrogen has the biggest impact on corn emergence, but that study compared only limited fertilizer sources and rates. This data should be able to compare both nitrogen and potassium rates which were the old standard for determining what can be placed in the seed furrow. Recently, South Dakota State University put a calculator tool online for determining seed safe rates that is based solely on emergence. Our preliminary data shows that emergence may not necessarily be affected but plant growth may be limited such that a delay in growth or emergence may significantly affect yield. For instance, the completed experiment with ammonium thiosulfate found that emergence was not significantly affected until after about 4 gpa was applied, but top and root growth significantly decreased with the first rate applied. If adequate moisture exists, this likely will not affect yield, but in dry conditions a significant yield loss might be expected.

Starter fertilizer has become an important tool used to increase yields in some areas of Minnesota. Developing the baseline data from in-furrow recommendations is important to provide information on the risks associated with placing fertilizer in contact with the seed. Improper rates can cause significant damage to corn emergence causing a financial loss to the producer in lost seed and time by having to replant. While the greenhouse data represents a more controlled environment than is seen the field it still is valuable to be able to rate the fertilizer sources in terms of damage and potential for growth increase. We also can provide information on delay in corn emergence which can be a critical factor at certain times of the year when delays can be attributed to yield loss. Together this should provide corn producers the data needed to assess the risks of changing management practices by looking at different sources of starter fertilizer for different situations within their fields.

Results and Discussion

Soils background information is given in Tables 1 and 2. The soils were chosen from different growing regions of the state to represent differing parent materials. The clay loam (CL) soil is a poorly drained soil formed under glacial till from Nicollet County, the fine sand (FS) was formed in glacial outwash and was collected from Isanti County, and the silt loam (SiL) was formed in loess and was collected from Olmsted County. The CL and SiL soils were high in both P and K while the FS tested high in P but low in K. Organic matter contents varied and were the highest for the CL and lowest for FS. Water content at field capacity was the lowest for FS. Of interest was the particle size determination which found more clay than expected in the FS and less silt for the SiL. In fact, these two soils actually differed in their textural class than what was given in the soil survey. However, for this work they still will be reported as what was given in the soil survey.

Table 1. Soil properties series information and physical and chemical properties for the clay loam (CL), fine sand (FS) and silt loam (SiL) soils used for the fertilizer evaluation study.

Soil			Soil Test†					
Texture	Series	Classification‡	N	P	K	S	pH	SOM
			--------------ppm--------------					-%-
CL	Le Sueur	A. Argiudoll	45	132	404	13	5.8	5.5
FS	Zimmerman	L. Udipsamment	8	45	62	3	7.3	0.7
SiL	Floyd	A. Hapludoll	54	53	266	10	5.2	3.8

† N, 0.1 *M* KCl extractable nitrate-N; P, Bray-P1 P; K, ammonium acetate extractable K; S, mono-calcium phosphate extractable sulfate-S; pH, soil pH 1:1 soil:water; SOM, soil organic matter (LOI).

‡A, aquic; L, lammelic.

Table 2. Soil physical and chemical properties for the clay loam (CL), fine sand (FSL) and silt loam (SiL) soils studied.

	Gravimetric		Particle Size		
Texture	H_2O	CEC	Sand	Silt	Clay
	---%---	meq 100g^{-1}	---------------%---------------		
CL	27.8	27.0	30.6	33.0	36.4
FS	10.1	4.5	79.9	6.4	13.7
SiL	24.1	16.6	39.3	36.7	24.0

A, aquic; L, lammelic..

Summary of critical levels for individual fertilizer runs

A summary of critical levels for the fertilizer sources based on final plant emergence and the average mass of plant produced is given in Table 3. In most cases, fertilizer reduced plant emergence as rate increased. There were some exceptions such as APP for the CL soil, 7-21-7 and KTS for both the CL and SiL soils, and UAN for the SiL. This was unexpected as the high rate used should have resulted in some reduction in stand. There were reductions for the FS indicating that the high rate possibly was not enough since the sand tended to see emergence problems sooner than the other two soils. The fertilizer sources that reduced stands the greatest were AMS, ATS, KCl, and Urea which was expected since these products have the highest salt indexes of all the sources. Even though emergence was not reduced, average plant mass declined with increasing fertilizer rate for the CL and SiL soils for 7-21-7 and KTS in which the rate that produced the greatest plant mass for KTS was 0 gal./ac. A higher rate of 7-21-7 could be applied and not reduce growth but the overall effect on growth indicates that an emphasis should be put on this factor when considering seed safe rates. Other models mainly consider emergence. Damage on the roots (not shown) coupled with the effects on plant mass would support the use of emergence in the calculation of seed safe rates. Overall, P fertilizer appeared to promote growth more than N, K, or S except for the fine sand which benefited from small rates of K and S.

Table 3. Summary critical fertilizer rates based on final plant emergence after 21 days and average plant mass per 21 seeds planted.

	Emergence after 14 days			Average Plant Mass		
Product	Soil	Critical Level†		Soil	Critical Level†	
		-Lb/ac-	-gal/ac-		-Lb/ac-	-gal/ac-
AMS	CL, SiL	0.0		CL, SiL	0.0	
	FS	34.8		FS	11.6	
APP	CL	--	--	CL	--	--
	FS	9.8	0.8	FS	14.3	1.2
	SiL	87.5	7.4	SiL	65.2	5.5
ATS	CL, SiL	0.0	0.0	All	0.0	0.0
	FS	0.0	0.0			
DAP	CL, SiL	34.8		CL, SiL	44.7	
	FS	34.8		FS	12.5	
7-21-7	CL, SiL	--	--	CL	53.6	4.9
	FS	91.1	8.3	FS	15.2	1.4
				SiL	81.3	7.4
KCl	CL	0.0		All	0.0	
	FS	3.6				
	SiL	4.5				
KTS	CL, SiL	--	--	CL	0.0	0.0
	FS	69.7	5.7	FS	11.6	1.0
				SiL	0.0	0.0
9-18-9	CL	16.1	1.5	CL	61.6	5.6
	FS	24.1	2.2	FS	33.0	3.0
	SiL	18.8	1.7	SiL	25.0	2.3
MAP	CL, SiL	27.7		All	22.3	
	FS	76.8				
UAN	CL	35.7	3.3	CL	8.9	0.8
	FS	5.4	0.5	FS	9.8	0.9
	SiL	--	--	SiL	--	--
Urea	CL, SiL	1.8		CL, SiL	0.0	
	FS	0.0		FS	0.0	

†+, concentration or uptake increased beyond the maximum rate applied; --, fertilizer rate was not significant.

‡CL, clay loam; FS, fine sand; SiL, silt loam; All, all soils.

Table 4. Summary of plant nitrogen (N) concentration and uptake response across starter rates. The critical level represents the rate that produced the highest concentration or uptake.

	Plant N Concentration			Plant N Uptake		
Product	Soil	Critical Level†		Soil	Critical Level†	
		-Lb/ac-	-gal/ac-		-Lb/ac-	-gal/ac-
AMS	CL, SiL	130.4		CL, SiL	0.0	
	FS	24.1		FS	21.4	
APP	CL, SiL	+	+	CL, SiL	--	--
	FS	153.6	13.0	FS	47.3	4.0
ATS	CL, SiL	27.7	2.5	CL, SiL	0.0	0.0
	FS	24.1	2.2	FS	17.9	1.6
DAP	CL, SiL	--		CL, SiL	68.8	
	FS	47.3		FS	33.9	
7-21-7	CL, SiL	242.0	22.0	CL	27.7	2.5
	FS	113.4	10.3	FS	74.1	6.7
				SiL	100.0	9.1
9-18-9	CL	+	+	CL	87.5	7.9
	FS	92.9	8.4	FS	46.4	4.2
	SiL	252.7	22.9	SiL	22.3	2.0
MAP	CL, SiL	--	--	ALL	22.3	
	FS	101.8				
UAN	CL, SiL	--	--	CL, SiL	--	--
	FS	13.4	1.2	FS	10.7	1.0
Urea	CL	57.2		CL	16.1	
	FS	16.1		FS	9.8	
	SiL	27.7		SiL	6.3	

†+, concentration or uptake increased beyond the maximum rate applied; --, fertilizer rate was not significant.

Critical levels based on plant N concentration and uptake is given in Table 4. Only fertilizer sources that contained N were considered and are included in the table. This will be true for all other nutrient concentration data. When sources such as KCl were run for N the relationships followed that of early plant growth and the critical levels did not vary indicating that the uptake was proportional to growth. If this is the case the concentration values will not vary. For N, the amount of fertilizer it took to maximize N concentration was greater than what maximized N uptake. In general patterns of uptake followed closely that of growth. In some cases N concentration was not maximized by the highest rate of fertilizer applied. This indicates that even if damage is occurring causing reduced plant growth, N is still being taken up at rates not needed by the plant. Plant N concentration therefore would likely increase causing significant issues especially if concentration is being used early in the season to assess nutrient sufficiency. Maximizing uptake should be the focus rather than maximizing N concentration in the plant.

Table 5. Summary of plant phosphorus (P) concentration and uptake response across starter rates. The critical level represents the rate that produced the highest concentration or uptake.

	Plant P Concentration			Plant P Uptake		
Product	Soil	Critical Level†		Soil	Critical Level†	
		-Lb/ac-	-gal/ac-		-Lb/ac-	-gal/ac-
APP	All	+	+	CL	--	--
				FS	42.0	3.6
				SiL	92.9	7.9
DAP	CL, SiL	+		CL, SiL	74.1	
	FS	106.3		FS	39.3	
7-21-7	All	203.6	18.5	CL	62.5	5.7
				FS	135.7	12.3
				SiL	145.6	13.2
9-18-9	CL, SiL	59.8	5.4	CL	110.7	10.0
	FS	92.9	8.4	FS	42.0	3.8
				SiL	25.0	2.3
MAP	CL, SiL	344.7		CL, SiL	88.4	
	FS	181.3		FS	20.5	

†+, concentration or uptake increased beyond the maximum rate applied; --, fertilizer rate was not significant.

Plant phosphorus (P) concentration and uptake data is summarized in Table 5. Plant P concentration was maximized at high rates of fertilizer application. A maximum could not be achieved for only two sources, APP for all soils and for the CL and SiL soils with DAP. Uptake, on the other hand, was again maximized at lower rates of application. The only source where there was no apparent difference in uptake over fertilizer rates was for APP. The sources that maximized uptake at the lowest fertilizer rate was 9-18-9 and APP.

Plant potassium (K) concentration was seldom affected by fertilizer rate for the CL and SiL soils. However, there were significant differences between rates and rate responses for the FS. This is probably due to the lower K soil test of the sand and a lower ability of the soil to hold and supply K to the growing crop. Uptake was maximized at lower rates, but the interesting result was for KCl and KTS there were benefits in K uptake occurring at higher rates of applied product. This was similar to effects on growth were there was as benefit of a small rate of K fertilizer on the FS compared to the other two soils which received no benefit in plant growth or uptake from K. What is interesting is that the benefits seem to outweigh the risk on this type of soil. Since we did not broadcast fertilizer on the soil we do not know if the same effect would occur. The broadcast application would reduce the risk for seedling damage but the proximity may be important in terms of uptake. Field studies would be beneficial in this case to be able to determine the effect on yield. If no yield benefit occurred the risk for damage would be too great for an application. In all cases the sources containing P could be applied at higher rates, but these sources also had some of the lowest Salt Index values of all of the products.

Table 6. Summary of plant potassium (K) concentration and uptake response across starter rates. The critical level represents the rate that produced the highest concentration or uptake.

	Plant K Concentration			Plant K Uptake		
Product	Soil	Critical Level†		Soil	Critical Level†	
		-Lb/ac-	-gal/ac-		-Lb/ac-	-gal/ac-
7-21-7	CL, SiL	--	--	CL	48.2	4.4
	FS	149.1	13.6	FS	75.0	6.8
				SiL	74.1	6.7
KCl	CL, SiL	--		CL, SiL	0.0	
	FS	25.0		FS	15.2	
KTS	CL, SiL	--	--	CL	27.7	2.3
	FS	136.6	11.2	FS	34.8	2.9
				SiL	0.0	0.0
9-18-9	CL, SiL	--	--	CL	87.5	7.9
	FS	90.2	8.2	FS	47.3	4.3
				SiL	25.0	2.3

†+, concentration or uptake increased beyond the maximum rate applied; --, fertilizer rate was not significant.

Table 7. Summary of plant sulfur (S) concentration and uptake response across starter rates. The critical level represents the rate that produced the highest concentration or uptake.

	Plant S Concentration			Plant S Uptake		
Product	Soil	Critical Level†		Soil	Critical Level†	
		-Lb/ac-	-gal/ac-		-Lb/ac-	-gal/ac-
AMS	CL, SiL	+		CL, SiL	0	
	FS	139.3		FS	8.0	
ATS	CL, SiL	+	+	CL, SiL	0.0	0.0
	FS	100.9	9.2	FS	24.1	2.2
KTS	CL, SiL	+	+	CL, SiL	--	--
	FS	+	+	FS	21.4	1.8

†+, concentration or uptake increased beyond the maximum rate applied; --, fertilizer rate was not significant.

The Final nutrient studied was sulfur (S). Only three products studied contained sulfur, but these three were among the riskiest for application directly on the seed. Similar to N, S uptake tended to increase up to and beyond the highest rates applied. Plant S concentration did peak for the FS but this was due to emergence being reduced to 0 with the highest one or two rates applied. In these cases the concentration increased then when to 0 when the source completely inhibited emergence. In contrast, S uptake was increased at times but only for the FS. This is similar to what was seen with the high salt fertilizer with K. We would expect some benefit from S on these soils due to the low supply capacity of S coming from what limited organic matter the soils had. However, the rate used has to be balanced in terms of uptake and risk for stand damage. With the high potential risk for seedling damage broadcast S may be a better alternative.

Seed Safe Prediction Models

The overall goal of this research was to determine if one or two models could be used to predict seed safe rates across a number of fertilizer sources. A prediction model put out by South Dakota State University is available that takes into account effects on emergence. For this work we wanted to focus not only on emergence but also growth as there were positive benefits on early plant growth from fertilizer sources containing P. Emergence and growth where studied individually and compared to the rate applied and various combinations of total N, P, K, and S applied. Two damage indexes were calculated based on the emerged and growth data. The first was the mean of the two values and the second was the product of the two values which are termed Damage Index 1 and Damage Index 2, respectively. Data in Figures 1 and 2 shows an example of the relationship between total N+K_2O applied and Damage Index 1 and salt index units (SIU) and Damage Index 2 (SIU will be discussed later on) for the CL soil. Indexes had to be generated since there was a significant amount of variation in the average growth potential from the separate experimental runs. The two prediction models will be discussed separately.

The total amount of N+K_2O was compared to Damage Index 1. The model created was used to predict the amount of N+K_2O that could be applied at a relative index value of 100. In this case, the model predicted 10.0, 5.5, and 10.3 lbs of N+K_2O could be applied to the CL, FS, and SiL soils, respectively. Our current rule of thumb states no more than 10 lbs N+K_2O which is consistent with the data. There were some data points that did not fully fit on the line indicating some products may vary from this relationship. Using this data the rates that could be applied were predicted for the various products (Table 8). Since the CL and SiL soils did not vary their data were averaged together. The range in the data represents the best fit line determined with the model and the lower limit of the 95% confidence interval. Since there is a significant risk for seedling damage using the lower limit would be a more conservative approach to limit risk. However, it should be noted that two of the products, ATS and 9-18-9, may not be accurately predicted with this model. From past work we know the thiosulfate ion in ATS can cause significant reductions in stand. Using the total N+K_2O model does not account for this risk. In addition, the K source in 9-18-9 is a low salt source so the K_2O fraction may not be important in terms of damage potential. It should be noted that the **<u>ATS rate predicted in Table 8</u>**

SHOULD NOT be used as it is too high to safely apply on the seed. This will be discussed in more detail later in this report.

For the second model we wanted to utilize a rate factor to determine how much to apply. Rate alone does not accurately weight a fertilizer source for damage potential. In order to weight the sources the salt index of each source (Table 10) was multiplied times the rate applied to calculate salt index units (SIU) applied and compared to Damage Index 2 (Figure 2). The model fit information indicated that this model worked just as well at the N+K_2O model. Predicted rate data is given in Table 9 for the sources in the study. The biggest difference in rates was from ATS which was predicted to be much lower than the N+K_2O model and 9-18-9 which was higher. In fact, the ATS rates are in line with what is currently being used by some growers. It should be noted though that all of this data assumes adequate moisture in the soil. The models cannot be used to predict what happens in dry soils. We can make some generalizations from comparing the two loam soils to the FS where water holding capacity is roughly half compared to the other soils. While it cannot be definitively proven, reducing a rate by roughly half may be warranted in dry springs to reduce risk for stand loss.

It is important to consider the data analyzed for each product when looking at the modeled data. For instance, several products were found to have critical levels at 0 lbs per acre indicating none should be applied. However, the two models predicted a small amount could be applied for all sources. Since we have not tested this model in the field it should be used with some risk. Two of the fertilizer sources were not predicted the same with both models. Figure 3 shows the comparisons in the prediction models for the soils and highlights that issue (predicted rates are in Kilograms per hectare, but the relationship is the same as rates given in lbs per acre). One thing we did do was to factor in the total S applied in ATS and took out the total K applied in 9-18-9 (Figure 4). When this was done both products fit along the same line as the rest. It was curious that the thiosulfate in KTS did result in a difference between the two models. It appears that there is a difference in the damage potential related to what other ion is included with thiosulfate. In addition, sulfate when included with ammonium in AMS did not appear to behave like thiosulfate in ATS. Therefore, the salt index model may be better to use for an unknown product being tested. The predicted rate using the N+K_2O model is slightly more conservative predicting a rate 85% of the other model for the CL and SiL soils. Both models predict rates equally as well for FS.

Conclusions

This study found that small rates of P applied as starter fertilizer could promote early plant growth and nutrient uptake. Starter N, K, and S seldom affected plant growth except for a sandy soil where small rates of K and S increased plant growth. Fertilizer sources with high salt index values reduced emergence and growth at lower application rates. Sources containing P had the lowest impact on emergence and growth, but also had the lowest salt index values. The fertilizer sources with the highest risk of seedling damage were ATS, AMS, KCl, and urea.

Two models were developed to predict seed safe fertilizer rates. The first model predicted that 10 lbs of N+K_2O could be applied in soils with loam textures while 5 lbs could be applied for a sandy soil. However, this model over-predicted the amount of ATS and under-predicted the amount of 9-18-9 that could be safely applied unless the amount of S was factored in with ATS and the amount of K was discounted for 9-18-9. The salt index of the fertilizer source could be used to determine the seed safe rate when factored with the rate applied. However, both models tended to predict small amounts of fertilizer could be applied for sources such as ATS, AMS, KCl, and Urea. Since these models assume adequate moisture care should be taken when using the data in the field as none of this data is field tested. Use of high salt products (ATS, KTS, AMS, KCl, and urea) in-furrow comes with high risk so the practice is not recommended.

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Table 8. Summary of predicted seed safe fertilizer rates for the studied fertilizer source using the prediction model consisting of the total nitrogen and potassium (K_2O) applied related to the mean of plant emergence and average plant mass produced. ***THIS MODEL OVER PREDICTS RATES FOR ATS. THE ATS VALUE SHOULD NOT BE USED.***

	Clay Loam				Fine Sand				Silt Loam			
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
	--lb/acre--		--gal/acre--		--lb/acre--		--gal/acre--		--lb/acre--		--gal/acre--	
AMS	33.0	44.7			16.1	24.1			31.3	45.5		
APP	70.5	94.7	6.0	8.0	33.9	50.9	2.9	4.3	66.1	94.7	5.6	8.0
ATS	58.9	78.6	5.4	7.1	28.6	42.0	2.6	3.8	55.4	78.6	5.0	7.1
DAP	39.3	52.7			18.8	28.6			36.6	52.7		
7-21-7	54.5	73.2	5.0	6.7	26.8	39.3	2.4	3.6	51.8	74.1	4.7	6.7
KCl	14.3	18.8			7.1	9.8			13.4	18.8		
KTS	33.9	45.5	2.8	3.7	16.1	24.1	1.3	2.0	31.3	45.5	2.6	3.7
9-18-9	42.9	57.2	3.9	5.2	20.5	30.4	1.9	2.7	40.2	57.2	3.6	5.2
MAP	64.3	85.7			31.3	46.4			59.8	86.6		
UAN	25.0	33.9	2.3	3.1	12.5	17.9	1.2	1.7	23.2	33.9	2.1	3.1
Urea	15.2	20.5			7.1	10.7			14.3	20.5		

Table 9. Summary of predicted seed safe fertilizer rates for the studied fertilizer source using the prediction model consisting of the salt index times rate applied related to the product of plant emergence times average plant mass produced.

	Clay Loam				Fine Sand				Silt Loam			
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
	--lb/acre--		--gal/acre--		--lb/acre--		--gal/acre--		--lb/acre--		--gal/acre--	
AMS	18.8	29.5			6.3	13.4			18.8	28.6		
APP	64.3	100.0	5.5	8.5	21.4	43.8	1.8	3.7	62.5	96.4	5.3	8.2
ATS	14.3	22.3	1.3	2.0	4.5	9.8	0.4	0.9	13.4	21.4	1.2	1.9
DAP	44.7	68.8			15.2	30.4			42.9	66.1		
7-21-7	46.4	72.3	4.2	6.6	15.2	32.1	1.4	2.9	44.7	69.7	4.1	6.3
KCl	10.7	17.0			3.6	7.1			10.7	16.1		
KTS	18.8	29.5	1.5	2.4	6.3	13.4	0.5	1.1	18.8	28.6	1.5	2.3
9-18-9	77.7	119.7	7.0	10.8	25.9	52.7	2.3	4.8	75.0	116.1	6.8	10.5
MAP	48.2	75.0			16.1	33.0			46.4	72.3		
UAN	20.5	32.1	1.9	3.0	7.1	14.3	0.7	1.3	19.6	30.4	1.8	2.8
Urea	17.0	26.8			5.4	11.6			17.0	25.9		

Table 10. Summary of fertilizer sources, salt indexes, nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) concentration, and treatment application rate (based on 30" rows) for the eleven dry and liquid fertilizers used in the greenhouse study. Treatment 1 was the control (0 lb ac^{-1}) rate for each fertilizer source.

		Treatment Application Rate				
Fertilizer Source	Salt Index	2	3	4	5	6
		--------------------------------------lb ac^{-1}--------------------------------------				
AMS	68.0	21	42	83	167	333
APP	20.0	8	21	42	83	167
ATS	90.4	14	28	55	111	222
DAP	29.2	8	17	33	67	133
7-21-7	27.8	10	21	40	81	163
KCl	120.0	22	46	91	182	363
KTS	68.0	4	9	18	36	71
9-18-9	16.7	11	21	44	87	174
MAP	26.7	10	25	50	100	200
UAN	63.0	14	36	72	144	288
Urea	74.4	12	28	56	113	224

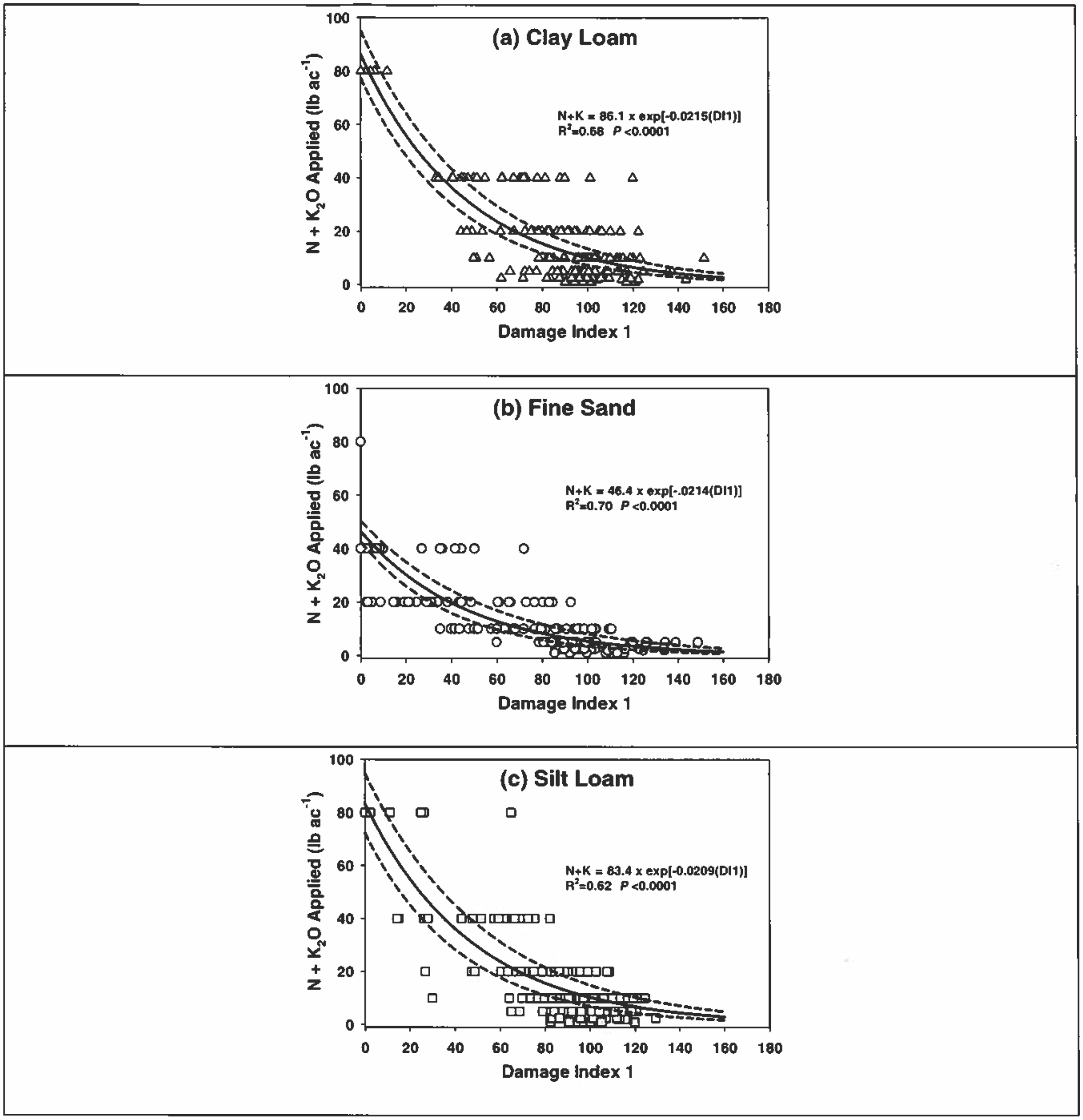

Figure 1. Relationship between Damage Index 1 and the total $N+K_2O$ applied for the three soils

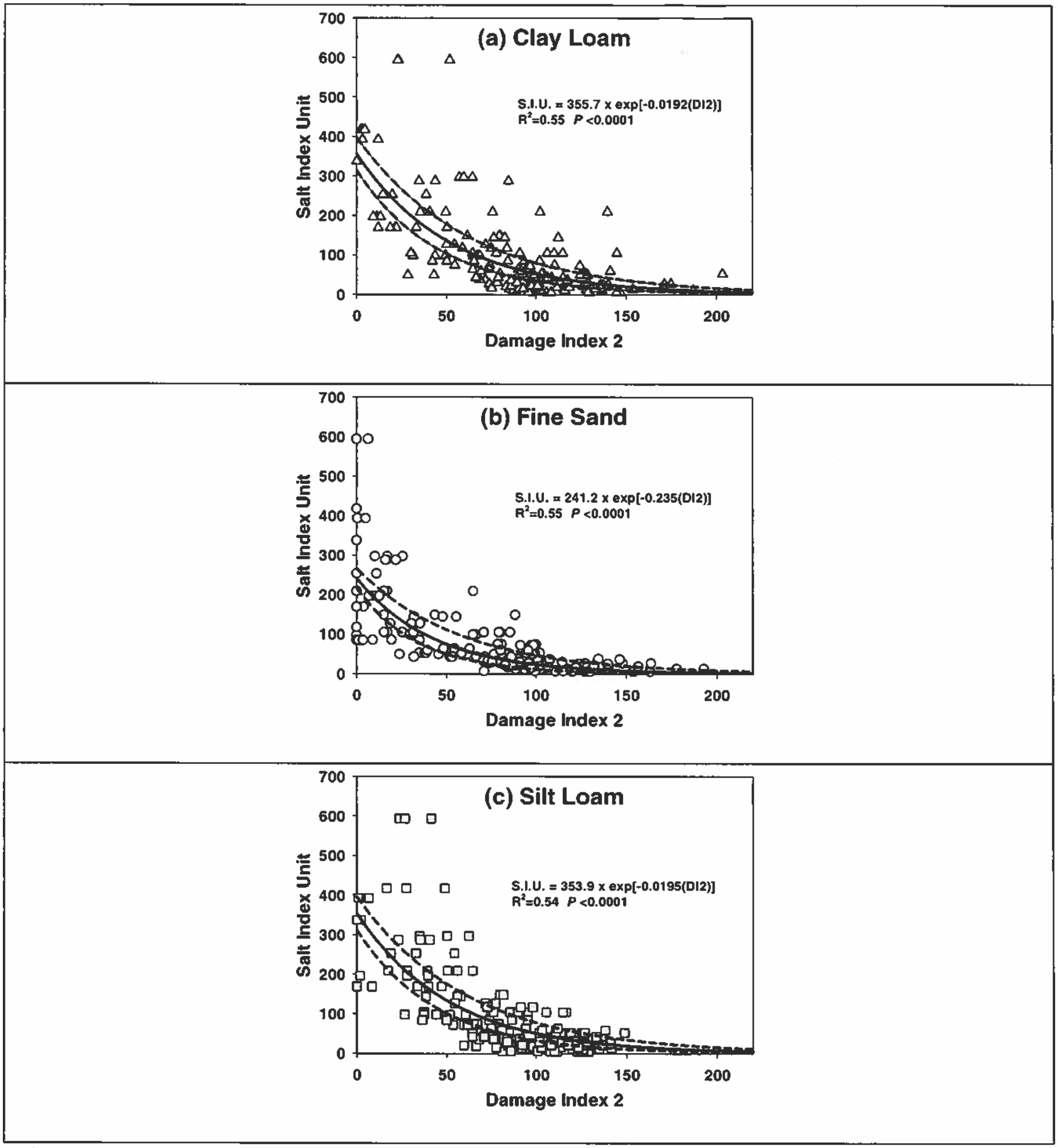

Figure 2. Relationship between Damage Index 2 and the salt index unit value for the three soils

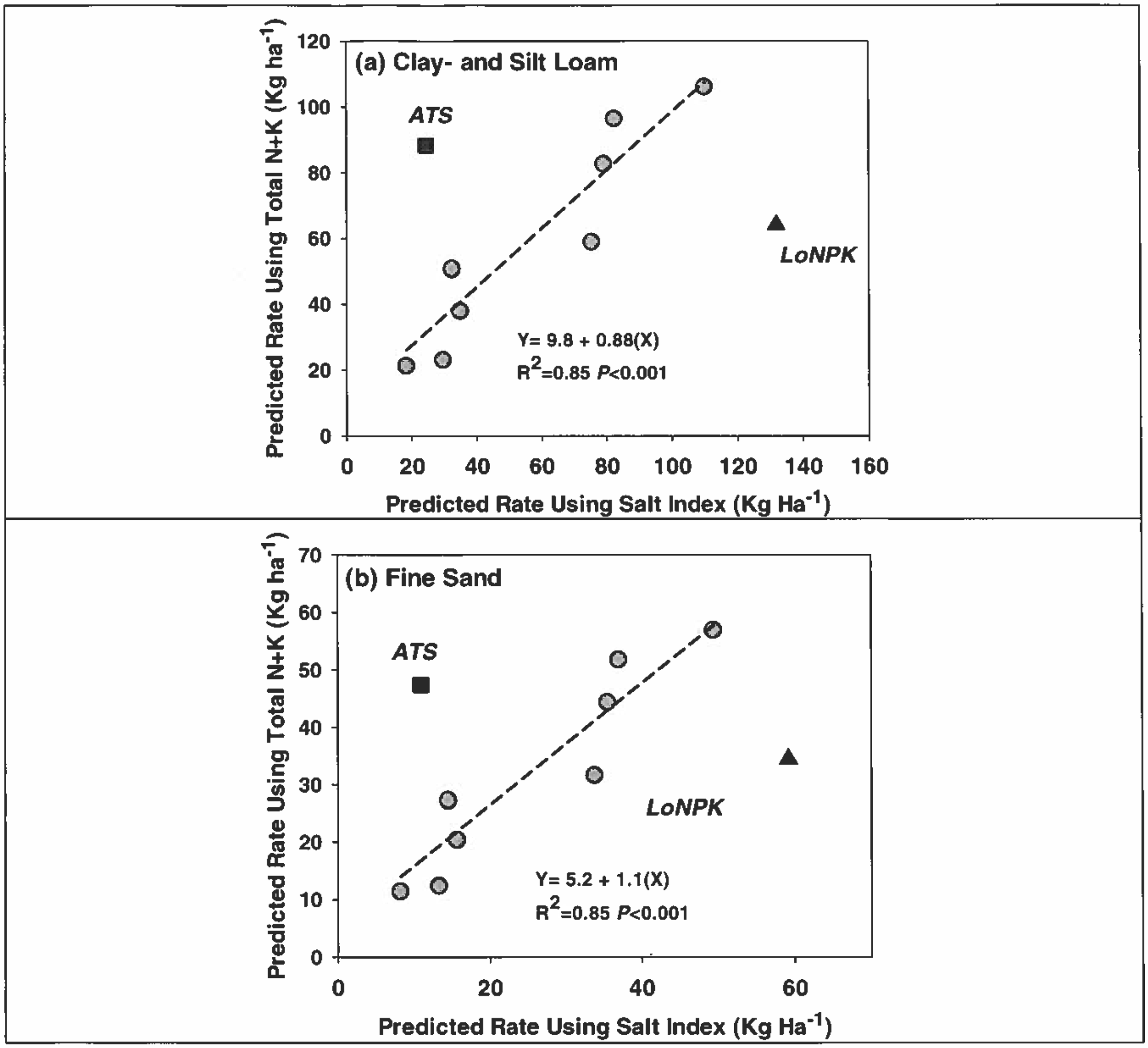

Figure 3. Relationship between the predicted seed safe fertilizer rate based on total N and K applied and fertilizer rate times the salt index. Values for the clay- and silt loam soils were averaged together in (a) and the data for the fine loamy sand is given in (b). The dashed line represents the linear relationship for all fertilizer sources except for ATS and LoNPK (9-18-9) which were excluded from the analysis.

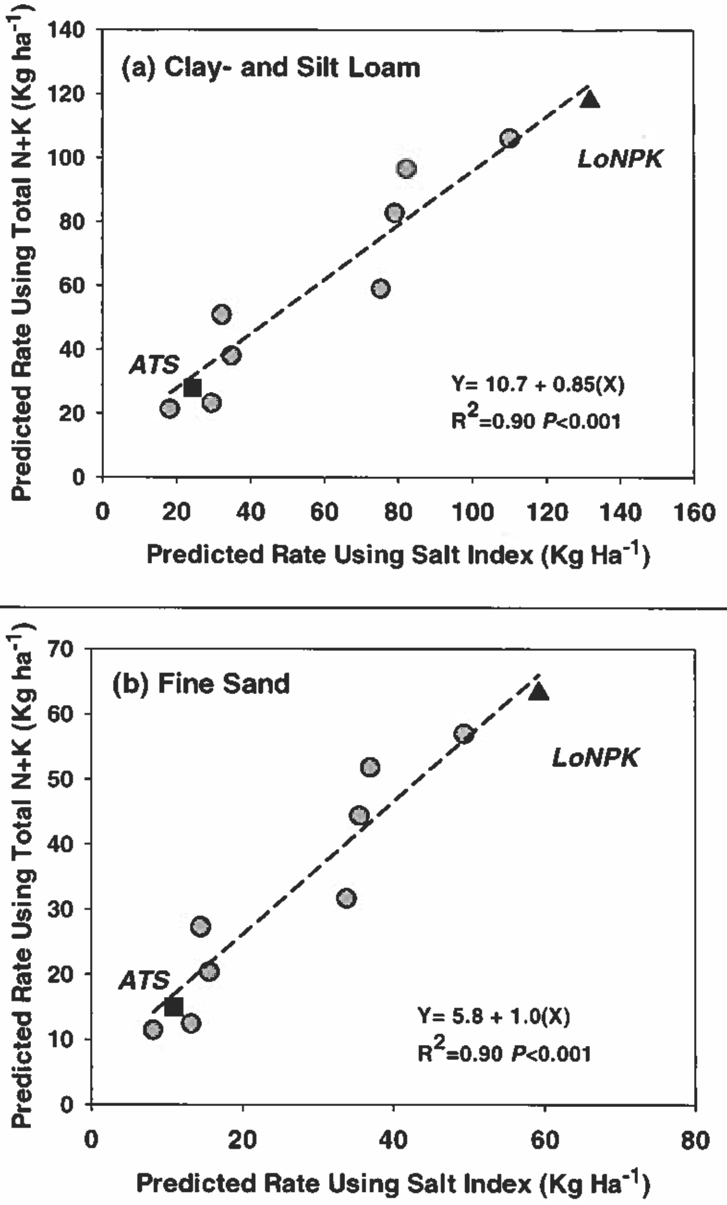

Figure 4. Relationship between the predicted seed safe fertilizer rate based on total N and K applied and fertilizer rate times the salt index. Values for the clay- and silt loam soils were averaged together in (a) and the data for the fine sand is given in (b). The dashed line represents the linear relationship for all fertilizer sources except for ATS and LoNPK (9-18-9) adjusted for total N and S applied for ATS and total N only for LoNPK instead of N plus K.