On-farm evaluation of fluid starter potassium fertilization for corn using precision agriculture technologies

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# TABLE OF CONTENTS

**LIST OF TABLES** iii

**CHAPTER 1. GENERAL INTRODUCTION** 1

  - **INTRODUCTION** 1
  - **THESIS ORGANIZATION** 3

**CHAPTER 2. ON-FARM EVALUATION OF FLUID STARTER POTASSIUM FERTILIZATION FOR CORN USING PRECISION AGRICULTURE TECHNOLOGIES** 4

  - **ABSTRACT** 4
  - **INTRODUCTION** 5
  - **MATERIALS AND METHODS** 9
  - **RESULTS AND DISCUSSION** 14
  - **CONCLUSIONS** 29
  - **REFERENCES** 31

**CHAPTER 3. GENERAL CONCLUSIONS** 51

**ACKNOWLEDGEMENTS** 54
LIST OF TABLES

Table 1. Year, location, planting date, hybrid, and soil test values for eight field trials. 35
Table 2. Predominant soil series of each site and mean initial soil-test K (0-15cm). 36
Table 3. Long-term average soil temperature at a 10 cm depth during April, May, and June near the research sites. 37
Table 4. Long-term average precipitation near the research sites. 38
Table 5. Potassium fertilization effects on grain yield across the entire strip length of each treatment at eight sites. 39
Table 6. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites. 40
Table 7. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites. 41
Table 8. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites. 42
Table 9. Potassium fertilization effects on corn grain yield for different soil series at each site. 43
Table 10. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) for different soil series at each site. 44
Table 11. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) for different soil series at each site. 45
Table 12. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) for different soil series at each site. 46
Table 13. Potassium fertilization effects on corn grain yield for different soil-test K interpretation classes within each site.

Table 14. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.

Table 15. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.

Table 16. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.
INTRODUCTION

Starter fertilization is a common practice used in some areas of the USA and the world. The placing of small amounts of granulated or fluid fertilizer in the seed furrow or near seedling roots usually increases plant early growth and nutrient uptake and sometimes grain yield. Questions about its use remain, however, mainly relating to the conditions in which its use is most effective and the relative starter effect of nitrogen (N), phosphorus (P), and potassium (K) of starter mixtures. In certain conditions band application of K fertilizer may be beneficial. Potassium is considered a relatively immobile nutrient and soil K diffuses to the roots through soil water from relatively short distances. Therefore, application of even a small amount of starter could increase plant growth and yield in conditions that limit seedling root growth (such as cold soil temperature, compaction, large residue cover that may result in cold and wet soils, and others). A crop response to starter could occur in these conditions even when soil-test levels would be adequate with normal conditions. Furthermore, if the potential for P or K retention by certain clay minerals in forms of low plant availability is high, the band placement may be beneficial for as well. Banding starter fertilizer near the seed provides a concentrated zone of nutrients that young plants can easily access. However, use of commercial fluid N-P or N-P-K starter mixtures by most farmers applying starter and in most research studies precludes firm conclusions about specific starter K effects on early crop growth and grain yield. Traditionally, major starter effects on corn and other grain crops have been attributed mainly to N and P, although some studies have
suggested that starter K could be beneficial in low-testing soils and conditions referred to above that limit growth of young plants.

Soil-test P and K levels in Iowa have been increasing over the years in farmers’ farms. This happens because of known residual effects of K fertilizers in most soils and because many farmers do not want to risk K deficiency in spite high soil-test levels in their fields. Large applications of P and K fertilizers for crops in soils with optimum soil-test K (STK) levels or high-testing soils seldom results in economic benefits. Therefore, use of a small amount of starter fertilizer K in these soils could alleviate producers' fears of a K deficiency and would correct induced deficiency because of largely unpredictable conditions explained above. Also, large spatial variability of K in fields with contrasting soil types, yield levels, or long histories of cropping and fertilization has been recognized for a long time. Precision farming technologies such as yield monitors, differential global positioning systems, and geographical information systems, allow producers to generate yield maps capable of identifying and estimating the yield variability over the landscape. This technology can be used to study treatment effects on yield and plant-tissues and relationships between their variability and soil characteristics over the landscape with much less cost than other methodologies. Furthermore, global positioning systems technology and geographical information systems allow for a more effective use of dense soil sampling and soil-test maps to study soil-test variation across a field.

Therefore, the objectives of this study were: (i) to evaluate early growth, early K uptake, and corn grain yield responses to in-furrow liquid K starter fertilization, (ii) to compare corn response to starter with responses to broadcast K fertilization rates commonly
used by Iowa farmers, and (iii) to evaluate these responses for field areas with different soil

test levels and soil series.

**THESIS ORGANIZATION**

This thesis will be presented as one paper suitable for publication in Agronomy

Journal. The title of the paper will be “On-Farm Evaluation of Fluid Starter Potassium

Fertilization for Corn Using Precision Agriculture Technologies.” The paper is divided in

sections that include an abstract, introduction, materials and methods, results and discussion,

conclusions, reference list, and tables. The paper is preceded by a general introduction and

followed by general conclusions.
CHAPTER 2. ON-FARM EVALUATION OF FLUID STARTER POTASSIUM FERTILIZATION FOR CORN USING PRECISION AGRICULTURE TECHNOLOGIES

A paper to be submitted to Agronomy Journal by
N. Bergmann and A.P. Mallarino

ABSTRACT

Use of fluid N-P or N-P-K starter mixtures in most research studies precludes firm conclusions about specific starter K effects on early crop growth and grain yield. This study evaluated corn (*Zea mays* L.) early growth, early plant K concentration and uptake, and grain yield response to fluid starter K fertilizer. Eight trials were conducted during 2007 and 2008 in Iowa farmers’ fields using a strip trial methodology, global positioning systems, yield monitors, and geographical information systems. Six sites were managed with chisel-plow tillage and two with no-tillage. Soil-test K (STK) was measured using a dense grid sampling approach (0.13-to 0.4-ha cells). Treatments replicated three times were a control, commercial fluid K$_2$CO$_3$ starter (0-0-25 N-P-K) applied in the seed furrow at 14 to 21 kg K ha$^{-1}$, broadcast K at 112 kg K ha$^{-1}$, and broadcast K plus starter K. Means from the entire length of the strips showed that K fertilization did not affect early plant dry weight (DW) or K uptake consistently, but increased K concentration at most sites and increased grain yield at three sites. At two sites broadcast K increased yield more than starter K, and at one site both fertilizers increased yield similarly. Sites with plant DW or K uptake responses did not
show a yield response. Starter K in addition to broadcast K did not increase yield further. Analyses of plant measurements by soil series or areas with STK in various STK interpretation classes for each field did not show consistent differences in responses to starter or broadcast K. Overall, the results showed that starter K seldom increased early corn DW or K uptake and the infrequent increases seldom resulted in increased grain yield. Starter K applied in addition to broadcast K rates commonly applied by farmers did not increased yield further.

Abbreviations: DGPS, global positioning systems; DW, dry weight; GIS, geographical information systems; STK, soil-test K.

**INTRODUCTION**

Starter fertilization is a common practice used for grain crops in some areas of the USA. The placing of small amounts of nutrients applied in bands beside and below the seeds or in the seed furrow significantly increases the concentration of nutrients in a small soil volume where seedling roots grow. Granulated or liquid starter fertilizers often are N-P or N-P-K mixtures, and sometimes other nutrients are added. Previous research summarized by thorough reviews (Randall and Hoeft, 1988; Bundy book chapter 2005) indicated that starter fertilization often increases corn early growth and nutrient uptake more compared with similar broadcast fertilization rates, and sometimes also compared with even larger broadcast rates. The early growth response to starter usually is large and more frequent with soil and climate conditions that limit root growth, nutrient uptake, the concentration in the soil of nutrient forms plants can absorb, or the diffusion of nutrients to the root. These reviews and more recent research also indicated, however, that starter effects on corn grain yield are not
as consistent as for early growth or nutrient uptake due to a variety of factors sometimes not completely understood.

Adoption of no-tillage by farmers has been increasing steadily. Early corn growth and grain yield response to N-P or N-P-K starter fertilization is more likely to occur with reduced tillage because of high residue cover keeps soil cooler and wetter during early growth (Kaspar et al., 1990; Mengel et al. 1998; Wolkowski, 2000; Vyn and Janovickek, 2001). This is not always the case, however, as other research has shown inconsistent differences across tillage systems that often were not clearly explained but were attributed to complex interactions between soil conditions, climate (both rainfall and temperatures), and planting dates. Vetsch and Randall (2002) reported that early corn height response to an N-P-K starter mixture was inconsistently affected by four tillage systems and corn yield response to starter was similar for all tillage systems. Vyn et al. (2002) evaluated corn early growth and grain yield response to broadcast, deep band, and half broadcast and half shallow-band fertilization. All treatments were applied to no-tillage, spring zone tillage, and spring mulch-tillage and they found that K sometimes increased corn yield with no-till or zone tillage but not with spring mulch tillage. Bermudez and Mallarino (2004) conducted seven strip trials on Iowa corn fields managed with no-till or tillage and found that responses of grain yield, early plant dry weight, and early nutrient uptake to N-P-K liquid starter were similar with tillage or no-tillage. Kaiser et al. (2005) worked on various Iowa farmers' field managed with no-till or tillage. The frequency and size of corn response to starter was similar for no-till or tilled fields, and in furrow P-K starter fertilization after a much larger broadcast P-K rate sometimes increased early growth further but never increased yield.
further. Work in the northern Great Plains (Osborne, 2005) with corn managed with tillage or no-tillage showed corn yield response to starter.

Starter fertilizers usually include two or more nutrients and the nutrients responsible for increased early plant growth or grain yield seldom are clearly identified. Phosphorous is an essential nutrient and plants are more in need of P when they are young than later in the season. Also, P is usually referred to as a relatively immobile nutrient compared to other nutrients and its diffusion to seedling roots is limited by cold soil temperatures. Therefore, it is not surprising that research findings showed that the crop response to starter fertilizer often is explained by P in the starter mixture mainly in soils testing low in P and sometimes also in high-testing soils (Randall and Hoeft, 1988; Bundy book chapter 2005; Roth, 2006).

However, research summarized by these reviews and other research also has shown that the corn response to starter often is explained by N in the mixture, especially in soils testing high in P. In his review, Bundy (book chapter 2005) suggested that responses to starter N tend to be more frequent in northern areas of the Corn Belt. In Iowa, for example, Bermudez and Mallarino (2003) compared liquid N and N-P starter fertilizers applied beside and below the corn seeds on eight high-testing fields managed with no-till and found that grain yield response always was explained by starter N.

Use of liquid N-P-K starter mixtures in most studies precludes firm conclusions about starter K effects on corn without the confounding effects of other nutrients in the mixture. The numerous studies using N-P-K or P-K nutrient mixtures have indicated that, as expected, the K included in the mixtures may explain part or all of the early corn growth and yield responses to starter in soil testing low in K. However, these studies provide conflicting evidence or no clear evidence of a true starter K effect. We believe that a true starter effect
exists when a plant growth increase is larger for starter than for a similar or larger nutrient rate applied by a different placement method. All previous Iowa research studies with liquid starter mixtures provided no useful clues one way or another (Bermudez and Mallarino, 2002; Bermudez and Mallarino, 2003; Bermudez and Mallarino, 2004; Kaiser et al., 2005). Bordoli and Mallarino (1998) and Mallarino et al. (1999) compared placement methods of granulated P or K fertilizers for corn at rates slightly higher than common starter rates at five Iowa locations testing low to high in P or K (the lowest rates were 0.14 kg P ha⁻¹ or 33 kg K ha⁻¹). They showed greater corn early growth and P uptake for P banded beside and below the seeds than for similar pre-plant broadcast P rates, and the response to banded P was also observed in high-testing soils. Similar comparisons for K fertilizer showed no differences between placement methods for early growth in soils testing low to high in K, although plant K concentration was greater with banded K.

Knowledge of the existence of a true starter K effect on corn and the conditions in which it is more likely is important to improve K use efficiency and the economics of production agriculture. This is because many producers' fields test optimum or high in soil K, most states fertilization guidelines recommend starter for these soils under certain conditions, and many starter fertilizers include expensive K compounds in an attempt to minimize seedling damage due to high salt concentration. Therefore, the objectives of this study were: (i) to evaluate corn early growth, early K uptake, and corn grain yield responses to in-furrow liquid K starter fertilization and (ii) to study the benefit of starter K fertilization in addition to broadcast K fertilization rates commonly used by Corn Belt farmers.
MATERIALS AND METHODS

This K fertilizer study with corn was conducted in eight Iowa farmers' fields from 2007 to 2008. Two-year trials were established in central, east, east-central, southeast, and northeast regions of Iowa. The fields were chosen to represent a wide range of STK levels and soil series of major Iowa corn production areas. Corn and soil management practices were those normally used by each farmer and varied among fields. Table 1 shows trials locations and other site information and Table 2 shows information for the dominant soil series at each site. At Sites 3 and 4 corn was managed with no-tillage, and the planters had a sweeper that removed residue from the row. At Sites 1, 2, 5, 6, 7 and 8 the tillage consisted of chisel-plowing in the fall and spring disking.

The study used an on-farm, strip-trial research methodology based on dense soil sampling, differential global positioning systems (DGPS) receivers, yield monitors, and geographical information systems (GIS) that was used before for research with starter mixtures, broadcast fertilizer, or liming (Bermudez and Mallarino, 2002 and 2004; Bianchini and Mallarino, 2002; Bermudez and Mallarino, 2007). Treatments replicated three times at each site were a control receiving no K fertilizer, 112 kg K ha\(^{-1}\) broadcast K (granulated KCl fertilizer), a target starter rate of 17 kg K ha\(^{-1}\) using a commercial liquid K\(_2\)CO\(_3\) starter product (0-0-25 N-P-K) applied to the seed furrow, and starter K in addition to broadcast K. The corn planters were equipped to apply liquid starter in the seed furrow. Row spacing was 76 cm at all sites. The planter starter attachments were calibrated at each site before planting corn and applying starter to apply the desired K rate. However, measurements of product applied indicated that the actual starter K rate applied was the same at each site but ranged from 14 to 21 kg K ha\(^{-1}\) across sites. The broadcast K was applied in the spring. This
broadcast K rate is the recommended rate in Iowa for soils testing Very Low in K, and is commonly applied by Iowa farmers before corn of corn-soybean rotations to maintain an Optimum STK level (Sawyer et al., 2002).

The experimental area of each trial ranged from approximately 7 to 11 ha across fields, and was established at least 45 m from field borders. Each area was divided across future corn rows into three blocks each further subdivided into four strips to fit the four treatments. The blocks corresponded to the three replicates of a split-plot design, in which the two broadcast treatments were randomized to large plots (each treatment to two adjacent strip) and the starter fertilizer treatments were in the subplots (each to one strip). Strip length was the same at each field but varied across fields according to field length. The strip lengths was 293 m at Sites 1, 2, 3 and 6, 366 m at Site 5, 695 m at Site 7, and 585 m at Site 8. Strip width varied across fields from 9 to 27 m according to planters, fertilizer spreaders, and combines width. Each trial was set up using a measuring tape, and a measuring wheel. Georeferences of the four corners of the experiment were taken with a DGPS receiver with a differential signal correction using WAAS (Wide Area Augmentation System), and the coordinates were exported to ArcGIS (Environmental Systems Research Inst., Redlands, CA) to make a coverage of the experimental layout.

The farmers applied P fertilizer across the entire experimental areas using rates higher than those recommended in Iowa for corn based on soil-test P and estimates of P removal with harvest because they wanted to apply once before corn the P needed by planned soybean crops for the next year. The farmers also applied N fertilizer at rates that were at least as high as the highest N rates recommended in Iowa (Blackmer et al., 1997), which are 168 kg N ha$^{-1}$ for corn after soybean and 224 kg N ha$^{-1}$ for corn after corn. Rainfall and temperature
data summarized in Tables 3 and 4 were obtained from weather stations located 10 to 40 km from the sites (Iowa Environmental Mesonet, mesonet.agron.iastate.edu/index.phtml).

Soil samples were collected before applying K treatments but after establishing the experimental layouts following a systematic grid-point sampling method (Wollenhaupt et al., 1994). The spacing between grid lines across the strips (and across future corn rows) coincided with the width of each replication (four strips, 36 to 109 m) and the separation along strips was 36 m for all sites (grid cell size was 0.13 to 0.4 ha). Composite soil samples (12 cores from a 15-cm depth) were collected from an area approximately 200 m² in size located at the center of each cell. The soil samples were analyzed for STK by the ammonium-acetate method (Warncke and Brown, 1988), soil pH was measured using a 1:1 soil/water ratio, and organic matter was measured using a combustion method (Wang and Anderson, 1998). Iowa State University soil test interpretation classes (Sawyer et al., 2002) were used to classify STK ranges. The STK classes for soil series classified as having low subsoil K (most in Iowa and in this study) are (in mg K kg⁻¹) \( \leq 90 \) for Very Low, 91 to 130 for Low, 131 to 170 for Optimum, 171 to 200 for High, and \( \geq 201 \) for Very High. The STK classes for soil series classified as having high subsoil K (in this study only the series Mahaska and Wiota) are (in mg K kg⁻¹) \( \leq 70 \) for Very Low, 71 to 110 for Low, 111 to 150 for Optimum, 151 to 180 for High, and \( \geq 181 \) for Very High. The STK data were imported into ArcGIS to calculate various statistics for the entire experimental area and for each soil series present in each field. Coordinates for soil series borders were imported to ArcGIS from digitized, 1:12000 scale Iowa soil survey maps (Iowa Cooperative Soil Survey, 2008).

Corn early growth was measured at the V5 to V6 growth stage (Ritchie et al., 1986) by sampling the above-ground portion of ten plants. The plant samples were collected from
the center of each cell defined by the treatment strip width and the distance between soil
sampling grid lines along the crop rows. The samples were dried at 65°C in a forced-air
oven, weighted, and ground to pass through a 2 mm screen. Total plant K was measured by
first digesting the ground samples in 70% concentrated HNO₃ and 30% H₂O₂ and then
measuring K concentration by inductively-couple plasma emission spectroscopy. Early K
uptake was calculated from dry weights (DW) and K concentrations. The plant DW, K
concentration, and K uptake data were imported into ArcGIS to calculate means for areas
defined by each strip and also for each soil series present in the fields.

Grain yield was harvested and recorded with combines equipped with impact flow-rate
yield monitors and GPS receivers with differential correction (WAAS). The monitors
were calibrated by weighing grain harvested along combine passes outside the experimental
areas. The yield monitors used were Ag Leader models PF 3000 or Insight (Ag Leader
Technology, Ames, IA), or AFS Pro 600 (CASE IH, Racine, Wisconsin) The monitors
recorded a yield value at 1-s intervals. Grain moisture was determined by a sensor located in
the combine auger, and yield was corrected to 155 g kg⁻¹ moisture. The yield monitor spatial
accuracy was checked in several field locations with a hand-held DGPS receiver. The yield
records were imported into ArcGIS for further processing. Yield data were unaffected by
borders because at least 40 m at each strip end were harvested but not used, and at least two
corn rows on each side of a strip border was harvested but not used (border data were deleted
using ArcGIS). The data also were analyzed for common yield monitor problems such as
unexpected combine stops or waterways, and affected data were deleted. ArcGIS was used
to calculate means for areas defined by each strip, for each soil series present in each field,
and for each soil sampling cell.
Treatment effects on the crop measurements were analyzed by three procedures using the MIXED procedure of SAS (SAS Institute, 2006). One procedure assessed treatment effects for the entire experimental area of each site, for which data input were means of all records for each strip (12 numbers for each site, from four treatments and three replications). The ANOVA for this procedure was conducted according to a randomized, complete-block, split-plot design assuming fixed treatment effects and random replication (blocks) effects. The treatment sums of squares were partitioned into main effects of broadcast and starter treatments and their interaction. Two other procedures assessed treatment effects for each soil series and field areas having STK within different Iowa interpretation categories using methods used by others (Bermudez and Mallarino, 2002 and 2004). For grain yield the data input were means of all yield monitor records for areas defined by the width of each strip and the separation distance of the soil sampling grid lines along the strips. For plant DW, K concentration, and K uptake measurements the input data were derived from one sampling point from each small cell defined by the width of each treatment strip and the separation distance of grid sampling lines along crop rows. Each line of the input data set for each site consisted of codes for treatment, replication, soil series, sampling cell, STK interpretation category as appropriate, and the values for each crop measurement. A split-plot ANOVA (broadcast K in large plots and starter K in subplots) was conducted with PROC MIXED for each soil series or each STK category, in which sources of variation were the treatments (assumed to be fixed effects) and the individual cells (assumed to be a random effect). These two procedures were applied only when the area of each soil series or STK interpretation category encompassed at least two replications (blocks) of the field design.
RESULTS AND DISCUSSION

Corn Response to Potassium Fertilization for the Entire Length of Strips

Grain Yield

Potassium fertilization increased ($P \leq 0.05$) corn grain yield as evaluated by means of data collected across the entire length of the treatment strip means at three of the eight sites (Sites 1, 4, and 6), and results are shown in Table 5. There was a significant interaction between broadcast and starter K at all responsive sites, which indicated that the response to K applied by one method was affected by the level of the other. At Sites 1 and 6 broadcast K alone increased grain yield more than starter K alone, and starter K applied in addition to broadcast K did not increase yield further. At Site 4, broadcast K alone and starter K alone increased corn yield more than the application of starter K in addition to broadcast K. We believe that the small differences among the three fertilizer treatments at this site (0.13 to 0.53 Mg ha$^{-1}$) resulted from site variability, however. It is difficult to explain why starter K in addition to broadcast K incorporated with tillage would result in lower yield than either treatment applied alone.

The mean initial STK values for these fields (Table 1) and current STK interpretations explained these responses only partially. At Site 1 STK was 214 ppm on average (Very High but near the High class) but ranged from Low to Very High. At Site 4 STK was 102 ppm on average (Low class) but ranged from Very Low to a value borderline between Low and Optimum. At Site 6 STK was 130 ppm on average (borderline between
Low and Optimum classes) but ranged from a value borderline between Very Low and Low to the upper range of the High class. Therefore, according to mean STK values, the responses were within expectations for Sites 4 and 6 but not for Site 1. Previous Iowa research has shown that the probability of corn response to K fertilization for STK interpretation classes Very Low, Low, Optimum, High, and Very High is 80, 60, 25, 5, and 1\% respectively (Sawyer et al., 2002). A yield response for a mean STK of 215 mg K kg\(^{-1}\) (Very High but borderline with the High class) at Site 1 is unlikely but possible. However, this yield response also could be explained by high within-site variability because STK was in the deficient range (less than High) in 33\% of the area. A lack of response to starter K when such a high broadcast K rate had been applied at all responsive sites coincide with results for P-K starter or broadcast mixtures reported by Kaiser et al. (2005). Information about soil temperature (10 cm depth) and precipitation (Table 3 and 4) near corn planting time did not help to explain a response or lack of response to starter fertilization.

**Early Plant Growth**

Potassium fertilization affected \((P \leq 0.05)\) corn early growth only at four sites (Sites 2, 3, 5, and 8), and the treatment differences were small and inconsistent (Table 6). There was an interaction between the two K application methods at Sites 2, 3, and 5. At Site 2, starter K alone increased corn growth slightly, while broadcast K alone or broadcast plus starter K did not increase growth or decreased it slightly. At Site 3, all K treatments increased early growth but broadcast K alone produced the highest response, however, while starter K in addition to broadcast K reduced growth slightly compared with broadcast K alone. At Site 5 all K treatments decreased early growth compared with the control but the
decrease was smaller for starter alone. At Site 8 there was no significant treatment interaction, and the data and statistics for the main effects indicate that starter K did not increase early growth while broadcast K alone increased it slightly. An interesting result was that sites in which K increased early plant DW, grain yield was not affected by K fertilization. The results for Sites 2 and 5 suggest that the total amount of K applied with broadcast and starter methods was excessive for corn early growth, while for Site 8 starter K reduced growth slightly. These effects probably were due to high salt concentration in the seedling root zone. Unfortunately, plant population was not measured so we cannot say if this effect was due to loss of plants or inhibited growth. The lack of early growth increases due to starter K or decreases are in sharp contrast with previous Iowa results for starter P-K or N-P-K mixtures applied to the seed furrow or besides and below the seeds (Bermudez and Mallarino, 2002, 2003, 2004; Kaiser et. al., 2005). In these previous studies the starter fertilizers increased early corn growth very frequently, even after applying broadcast P and K or in high-testing soils, and with or without increasing grain yield.

**Early Plant K Concentration and Uptake**

One or more K fertilization treatments increased \((P \leq 0.05)\) early plant K concentrations at five sites (Sites 3 through 7) (Table 7). At Sites 3, 4, and 5 the increases were statistically similar for all treatments (no interactions). At Sites 2 and 6, however, the data and significant interactions indicate that broadcast K alone increased K concentration further than starter K alone. It is of interest to note that grain yield responses (Table 5) were observed only at two Sites (Sites 4 and 6) where fertilization increased early plant K concentration but where it did not increase early plant DW.
Early corn K uptake responses integrated responses of early plant DW and K concentration but the influence of early DW responses was stronger and, therefore, results were as inconsistent as for early DW (Table 8). One or more K treatments influenced early K uptake \((P \leq 0.05)\) at three sites (Sites 1, 2, and 3). There were significant interactions between broadcast and starter treatments at Sites 1, 2, and 3. At Site 1, broadcast K alone increased K uptake while starter K decreased it slightly. At Site 2, only starter alone increased K uptake. At Site 3, all fertilizer application increased K uptake but the increase was highest when broadcast K was applied with or without starter K. We believe that these inconsistent K effects on early K uptake were mainly due to inconsistent, small, and highly variable effects on early growth. An interesting result was that sites in which K increased early K uptake, grain yield was not affected by K fertilization.

**Corn Response to Potassium Fertilization By Soil Series**

Soil series may be an important source of variation in corn response to K fertilization within each site because of potential differences in STK and other soil properties that may affect crop growth and response to K. This analysis was conducted for all measurements from the two dominant soils at all sites except for Site 4, where there was only one dominant soil. All other soils present in the sites did not fulfill established replication requirements.

**Grain Yield**

Table 9 shows grain yields for the different soil series within each field. Results for Site 1 showed that the response for means across the entire length of the strips observed at this site (Table 5) is explained by a response only for areas with Zook soil, being greater for
broadcast K than for starter K, because there was no significant or clear responsive trend for the Koszta soil. At Site 6, the observed response for means across strips (Table 5) is explained by a small and statistically significant response for areas with Koszta soil and for a larger response for the Wiota soil. Data in Table 2 show that at Site 1 mean STK was similar and High for both soil series while at Site 6 STK was borderline between Low and Optimum for areas with Koszta soil and Low for areas with Wiota soil. Therefore, we believe that the differences between soil series for these two fields might be explained by a combination of within-soil variation (in yield and STK) and soil properties other than STK that influence crop response to K fertilization. At Site 1 the STK average was approximately the same for both soils but with lowest minimum STK for the Koszta soil. However, the Zook soil properties may favor a larger K requirement than for the Koszta soil. The Zook soil is a very deep, silty-clay-loam, poorly drained soil formed in alluvium while the Koszta soil also is very deep but the top layer is of coarser silt-loam texture and is better drained than Zook (Iowa Cooperative Soil Survey, 2008). Previous research has shown greater crop K needs for poorly drained Iowa soils (Mallarino et al., 2002; Mallarino et al., 2004; Sawchik and Mallarino, 2008). At Site 6, STK was in the responsive range for both soils but was clearly lower for the Wiota soil. This matches well the magnitude of yield response, but not the statistical results. However, the more poor drainage and finer topsoil texture of the Koszta soil could determine a more consistent response to K than for the better drained and coarser-textured Wiota soil. The Wiota series consists of very deep, silty-clay-loam, moderately well drained soils formed in alluvium.

There was a yield response to K fertilization for at least one soil series at Sites 3, 5, and 7 (Table 9), where there was no grain yield responses for whole-strip averages. At Site
there was a response for the Webster soil but a non significant responsive trend for the Clarion soil. The STK mean levels were approximately similar and in the Optimum class for both soils but there were lowest and highest STK values for the Webster soil, including values as low that were classified into the Very Low class (Table 2). Also, other soil properties suggest a more likely and greater response to K for the Webster soil than the Clarion soil because Webster is more poorly drained and its topsoil has a finer texture. At Site 5, there was a response of an approximately similar magnitude for areas with Floyd and Tripoli soils. For both soil series there was a response to broadcast K alone and starter K alone, being slightly higher for broadcast K alone. Starter K in addition to broadcast K did not increase yield further or decreased it slightly. The mean STK levels for both soils were in the Optimum class (Table 2), where a small to moderate response is expected but was lower for the Floyd soil. The Floyd series is a very deep, loamy, somewhat poorly drained soil formed in loamy sediments and underlying glacial till. The Tripoli series is also a very deep soil, formed in loamy sediments and underlying glacial till, but its upper layer is of clay-loam texture and is more poorly drained than Floyd. Therefore, both STK and internal drainage characteristics probably explain the response in both soils. At Site 7, there was a significant response for areas with Mahaska soil (greater for starter K alone than for broadcast K alone and no further response from starter applied in addition to broadcast) but not even a responsive trend for areas with Taintor soil. A higher response for the Mahaska soil is reasonable because data in Table 2 show that STK was borderline between High and Very High, while areas of Taintor soil tested much higher. Both soil series consist of very deep, silty-clay-loam, somewhat poorly drained soils formed in loess. The magnitude of the
yield response in areas of Mahaska soil was higher than expected, but according to previous Iowa data it can occur with a 5% probability.

**Early Plant Growth**

Table 10 shows early plant DW data for different soil series within each field. At Site 2, where the whole-strip analysis showed that only starter K alone increased early corn DW slightly, the analysis by soil series showed essentially the same response for both Readlyn and Kenyon soils. At Site 3, where the whole-strip analysis showed that only broadcast K increased early DW slightly, the analysis by soil series showed a similar plant growth response for areas of Clarion and Webster soils. At Site 5, where the whole-strip analysis showed that all K treatments reduced early DW, the analysis by soil series showed a decrease or no increase for the Floyd soil and a decrease for the Tripoli soil. At Site 8, where the whole-strip analysis showed that only broadcast K increased early DW, the analysis by soil series showed a similar to Mahaska soil and a larger but a statistically non-significant responsive trend for all K treatments in areas with the Otley soil. We expected a growth response for both soil series in this field because there were los STK values for both soils (Table 2), and both are very deep soils formed in loess with a moderate permeability that may result in increased K needs. Therefore, we cannot explain the differential response between soils.

The analysis by soil series also showed an early corn DW response to K fertilization for at least one soil series at Sites 1 and 7 (Table 10), where the analysis of responses for the whole-strip averages showed no statistically significant growth responses. At Site 1, there was a significant early DW response for the Zook soil (being larger for broadcast K alone)
but no response for the Koszta soil, which coincide with the observed grain yield responses. In general, Zook soils are located on areas low in the landscape or flood plain areas where the drainage is poor and the growth response to K fertilization is more likely. At Site 7 the only statistically significant result was that starter K alone increased early DW in areas of Mahaska soil, although there was an even larger non-significant responsive trend for all K treatments in areas of Taintor soil. The initial STK level for Mahaska soil was borderline between the High and the Very High classes while it was even higher for the Taintor soil. Both series consist of very deep, silty-clay-loam, somewhat poorly drained soils formed in loess so we do not understand the differential responses between soils.

It is of interest to compare corn early growth and grain yield responses for the analysis by soil series. Potassium fertilization (starter or broadcast) increased early plant DW in three of the six soil series in which K also increased grain yield (Zook in Site 1, Webster in Site 3, and Mahaska in Site 7) but did not affect or decreased early DW in three of the yield responsive soil series (Floyd and Tripoli in Site 5 and Koszta in Site 6). On the other hand, at least one K treatment increased early DW in three soil series in which K did not increase yield (Readlyn in Site 2, Clarion in Site 3, and Mahaska in Site 8) and decreased early DW where K also decreased yield (Kenyon in Site 2).

**Early Plant K Concentration and Uptake**

The analysis by soil series showed a statistically significant \( P \leq 0.05 \) early corn K concentration response to K fertilization for most soils (Table 11). This result was also observed for the whole-strip analysis, and it is in sharp contrast to results for early corn DW. Potassium fertilization did not increase plant K concentration only for one of the two
dominant soil series in Sites 1 (Koszta), 5 (Floyd), and 7 (Taintor). For the responsive soil series, the K concentration increases from broadcast K alone and starter K alone were similar for three site-series combinations (both Clarion and Webster soils at Site 3 and Koszta at Site 6) but were larger for broadcast alone for six instances (Zook at Site 1, both Readlyn and Kenyon at Site 2, Tripoli at Site 5, Wiota at Site 6, and Mahaska at Site 7). The starter K alone did not increase K concentration more than broadcast alone at any site except for the Clarion soil at Site 3. Starter K in addition to broadcast K increased K concentration further than broadcast alone for both Clarion and Webster soils at Site 3 and both Koszta and Wiota soils at Site 6.

The analysis of plant K uptake responses showed fewer responses to K fertilization than for K concentration, a result which also was observed for the analysis for the whole strips, probably because the inconsistent early growth responses had a larger impact on K uptake than K concentration responses. At Site 1 all K treatments increased K uptake in areas of Zook soil although starter in addition to broadcast K decreased uptake compared with broadcast K alone, while all treatments decreased K uptake in areas of Koszta soil. At Site 2, only starter K alone increased K uptake in areas of Readlyn soil, while no treatment affected K uptake in areas of Kenyon. At Site 3 all K treatments increased K uptake in areas of both dominant soils, although applying both starter and broadcast K increased K uptake the most in areas of Clarion soil and broadcast K increased uptake the most in areas of Webster soil. At Site 5 all K treatments decreased K uptake in areas of Tripoli soil but did not affect it in areas of Floyd soil. A similar result was observed at Site 8, where all K treatments decreased K uptake in areas of Mahaska soil but did not affect it in areas of Otley soil.
Comparisons of early plant K uptake and grain yield responses by soil series showed inconsistent results. Potassium fertilization (starter or broadcast) increased K uptake in two of the six soil series in which K increased grain yield (Zook in Site 1 and Webster in Site 3), but did not affect or decreased uptake in four yield responsive series (Floyd and Tripoli in Site 5; Koszta in Site 6; and Mahaska in Site 7). On the other hand, at least one K treatment increased uptake in two series in which K did not increase yield (Readlyn in Site 2 and Clarion in Site 3).

Corn Response to Potassium Fertilization by Soil-Test Potassium Interpretation Classes

Grain Yield

Table 13 shows grain yield data for field areas testing within different STK interpretation classes. This assessment is important because the response to starter or broadcast K may be affected by the initial STK level. Based on previous research in Iowa, we expected large and frequent responses to K fertilization for the two low-testing STK classes, moderate and less frequent responses for the Optimum class, and small and infrequent responses for the high-testing classes. Our results indicate that both the frequency and magnitude of yield response to K fertilization indeed decreased from the Very Low to the Very High STK classes, but the frequency of the response for each class departed significantly from the expected frequency. Data and statistics from Table 13 indicate that the frequency of a yield response (to one or more treatments), was 100, 60, 57, 60, and 60% for
the classes Very Low, Low, Optimum, High, and Very High, respectively. This should not be surprising, however, because the previous STK calibration research was based on many field trials over several years, and the number of field areas testing within the five interpretation classes in our study was not as large as to be able to establish probabilities of response. Therefore, according to the main objectives of this study, in this section we emphasize the comparison of responses to broadcast and starter K for the different STK interpretation classes present in the fields.

Only Site 4 had areas testing Very Low, for which there was a large and approximately similar yield increase from either starter K and broadcast K applied alone, and a comparatively smaller additional yield increase with application of both. Five sites had areas testing Low (Sites 2, 3, 4, 6, and 8). For this STK class there were no yield responses at Sites 2 and 3; large and approximately similar responses to starter K and broadcast K alone but smaller to application of both at Sites 4 and 6; and a small response only to starter K at Site 8. We cannot clearly explain the response only to starter K alone for low-testing areas at Site 8. This field was managed with tillage and the measurements collected do not indicate a likely reason for a lack of response to the high rate of broadcast K applied. Therefore, we believe this was the result of site variability or experimental error.

Most sites had areas with STK testing Optimum, with Site 4 being the only exception. For this STK class there was no yield response at Sites 1, 2, and 7; a larger response to broadcast K than to starter K and no response to starter K in addition to broadcast K at Sites 3, 5, and 6; and approximately similar responses to starter K alone and broadcast K alone but smaller response to starter K in addition to broadcast K at Site 8. A response to broadcast K
for areas testing Optimum at Site 8 is in contrast to a lack of response for areas testing Low discussed before, which is a puzzling result.

There were field areas testing High and Very High at four sites (Sites 2, 3, 7, and 8), areas testing High but not Very High at Site 5, and areas testing Very High but not High at Site 1. There were no yield responses in high-testing areas at Sites 2 and 8, but there were responses at high-testing areas of the other sites. At areas testing High, there was a yield response only to starter K at Site 3 and a larger response to broadcast alone than to starter alone at Sites 5 and 7. We cannot explain a lack of yield response to broadcast K rate for areas testing High at Site 3. This field was managed with no-till, but we doubt the high broadcast K rate applied would have not resulted in increased yield if K had been needed, and no previous Iowa data has suggested such a rate could reduce yield. At sites with areas testing Very High in STK, there was a larger response to broadcast K alone than to starter K alone at Sites 1 and 3, and a larger response to starter alone than to broadcast alone at Site 7. Yield for broadcast plus starter K was statistically similar to yield with broadcast K alone for all high-testing areas.

**Early Plant Growth**

Table 14 show early corn DW data for field areas with STK testing within several STK interpretation classes. For field areas testing Very Low in STK (only at Site 4), no K treatment affected early DW. For areas testing Low (Sites 2, 3, 4, 6, and 8), no K treatment affected early DW at Sites 4 and 8; starter K did not affect DW but broadcast K decreased it at Sites 2 and 6; and each fertilizer applied alone increased DW at Site 3 but starter in addition to broadcast K decreased it compared with either fertilizer applied alone. Early
plant DW responses for areas testing Optimum in STK at seven sites also were very inconsistent across sites and STK classes. No K treatment affected early DW in three instances (Sites 1, 6, and 7), starter K alone increased DW but broadcast K decreased it at Site 2, starter K did not affect DW but broadcast K increased it at Sites 3 and 8, and all treatments decreased DW at Site 5.

There were field areas testing High at three sites (Sites 2, 5, and 8) and Very High at four sites (Sites 2, 3, 7, and 8), for which early corn DW responses also were inconsistent. For areas testing High, at Sites 3 and 7 there were no K treatment effects on early DW, at Site 2 starter K increased DW but broadcast K decreased it, at Site 5 starter K did not affect DW but broadcast K decreased it, and at Site 8 starter K decreased DW but broadcast K did not affect it. For areas testing Very High, at Site 1 no K treatment affected early DW, at Site 2 starter K increased DW but broadcast K decreased it (the same as for areas testing High), at Sites 3 and 7 starter or broadcast K alone increased DW but application of both did not, and at Site 8 starter decreased DW while broadcast K did not affect it.

The analysis of early corn DW data showed that early DW response to starter K or broadcast K fertilization was very inconsistent across a wide range of STK values. This result also was observed for the whole-strip analysis and the analysis by soil series. Potassium K fertilization sometimes increased, decreased, or did not affect early corn DW across Very Low to Very High STK classes.

**Early plant K Concentration**

Data in Table 15 show that K fertilization usually increased early plant K concentration and seldom decreased it, but the increases were inconsistent across sites and
STK classes. No treatment affected plant K concentration at areas testing Very Low in K (at Site 4). For field areas where the STK level was Low, positive responses were observed at Sites 2, 3, 4, and 6, when starter alone or broadcast with or without starter were applied. Application of starter in addition to broadcast K did not increase K concentration further at Site 2, however. For field areas where the STK level was Optimum (at seven sites) the fertilizer treatments increased early plant K concentration at five sites. Broadcast K alone increased K concentration at these five sites, but starter K alone did not increase it at Site 1 and increased it less than broadcast at Sites 2, 3, 5, and 6. Application of starter K in addition to broadcast K did not clearly increase K concentration further compared to broadcast alone at Sites 1 and 2, but it did increase K concentration further at Sites 3, 5 and 6.

For field areas where the STK level was High or Very High, K fertilization affected plant K concentration at Sites 2, 3, 7, and 8, but the responses were inconsistent across sites and STK classes. At Site 2, starter K decreased K concentration when STK was High and broadcast K decreased it when STK was Very High. At Site 3, no K treatments affected K concentration when STK was High and only starter K increased it when STK was Very High. At Site 7, the responses were very small for STK classes High and Very High, and the data and statistics for both classes indicated a K concentration decrease for starter K alone and a very small increase or no response for broadcast K. At Site 8, broadcast K decreased K concentration for areas testing High while starter K decreased it for areas testing Very High.

**Early Plant K Uptake**

Table 16 shows early K uptake data for different STK classes within each field. The early K uptake response to K fertilization was infrequent and inconsistent across most STK
classes and sites. This result was expected because of very inconsistent early plant DW responses (K did not affect, increased, or decrease growth), and because the frequent K concentration responses were inconsistent across STK classes. Potassium uptake responses were observed for some STK classes only at Sites 1, 2, 3, 6, and 8. For the Low STK class, there was a K uptake response only at Site 3, where both fertilizers increased uptake but the starter K effect was less when broadcast K had been applied. For the Optimum STK class there was a K uptake response at Sites 1, 2, 3, and 6. Starter K decreased K uptake at Site 1, only starter K alone increased it at Site 2, and starter K alone and broadcast K alone increased it at Sites 3 and 6.

For the high-testing classes there was an early K uptake response at Sites 3 and 8. At Site 3 starter K and broadcast K treatments increased K uptake for STK classes High and Very High, but the increases were smaller or did not exist for starter K applied in addition to broadcast K. For both High and Very High STK classes at Site 8, broadcast K did not affect K uptake but starter K decreased it.

Summary of Crop Response to K by Soil-Test Classes

In instances when at least one K treatment increased grain yield for field areas testing Very Low to Optimum (eight instances across all sites; Sites 3, 4, 5, 6, and 8), broadcast K alone increased yield further than starter K alone in three instances, starter K increased yield more than broadcast K in one instance, increases were similar for the other three instances, and starter K in addition to broadcast K increased yield further only in one instance (area testing Low Site 8). A similar comparison for field areas testing High or Very High (six responsive instances across all sites; in Sites 1, 3, 5, and 7), broadcast K increased yield more
than starter K in four instances, starter K increased yield more than broadcast K in one instance, there was a similar increase in one instance, and starter K in addition to broadcast K increased yield further in one instance (area testing High in Site 3). Therefore, an important result was that the small starter K rate often resulted in similar yield increases than the much higher broadcast K application rate. Results for early plant DW showed an approximately similar proportion of instances in which starter K or broadcast K had no effect, an increasing effect, or a decreasing effect with no apparent relation to the STK class. Results for early K concentration showed more consistent responses to K fertilization, however. Starter or broadcast K usually increased or did not affect plant K concentration for the classes Very Low, Low and Optimum but decreased it as often as they increased it for the high-testing classes. Also, broadcast K usually increased K concentration more than starter K. The results for early K uptake integrated K effects on early growth and K concentrations and showed infrequent responses. Broadcast K fertilizer did not affect or increased K uptake with about the same frequency with no apparent relation to STK classes. Starter K also usually did not affect or increased K uptake, but sometimes decreased it. The decreases were observed in both low- and high-testing areas.

**CONCLUSIONS**

Analysis of data for the whole strip length showed that K fertilization increased corn grain yield at three of eight sites. At two sites, broadcast K increased yield more than starter K. At one site, both broadcast and starter K increased yield similarly. Application of starter K in addition to broadcast K did not increase yield at any site. The initial mean STK for the fields and current STK interpretations explained the responses only partially. Broadcast or
starter K fertilization effects on corn early growth were inconsistent across sites. Early plant DW was not affected, increased, or decreased by K application, there were no consistent differences between broadcast and starter K fertilization although application of both often decreased early DW, and the few instances with DW increases did not result in grain yield increases. Early plant K concentration often was increased by K fertilization and seldom was decreased. Broadcast K often increased K concentrations more than starter K. Early K uptake responses to K were inconsistent, with approximately similar occurrences of no effect, increase, or decrease mainly because of inconsistent K effects on early growth.

Analysis of data for different soil series within each field showed that both STK levels and soil characteristics (most likely a combination of drainage and texture) determined differential grain yield responses to K fertilization within a field. However, there were no clear or consistent differences between soil series concerning relative differences between broadcast and starter K fertilization for early growth measurements or grain yield. A consistent result across all soil series was, however, that starter K in addition to broadcast K did not increase early corn growth or grain yield further than broadcast fertilization alone.

The analysis of grain yield responses to K fertilization for field areas testing within different STK interpretation classes also showed that the responses were explained not just by STK levels but also by soil properties. For example, moderate responses in high-testing areas of some fields occurred mainly in soils with poor drainage and finer textures.

However, sometimes the yield response or lack of response could not be explained by the methods used. Differences between broadcast and starter K fertilization effects for early plant measurements and grain yield was not consistently related to the STK class. The early plant DW increase or decrease from starter K application was not related to the STK
interpretation class. In instances when at least one K treatment increased grain yield for field areas testing Very Low to Optimum (eight instances across all sites), broadcast K alone increased yield more than starter K alone in three instances, starter K increased yield more than broadcast K in one instance, increases were similar for the other three instances, and starter K in addition to broadcast K increased yield further only in one instance. A similar comparison for field areas testing High or Very High (six responsive instances across all sites), broadcast K increased yield more than starter K in four instances, starter K increased yield more than broadcast K in one instance, there was a similar increase in one instance, and starter K in addition to broadcast K increased yield further only in one instance.

Overall, the results of the study showed that starter K application seldom increased early corn growth and K early uptake, and that the infrequent increases seldom resulted in increased grain yield. Starter K applied in addition to broadcast K rates commonly applied by farmers seldom increased yield further.

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### Table 1. Year, location, planting date, hybrid, and soil test values for eight field trials.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>County</th>
<th>Planting date</th>
<th>Hybrid ‡</th>
<th>Soil-test values †</th>
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<td>14-May</td>
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† STK, ammonium acetate K; Min, minimum; Max, maximum; OM, organic matter.
‡ P = Pioneer, DK = Dekalb, NT = NuTech.
Table 2. Predominant soil series of each site and mean initial soil-test K (0-15cm).

<table>
<thead>
<tr>
<th>Site</th>
<th>Dominant soil classification</th>
<th>Soil texture</th>
<th>Soil-test K †</th>
<th>Area</th>
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<td>Subgroup</td>
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† Ammonium acetate K method; Min, minimum; Max, maximum.
Table 3. Long-term average soil temperature at a 10 cm depth during April, May, and June near the research sites.

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<th>Year</th>
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<th>County</th>
<th>Average 10 cm soil temperature †</th>
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<td></td>
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<td>April 1-15</td>
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<tr>
<td>2007</td>
<td>1</td>
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<tr>
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<td>2008</td>
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<td>Washington</td>
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</table>

† Soil temperature information was recorded at standard meteorological stations located distant 10 to 40 km from the sites.
Table 4. Long-term average precipitation near the research sites.

<table>
<thead>
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<th>Year</th>
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† Soil precipitation information was recorded at standard meteorological stations located distant 10 to 40 km from the sites.
Table 5. Potassium fertilization effects on grain yield across the entire strip length of each treatment at eight sites.

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† Main effects and interactions.
Table 6. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites.

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† Main effects and interactions.
Table 7. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites.

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† Main effects and interactions.
Table 8. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) across the entire strip length of each treatment at eight sites.

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† Main effects and interactions.
Table 9. Potassium fertilization effects on corn grain yield for different soil series at each site.

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† Main effects and interactions.
‡ Site 4 is not included because there was only one dominant soil series.
Table 10. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) for different soil series at each site.

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† Main effects and interactions.
‡ Site 4 is not included because there was only one dominant soil series.
Table 11. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) for different soil series at each site.

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† Main effects and interactions.
‡ Site 4 is not included because there was only one dominant soil series.
Table 12. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) for different soil series at each site.

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† Main effects and interactions.
‡ Site 4 is not included because there was only one dominant soil series.
Table 13. Potassium fertilization effects on corn grain yield for different soil-test K interpretation classes within each site.

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<td>13.97 14.04</td>
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</table>

† Main effects and interactions.
Table 14. Potassium fertilization effects on early corn growth (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.

<table>
<thead>
<tr>
<th>Site</th>
<th>STK class</th>
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<th>Broadcast K</th>
<th>Statistics †</th>
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<td>4.6</td>
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† Main effects and interactions.
Table 15. Potassium fertilization effects on early corn K concentration (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.

<table>
<thead>
<tr>
<th>Site</th>
<th>STK class</th>
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<th>Broadcast K</th>
<th>Statistics †</th>
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<td>0.90</td>
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† Main effects and interactions.
Table 16. Potassium fertilization effects on early corn K uptake (V5 to V7 growth stage) for different soil-test K interpretation classes within each site.

<table>
<thead>
<tr>
<th>Site</th>
<th>STK class</th>
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† Main effects and interactions.
CHAPTER 3. GENERAL CONCLUSIONS

The objectives of this study were to evaluate corn grain yield and early plant-tissue responses to in-furrow liquid K starter fertilization and to determine the benefit of starter K fertilization for corn in addition to broadcast K fertilization rates commonly used by Corn Belt farmers. The study involved eight strip trials conducted at Iowa farmers’ fields from 2007 to 2008.

Analysis of data for the whole strip length showed that K fertilization increased corn grain yield at 3 of 8 sites. At two sites, broadcast K increased yield more than starter K. At another site, both broadcast and starter K increased yield similarly. Application of starter K in addition to broadcast K did not increase yield at any site. The initial mean soil-test K (STK) for the fields and current STK interpretations explained the responses only partially. For example, grain yield responses to K in several high-testing fields or areas within a field might have been explained by soil poor drainage. Broadcast or starter K fertilization effects on corn early growth were inconsistent across sites. Growth was not affected, increased, or decreased by K application, there were no consistent differences between broadcast and starter K fertilization although application of both often decreased growth, and the few instances with growth increases did not result in grain yield increases. Early plant K concentration often was increased by K fertilization and seldom was decreased. Broadcast K often increased K concentrations more than starter K, which was explained by the higher rate of K fertilizer applied with the broadcast placement method. Early K uptake responses to K were inconsistent, with approximately similar occurrences of no effect, increase, or decrease mainly because of inconsistent K effects on early growth.
Analysis of data for different soil series showed that both STK levels and soil characteristics (most likely a combination of drainage and texture) determined differential grain yield responses to K fertilization within a field. However, there were no clear or consistent differences between soil series concerning relative differences between broadcast and starter K fertilization for early growth measurements or grain yield. A consistent result across all soil series was, however, that starter K in addition to broadcast K did not increase early corn growth or grain yield further than broadcast fertilization alone.

The analysis of grain yield responses to K fertilization for field areas testing within different STK interpretation classes also showed that the responses were explained not just by STK levels but also by soil properties. For example, moderate responses in high-testing areas of some fields occurred mainly in soils with poor drainage and finer textures. However, sometimes the yield response or lack of response could not be explained with the methods or measurements used. Differences between broadcast and starter K fertilization effects for early plant measurements and grain yield was not consistently related to the STK class. The early growth increases or decreases from starter K application and was not related to the STK interpretation class. In instances when at least one K treatment increased grain yield for field areas testing Very Low to Optimum (eight instances across all sites, broadcast K alone increased yield further than starter K alone in three instances, starter K increased yield more than broadcast K in one instance, increases were similar for the other three instances, and starter K in addition to broadcast K increased yield further only in one instance. A similar comparison for field areas testing High or Very High (six responsive instances across all sites), broadcast K increased yield more than starter K in four instances, starter K increased yield more than broadcast K in one instance, there was a similar increase
in one instance, and starter K in addition to broadcast K increased yield further in one instance.

Overall, the results of the study showed that starter K application seldom increased early corn growth and K uptake and the infrequent increases seldom resulted in increased grain yield. Starter K applied in addition to broadcast K rates commonly applied by farmers seldom increased yield further.
ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Antonio Mallarino, for all of his support and encouragement during this process. His enthusiasm and interest throughout my time here has been the major driving force in helping me to accomplish this goal.

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