Development of Fertilization Practices for Sustaining Mississippi Soybean Yield and Quality

22-2021

Project Leader: Michael S. Cox – **MCox@pss.msstate.edu**
Tyler L. Richmond – **TLR212@msstate.edu**

ABSTRACT

Potassium (K) deficiency of soybean [*Glycine max* (Merr.) L.] is common throughout the mid-southern United States. Visual symptoms of K deficiency may be absent or subtle during early and mid-reproductive growth stages. Correcting K deficiency in-season is problematic due to limited research. Information regarding soybean yield response to in-season fertilizer-K application time is limited to growth stages prior to the onset of R1. Research is limited on new higher yielding soybean varieties that are on the market today. The objective of this study was to evaluate influences of in-season potassium application timing during reproductive growth stages on soybean yield on clay and silt-loam soils. Field experiments were established in 2019, 2020, and 2021 at two locations representing soybean production areas in MS. K fertilization was applied at three different timings throughout the reproductive growth stages (R3, R5.5, and R6.5) and postharvest while utilizing four different K fertilization rates (0, 45, 90, and 135 kg K ha^{-1}). The experiment was designed a randomized complete block that was replicated 4 times at each site-year with a factorial arrangement. Mean data was subjected to analysis of variance (ANOVA) using Fishers Protected LSD (α=0.05). Results indicate that potassium application rate and timing during soybean reproductive growth stages do not increase yield on soils with adequate K present. Soybean trifoliate leaf tissue K analysis and petiole sap K analysis had no response during reproductive growth stages when K fertilization occurred on soils with ample K. Soybean grain yield showed no response to K fertilization timing and had a negative response (-140 kg ha^{-1}) when the maximum K fertilization rate (135 kg K ha^{-1}) was applied.

INTRODUCTION

Potassium (K) is a key macronutrient required to promote vegetative growth and maximize soybean [*Glycine max* (L.) Merr.] yield and is often lacking in sufficient quantity in soil. A survey conducted in 2019 by USDA-NASS (2020a) reported that 43% of the soybeans grown in 19 survey-program states received 81 kg K ha^{-1} (72 lb K $acre^{-1}$) with a total use rate of 1461.2 million kg K (3,221.4 million lb K) applied. The average rate [115 kg fertilizer-K ha^{-1} (103 lb K_2O $acre^{-1}$)] of K applied by Mississippi producers was greater than the United States average, but K was applied to a similar percentage (44%) of the production area in Mississippi compared to the United States. Information from 46 years of fertilizer-K use in the U.S. suggests that soybean producers are applying greater K rates to a larger percentage of the production area over time (USDA-ERS, 2019). Despite the increased use of fertilizer K, information about the K fertility status of soils in the U.S. generally shows that soil K availability in the Midwest and Mid-south is declining (IPNI, 2015). However, Oldham and Golden (2012) indicated that soil test K levels in the high category throughout the Mississippi delta have increased over the last 50 years to nearly 80%. Even with high soil test K levels, producers in the Mississippi Delta are still applying K fertilizer. Prior research on soybean response to in-season K fertilization is limited (Slaton et al., 2020).

Plant tissue analysis is used to separate sufficient and deficient nutrient concentrations by comparing tissue from field samples to published benchmark concentrations called the critical nutrient level (CNL; Bell et al., 1995). To ensure the CNL or sufficiency level for a plant is accurate, the growth stage at which the plant is sampled should be taken into consideration. Since nutrient concentration varies among growth stages, research has been conducted evaluating which growth stage has the strongest correlation with the relative yield potential of soybeans (Parvej et al., 2015). Soybean K uptake follows a sigmoidal pattern with a relatively low K uptake during vegetative growth (Bender et al., 2015; Parvej et al., 2015). Bender et al. (2015) showed that maximum K uptake (140-192 kg ha^{-1} [125-171 lb ac^{-1}]) of

soybean yielding 3480 kg ha^{-1} (52 bu ac^{-1}) peaked near the R6.0 stage but the maximum uptake rate of approximately 2.8 kg K ha^{-1} d^{-1} (2.5 lb K ac^{-1} d^{-1}) occurred near the R3 stage in the Mid-West. Parvej et al. (2015) also reported similar data in irrigated soybean grown in the Mid-South; soybean grown in Arkansas exhibited maximum aboveground K uptake (130 kg K ha^{-1} [116 lb K ac^{-1}]) occurring at the R5.5 to R6 stage and maximum K uptake rate (2.6 kg K ha^{-1} d^{-1} [2.3 lb K ac^{-1} d^{-1}]) peaking at the R3-R4 stage. The percentage of total K uptake that occurred by the initiation of reproductive growth increased as the soybean maturity group increased due to the longer duration of vegetative growth and that the maximum K uptake rates tended to be greater for varieties with shorter growth durations (Parvej et al., 2015).

Nutrient concentrations vary among plant species, parts, and growth stages during development (Scott and Brewer, 1980). Soybean trifoliate leaf K concentrations are considered sufficient (≥19 g K kg^{-1}) and deficient (≤ 15 g K kg^{-1}) at the R2 growth stage (Grove et al., 1987; Sabbe et al., 2000; Slaton et al., 2010). Critical nutrient ranges can be used to help diagnose a deficiency before visual symptoms are expressed.

The K concentration in trifoliate leaves at the R2 stage is positively correlated (R^2 = 0.32-0.82) with relative soybean yield and a good indicator of the plant's K nutritional status (Slaton et al., 2010; Clover and Mallarino, 2013). Parvej et al. (2016) found that the petiole-K concentrations were almost double that of the trifoliate leaves. Given that petiole K concentrations are greater than those of trifoliate leaves, petioles might be the preferred tissue for sap extraction. Parvej et al. (2016) proposed three continuous critical K concentration curves for soybean trifoliate leaves and petioles. The first curve being a linear regression representing upper and lower boundaries for K nutrient status that continuously declined from the R2 to R6 growth stages (lower boundary R^2 = 0.91, upper boundary R^2 = 0.97). The second curve was a quadratic model showing the same K decline in both petiole and leaf tissue (lower boundary R^2 = 0.99, upper boundary R^2 = 0.99). The final model combined both previous curves to determine a sufficient, critical, and deficient range at growth stages ranging from R2 to R6 (Parvej et al., 2016).

Parvej et al. (2015) and Bender et al. (2015) summarized the distribution of K among plant physiology throughout the season. By the onset of reproductive growth, the petioles and stems of soybean

contain as much as 20 to 40% of the total K taken up during the season, the greatest percentage among vegetative plant structures. By the R4 growth stage, stems and petioles contain nearly two-thirds of the plants aboveground K content with the amount decreasing rapidly as K translocates to the developing pods and seed during mid and late reproductive growth stages. Parvej et al. (2016) showed that trifoliate leaf and petiole K concentrations tend to increase during vegetative growth, peak in early reproductive growth, and decline at a linear rate during reproductive growth. Due to the continual change in tissue K concentrations, leaf and petiole K concentrations at the R1 growth stage ($R^2 < 0.15$) showed the lowest correlation with relative soybean yield compared to the R2 - R5 growth stages ($R^2 = 0.62$-0.85). The correlation between leaf or petiole K concentration and relative yield declined after R5.5 due, in part, to the extremely low tissue K concentrations. Parvej et al. (2016) suggested using petiole soybean tissue for diagnostic sampling because of its greater K concentration compared to leaves and the wider range of concentrations across time. Parvej et al. (2016) reported a higher average R^2 value for petiole tissue K ($R^2 = 90$) to yield when compared to trifoliate tissue K ($R^2 = 85$) concentrations to yield.

Petiole sap testing is not intended to replace laboratory plant analysis, but to serve as a viable means to acquire immediate, in-field nutrient results to make more timely nutrient management decisions. Ion-specific electrodes such as the Cardy meter (Horiba, Kyota, Japan) have previously been tested for monitoring plant sap N and K concentration primarily for vegetable crops (Hochmuth, 1994; Rosen et al., 1996; Taber and Lawson, 2007). Fresh tissue sap analysis for row crops has been developed for NO_3-N analysis and has seen limited use in barley (*Hordeum vulgare* L.; Thompson et al., 2004), sugarbeet (*Beta vulgaris* L; Halvorson et al., 1975), and potato (Rosen et al., 1996). Hochmuth (1994) tested petiole-sap N and K concentrations for specialty crops including broccoli (*Brassica oleracea* L.), cucumber (*Cucumis sativus*), eggplant, muskmelon (*Cucumis melo* L.), pepper (*Capsicum*), potato, squash (*Cucurbita pepo* L.), strawberry (*Fragaria* × *ananassa*), tomato (*Solanum lycopersicum*), and watermelon. Sap NO_3 and tissue NO_3 were both good indicators of barley NO_3 levels and yield potential ($R^2 = 0.72$ - 0.82), however they were better at predicting protein response and seed quality (Thompson et al., 2004). Halvorson et al. (1975), reported slightly higher NO_3 in plant petiole sap when compared to dry petiole NO_3 content while

forming a linear regression model (R^2 = 0.97) comparing the two. Petiole sap was also used to determine critical nutrient levels of NO_3 and K in potatoes (Rosen et al., 1996). Taber and Lawson (2007), reported good correlations between tomato petiole sap K and leaf tissue K (R^2 = 0.82). Sap testing is not new to vegetables and specialty crops, however, this form of testing is new to row crops.

Tabor and Lawson (2007) reported that the correlation of tomato petiole sap measured with the ion specific electrode (Cardy meter) and traditional methods were best correlated when the sap was diluted (1:1) with deionized water. Rosen et al. (1996) and Tabor and Lawson (2007) both reported that accurate assessment of petiole sap K concentration with the Cardy meter required petiole sap to be diluted, especially when the sap K concentration was relatively high. However, the Cardy meter used in the referenced research is no longer available. In 2013, Horiba updated their K-ion-specific electrode to the LAQUAtwin Potassium K^+ Compact Ion Meter. Horiba claims that the newer electrode has an accuracy of ±10% or ±10 ppm and a range of 4-9900 ppm (http://www.horiba.com/laquatwin/en/lineup/index.html#k).

Increased acceptance of precision agriculture and attention in ultra-high yielding crops have generated interest in the ability to monitor plant nutrition status during the season to ensure that nutrients are not limiting yield. Potassium deficiency of high-yielding soybeans is a concern, especially during the peak K uptake period during mid- to late-reproductive stages. A low-cost and rapid method of determining the in-season soybean K nutritional status would be of value not only for high-yield production situations, but also for general troubleshooting and for fields fertilized with nominal K rates using recommendations that prescribe to the sufficiency philosophy.

Soybeans are commonly grown on fine textured soils with high CEC throughout the Mississippi Delta. We currently base our recommendations on a “build and maintain” nutrient approach, meaning we apply more nutrients than what the crop will need in order to build soil nutrient levels. Research is needed to determine if extra K, applied in-season, benefits the current crop yield and/or plant K status. The objectives of this study were (a) determine how soybean respond to fertilizer K during reproductive growth stages when sufficient soil test K is available, (b) determine how soybean trifoliate leaf K content

responds to fertilizer K, and (c) determine how soybean petiole sap K content responds to fertilizer K. The overall goal objective of this project is to determine if applying potash to K sufficient soils at different times in-season can increase yield plant K status on two different soil textures.

Materials and Methods

Site Description

Seven field experiments were established on Mississippi Agricultural and Forestry Experiment stations in 2019, 2020, and 2021. Three experiments were established on a Commerce very fine sandy loam (vfsl) (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquept) (33°26'02.39" N 90°54'31.70" W) at the Mississippi State Delta Research and Extension Center (DREC) near Stoneville, MS. Three experiments were established on a Tunica clay (c) (Clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Vertic Epiaquept) (33°26'03.66" N 90°54'27.42" W) at DREC. One experiment was established at the Mississippi State North Mississippi Research and Extension Center (NMREC) on a Catalpa silty clay loam (scl) (fine, smectitic, thermic Fluvaquentic Hapludoll) (34°09'56.01" N 88°44'33.45"W). Studies at DREC were conducted in 2019, 2020, and 2021, while the study at NMREC was conducted in 2020. The experiments will be identified with the site abbreviation, year, and 'a' (very fine sandy loam) or 'b' (clay) to differentiate between multiple trials conducted at the same experiment station and year, hence, DREC-2019a represents the study at DREC conducted in 2019 on the very fine sandy loam while DREC-2019b represents the study conducted at DREC in 2019 on the clay . Soil series were determined using web soil survey (https://websoilsurvey.nrcs.usda.gov), while soil chemical properties were analyzed by Mississippi State University (MSU) Extension Soil Testing Laboratory (http://extension.msstate.edu/content/soil-testing). The site names and selected soil chemical property information are summarized in Table 2.1. 'Asgrow 45X8' (DREC-2019a, DREC-2019b, DREC-2020a, DREC-2020b; Bayer Crop Science, Monheim, Germany), 'Asgrow 46X6' (NMREC-2020; Bayer Crop Science, Monheim, Germany), and 'Asgrow 47XF0' (DREC-2021a, DREC-2021b; Bayer Crop Science, Monheim, Germany) all mid-maturity group IV soybeans were planted in all site-years at a rate of 296,400 seed ha^{-1} (120,000 seed $acre^{-1}$) on 101.6 cm row spacing using a John Deere small-plot air planter

(John Deere 1730, Deere and Company, Moline, IL). Planting and emergence dates are shown in Table 2.2. Each plot consisted of four 10.7 m (35 ft) rows. In general, all soybean management strategies followed MSU Extension recommended practices based on furrow irrigated soybean production systems.

Treatments

Fertilizer K_2O (0-0-60) was applied at the R3, R5.5, R6.5, and postharvest at rates of 0, 45, 90, and 135 kg K ha^{-1} (0, 40, 80, and 120 lb K $acre^{-1}$). SoyPheno (Mississippi State University Extension, Starkville, MS) was used to help predict specific growth stages at which fertilization occurred. A randomized complete block design was used at each location with a 4x4 factorial arrangement replicated 4 times.

Soil Sampling and Analysis

Composite soil samples were collected pre-plant from each plot for each site year. Each composite sample consisted of six, 2-cm o.d. subsamples from the 0-to 10-cm soil depth. Soil samples were oven-dried at 110°C and crushed to pass through a 2-mm sieve. Samples were analyzed for soil organic matter by combustion (Schulte and Hopkins, 1996), soil pH in a 1:2 v/v soil: water mixture (Sikora and Kissel, 2014), and available Ca, Mg, K, Na, and P measured using the Lancaster soil test extractant (Cox, 2001) and Inductively Coupled Argon Plasma Spectroscopy.

Plant Sampling and Analysis

Plant tissue samples were collected from each site one week after K fertilizer was applied. On each sample date, trifoliate leaves and petioles located on the third node from the top of each plant (most recently matured leaf) were collected from 20 plants in each plot. The petiole and trifoliate leaves of the samples were separated, and each trifoliate leaf was placed in a labeled bag and dried at 65°C. The dried trifoliate leaves were then ground in a Wiley mill to pass a 1 mm sieve, digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990), and analyzed for nutrient content by inductively coupled plasma atomic emission spectroscopy (Arcos-160 SOP, Spectro, NJ).

Once separated, the petioles were placed in a refrigerator and processed within 24 h after collection. The petioles were cut into 2 cm segments using a knife and composite cutting board, which

were rinsed with deionized water after each sample. Petiole segments were then placed into a hydraulic plant sap press (Spectrum Technologies, Inc., Aurora, IL) and pressed into 5.0 mL micro centrifuge tube (Fisher Scientific International, Inc., Hampton, NH). This procedure generally extracted 0.50 to 2.0 mL of sap. The centrifuge tubes were immediately frozen and stored until analyzed for K using an ion specific electrode (ISE; HKIM) Horiba B-731 LAQUAtwin Compact K Ion Meter, Horiba, Kyota, Japan.

The ISE was calibrated using the two standards (150 and 2000 mg K L^{-1}). The frozen sap solutions were thawed to room temperature, each 5.0 mL vial was hand shaken for 15 s, and a 0.5 mL of sap was analyzed by ISE. After the sap-K concentration was determined, the sap solution was transferred back to the original centrifuge tube, and the sensor was rinsed with deionized water to prepare for the next sample.

At maturity, the center two 10.7 m (35 ft) rows were harvested with a Kincaid small plot combine (Kincaid 8-XP, Haven, KS) equipped with a HarvestMaster grain gauge for seed yield determination. Seed weight was adjusted to a uniform seed moisture content of 130 g kg^{-1} for grain yield calculations.

Soybean Tissue K Response to K Fertilization

Potassium rate effects on leaf and petiole sap K were analyzed separately at R3, R5.5, and R6. Data were subjected to analysis of variance (ANOVA) using the Glimmix procedure and Fisher's protected least significant difference (LSD; α=0.05). Significant mean yield differences were compared using LSMEANS (α=0.05) statements. Cook's D and studentized residual ($\pm$2.5) statistics were used to identify and remove outlying data points with influence. Replications and site-year were considered random for this analysis.

Soybean Yield Response to K Fertilization

Independent main effects and their interactions were considered while finalizing the model. The final model was derived by removing the most complex and non-significant (P>0.15) factors and interactions. Data was subjected to analysis of variance (ANOVA) using Fisher's protected least

significant difference (LSD; α=0.05) and the GLIMMIX procedure in SAS v. 9.4 (SAS Institute Inc., Cary, NC). Significant mean yield differences were compared using LSMEANS (α=0.05) statements. Cook's D and studentized residual (±2.5) statistics were used to identify and remove outlying data points with influence. Replications and site-year were considered random effects for this analysis.

Results and Discussion

Soybean Trifoliate Tissue K Response to K Fertilization

Soybean trifoliate leaf tissue K was not affected by K rate at the R3, R5.5, and R6.5 growth stages on soils with sufficient soil K prior to planting (Table 2.3; Figure1). Mean soybean trifoliate tissue K content ranged from 13.6596 – 13.9563 (R3), 11.1654 – 11.5087 (R5.5), and 10.8715 – 11.3901 (R6.5) g K kg^{-1}. Higher trifoliate tissue K concentrations have also been reported in numerous studies at the R2 growth stage and established our current potassium critical nutrient range (Grove et al., 1987; Sabbe et al., 2000; Slaton et al., 2010;Parvej et al., 2016). The current sufficient soybean trifoliate K concentration occurs when ≥19 g K kg^{-1} and deficiencies occur when ≤ 15 g K kg^{-1} are present at the R2 soybean growth stage (Grove et al., 1987; Sabbe et al., 2000; Slaton et al., 2010; Parvej et al., 2016). Relative yield was maximized when trifoliate leaf K concentrations were 18, 12, and 10 g K kg^{-1} at the R3, R5.5, and R6 growth stages, respectively (Parvej et al., 2016). Efficient uptake of fertilizer K applied post soybean emergence up to the R2 growth stage has been reported (Slaton et al., 2020). When compared to the previous studies, the trifoliate leaf tissue K in our study was considered low, even with sufficient soil K levels. The lack of a significant K rate effect for trifoliate leaf tissue K at all three fertilization timings suggest that adequate soil K was present. No visible symptoms of K deficiency were observed.

Trifoliate leaf tissue K was not highly correlated to yield or petiole sap K at the fertilization applications timings based on the calculated r values (Table 2.5). Yield and tissue K content correlations at the R3 (R^2 = 0.026), R5.5 (R^2 = 0.143), and R6.5 (R^2 = 0.071) stages indicate that plant tissue K concentrations beyond the R2 growth stage need to be examined further on soils when sufficient K is not present. Parvej et al. 2016 reported significantly greater correlations between relative yield and trifoliate

tissue K concentration at the R3 (R^2 = 0.77), R5.5 (R^2 = 0.70) and R6 (R^2 = 0.48) growth stages. These higher correlations are likely due to a positive response to K fertilization. However, the correlation figures between trifoliate tissue K content and petiole sap K content (Fig. 2.4) do show a general trend where both tests detected decreased K content within the plant as the growing season progressed. However, the correlation figures between trifoliate tissue K content and soybean grain yield (Fig. 2.5) do not portray a definitive trend, which is likely attributed to the lack of response to K fertilization rate and timing. Meaning, that yield stayed relatively constant across all K fertilization rates, suggesting our current MSU soil test recommendations are correct.

Soybean Petiole Sap K Response to K Fertilization

Soybean petiole sap K was not affected by K rate at the R3, R5.5, and R6.5 growth stages (Table 2.3; Figure 2). Mean petiole sap K content ranged from 3.1275 – 3.2587 (R3), 1.88964 – 2.11482 (R5.5), and 1.40258 – 1.47714 (R6.5) g K kg^{-1}. The decreasing trend is similar between petiole tissue K concentrations reported by Parvej et al. 2016. Relative yield in the Parvej study was maximized when petiole tissue K concentrations were 35, 16, and 10 g K kg^{-1} at the R3, R5.5, and R6 growth stages, respectively (Parvej et al., 2016). The lack of a significant K rate effect for petiole sap K at all three fertilization timings suggest that adequate soil K was present.

Petiole sap K content correlation to yield was higher than that of the trifoliate tissue K content at all three of the growth stages at which the samples were collected (Table 2.5). Yield and petiole sap K content correlation at the R3 (R^2 = 0.47), R5.5 (R^2 = 0.32), and R6.5 (R^2 = 0.08) indicate that this is a possible method for in-field K nutrient testing for soybean. However, there were extremely low correlations between petiole sap K content and trifoliate leaf tissue K content at the given growth stages: R3 (R^2 = 0.0001), R5.5 (R^2 = 0.001), and R6.5 (R^2 = 0.10). This could be due to the trifoliate leaves being removed directly from the same petioles analyzed in this test. Correlation figures between petiole sap K content and soybean grain yield (Fig. 2.6) do not portray a definitive trend, similar between the trifoliate tissue K data, which is likely attributed to the lack of response to K fertilization rate and timing. This data

having no definitive positive response suggests our current MSU soil test recommendations are correct, even for new high yielding soybean varieties. Observing the same general trends as trifoliate tissue testing, suggests that in-field nutrient testing may be a viable option, once more research is conducted. The Horiba B-731 LAQUAtwin Compact K Ion Meter detected lower petiole sap K levels later in the growing season, which was also detected by the trifoliate tissue K analysis, even when no positive soybean yield response to K fertilization occurred on soils with sufficient K present.

Soybean Yield Response to K Fertilization

There was no significant interaction between K fertilizer timing and K rate. However, the effect of K rate was significant when related to soybean grain yield (Table 2.4; Fig 2.3). For this study, soybeans receiving 0, 45, 90, and 135 kg K ha^{-1} yielded 4312, 4322, 4288, and 4182 kg ha^{-1}, respectively. Soybean receiving 0, 45, and 90 kg K ha^{-1} had significantly higher grain yields than soybean receiving the highest K fertilization rate (135 kg K ha^{-1}). The highest rate of K fertilizer (135 kg ha^{-1}) presented an adverse effect on yield in soils with ample soil K available. Averaged across all fertilizer K treatments, grain yield averaged 4276 kg ha^{-1}, which is 626 kg ha^{-1} higher than the average irrigated soybean yield in the Mississippi Delta in 2020 (Gregory, 2020). Soybean grain yields were maximized, despite showing a deficient trifoliate leaf K content range.

Nelson et al. (2005) reported that foliar fertilizer K applied at the soybean growth stage V4 and R1 increased soybean grain yield when compared to the untreated control when low to medium soil test K levels are present. It has been reported that applying early season (V4-R2) foliar fertilizer K is more effective at increasing soybean grain yield than when applying foliar fertilizer K later (R3-R4) in the growing season (Nelson et al., 2005). Soybean will positively respond to K fertilization during the reproductive growth stages, when K deficiency occurs (Nelson et al., 2005; Slaton et al., 2010; Parvej et al., 2016; Slaton et al., 2020). However, for this study, no K deficiency occurred resulting in no positive soybean response (i.e: trifoliate tissue K content, petiole sap K content, and grain yield).

Conclusion

Soybean trifoliate leaf K content and petiole sap K content were not affected by K fertilizer rate at the R3, R5.5, and R6.5 growth stages. However, both means of soybean K nutritional status demonstrated the same trends where soybean K content in the trifoliate and petiole decreased as the growing season progressed beyond the R3 growth stage. Due to no response, we can infer that soil test K levels in the high range will not respond to K fertilization. Grain yield did not positively respond to K fertilization. We observed an inverse effect when the high rate (135 kg K ha^{-1}) was applied to soils with sufficient K.

More research needs to be conducted on in-field plant K monitoring. The Horiba B-731 LAQUAtwin Compact K Ion Meter shows great potential of being an effective tool at measuring plant K levels, once a correlation calibration curve is developed on a wider range of soil test K levels and soybean growth stages. The Horiba will allow producers to monitor plant nutrient status on a real-time scale. Currently, plant tissue analysis requires a minimum of four days to receive results. Based on previous research, we know that correcting nutrient deficiencies during reproductive growth stages is time critical (Nelson et al., 2005; Slaton et al., 2010; Parvej et al., 2016; Slaton et al., 2020). We know that a significant soybean grain yield response to K fertilization is possible until the R5 growth stage when K deficiency occurs (Slaton et al., 2020). Being able to monitor plant nutrient status at any given time in the field could be crucial to maximizing profitability.

Based on this study, soybean planted on soils that have sufficient available K, should not receive additional fertilizer K. The addition of granular fertilizer K during reproductive growth stages did not increase soybean nutrition K status or grain yield, when sufficient soil K was available. Over applying high rates of fertilizer K based on the soil test is not beneficial for the current growing season and lead to

possible adverse effects. For producers to remain profitable, we recommend following the current MSU extension guidelines.

References

Bell, P.F., Hallmark, W. B., Sabbe, W. E., & Dombeck, D. G. (1995). Diagnosing nutrient deficiencies in soybean, using M-DRIS and critical nutrient level procedures. Agron. J. 87:859-865.

Bender, R. R., Haegele, J. W., & Below, F. E. (2015). Nutrient uptake, partitioning, and remobilization in modern soybean varieties. Agron J. 107:563-573.

Cox, M. S. (2001). The Lancaster soil test method as an alternative to the mehlich 3 soil test method[1]. Soil Sci. 166(7):484-489.

Gregory, E. (2020). 2020 row-crop Returns Summary. Pub 3422 (POD-02-20). Mississippi State University Ext. Starkville, MS.

Grove, J. H., Thom, W. O., Murdock, L. W., & Herbeck, J. H. (1987). Soybean response to available potassium in three silt loam soils. Soil Sci. Soc. Am. J. 51:1231-1238.

Halvorson, A. D., Hartman, G. P., & Reule, C. A. (1975). Predicting sugarbeet dried petiole no3-n by using fresh petiole juice 1. Agron. J. 67(5):637-639.

Hochmuth, G. J. (1994). Plant petiole sap-testing for vegetable crops. Circular 1144. Florida Coop. Ext. Serv., Univ. of Florida, Gainesville.

International Plant Nutrition Institute (IPNI). (2015). Soil test levels in North America. IPNI Publication No. 30-3115. Norcross, GA.

Jones, J. B., & Case, V. W. (1990). Sampling, handling, and analyzing plant tissue samples. In: R.L. Westerman, editor, Soil testing and plant analysis. 3rd ed. SSSA Book Ser. 3. SSSA, Madison, WI. p. 389–428.

Nelson, K. A., Motavalli, P. P., & Nathan, M. (2005). Response of notill soybean [*Glycine max* (L.) Merr.] to timing of preplant and foliar potassium applications in a claypan soil. Agronomy J. 97: 832–838.

Parvej, R. Md., Slaton, N. A., Purcell, L. C., & Roberts, T. L. (2015). Potassium fertility effects yield components and seed potassium concentration of determinate and indeterminate soybean. Agron. J. 107:943-950.

Parvej, R. Md., Slaton, N. A., Purcell, L. C., & Roberts, T. L. (2016). Soybean yield components and seed potassium concentration responses among nodes to potassium fertility. Agron. J. 108:854-863.

Rosen, C. J., Errebhi, M., & Wang, W. (1996). Testing petiole sap for nitrate and potassium: A comparison of several analytical procedures. HortSci. 31:1173-1176.

Sabbe, W.E., Lessman, G. M., & Bell, P. F. (2000). Soybean. In: C.R. Campbell, editor, Reference sufficiency ranges for plant analysis in the southern region of the United States. Southern Coop. Ser. Bull. 394. North Carolina Dep. Agric. Consumer Serv. Agron. Div., Raleigh, NC. http://www.ncagr.gov/agronomi/saaesd/scsb394.pdf. p. 33–34.

Scott, H. D., & Brewer, D. W. (1982). Characterization of nutrient transport coefficients in field-grown soybeans. Soil Sci. Soc. Am. J. 46:998-1004.

Schulte, E. E., & Hopkins, B. G. (1996). Estimation of organic matter by weight loss-on-ignition. p. 21–31. In: F.R. Magdoff et al., editors, Soil organic matter: Analysis and interpretation. SSSA Spec. Publ. 46. SSSA, Madison, WI

Sikora, F. J., & Kissel, D. E. (2014). Soil pH. In: F.J. Sikora and K.P. Moore, editors, Soil test methods from the southeastern United States. Southern Coop. Ser. Bull. 419. Clemson Univ. www.clemson.edu/sera6/MethodsManualFinalSERA6.pdf (accessed 13 Feb. 2020). p. 48–53.

Slaton, N. A., Golden, B. R., DeLong, R. E., & Mozaffari, M. (2010). Correlation and calibration of soil potassium availability with soybean yield and trifoliate potassium. Soil Sci. Soc. Am. J. 74:1642-1651.

Slaton, N. A., Fryer, M. S., Roberts, T. L., DeLong, R. E., Dempsey, R. J., Parvej, M. R., Hedge, J., & Massey, C. G. (2013). Validation of soil-test-based fertilizer recommendations for irrigated soybean. In: N.A. Slaton, editor, Arkansas Soil Fertility Studies 2014. Res. Ser. 616. Univ. of Arkansas, Fayetteville. p. 68-71.

Slaton, N. A., Roberts, T. L., Ross, J. W., & Richmond, T. L. (2020). Irrigated soybean response to granular fertilizer potassium application timing. Agron. J. 112:4344-4357.

Taber, H. G., & Lawson, V. (2007). Use of diluted tomato petiole sap for potassium measurement with the cardy electrode meter. Comm. Soil Sci. Plant Anal. 6(7):713-718.

Thompson, T. L., Ottman, M. J., & Riley-Saxton, E. (2004). Basal Stem Nitrate Tests for Irrigated Malting Barley. Agron. J. 96(2):516-524.

USDA-ERS. (2019). 2018 Soybean production costs and returns per planted acre [online]. USDA, Washington, D.C. Available at: https://www.ers.usda.gov/data-products/commodity-costs-and-returns/commodity-costs-and-returns/#Recent%20Cost%20and%20Return (accessed 2 March 2020).

USDA-NASS. (2020a). 2019 agricultural chemical use survey soybeans [Online]. USDA, Washington, D.C. Available at: https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2019_Peanuts_Soybeans_Corn/ChemUseHighlights_Soybeans_2019.pdf (accessed 24 June 2020).

Zhang, L., J. Zhang, Watson, C. E., & Kyei-Boahen, S. (2004). Developing phenological prediction tables for soybean. www.plantmanagementnetwork.org/cm/. Crop Manage. doi:10.1094/CM-2004-1025-01-RS.

Tables

Table 2.1. Selected soil property means of seven K application timing trials conducted on very fine sandy loam (VFSL), silty clay loam (SCL), and clay (C) soils at seven site-years.

					Lancaster extractable nutrients			
Site-year†	Soil Texture	Soil pH	Soil CEC	SOM	P	K	Ca	Mg
				---g kg^{-1}---	----------mg kg^{-1}----------			
DREC-2019a	VFSL	6.4	9.8	1.46	38	186	1201	221
DREC-2019b	C	8.2	26.1	2.12	62	207	4077	706
DREC-2020a	VFSL	6.7	9.3	0.96	35	168	1176	209
DREC-2020b	C	7.8	23.7	1.64	62	275	3448	657
NMREC-2020	SCL	8.1	21.0	2.37	26	158	25065	69
DREC-2021a	VFSL	6.4	12.7	1.28	63	253	1785	329
DREC-2021b	C	8.0	30.1	2.30	74	249	4057	1099

† DREC - Delta Research and Extension Center located in Stoneville, Mississippi, NMREC - North Mississippi Research and Extension Center located in Verona, Mississippi.

Table 2.2. Selected dates of agronomically important events including potash-K fertilizer application date, planting date, emergence date, and harvest date at seven site-years.

Site-year†	Soybean Variety	Planting Date	Emergence Date	Harvest Date	K application date			
					R3	R5.5	R6.5	PH
					----------Month/day----------			
DREC-2019a	AG45X8	04/30	05/06	09/18	06/28	07/19	08/13	10/02
DREC-2019b	AG45X8	05/22	05/29	10/02	07/19	08/13	08/27	10/04
DREC-2020a	AG45X8	05/04	05/12	10/07	07/14	08/10	08/25	10/23
DREC-2020b	AG45X8	05/26	06/05	10/22	07/27	08/19	08/31	10/23
NMREC-2020	AG46X6	05/12	05/21	10/07	07/21	08/11	08/24	10/07
DREC-2021a	AG47XF0	04/28	05/04	10/12	06/28	07/26	08/16	10/13
DREC-2021b	AG47XF0	05/18	05/24	10/12	07/15	08/16	08/26	10/13

† DREC is the Delta Research and Extension Center located in Stoneville, Mississippi, NMREC is the North Mississippi Research and Extension Center located in Verona, Mississippi.

Table 2.3. Analysis of covariance p-values for tissue-K and sap-K for soybean at three fertilizer K timings during reproductive growth stages as affected by K rate (KR) as defined by the final model for seven trials conducted at the Delta Research and Extension Center (DREC) located in Stoneville, Mississippi, and the North Mississippi Research and Extension Center (NMREC) located in Verona, Mississippi. P-values were used to determine final models and considered non-significant when *P*>0.15.

Site-year	Source of variation	df†	R3 Tissue K Content	R5.5 Tissue K Content	R6.5 Tissue K Content	R3 Sap K Content	R5.5 Sap K Content	R6.5 Sap K Content
			----------*P*-value----------					
DREC-2019a	KR	3	0.6361	0.3922	0.6911	0.8460	0.1079	0.3724
DREC-2019b	KR	3	0.2874	0.3231	0.5491	0.0189	0.5421	0.2211
DREC-2020a	KR	3	0.7344	0.0927	0.3733	0.2313	0.7118	0.5406
DREC-2020b	KR	3	0.1587	0.8807	0.0766	0.5478	0.0843	0.8770
NMREC-2020	KR	3	0.6785	0.5370	0.7196	0.7401	0.5501	0.2153
DREC-2021a	KR	3	0.9412	0.1782	0.5283	0.6807	0.2592	0.1560
DREC-2021b	KR	3	0.3962	0.9780	0.8469	0.3697	0.8341	0.7594
Combined	KR	3	0.5817	0.3931	0.1617	0.6987	0.0799	0.7143

† The df for the final model is the sum of the df for each model term (intercept and linear) listed as a source of variation.
‡ NS, not significant (*P*>0.15) in the final model.

Table 2.4. Analysis of covariance p-values for soybean yield at three fertilizer K timings (KT) during reproductive growth stages as affected by K rate (KR) as defined by the final model for seven trials conducted at the Delta Research and Extension Center (DREC) located in Stoneville, Mississippi, and the North Mississippi Research and Extension Center (NMREC) located in Verona, Mississippi. P-values were used to determine final models and considered non-significant when $P>0.15$.

Site-year	Source of variation	df†	Yield
			----*P*-value----
DREC-2019a	KT	3	0.1237
	KR	2	0.0451
	KT × KR	6	0.7518
DREC-2019b	KT	3	0.2921
	KR	2	0.9541
	KT × KR	6	0.6731
DREC-2020a	KT	3	0.1102
	KR	2	0.0602
	KT × KR	6	0.0605
DREC-2020b	KT	3	0.5538
	KR	2	0.1951
	KT × KR	6	0.8939
NMREC-2020	KT	3	0.3550
	KR	2	0.2325
	KT × KR	6	0.0220
DREC-2021a	KT	3	0.0510
	KR	2	0.7881
	KT × KR	6	0.3805
DREC-2021b	KT	3	0.3479
	KR	2	0.6509
	KT × KR	6	0.3142
Combined	KT	3	0.3065
	KR	2	0.0078
	KT × KR	6	0.1651

† The df for the final model is the sum of the df for each model term (intercept and linear) listed as a source of variation.

‡ NS, not significant ($P>0.15$) in the final model.

Table 2.5. Correlation coefficients for yield, petiole sap K, trifoliate tissue K, and soil K components for all seven site-years. correlation values were considered non-significant when *P*>0.10 or R<0.5.

Pearson correlation coefficients
Prob > |r| under H0: Rho=0
Number of observations

	Act Yld †	R3 Sap	R5.5 Sap	R6.5 Sap	R3 Tissue K	R5.5 Tissue K	R6.5 Tissue K	Soil K
Act Yld	1.0000	0.68423	0.56185	NS	NS	NS	NS	NS
	--	<0.0001	<0.0001	<0.0001	0.0888	<0.0001	0.0045	0.0011
	362	112	112	112	111	111	112	362
R3 Sap	0.68423	1.00000	0.68867	NS	NS	NS	NS	NS
	<0.0001	--	<0.0001	0.0690	NS	NS	0.5050	<0.0001
	112	112	28	28	111	27	28	112
R5.5 Sap	0.56185	0.68867	1.00000	NS	NS	NS	NS	0.51518
	<0.0001	<0.0001	--	<0.0001	NS	NS	NS	<0.0001
	112	28	112	112	28	111	28	112
R6.5 Sap	NS	NS	0.71305	1.00000	0.62325	NS	NS	NS
	<0.0001	0.0690	<0.0001	--	0.0004	0.0474	0.0006	0.0015
	112	28	28	112	28	27	112	112
R3 Tissue K	NS	NS	NS	0.62325	1.00000	0.60051	0.69158	NS
	0.0888	NS	NS	0.0004	--	0.0009	<0.0001	<0.0001
	111	111	28	28	111	27	28	111
R5.5 Tissue K	NS	NS	NS	NS	0.60051	1.00000	0.91309	NS
	<0.0001	NS	NS	0.0474	0.0009	--	<0.0001	0.0315
	111	27	111	27	27	111	27	111
R6.5 Tissue K	NS	NS	NS	NS	0.69158	0.91309	1.00000	NS
	0.0045	NS	NS	0.0006	<0.0001	<0.0001	--	0.0002
	112	28	28	112	28	27	112	112
Soil K	NS	NS	0.51518	NS	NS	NS	NS	1.00000
	0.0011	<0.0001	<0.0001	0.0015	<0.0001	0.0315	0.0002	--
	362	112	112	112	111	111	112	364

† Abbreviations for the correlation analysis represent: Act yld, actual grain yield (kg ha^{-1}), Sap K (g K kg^{-1}), Tissue K (g K kg^{-1})

FIGURES

Fig. 2.1. Soybean trifoliate tissue K concentrations measured at three different growth stages (R3, R5.5, and R6.5) for seven site-years at the Delta Research and Extension Center and North Mississippi Research and Extension Center in 2019, 2020, and 2021.

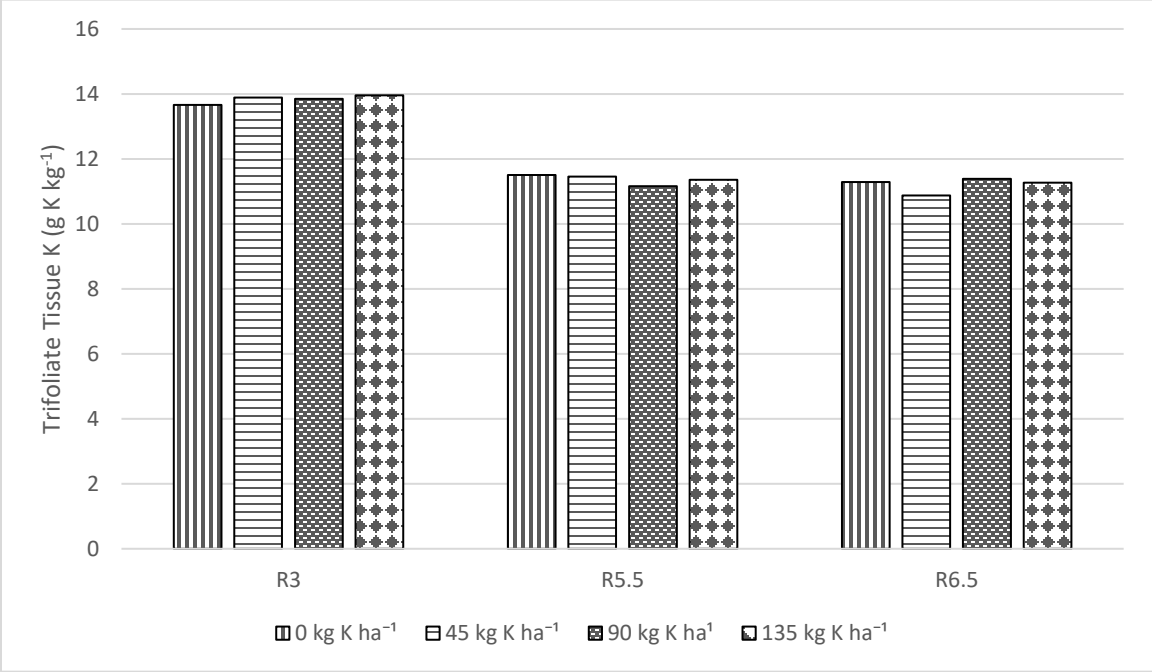

Fig. 2.2. Soybean petiole sap K concentrations measured at three different growth stages (R3, R5.5, and R6.5) for soybeans receiving four K fertilizer rates (0, 45, 90, and 135 kg K ha^{-1}) for seven site-years at the Delta Research and Extension Center and North Mississippi Research and Extension Center in 2019, 2020, and 2021.

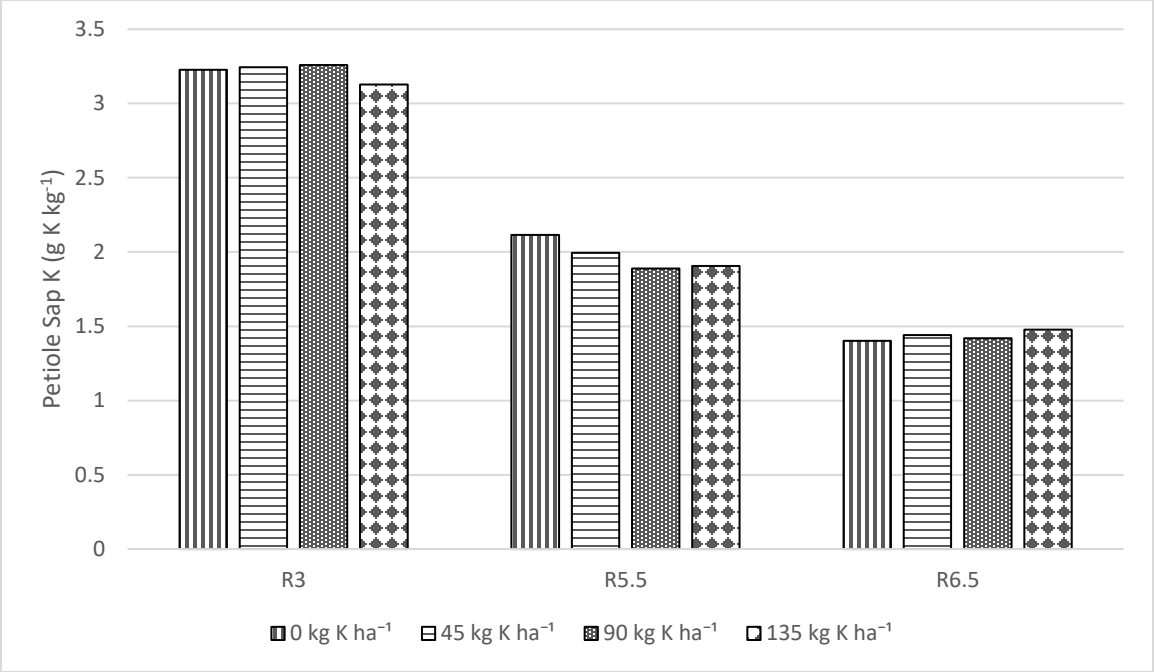

Fig. 2.3. Mean soybean grain yield for soybeans receiving four K fertilizer rates (0, 45, 90, and 135 kg K ha^{-1}) for seven site-years at the Delta Research and Extension Center and North Mississippi Research and Extension Center in 2019, 2020, and 2021.

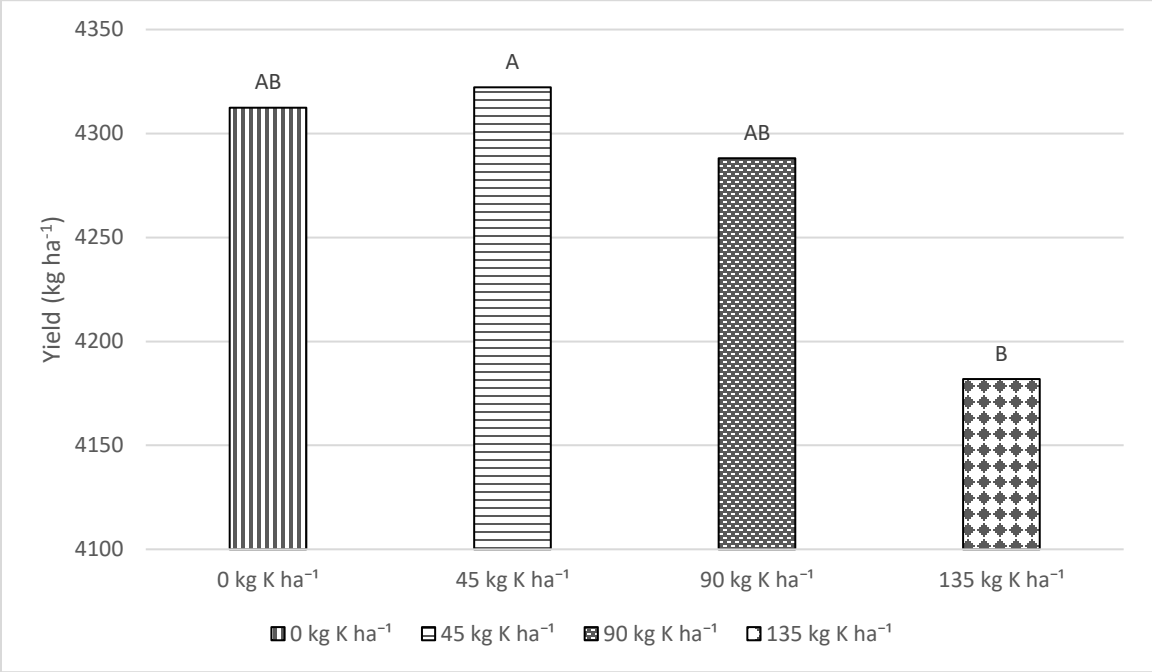

Fig. 2.4. Correlation figure between petiole sap K content and trifoliate leaf K content at the R3 (A), R5.5 (B), and R6.5 (C) growth stages.

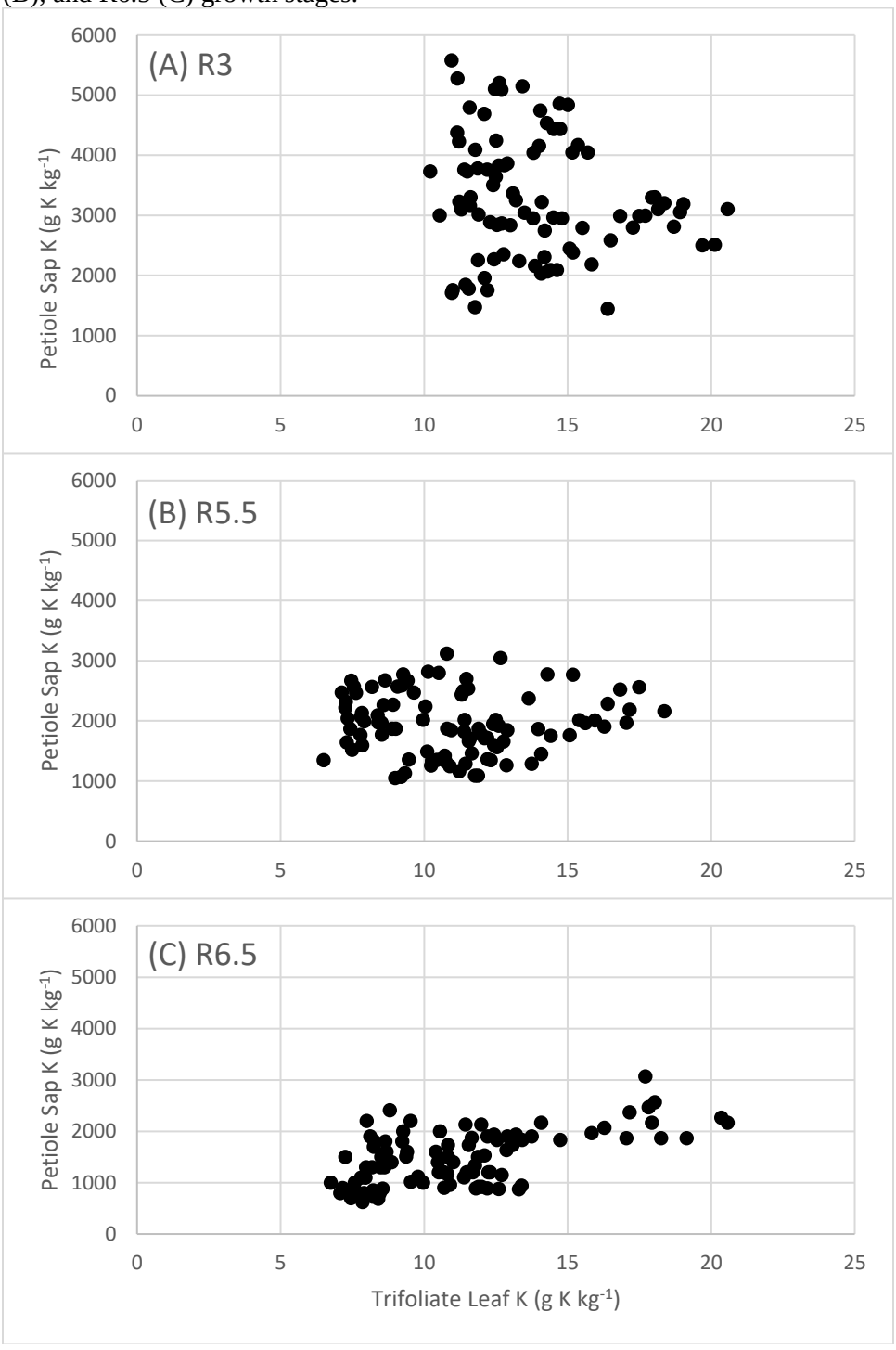

Fig. 2.5. Correlation figure between grain yield and trifoliate leaf K content at the R3 (A), R5.5 (B), and R6.5 (C) growth stages.

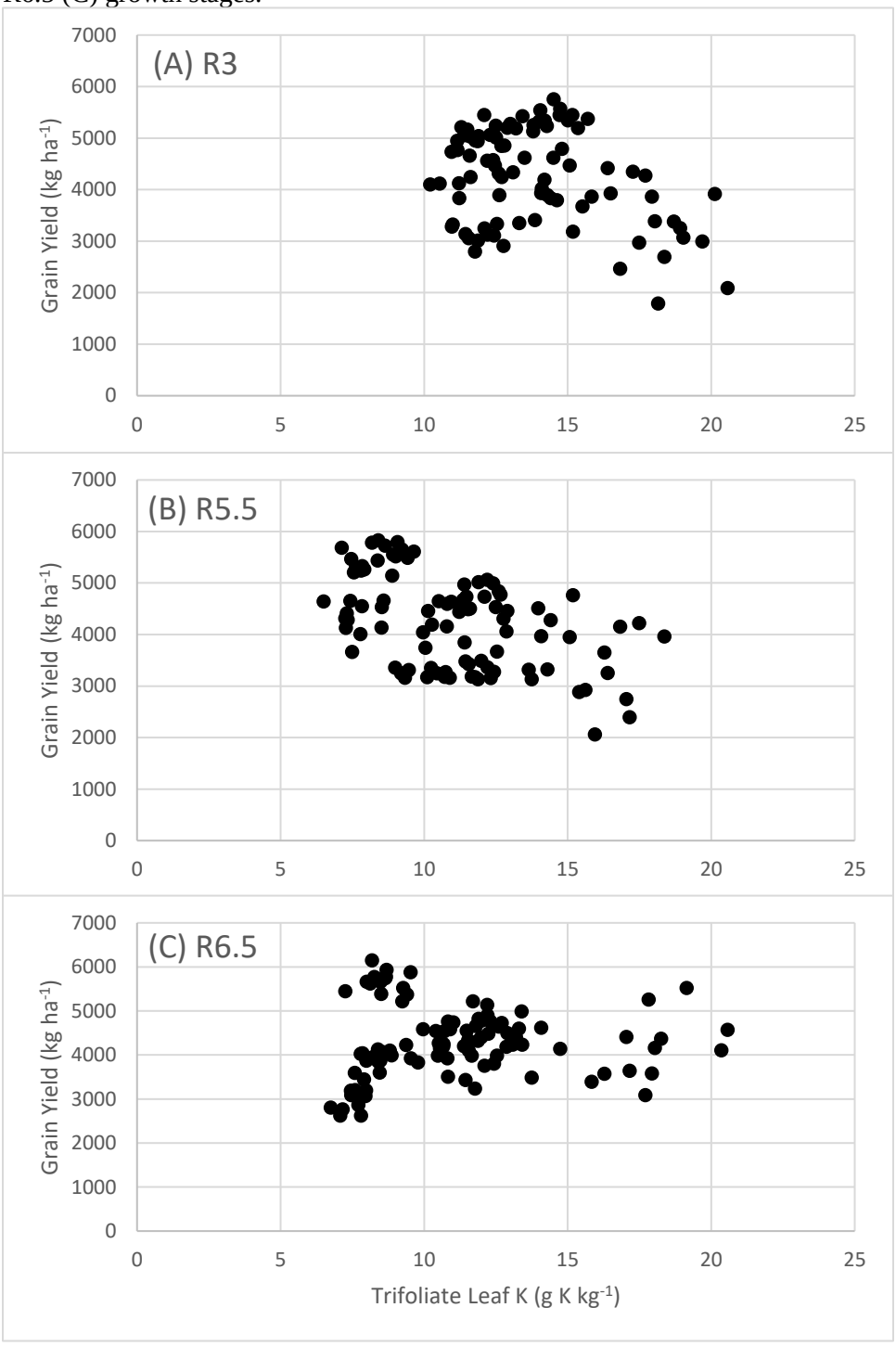

Fig. 2.6. Correlation figure between grain yield and petiole sap K content at the R3 (A), R5.5 (B), and R6.5 (C) growth stages.