

Evaluation of in-season wheat nutrient uptake changes and nitrogen management for grain and dual purpose winter wheat

by

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B.S., Kansas State University, 2014

A THESIS

Submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2017

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2017

Abstract

An effective nutrient management plan is essential for optimum wheat (*Triticum aestivum*) yields. The objectives of the first study were to: i.) evaluate changes in concentration of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), copper (Cu), manganese (Mn), and zinc (Zn), within separate plant parts, throughout the growing season, ii.) evaluate the uptake pattern and redistribution of each of these nutrients within the plant throughout the season, and iii.) evaluate the impact of micronutrient and S fertilization on concentration and uptake of nutrients and the potential use of fertilization for biofortification. Three locations were established and sampled every 7 to 10 days during the spring. Samples were divided into leaf, stem, head, spike and grain fractions and analyzed for nutrient concentration. Concentration levels tended to decrease throughout the season in non-grain plant fractions and stay relatively constant in the grain. Harvest grain concentration of Zn was significantly higher with micronutrient fertilization at all locations, suggesting the possibility of Zn biofortification through fertilization. S, Cu, and Zn showed nutrient accumulation increases in all plant fractions until the time period around anthesis (Feekes 10.5.1), at which point leaf and stem fractions decreased in total accumulation while nutrients were remobilized to the grain. N, P, K and Mn showed a similar trend although timing of remobilization varied between locations and treatments. The objectives of the second study were to i.) evaluate the interaction of wheat grazing management and soil and fertilizer N requirements with emphasis on dual purpose wheat, ii.) assess the use of NDVI sensors for N management and forage quantity assessment in wheat grazing systems, and iii.) evaluate forage quality and quantity interactions with N management. Three locations were established and fertilized with N application rates of 0, 34, 67, and 101 kg ha⁻¹ in the fall, followed by simulated grazing. Spring topdress applications were

made at rates of 0 and 90 kg ha⁻¹, or a sensor based rate. The impact of grazing on grain production varied by location. NDVI readings correlated with biomass at two of three locations and N recommendations using NDVI sensors resulted in significantly lower N rates and similar yield results to high N application rates. Forage dry matter and N concentration increased with higher N rates.

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Acknowledgements

I would like to first acknowledge my parents and family for their exceptional support throughout my entire college career and life. I would like to thank my major professor, Dr. Dorivar Ruiz Diaz for the opportunity to pursue my graduate degree as well as his patience and guidance during my time as a graduate student. I also want to acknowledge the other members of my committee, Dr. Nathan Nelson and Dr. Gary Cramer. I would like to acknowledge everyone who I have worked with and who have helped me with my project along the way including: Cristie Edwards who helped me tremendously along the way, especially with statistics and how to write a thesis. Dana Mayer, Ashley Lorence, and Fernando Hansel, all who helped me many times in the field with less than exhilarating tasks. Brett Darbyshire, Lorena Solar, Diego Mayorga, Cintia Sciarresi, and Talha Shahryar for helping me process samples in the lab. Alex Tonon Rosa, Nicole Gutierrez, Hugo Gonzalez, and Andrew Stammer for helping me learn throughout my time as a graduate student. I would also like to acknowledge Dr. Dave Mengel, Dr. Ray Asebedo, Timothy Foster and Dr. Robert Florence, all of who were part of a soil fertility team I worked for as an undergraduate and without them, I would never have made the decision to attend graduate school. I am sure I am still forgetting many who have helped me along the way but I cannot extend enough gratitude to every individual I have been fortunate enough to meet and interact with during the time I have spent here at Kansas State University. I would also like to thank the Kansas Crop Improvement Association, Kansas Wheat Commission and the USDA Project No. 2012-02355 through the National Institute for Food and Agriculture's Agriculture and Food Research Initiative, Regional Approaches for Adaptation to and Mitigation of Climate Variability and Change for funding these research projects.

Chapter 1 - General Introduction

Introduction

Winter wheat (*Triticum aestivuum*) was planted on 3.4 million hectares in 2015, roughly double the amount of corn or soybeans planted (USDA, 2016). The highest yielding year on record for winter wheat in Kansas was 2016 with an estimated average of 3830 kilograms per hectare (USDA, 2016). Winter wheat for human consumption requires continuous improvements in grain yield levels as well as grain quality including nutritional value of wheat grain.

Optimizing nutrient management can improve grain yield and quality in winter wheat.

The most recent evaluation of nutrient uptake patterns in winter wheat was published by Karlen and Whitney in 1980. The 10-year grain yield average between 1971 and 1980 was 2170 kilograms per hectare compared to 2670 for the years between 2007 and 2016. This increase in average yield coupled with new plant genetics can result in significant changes in nutrient uptake patterns as well as changes in concentration levels throughout the plant. In order to continue to increase wheat yields, it is imperative to have a strong understanding of the nutrient concentration and uptake patterns to identify critical periods of rapid nutrient accumulation as well as the impact of timing on nutrient concentration. This evaluation also needs to be updated to consider new genetics, yield potential and changes in management over time.

Wheat is considered of global relevance as one of the three most consumed human food sources in the world along with maize (*Zea mays*) and rice (*Oryza sativa*). The massive staple consumption of wheat paired with the widespread micronutrient deficiency in human nutrition, especially zinc (Zn), make it a key crop for potential improvements in grain nutrient biofortification.

Grazing and grain dual purpose system for wheat can be particularly important in some regions of the Great Plains. A dual-purpose system can be highly profitable for producers as long as soil moisture and soil nutrient levels are adequate to support the increased demand. Other key aspects include proper management decisions by the producer such as variety choice and grazing timing (Redmon et. al., 1995). A crucial component in optimizing forage and grain production is proper nitrogen (N) management. In one study grazing removed 38 kg ha⁻¹ of N from the cropping system indicating the need for additional nitrogen in a dual purpose situation when compared to grain only (Virgona et. al., 2006). Producers also must apply nitrogen at the proper rate and time to optimize forage and grain production and minimize any N losses.

Thesis Organization

This thesis is presented as a series of three chapters. The titles of the chapters are: “Seasonal nutrient concentration changes in wheat plant parts”; “Evaluation of nutrient uptake and partitioning in winter wheat”, and “Nitrogen fertilizer management for winter wheat under dual purpose grazing and grain production.” Each chapter includes an abstract, introduction, materials and methods, results and discussion, conclusions, and references. The three chapters are preceded by a general introduction and proceeded by general conclusions (Chapters 1 and 4).

References

Groskurth, D. C., 2016. Kansas Acreage News Release. National Agricultural Statistics Service News Release. United States Department of Agriculture.

Groskurth, D. C., 2016. Kansas Wheat History. National Agricultural Statistics Service News Release. United States Department of Agriculture.

Karlen, D. L., & D. A. Whitney. 1980. Dry matter accumulation, mineral concentrations, and nutrient distribution in winter wheat. p. 281-288. *Agronomy Journal*, 72(2).

Redmon, L. A., Horn, G. W., Krenzer, E. G., & Bernardo, D. J. (1995). A review of livestock grazing and wheat grain yield: boom or bust?. *Agronomy Journal*, 87(2), 137-147.

Virgona, J. M., F. A. J. Gummer, and J. F. Angus. "Effects of grazing on wheat growth, yield, development, water use, and nitrogen use." *Crop and Pasture Science* 57.12 (2006): 1307-1319.

Chapter 2 - Seasonal nutrient concentration changes in wheat plant parts

ABSTRACT

Understanding the seasonal changes in nutrient concentration in winter wheat (*Triticum aestivum*) plant fractions can help to improve the use of tissue analysis as a tool for nutrient management. The objective of this study was to evaluate seasonal changes in macro, secondary, and micronutrient concentration throughout the growing season and evaluate the impact of micronutrient fertilization in tissue analysis values. This study was established at three locations in Kansas, two locations during the 2014-2015 season, and one location during the 2015-2016 season. The experimental design was a randomized complete block design with two treatments; a standard fertilization and standard fertilization plus treatment. The standard fertilization was nitrogen (N) at rates of 113, 119 and 102 kg ha⁻¹ at locations 1, 2 and 3, phosphorus (P) at rates of 86, 90, and 90 kg (P₂O₅) ha⁻¹ at each location, and potassium (K) at a rate of 56 kg (K₂O) ha⁻¹. The plus treatment added 17 kg ha⁻¹ of zinc (Zn), 11 kg ha⁻¹ of manganese (Mn), 11 kg ha⁻¹ of copper (Cu), 3 kg ha⁻¹ of boron (B), and 45 kg ha⁻¹ of sulfur (S) to the standard treatment. Aboveground plant biomass was collected every 7 to 10 days during the growing season and analyzed for N, P, K, S, Cu, Mn, and Zn concentrations as well as dry matter levels. Grain was harvested for yield and analyzed for the same nutrient concentrations. Significantly higher grain yields from S and micronutrient fertilizer were observed at one out of three locations. Harvested grain showed significantly higher Zn content for all locations and higher in Cu at two locations when micronutrient fertilizer was applied.

INTRODUCTION

Seasonal changes in nutrient concentration within the different plant fractions can be highly beneficial for the use of tissue analysis as a diagnostic tool, and a better understanding of tissue nutrient concentration effect on grain yield. Concentration levels can help indicate plant nutrient stress and in some cases, yield potential.

Understanding how concentration levels change throughout the growing season in healthy wheat plants can provide a baseline for further advancements in tissue sampling timing. Furthermore, evaluating the concentration changes as they occur in separate plant fractions can show critical time periods of nutrient changes and how they relate to different developmental stages of the plant. The nutrient concentration change compared to timing can be used to identify the reasoning for concentration differences in tissue samples meant for field diagnostics. Many studies were conducted in years past on older wheat varieties focusing on whole plant wheat concentration changes.

Karlen and Whitney (1980) found that whole plant concentration of N, P, and K in wheat all fell throughout the spring. Preez and Bennie (1991) showed similar findings for N and P although K concentration increased by roughly 10 g kg^{-1} during three weeks to approximately two months after planting. Preez and Bennie (1992) also showed a small increase in Mn concentration similar to K roughly 50 days after planting before decreasing in a curvilinear trend. Copper and Zn in this study showed a curvilinear decrease throughout the season. The concentration decrease that these nutrients show is attributed to the slower rate of uptake compared to carbon accumulation (Gregory et. al., 1979). This decline reflects the decrease in nutrient sufficiency levels later in the season (Mengel and Ruiz Diaz, 2009).

Along with whole plant concentration changes, few studies have been conducted on nutrient concentration changes throughout the separate plant fractions. Karlen and Whitney (1980) found that N concentrations decreased linearly in living leaves and stems from jointing to maturity. Bauer et. al. (1987) also showed leaf N concentration to decrease linearly throughout the season but showed stem N concentration to be a curvilinear decrease with the most rapid rate between stem elongation and flag leaf (Feekes 6-Feekes 8). Karlen and Whitney (1980) showed that P, sulfur (S) and Copper (Cu) all decreased in the living leaves while P, K, and zinc (Zn) decreased in stems, from jointing to flowering. Bauer et al. (1987) also showed P to decrease in both leaves and stems throughout the season in a curvilinear relationship. Boatwright and Haas (1961) also showed very similar results with N and P concentrations decreasing in leaf, stem and spike fractions, throughout the season, while grain concentrations were unchanging.

Karlen and Whitney also showed that N concentrations remained relatively constant in the head and grain fractions from boot to maturity and flowering to maturity respectively (1980). In the head, K and Zn showed a decrease from booting to maturity whereas N, P, S, all stayed relatively constant (Karlen and Whitney, 1980). Grain showed a very similar pattern with all nutrients remaining constant from heading to maturity with exception to Mn and Zn which did not show a consistent trend (Karlen and Whitney, 1980).

Boatwright and Haas (1961) found that fertilization with N and P caused significantly greater N and P concentrations in vegetative plant parts early in the season but levels were similar late in the season. This same study showed significant grain concentration increases, in N and P, at maturity due to fertilization.

Nutrient concentration levels of wheat grain intended for human consumption can have a considerable impact on the nutritional value of the food. Low levels of micronutrients in the

grain can lead to nutritive deficiency of populations with a large portion of diet intake from a low number of crop sources. For example, micronutrient deficiencies of iron (Fe) and Zn are prevalent in populations with a high percentage of the diet being direct wheat consumption (Borril et. al., 2014). It is estimated that 15 to 20 percent of the world population is at risk for Zn deficiency due to inadequate supplies of Zn in food sources (Wessels and Brown, 2012). Iron deficiency is predicted to affect even more people worldwide, up to 25% (Caballero, 2002).

Biofortification of wheat is generally centered on Fe and Zn because they are the most widely deficient nutrients in diets worldwide. Zhou et. al. (2012) showed that heavy Zn fertilization increased grain Zn levels by up to 90% and grain yield by as much as 5%. This suggests that it is possible to increase Zn concentration in grain while also increasing grain yields. Target Zn concentration level increase for purposes of biofortification is 12 mg kg⁻¹ as defined by the HarvestPlus biofortification progress briefs (2014). HarvestPlus also sets the target concentration level of Zn at 35 mg kg⁻¹ for wheat grain. Fertilization of wheat with Fe was shown to be less effective by Aciksoz et. al. (2011), with direct Fe applications showing minimal or no impact on Fe concentration.

The objectives of this study were to i) describe the seasonal changes in nutrient concentration levels, within separate plant fractions, throughout the growing season and ii.) evaluate the effect of micronutrient fertilization on grain yield and micronutrient enrichment for improvement of human nutritive value.

MATERIALS AND METHODS

This study was conducted at two locations during the 2014-2015 growing season and one location during the 2015-2016 season. The experimental design of the study was a randomized complete block design with two treatments and four replications. Individual plot size was 55.7

square meters for all locations, 6.1 meters by 9.1 meters at locations 1 and 3 and 5.5 meters by 10.1 meters at location 2. All locations were non-irrigated and used conventional tillage.

Both treatments received an application of a broadcast blend of mono ammonium phosphate (MAP) [11-52-0 (N-P₂O₅-K₂O)] and potassium chloride (KCl) [0-0-62 (N-P₂O₅-K₂O)] for a total application rate of 12 kg ha⁻¹ of N, 56 kg ha⁻¹ of P₂O₅, and 56 kg ha⁻¹ of K₂O. The micronutrient (NPK+Micros) treatment received a broadcast blend of 17 kg ha⁻¹ of Zn, 11 kg ha⁻¹ of Mn, 11 kg ha⁻¹ of Cu, 3 kg ha⁻¹ of boron, and 45 kg ha⁻¹ of S in addition to the previously described N, P, and K fertilizer.

Location 1 was established in Manhattan, KS (Riley Co) (39°12'26"N; 96°35'46"W) (Table 2.1). A mixture of urea ammonium nitrate (UAN) 28% N and ammonium polyphosphate (APP) [10-34-0 (N-P₂O₅-K₂O)] containing 56 kg ha⁻¹ of N and 30 kg ha⁻¹ of P₂O₅ was applied pre-plant in late July, along with the previously mentioned broadcast blend applied after planting, for a total of 68 and 86 kg ha⁻¹ N and P applied during the fall. Spring top-dress of N was completed with 45 kg ha⁻¹ of N applied in the spring as UAN (28-0-0) to the entire study area. The total amount of N applied during the entire season was 113 kg ha⁻¹.

Location 2 was in Belleville, KS (Republic Co) (39°48'53"N; 97°40'22"W) (Table 2.1). An application of a liquid mixture of UAN (28-0-0) and APP (10-34-0) containing 90 kg ha⁻¹ of N and 34 kg ha⁻¹ of P₂O₅ was applied pre-plant, along with the previously mentioned broadcast blend applied after planting, for a total of 102 kg ha⁻¹ and 90 kg ha⁻¹ N and P applied in the fall. In the spring, an additional 17 kg ha⁻¹ of N was applied as broadcast urea. The total amount of N applied during the entire season was 119 kg ha⁻¹.

Location 3 was established in Ashland Bottoms (Riley Co) (39°8'45"N; 96°37'49"W) (Table 2.1). A liquid broadcast blend of UAN (28-0-0) and APP (10-34-0) was applied pre plant

containing 56 kg ha⁻¹ of N and 34 kg ha⁻¹ of P₂O₅, along with the previously mentioned broadcast blend applied after planting, for a total of 68 kg ha⁻¹ and 90 kg ha⁻¹ N and P applied during the fall. In the spring, an additional 34 kg ha⁻¹ of N was applied as surface banded UAN (28-0-0). The total amount of N applied during the entire season was 102 kg ha⁻¹.

Soil Sampling and analyses

Soil samples were collected from each plot at the time of planting at the 0-15 cm and 0-60 cm. Samples were dried at 40°C and ground to pass a 2mm sieve before analysis. The 0-15 cm samples were analyzed for pH with a 1:1 (soil:water) method (Watson and Brown, 1998), soil test P with the Mehlich-3 extraction (Frank et al., 1998), K by the ammonium acetate extraction (Warncke and Brown, 1998), organic matter by loss on ignition (Combs and Nathan, 1998), Cu, Mn, and Zn, with the DTPA extraction (Whitney, 1998). Samples collected at the 0-60 cm depth were analyzed for nitrate using the KCl extraction (Gelderman and Beegle, 1998), Cl with a calcium nitrate extraction (Gelderman et al., 1998), and S using a calcium phosphate extraction (Combs et. al.,1998). Soil test results are listed in Table 2.2.

Plant Tissue Sampling and Analysis

Above ground plant sampling started in the fall before wheat dormancy in the winter. One sampling was completed in the fall for locations 1 and 2, and two fall samplings for location 3. Sampling ceased throughout the winter and was reinitiated at spring green-up, with subsequent sampling once every 6 to 12 days depending on weather, for a total sampling number of 12 at location 1, 13 at location 2, and 15 at location 3. Plant samples were hand-clipped at ground level from two rows positioned roughly 1 m inside left and right plot edges, at a length of 76 cm. Total sampling area was .387 m² at locations 1 and 3 and .29 m² at location 2. Samples were taken from the front left corner of the plot at the first sampling time and then moved progressively up

the plot with roughly 50 cm between sample locations. Once sampling position reached the end of the plot, the samples were taken from the right front corner of the plot and moved up the plot on that side. This allowed the central area of the plot to remain undisturbed for the purpose of grain harvest. Samples were then separated into plant fractions that include leaf, stem, spike and grain depending on the growth stage. Samples were then dried at 60°C, weighed for biomass and ground to pass a 2mm mesh. They were then analyzed for total N using a sulfuric peroxide digest (Matsunaga & Shiozaki, 1987) and Zn, Cu, Mn, S, P, and K using a nitric perchloric digest (Giesecking et. al., 1935).

Grain Harvest and Analysis

Grain was harvested from the center of the plots where previous plant sampling did not occur, using a plot combine at a width of 1.4 m and the length of the plot. Grain was then weighed for yield and tested for moisture and test weight before being ground to pass a 2-mm mesh and analyzed for total N using sulfuric peroxide digest and Zn, Cu, Mn, S, P, and K using a nitric perchloric digest. Reported grain yield is adjusted to 13 % moisture.

Statistical Analysis

Statistical analysis by location was performed using the GLIMMIX procedure in SAS 9.4 (SAS Institute Inc, 2012). Plant tissue nutrient concentration was analyzed using sampling time as repeated measure in the model and blocks as random effect. Grain yield analysis at the end of the season was done using blocks as random effect. A significance level of 0.10 was used for analysis.

RESULTS AND DISCUSSION

Leaf tissue nutrient concentration

Leaf tissue biomass and nutrient concentration levels throughout the season show somewhat varied results across locations. Sampling date had a significant impact on every nutrient at all locations (Table 2-3). Leaf biomass at location 1 showed some increase in early spring and a decrease by harvest, however biomass levels were highly variable during the growing season (Fig 2.1). Leaf biomass at locations 2 and 3 increased rapidly until anthesis (Feekes 10.5.1) (Wise et. al, 2011) at which point it starts to decrease until harvest (Fig. 2-2 and 2-3). Location 3 showed a significant biomass response to the application of S and micronutrients. This response may be due to a S fertilizer response considering the low soil OM and S levels (Table 2.2) (Rasmussen et. al., 1975).

Nitrogen concentration in the leaf followed similar overall trends for all locations, with higher concentration at early growth stages and decreasing until harvest (Fig. 2.1, 2.2, and 2.3). This trend for N concentration in the leaf agrees with previous studies (Karlen and Whitney, 1980). The application of S and micronutrients show no effect on leaf N concentration throughout the growing season.

Phosphorus leaf tissue concentration showed an overall decrease over the growing season for all locations (Fig. 2.1, 2.2, and 2.3). The rate of decrease in P tissue concentration is generally faster during early growth until anthesis (Feekes 10.5.1) and little changes until harvest. Potassium tissue concentration showed a very similar trend for all locations (Fig. 2.1, 2.2, and 2.3). The concentration of K showed a small increase around spring green-up then decreasing until anthesis (Feekes 10.5.1) at which point the rate of decrease becomes very rapid until

harvest. Gregory et. al. (1979) suggests this loss of K is efflux from the plants back through the roots while Miller (1939) claims leaching from senescing leaves may also be occurring.

Sulfur concentration in the leaf tissue generally showed an increase around green-up until anthesis (Feekes 10.5.1) for all locations and then rapidly decreasing until harvest (Fig. 2.1, 2.2 and 2.3). Locations 2 and 3 showed significantly higher tissue S concentration throughout the growing season with the application of S and micronutrients (Fig. 2.2 and 2.3). Copper leaf tissue concentration was generally constant during the growing season, with a slight decrease in concentration as the season progresses, however with some variability for all locations (Fig. 2.1, 2.2 and 2.3). The application of Cu fertilizer resulted in significant increase in Cu leaf tissue concentration for all locations. Relatively higher Cu concentration was significant at early and late growth stages. Manganese concentration in the leaf tissue varied during the growing season, however, the overall trend for all locations were for an increase in Mn concentration (Fig. 2.1, 2.2 and 2.3). Location 1 showed higher Mn concentration with the application of Mn fertilizer for several sampling points during the growing season, particularly during early and late stages (Fig. 2.1). Zinc concentration in the leaf was generally higher early in the season and decreased during late growth stages, with similar trends for all locations (Fig. 2.1, 2.2 and 2.3). Furthermore, the application of Zn fertilizer treatments resulted in an overall increase in tissue Zn concentration at all locations.

Stem tissue nutrient concentration

Stem biomass and nutrient concentration levels showed less variable patterns during the growing season for all locations when compared to concentrations in the leaf (Fig. 2-4, 2-5, 2-6). Stem biomass increased rapidly at all locations early in the season until anthesis (Feekes 10.5.1) and decreasing at the end of grain fill. Stem biomass at location 3 was significantly higher with

the application of S and micronutrient fertilizers (Fig. 2.4, 2.5 and 2.6). This response was similar to the biomass response in the leaf, and was likely due to the applied S fertilizer because of the high amount of applied S and location conditions susceptible to S deficiency such as deep sand profile, low organic matter and high rainfall (Table 2.1, 2.2). Nitrogen concentration levels decreased from the start of stem elongation until harvest at all locations. Trends for P and K were also similar to N and showed a significant decrease at all locations. Sulfur trends were similar for all locations with higher concentration during early growth stages (Fig. 2.4, 2.5 and 2.6). Sulfur concentration in the stem was significantly higher with the application of S fertilizer and differences in concentration levels were particularly noticeable during late growth stages. Sulfur concentration values from location 1 at Feekes 10.5.4 were omitted due to excessively high values, potentially caused by sampling error (Figure 2.4). Copper decreased slightly throughout the season at all locations with some effect of Cu fertilizer application on Cu stem tissue concentration. Manganese concentration decreases throughout the season with significantly higher concentration levels in the treatment with S and micronutrients. Zinc concentration in the stem generally decreased throughout the season, with an overall increase in concentration with the application of Zn fertilizer (Fig. 2.4, 2.5 and 2.6). Furthermore, Zn fertilizer application resulted in a slight increase in Zn tissue concentration in the stem at the end of the growing season with significantly higher Zn values for the last two sampling dates.

Head tissue nutrient concentration

The head fraction was separated from stems when the heads were clearly differentiated from the stem (around Feekes 8-10 for all locations). The number of sampling dates for the head fraction was 4 at location 1 and 5 for locations 2 and 3, beginning at Feekes 11.2 the head fraction was further separated into the two fractions of spike and grain. The head biomass

increased linearly for all locations while N, P, K and Zn tissue concentration decreased in fairly linear trends. Head biomass at location 3 showed a significant effect of S and micronutrient fertilization, with a significant increase in biomass particularly for late growth stages. However, N, P, K and Zn tissue concentration were not affected by fertilizer application. Sulfur concentration generally decreases during the growing season in the head fraction, with significantly higher S concentration with S fertilizer application at location 3 (Fig. 2.7, 2.8 and 2.9). Manganese concentration in the head tissue showed an overall increase over time for all locations with no significant effect of Mn fertilizer application. Copper tissue concentration generally decreases for all locations with no clear effect of Cu fertilizer application.

Spike nutrient concentration

Nutrient concentration levels for spike fractions were evaluated for the final two sampling dates when spike and grain samples were separated at the growth stages Feekes 11.2 and 11.3. At all locations S showed a significant decrease from the first to second sampling date with no significant differences between fertilizer treatments (Table 2.3, 2.4). Copper did not show any discernible trend. Zinc showed a significant decrease at location 3 while Mn increased at the same location.

Grain nutrient concentration

Grain samples were collected during the same dates as spike samples with two sampling dates for each location. Grain biomass increased from one sampling date to the next at all locations (Table 2.5). Location 3 showed a significantly higher grain biomass for the treatment with S and micronutrient fertilizer. Nitrogen concentration in the grain showed little change between sampling time and treatments for all locations. Phosphorus, K and Mn all show decreases in both treatments with no significant differences. Potassium, S, Cu and Mn showed

little change between sampling times and treatments at all locations. Zinc concentration in the grain showed an increase with the application of Zn fertilizer particularly at locations 1 and 3.

Grain yield and nutrient concentration at harvest

Yield and nutrient concentrations of harvest grain in all treatments and locations are shown in Table 2.6. Yield results show a significantly higher yield for the treatment with S and micronutrient fertilizer at location 3. This yield increase is most likely due to the additional S fertilizer given the low soil test S levels (Table 2.2). Nitrogen concentration in the grain was significantly higher at location 3 with the NPK only treatment, likely due to lower yields and the same amount of N fertilizer applied. The NPK+Micros treatment was also significantly higher in Zn concentration levels at all locations. At all three locations the NPK+Micros treatment reached the target level of 35 mg kg⁻¹ provided by HarvestPlus. Averaged across all locations Zn concentration was increased by 10 mg kg⁻¹. This is still under the HarvestPlus target of 12 mg kg⁻¹ increased concentration level however, it shows fertilization of Zn to be one potential tool for biofortifying wheat. Across all sites average Zn removal was 0.14 kg ha⁻¹ which is 0.008% of the applied amount of Zn. This reflects the high amount of fertilizer Zn that is required to increase concentration levels. Further studies are necessary to show the amount of concentration increase that heavy Zn fertilization increases concentration in proceeding years. Copper concentration levels were significantly higher in the NPK+Micros treatment at locations 1 and 2, however were much lower and not significantly different at location 3 likely due to much lower soil test Cu levels and higher sand content in the soil.

CONCLUSIONS

Yield increase from S and micronutrient fertilization was seen at only one location and was most likely attributed to S fertilization due to low soil S levels. General macronutrient

concentration trends showed declining values throughout the season in vegetative parts and maintaining in grain throughout development. These results are similar to previously conducted studies. Significantly higher concentration levels, from S and micronutrient fertilizer application, were found for Cu and Zn within most plant parts, as well as S within leaves and stems. In harvest grain, Zn was significantly higher in the NPK+Micros treatment at all locations. Average Zn concentration level was 40 mg kg⁻¹ in the NPK+Micros treatment, an increase of 10 mg kg⁻¹ over the NPK treatment. These values are above and very near the target values of 35 and 12 mg kg⁻¹ established by HarvestPlus. Results from this study showed that Zn fertilization is a useful tool that can be implemented for biofortification purposes.

REFERENCES

- Aciksoz, S. B., A. Yazici, L. Ozturk, & I. Cakmak, 2011. Biofortification of wheat with iron through soil and foliar application of nitrogen and iron fertilizers. P. 215-225. *Plant and Soil*, 349(1-2).
- Bauer, A., A. B. Frank, and A. L. Black. 1987. Aerial parts of hard red spring wheat. II. Nitrogen and phosphorus concentration and content by plant development stage. P. 852-858. *Agronomy journal* 79.5.
- Beaton, J. D. & G. S. Sekhon. 1985. Potassium nutrition of wheat and other small grains. P. 701-752 *Potassium in agriculture*.
- Boatwright, G. O., and H. J. Haas. 1961. Development and composition of spring wheat as influenced by nitrogen and phosphorus fertilization. P. 33-36 *Agronomy Journal* 53.1.
- Borrill, P., J. M. Connorton, J. Balk, A. J. Miller, D. Sanders, & C. Uauy. 2014. Biofortification of wheat grain with iron and zinc: integrating novel genomic resources and knowledge

- from model crops. P. 98-105 From soil to seed: micronutrient movement into and within the plant, *Front Plant Sci* 5:53.
- Caballero, B. 2002. Global patterns of child health: the role of nutrition. P. 3-7. *Annals of Nutrition and Metabolism*, 46(Suppl. 1).
- Cakmak, I. 2010. Biofortification of cereals with zinc and iron through fertilization strategy. P. 4-6 19th World Congress of Soil Science, *Soil Solutions for a Changing World*. Brisbane, Australia
- Cakmak, I. 2008. Enrichment of cereal grains with zinc: agronomic or genetic biofortification?. P. 1-17 *Plant and soil*, 302(1-2).
- Combs, S. M., J. L. Denning & K. D. Frank. 1998. Sulfate-sulfur. P. 35-40. In: J.R. Brown (ed.) *Recommended chemical soil test procedures for the North Central Region*. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Combs, S.M., and M.V. Nathan. 1998. Soil organic matter. P. 53–58. In: J.R. Brown (ed.) *Recommended chemical soil test procedures for the North Central Region*. North Central 17 Reg. Res. Publ. 221 (Rev.). SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Du Preez, C. C., and A. T. P. Bennie. 1991. Concentration, accumulation and uptake rate of macronutrients by winter wheat under irrigation. P. 31-37. *South African Journal of Plant and Soil* 8.1
- Du Preez, C. C., and A. T. P. Bennie. 1992. Concentration, accumulation and uptake rate of Cu, Fe, Mn and Zn by wheat under irrigation. P. 4-9. *South African Journal of Plant and Soil* 9.1.

- Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. P. 21–26. In: J.R. Brown (ed.)
Recommended chemical soil test procedures for the North Central Region. North Central
Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Gelderman, R. H., & D. Beegle, 1998. Nitrate-nitrogen. P. 17-20. In: J.R. Brown (ed.)
Recommended chemical soil test procedures for the North Central Region. North Central
Reg. Res. Publ, 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Giesecking, J.E., Snider, H.J., and Getz,C.A. 1935. Destruction of organic matter in plant material
by the use of nitric and perchloric acids. P. 185-186. Ind. and Eng. Chem.,Anal.Ed.,V.7,
- Gregory, P. J., D. V. Crawford, & M. McGowan. 1979. Nutrient relations of winter wheat: 1.
Accumulation and distribution of Na, K, Ca, Mg, P, S and N. P. 485-494 The Journal of
Agricultural Science 93.02
- HarvestPlus Brief. 2014. Breeding Crops for Better Nutrition. Washington, DC, USA.
- Karlen, D. L., & D. A. Whitney. 1980. Dry matter accumulation, mineral concentrations, and
nutrient distribution in winter wheat. P. 281-288. Agronomy Journal, 72(2).
- Lamond, R. E. 1997. Sulphur in Kansas: Plant, Soil, and Fertilizer Considerations. MF-2264
Kansas State University Agricultural Experiment Station and Cooperative Extension
Service, Kansas State University.
- Leikam, D.F., R.E. Lamond, & D.B. Mengel. 2003. Soil test interpretations and fertilizer
Recommendations. MF-2586. Kansas State University Agricultural Experiment Station
and Cooperative Extension Service, Kansas State University.
- Matsunaga, T., & Shiozaki, H. 1989. Sulfuric acid-hydrogen peroxide digestion for the
determination of total nitrogen in plant material containing nitrate nitrogen. Japanese
Journal of Soil Science and Plant Nutrition (Japan).

- Mengel, D. and D.A. Ruiz Diaz. 2009. Plant analysis for wheat: Be sure it's done at the proper stage of growth. Agron. e-Update Kansas State University ext. No. 193.
- Murphy, K. M., P. G. Reeves, & S. S. Jones. 2008. Relationship between yield and mineral nutrient concentrations in historical and modern spring wheat cultivars. P. 381-390 *Euphytica*, 163(3).
- Paulsen, G. M. 1997. Growth and Development. P. 2-7 Wheat production handbook. C-529. Kansas State Univ. Coop. Ext. Serv., Manhattan, KS.
- Portmann, D. 2012. Cadmium and zinc uptake in wheat as affected by nitrogen fertilization and agricultural management, M.Sc. diss., Swiss Federal Institute of Technology, Zürich.
- Rasmussen, P. E., R. E. Ramig, R. R. Allmaras, and C. M. Smith. 1975. Nitrogen-sulfur relations in soft white winter wheat. II. Initial and residual effects of sulfur application on nutrient concentration, uptake, and N/S ratio. P. 224-228. *Agronomy journal* 67, no. 2.
- SAS Institute. 2013. The SAS system for Windows. Version 9.4. SAS Inst., Cary, CN.
- Schlegel, A. J., C. A. Grant. 2006. Soil fertility. P. 141-194 *Dryland agriculture*, (Ed. 2).
- Torun, A., I. Gültekin, M. Kalayci, A. Yilmaz, S. Eker, & I. Cakmak. 2001. Effects of zinc fertilization on grain yield and shoot concentrations of zinc, boron, and phosphorus of 25 wheat cultivars grown on a zinc-deficient and boron-toxic soil. P. 1817-1829 *Journal of plant nutrition*, 24(11).
- Velu, G., I. Ortiz-Monasterio, I. Cakmak, Y. Hao, & R. P. Singh. 2014. Biofortification strategies to increase grain zinc and iron concentrations in wheat. P. 365-372 *Journal of Cereal Science*, 59(3).

- Warncke, D., and J.R. Brown. 1998. Potassium and other basic cations. P.31-34. In J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.
- Watson, M.E., and J.R. Brown. 1998. pH and lime requirement. P.13-16. In J. R. Brown (Ed.) Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn, Columbia.
- Wessells, K. R., and K. H. Brown 2012. Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLoS ONE 7:e50568.
- Westfall, D. G., D.A. Whitney, D. M. Brandon & R. L. Westerman. 1990. Plant analysis as an aid in fertilizing small grains. P. 495-519. Soil testing and plant analysis., (Ed. 3).
- Whitney, D.A. 1998. Micronutrients: Zinc, Iron, Manganese and Copper. P. 41-44. In Recommended Chemical Soil Test procedures for North Central Region. North Central Regional Publ.221(Rev.) Missouri Agric. Exp. Stn. Columbia.
- Whitney, D.A. 1997. Nutrient Management. P. 12-15. Wheat production handbook. C-529. Kansas State Univ. Coop. Ext. Serv., Manhattan, KS.
- Widmar, A., D.A. Ruiz Diaz. 2013. Evaluation of secondary and micronutrients for soybean and wheat production . M.Sc. diss., Kansas State Univ., Manhattan, KS.
- Wise, K., B. Johnson, C. Mansfield, & C. Krupke 2011. Managing wheat by growth stage. Purdue Extension ID-422
- Zou, C. Q., Y. Q. Zhang, A. Rashid, H. Ram, E. Savasli, R. Z. Arisoy, I. Ortiz-Monasterio, S. Simunji, Z. H. Wang, V. Sohu, M. Hassan, Y. Kaya, O. Onder, O. Lungu, M. Yaquab Mujahid, A. K. Joshi, Y. Zelenskiy, F. S. Zhang, I. Cakmak. 2012. Biofortification of

wheat with zinc through zinc fertilization in seven countries. P. 119-130. Plant and soil
361, no. 1-2.

Table 2-1. Description of locations in 2014-2015 and 2015-2016.

Location	Year	County	Soil Series [†]	Soil Subgroup	Precipitation			Variety	Planting Rate	Planting Date
					30-yr	1-yr	Season			
					----- mm -----				kg ha-1	
1	2014-2015	Riley	Smolan ScL	Pachic Argiustolls	904	777	599	Hotrod	45	10/6/2014
2	2014-2015	Republic	Crete SL	Pachic Udertic Argiustolls	775	655	381	Everest	102	10/7/2014
3	2015-2016	Riley	Belvue SL	Typic Udifluvents	904	988	652	Everest	45	10/6/2015

[†] SCL, Silty clay loam; SL, Silty loam

Table 2-2. Initial soil test results from each location.

Soil parameter †	Location		
	1	2	3
pH	5.9	4.6	5.4
OM (g kg ⁻¹)	21.5	29.0	16.0
P (mg kg ⁻¹)	36	59	69
K (mg kg ⁻¹)	293	475	232
Cu (mg kg ⁻¹)	1.5	1.7	0.7
Mn (mg kg ⁻¹)	25.5	82.5	14.5
Zn (mg kg ⁻¹)	1.1	1.2	1.1
NO ₃ -N (mg kg ⁻¹)	13.0	21.5	21.0
Cl (mg kg ⁻¹)	2.8	6.2	4.5
S (mg kg ⁻¹)	9.8	13.8	1.9

† pH 1:1 soil:water, organic matter, loss on ignition, P, Mehlich-3, K, ammonium acetate, Cu, Mn, Zn, DTPA Extraction, NO₃-N, potassium chloride extractant, Cl, calcium nitrate extraction, S, calcium phosphate extraction. pH, organic matter, P, K, Cu, Mn, Zn were all sampled at 0-15 cm depth. NO₃-N, Cl, S were all sampled at 0-60 cm depth.

Table 2-3. Significance of F values for fertilizer treatment (FT), sampling date (SD), and the interaction of fertilizer treatment by sampling date effects on N, P, K, S, Cu, Mn, and Zn concentrations in leaf, stem, head, spike and grain fractions at all location.

Nutrient	Leaf			Stem			Head			Spike			Grain		
	FT†	SD	FT × SD	FT	SD	FT × SD	FT	SD	FT × SD	FT	SD	FT × SD	FT	SD	FT × SD
----- P < F -----															
<u>Location 1</u>															
N	0.442	<0.001	0.691	0.768	<0.001	0.456	0.497	<0.001	0.998	0.935	0.030	0.495	0.349	0.030	0.195
P	0.484	<0.001	0.927	0.744	<0.001	0.404	0.871	<0.001	0.556	0.898	0.558	0.918	0.696	0.267	0.571
K	0.761	<0.001	0.128	0.527	<0.001	0.677	0.844	<0.001	0.842	0.321	<0.001	0.634	0.419	<0.001	0.362
S	0.132	<0.001	0.156	0.209	<0.001	0.246	0.988	<0.001	0.669	0.359	0.056	0.842	0.138	0.142	0.579
Cu	<0.001	<0.001	0.002	0.138	<0.001	0.912	0.114	0.036	0.229	0.561	0.710	0.091	0.060	0.045	0.125
Mn	0.164	<0.001	0.716	0.268	<0.001	0.720	0.177	<0.001	0.840	0.268	0.265	0.495	0.353	0.642	0.760
Zn	0.002	<0.001	0.249	0.010	<0.001	0.189	0.205	0.001	0.977	0.044	0.574	0.130	0.010	0.228	0.338
<u>Location 2</u>															
N	0.716	<0.001	0.628	0.761	<0.001	0.057	0.066	<0.001	0.079	0.103	0.012	0.263	0.776	0.570	0.803
P	0.466	<0.001	0.957	0.315	<0.001	0.452	<0.001	<0.001	0.000	0.235	0.018	0.079	0.628	0.508	0.518
K	0.754	<0.001	0.173	0.963	<0.001	0.367	0.012	<0.001	0.008	0.230	0.318	0.739	0.798	0.000	0.372
S	<0.001	<0.001	0.345	0.004	<0.001	0.495	0.712	<0.001	0.033	0.747	0.002	0.550	0.526	0.099	0.866
Cu	<0.001	<0.001	<0.001	0.008	<0.001	0.631	0.092	<0.001	0.185	0.634	0.340	0.207	0.861	0.634	0.396
Mn	0.185	<0.001	0.878	0.111	<0.001	0.752	0.401	<0.001	0.409	0.798	0.278	0.375	0.816	0.765	0.661
Zn	0.001	<0.001	0.076	0.003	<0.001	0.068	0.303	<0.001	0.109	0.920	0.936	0.889	0.783	0.328	0.188
<u>Location 3</u>															
N	0.281	<0.001	0.458	0.033	<0.001	0.792	0.021	<0.001	0.332	0.470	0.158	0.768	0.006	0.942	0.578
P	<0.001	<0.001	0.082	0.032	<0.001	0.952	0.523	<0.001	0.885	0.401	0.173	0.589	0.024	0.181	0.806
K	0.207	<0.001	0.599	0.371	<0.001	0.008	0.309	<0.001	0.868	0.107	0.111	0.029	0.339	0.915	0.309
S	<0.001	<0.001	0.172	<.0001	<0.001	0.042	0.050	0.006	0.384	0.342	0.076	0.699	0.997	0.385	0.261
Cu	<0.001	0.001	0.006	0.001	<0.001	0.003	0.290	0.161	0.239	0.285	0.244	0.215	0.736	0.549	0.945
Mn	0.133	<0.001	0.986	0.025	<0.001	0.390	0.432	<0.001	0.077	0.322	0.006	0.150	0.547	0.136	0.734
Zn	0.001	<0.001	0.672	0.001	<0.001	0.324	0.057	<0.001	0.566	0.167	0.023	0.694	0.085	0.713	0.180

† FT, Fertilizer Treatment, SD, Sampling date

Table 2-4. Nutrient concentration in spike fraction of plants at the last two whole plant sampling dates before harvest.

Treatment [†]	Biomass kg ha ⁻¹	N	P	K	S	Cu	Mn	Zn
		----- g kg ⁻¹ -----				---- mg kg ⁻¹ ----		
Location 1: June 4th								
NPK	1668	9.3	1.0	5.8	0.75	3.8b‡	39	15
NPK+Micros	1915	8.7	1.1	6.1	0.85	5.3a	54	20
Location 1: June 17th								
NPK	1627	5.8	1.0	2.6	0.64	4.7	42	13b
NPK+Micros	1381	6.5	1.0	3.1	0.73	3.9	63	26a
Location 2: June 9th								
NPK	2051b	11.0	2.0	8.9	0.90	6.2	160	20
NPK+Micros	2164a	10.8	2.0	8.6	0.91	4.5	156	20
Location 2: June 16th								
NPK	1876a	9.1a	1.9a	8.6	0.76	5.5	161	20
NPK+Micros	1744b	8.1b	1.5b	8.4	0.73	8.8	172	21
Location 3: June 3rd								
NPK	1108b	6.8	1.9	7.6a	0.64	1.9	98	14
NPK+Micros	2016a	6.2	1.8	6.3b	0.62	1.8	81	24
Location 3: June 10th								
NPK	1387	5.8	2.3	6.3	0.54	1.8b	108	10
NPK+Micros	1531	4.8	2.0	5.7	0.48	2.5a	105	18

† NPK treatment received a total of 113 kg ha⁻¹ N, 86 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 1, 119 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 2, and 102 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 3. NPK+Micros treatment received the same amounts of N, P₂O₅, and K₂O amounts as the NPK treatment plus 17 kg ha⁻¹ of Zn, 11 kg ha⁻¹ of Mn, 11 kg ha⁻¹ of Cu, 3 kg ha⁻¹ of B, and 45 kg ha⁻¹ of S.

‡ Letters represent a statistical difference between treatments at a probability level of 0.1.

Table 2-5. Concentration levels of nutrients in grain fraction of plants at the last two whole plant sampling dates before harvest.

Treatment [†]	Biomass kg ha ⁻¹	N	P	K	S	Cu	Mn	Zn
		----- g kg ⁻¹ -----				----- mg kg ⁻¹ -----		
Location 1: June 4th								
NPK	3710	18	3.3	4.2	1.18	3.9b‡	37	26b
NPK+Micros	4130	18	3.3	4.2	1.26	5.0a	43	35a
Location 1: June 17th								
NPK	4650	18	2.9	2.8	1.23	3.7	35	27b
NPK+Micros	4703	20	3.1	3.1	1.34	4.0	39	41a
Location 2: June 9th								
NPK	3321	22	4.3	6.3	1.39	4.1	77	38
NPK+Micros	3233	22	4.3	6.3	1.34	3.9	76	34
Location 2: June 16th								
NPK	3730	22	4.3	5.6	1.24	3.6	74	37
NPK+Micros	3891	22	4.2	5.5	1.21	4.0	77	41
Location 3: June 3rd								
NPK	2238b	22a	4.6	5.2	1.12	2.3	48	29b
NPK+Micros	4022a	18b	4.3	4.9	1.17	2.4	52	40a
Location 3: June 10th								
NPK	3054	22a	4.8	5.0	1.20	2.5	56	33
NPK+Micros	3967	18b	4.6	5.1	1.15	2.7	58	38

[†] NPK treatment received a total of 113 kg ha⁻¹ N, 86 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 1, 119 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 2, and 102 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 3. NPK+Micros treatment received the same amounts of N, P₂O₅, and K₂O amounts as the NPK treatment plus 17 kg ha⁻¹ of Zn, 11 kg ha⁻¹ of Mn, 11 kg ha⁻¹ of Cu, 3 kg ha⁻¹ of B, and 45 kg ha⁻¹ of S.

[‡] Letters represent a statistical difference between treatments at a probability level of 0.1.

Table 2-6. Grain yield and nutrient concentration in the grain at harvest for at all locations.

Treatment [†]	Yield kg ha ⁻¹	N	P	K	S	Cu	Mn	Zn
		-----g kg ⁻¹ -----				--- mg kg ⁻¹ ---		
		<u>Location 1</u>						
NPK	4570	19	3.3	3.1	1.2	3.5b [‡]	36	28b
NPK+Micros	4696	18	3.3	3.1	1.3	4.0a	37	40a
		<u>Location 2</u>						
NPK	3818	21	4.4	4.7	1.3	3.5b	74	38b
NPK+Micros	3643	21	4.3	4.6	1.3	4.0a	78	45a
		<u>Location 3</u>						
NPK	3310b	19a	3.3	3.1	1.0	1.2	41b	26b
NPK+Micros	4014a	17b	3.3	3.3	1.0	1.2	48a	37a

[†] NPK treatment received a total of 113 kg ha⁻¹ N, 86 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 1, 119 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 2, and 102 kg ha⁻¹ N, 90 kg ha⁻¹ P₂O₅, 56 kg ha⁻¹ K₂O from fertilizer at location 3. NPK+Micros treatment received the same amounts of N, P₂O₅, and K₂O amounts as the NPK treatment plus 17 kg ha⁻¹ of Zn, 11 kg ha⁻¹ of Mn, 11 kg ha⁻¹ of Cu, 3 kg ha⁻¹ of B, and 45 kg ha⁻¹ of S.

[‡] Letters represent a statistical difference between treatments at a probability level of 0.1.

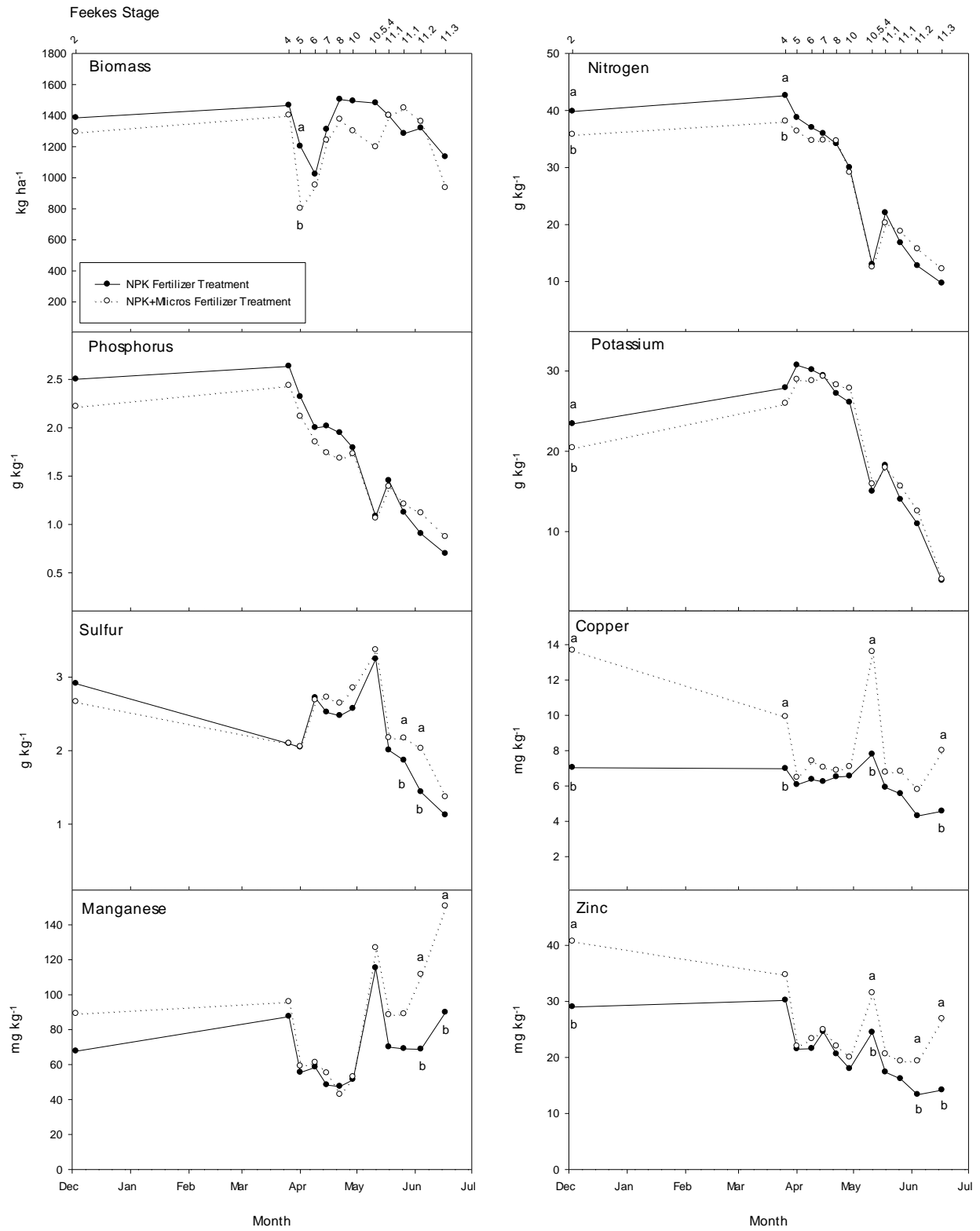


Figure 2-1. Concentration levels of nutrients in the leaves at various sampling times throughout the growing season, initiated on December 3rd and concluded on June 17th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #1.

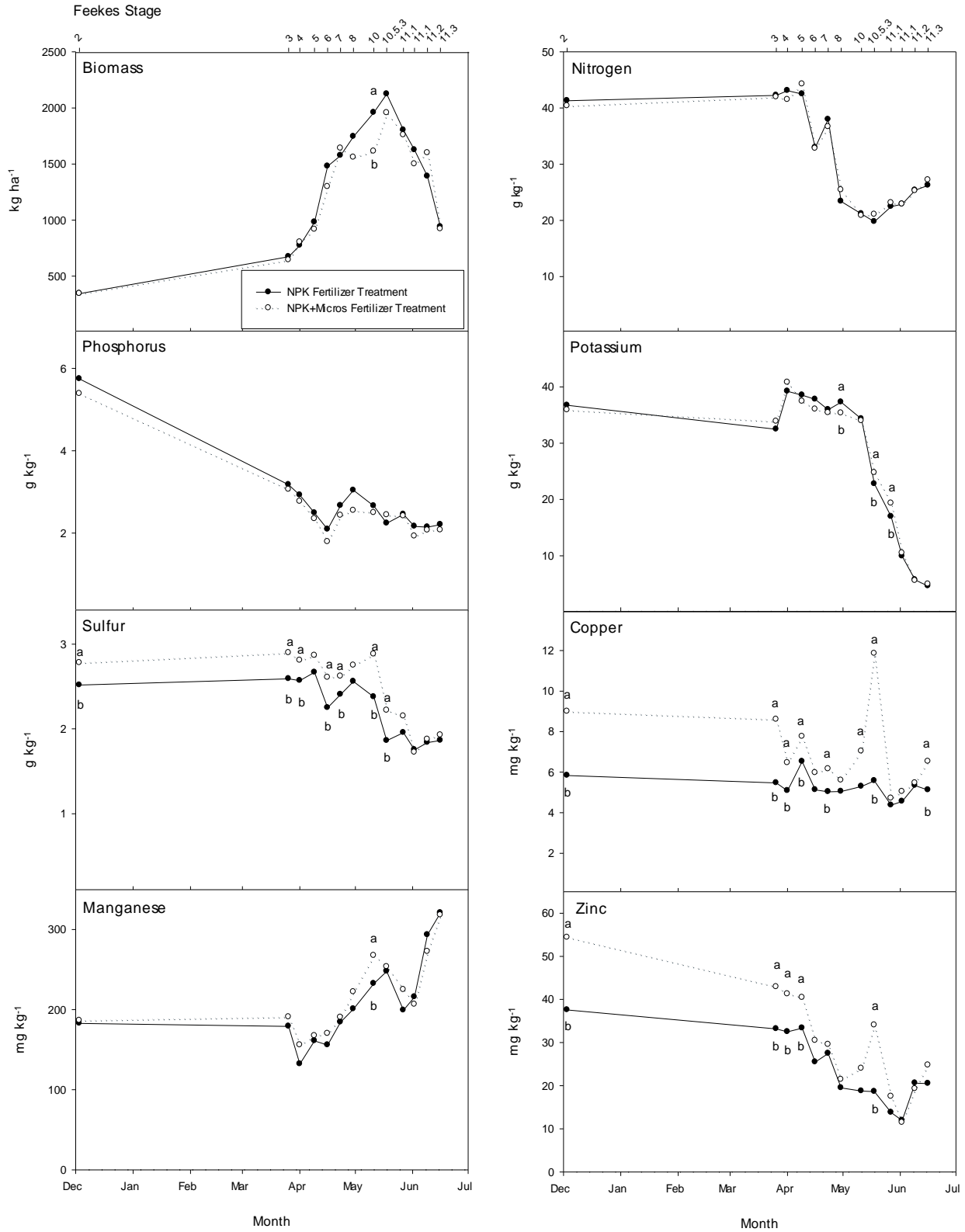


Figure 2-2. Concentration levels of nutrients in the leaves at various sampling times throughout the growing season, initiated on December 3rd and concluded on June 16th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #2.

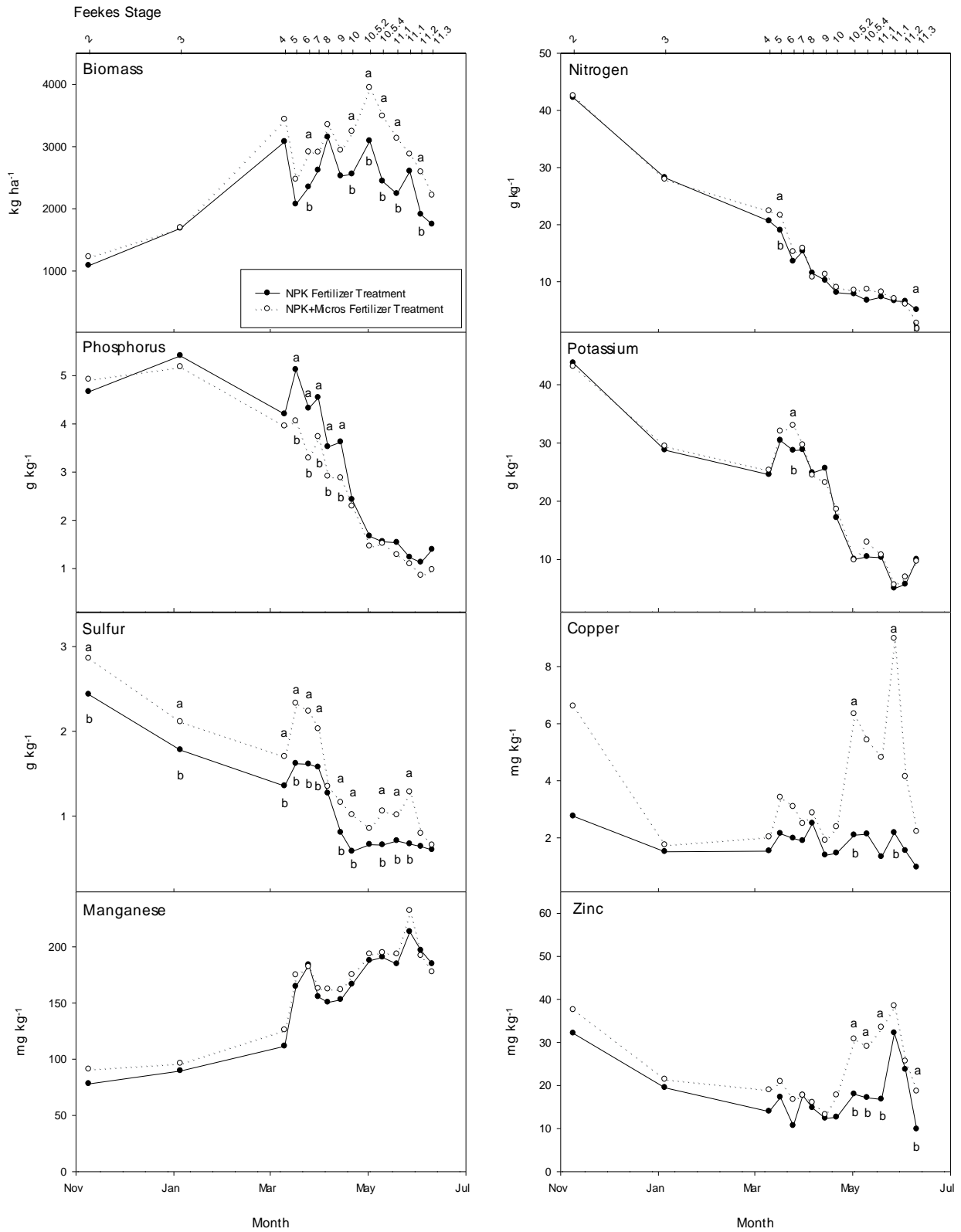


Figure 2-3. Concentration levels of nutrients in the leaves at various sampling times throughout the growing season, initiated on November 9th and concluded on June 10th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #3.

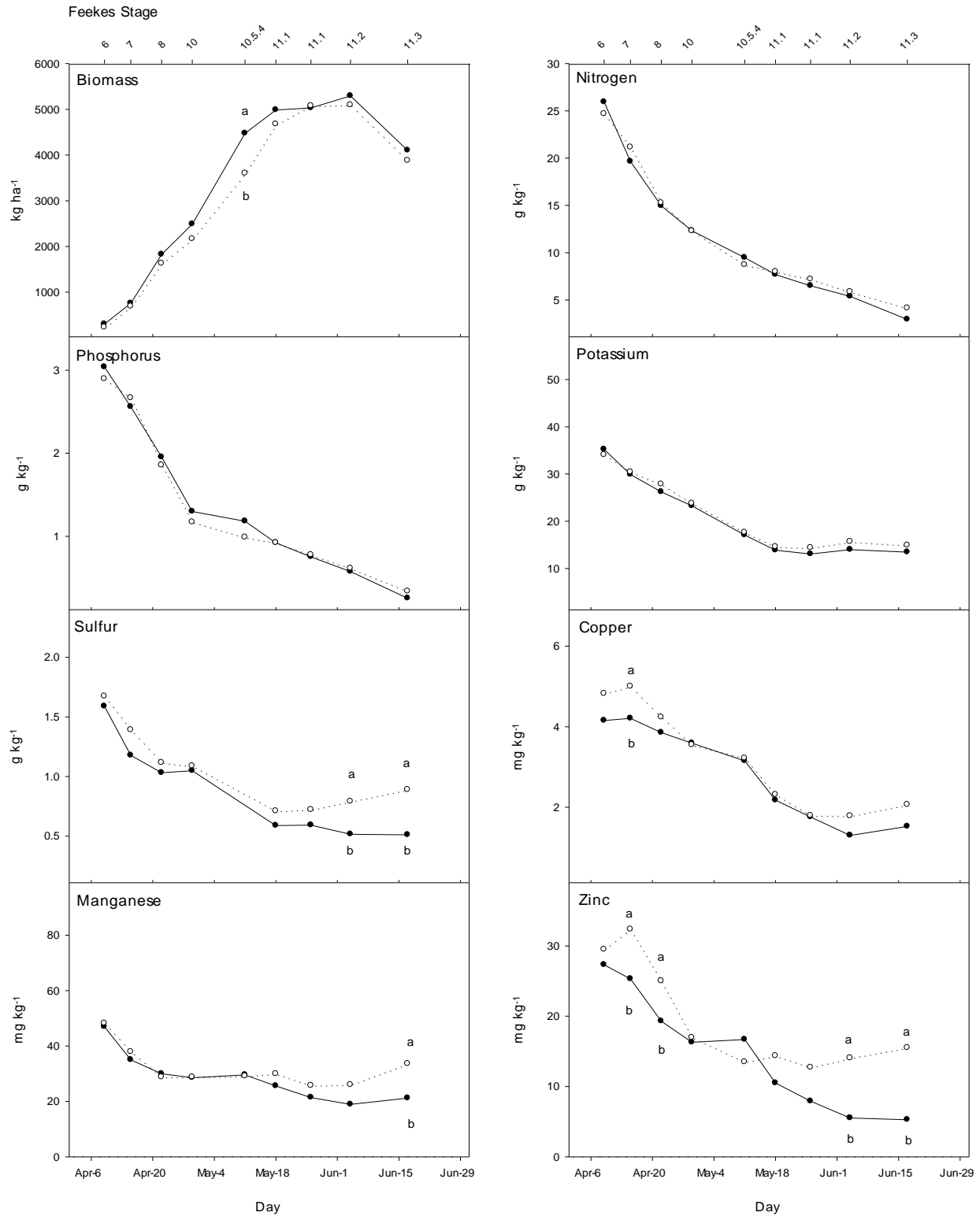


Figure 2-4. Concentration levels of nutrients in the stems at various sampling times throughout the growing season. Separation of stems and leaves began on April 9th and continued until June 17th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at location #1.

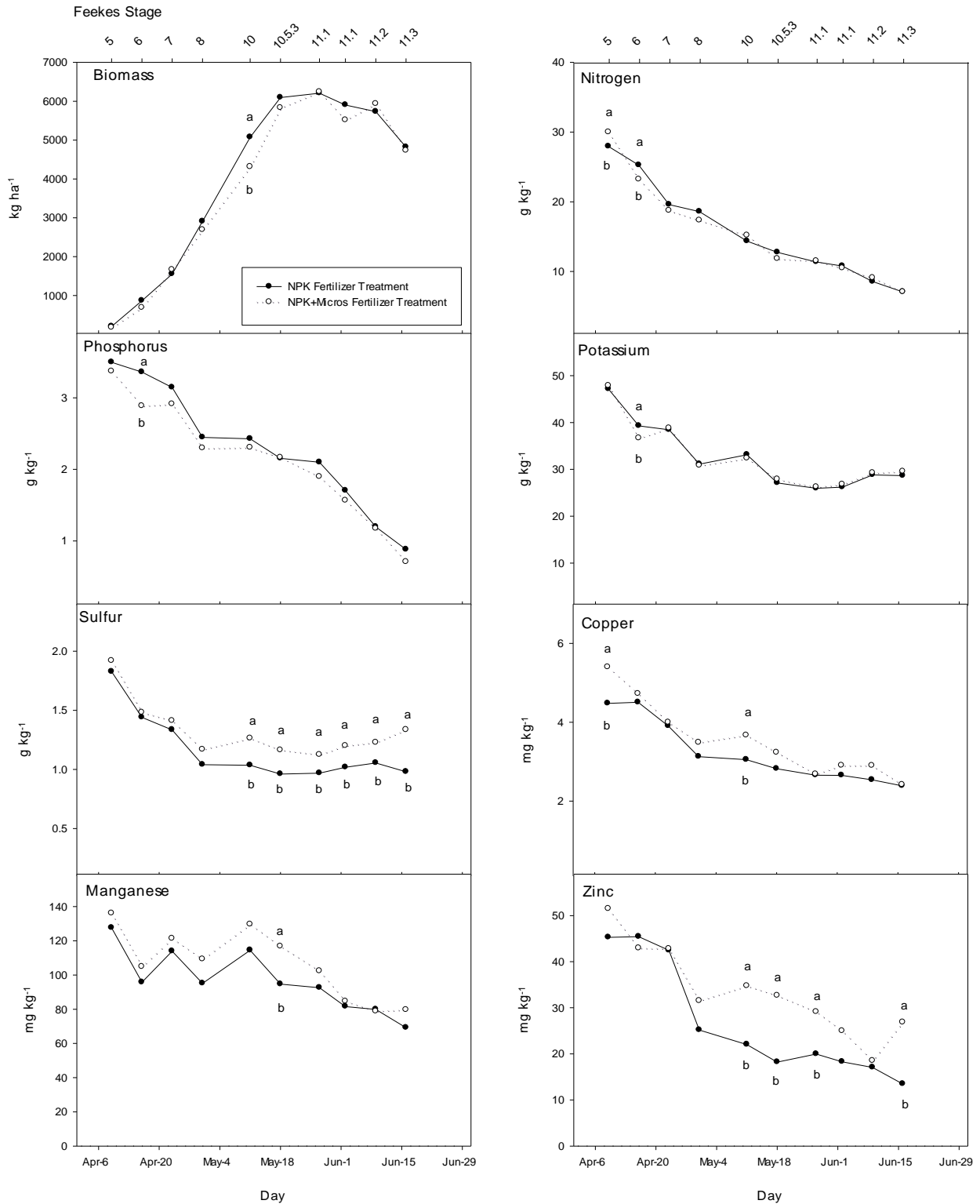


Figure 2-5. Concentration levels of nutrients in the stems at various sampling times throughout the growing season. Separation of stems and leaves began on April 9th and continued until June 16th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at location #2.

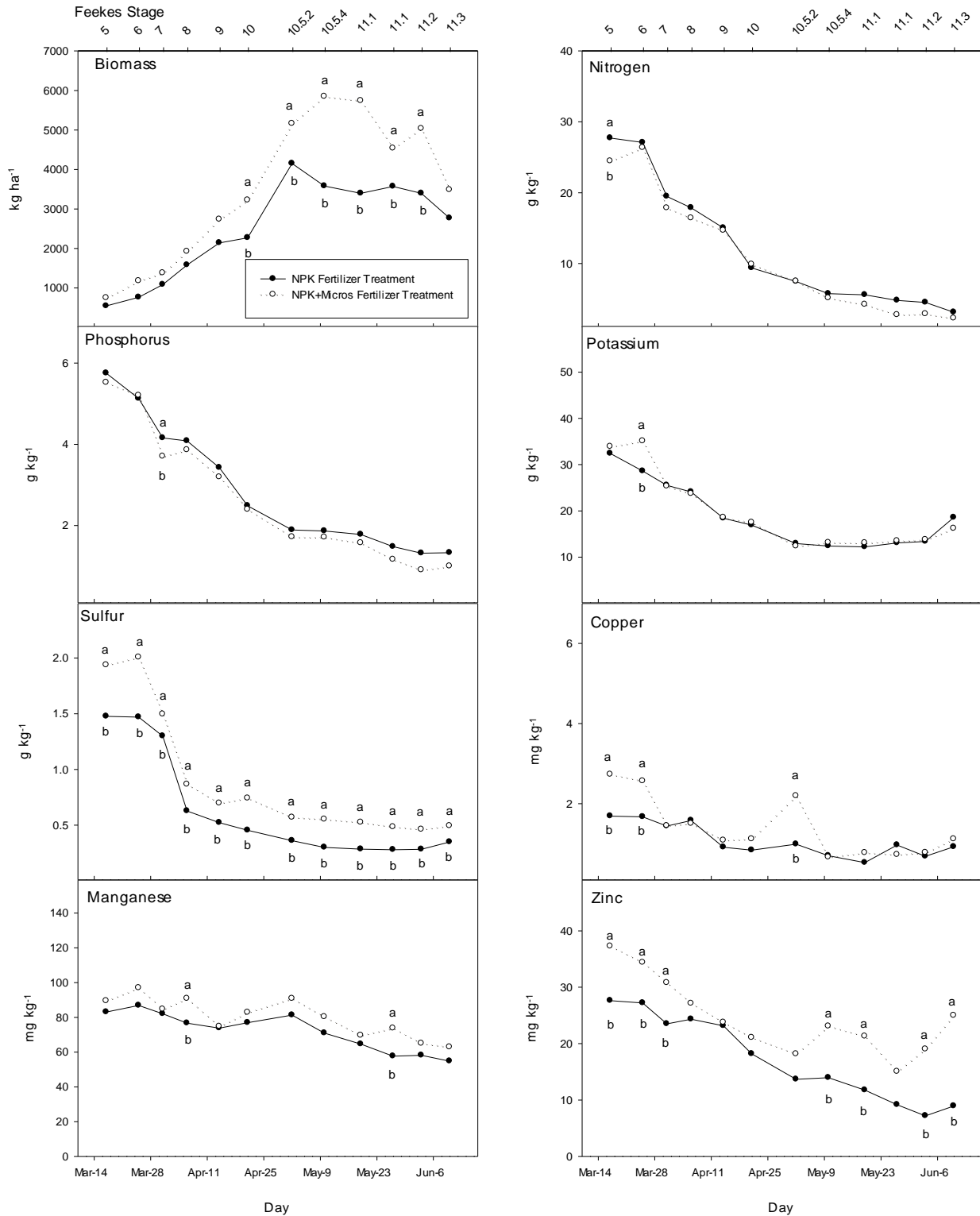


Figure 2-6. Concentration levels of nutrients in the stems at various sampling times throughout the growing season. Separation of stems and leaves began on March 17th and continued until June 10th. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at location #3.

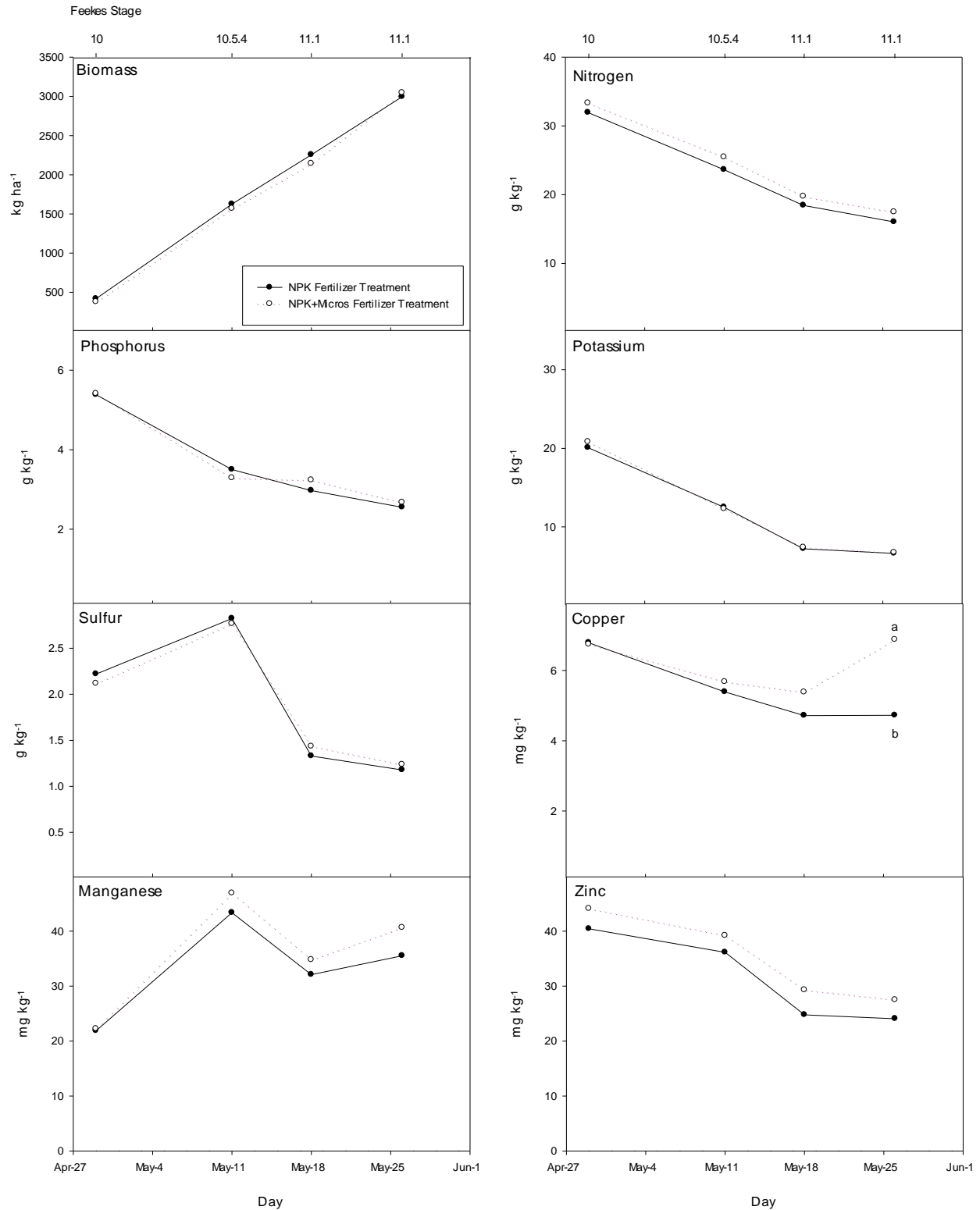


Figure 2-7. Concentration levels of nutrients in the heads at various sampling times throughout the growing season. Separation of heads from stems began on April 29th and continued until June 4th when heads were then separated into spike and grain. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #1.

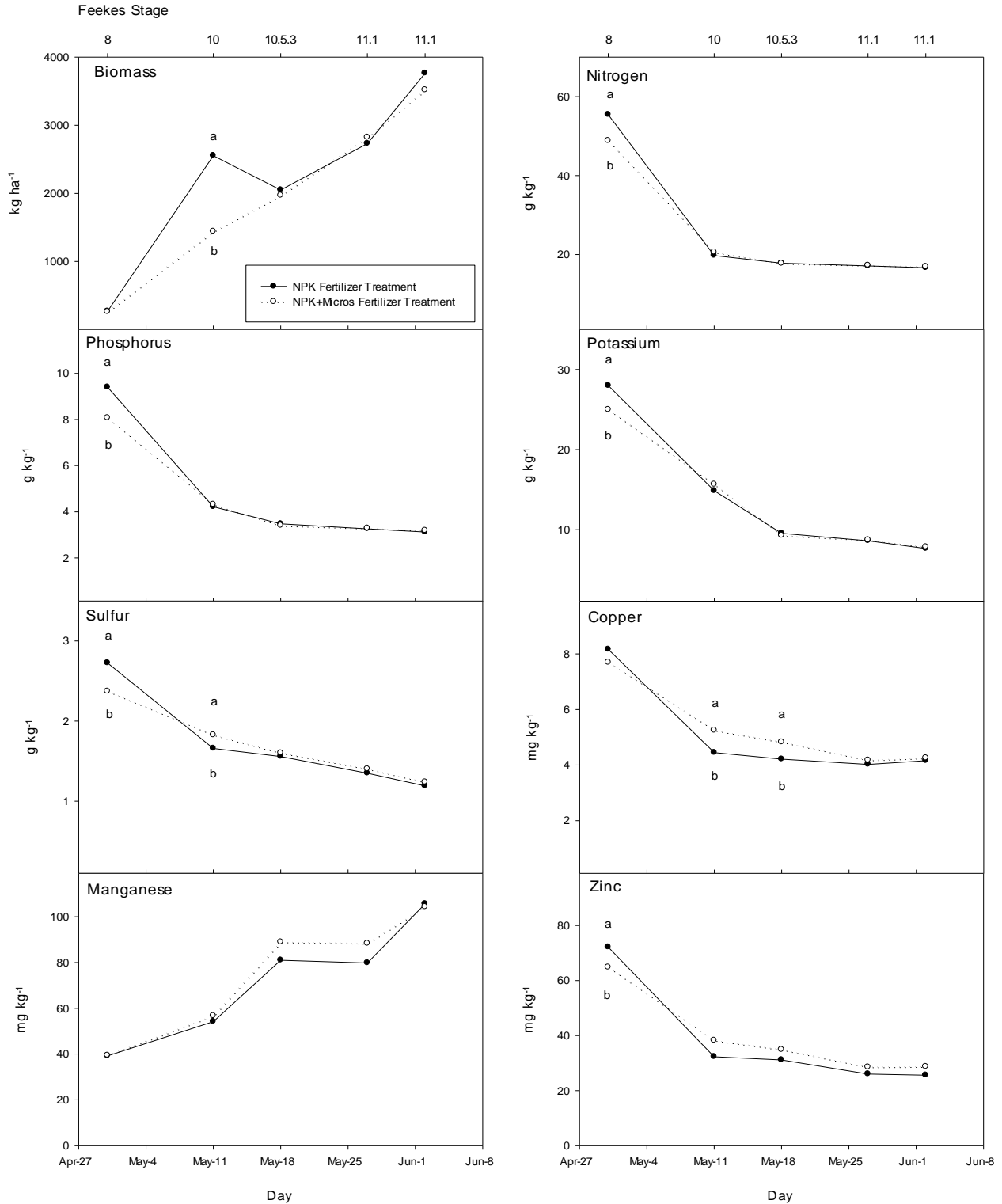


Figure 2-8. Concentration levels of nutrients in the heads at various sampling times throughout the growing season. Separation of heads from stems began on April 30th and continued until June 9th when heads were then separated into spike and grain. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #2.

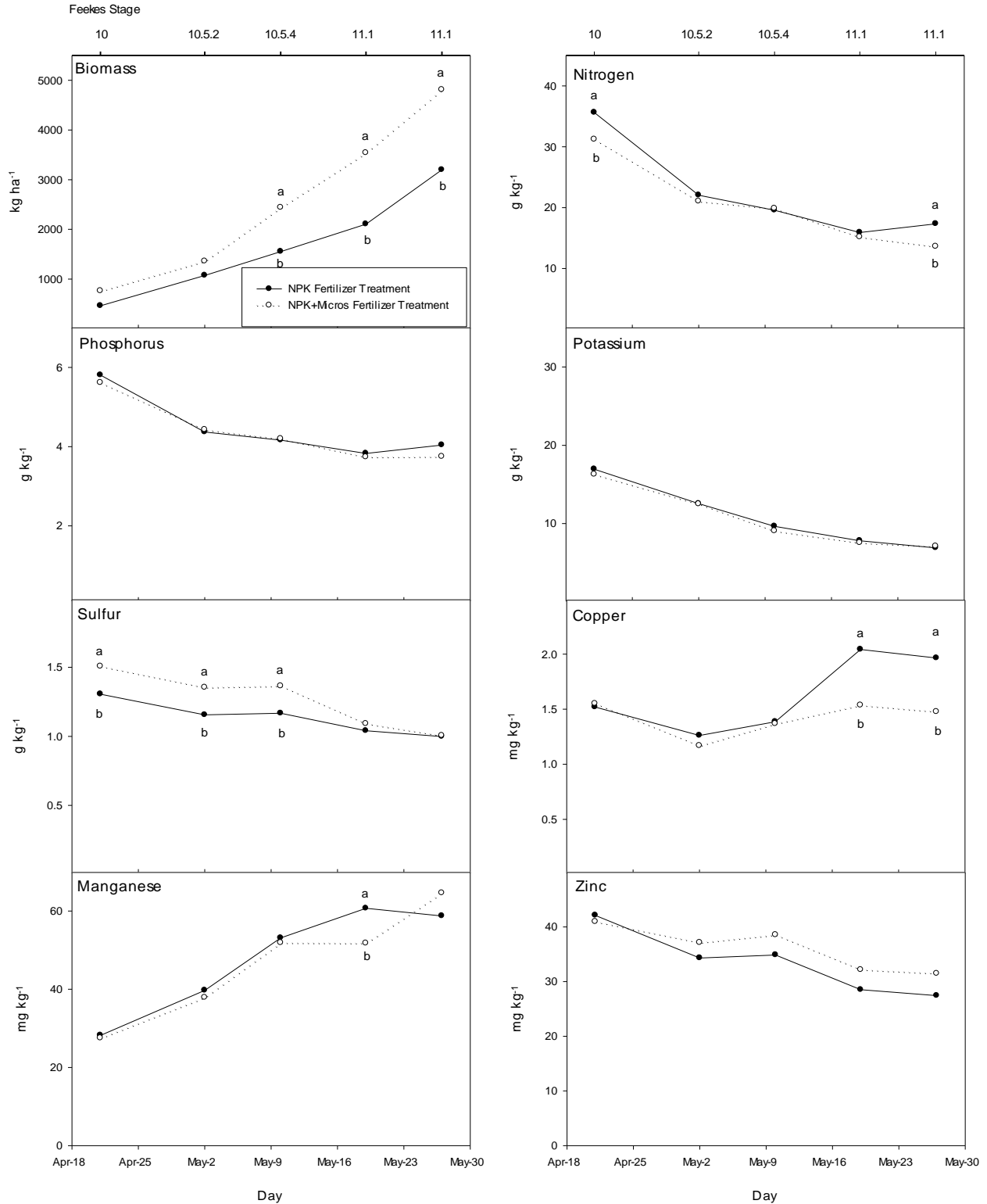


Figure 2-9. Concentration levels of nutrients in the heads at various sampling times throughout the growing season. Separation of heads from stems began on April 21st and continued until June 3rd when heads were then separated into spike and grain. Figures show both NPK fertilizer and NPK+Micros fertilizer treatments at Location #3.

Chapter 3 - Evaluation of nutrient uptake and partitioning in winter wheat

ABSTRACT

The nutrient uptake and partitioning patterns of winter wheat (*Triticum aestivum*) has been studied in the past however, advancing wheat genetics and new varieties warrant further research into the area. The objective of this study was to evaluate the macro, secondary, and micronutrient uptake and partitioning patterns of winter wheat throughout the growing season and evaluate potential nutrient remobilization differences due to micronutrient fertilization. This study was established at three locations in Kansas, two locations during the 2014-2015 season, and one location during the 2015-2016 season. The experimental design was a randomized complete block design with two treatments; a standard fertilization and standard fertilization plus treatment. The standard fertilization was nitrogen (N) at rates of 113, 119 and 102 kg ha⁻¹ at locations 1, 2 and 3, phosphorus (P) at rates of 86, 90, and 90 kg (P₂O₅) ha⁻¹ at each location, and potassium (K) at a rate of 56 kg (K₂O) ha⁻¹. The plus treatment added 17 kg ha⁻¹ of zinc (Zn), 11 kg ha⁻¹ of manganese (Mn), 11 kg ha⁻¹ of copper (Cu), 3 kg ha⁻¹ of boron (B), and 45 kg ha⁻¹ of sulfur (S) to the standard treatment. Aboveground plant biomass was collected every 7 to 10 days during the growing season, weighed, and analyzed for N, P, K, S, Cu, Mn, and Zn. Results showed the most rapid growth and nutrient accumulation between Feekes 6 and 9. High amounts of N, P, S, Cu and Zn were remobilized from vegetative structures to the grain. K and Mn showed much higher accumulation in the vegetative structures and little remobilization to grain. Zinc was most impacted from fertilization with higher total uptake at all three locations at the end of the growing season.

INTRODUCTION

A good understanding of the nutrient uptake patterns of winter wheat, throughout the growing season, is critical to the pursuit of increased wheat yields and more efficient use of fertilizer. The importance of N, P, and K uptake timing are known however, it is just as important to have a clear understanding of the secondary and micronutrients as well. The timing of rapid nutrient uptake and dry matter accumulation can help predict the key stages of growth where high levels of nutrients are most needed.

The rate of dry matter accumulation is a key component driving nutrient uptake. Karlen and Whitney (1980) found the most rapid period of dry matter increase to be from jointing (Feekes 6) to anthesis (Feekes 10.5.1) (Wise et. al., 2011). Meng et al. (2013) also found this same period of rapid dry matter increase and found that 64% of total dry matter accumulated by anthesis (Feekes 10.5.1). Hocking (1994) also states that a majority of total dry matter had accumulated by anthesis (Feekes 10.5.1) in spring wheat. The rate at which dry matter accumulates and the peak amount of dry matter can be influenced by environmental factors as well as fertilization (Holtz, 2007). Boatwright and Haas (1961) showed phosphorus fertilization to advance the timing of peak dry matter accumulation. Higher rainfall amounts contributed to delaying the peak dry matter timing (Dordas, 2008). Dry matter has also been found to decrease during ripening due to leaf senescence (Karlen and Whitney, 1980).

Macronutrient uptake and partitioning patterns are closely related to dry matter accumulation, and are influenced by factors such as cultivar and water availability. High rates of dry matter accumulation, driven by fast growing cultivars and high amounts of water availability, cause a significant increase in the rate at which macronutrients are accumulated. Although all macronutrients are needed in higher quantities when growth is rapid, variances between uptake

timing of each nutrient do exist. These variances make it important to separately evaluate the uptake patterns of each nutrient. Critical points when describing uptake and accumulation patterns are time periods of rapid accumulation, peak nutrient accumulation, amount of nutrient translocation occurring, and the impact of nutrient availability on these factors.

The amount of N accumulated between planting and spring green-up generally ranges from 8 to 22% in relation to the maximum N accumulated throughout the season (Miller, 1939). Early spring N accumulation is much more rapid with as much as 61% of total accumulated N present in the plant by Feekes 5 (Holtz, 2007) (Wise et. al., 2011). Clarke et. al. (1990) found that anywhere from 67% to 102% of total N present at harvest is accumulated by anthesis (Feekes 10.5), with an average of 81%. Waldren and Flowerday (1979) also found 80% of total N to be present in the plant by anthesis (Feekes 10.5) and 71% of total plant N located in the grain at maturity. Campbell et. al. (1977) showed this value is generally higher during dry years with 65% to 80% total N accumulated by anthesis (Feekes 10.5.1) compared to 45% to 70% during wet years in their study. Gregory et. al. (1981) found that N translocation from plant shoots to grain accounted for more total grain N when there were low rainfall conditions during grain filling (Feekes 11.1-11.4).

Uptake rate and translocation can be affected by nutrient availability along with environmental factors. Boatwright and Haas (1961) found that N translocation was effected by both N and P availability. They stated that “if P is limited, N uptake may continue until soft dough; and if both nutrients are limiting, N uptake from the soil will continue until the plants reach maturity.” This implies that if the plant accumulates enough N and P by anthesis (Feekes 10.5.1) it will not continue to accumulate N even if more is available. Dordas (2009) had very

similar findings that showed when nitrogen fertilizer was applied, N translocation from vegetative structures to grain occurred at higher rates.

Phosphorus uptake shows many similarities in pattern with N, however some differences do exist. Rapid P uptake was found to occur later than N and coincided with the rapid production of newly formed plant parts such as stems and heads (Miller, 1939). Zhan et. al. (2015) showed the most rapid uptake of P to occur between stem elongation (Feekes 6) and anthesis (Feekes 10.5.1). Peak total accumulated P levels were found to occur at varying times between completion of heading (Feekes 10.5) (Boatwright and Haas, 1961) and soft dough (Feekes 11.2) (Waldren and Flowerday, 1979). Grain P levels are heavily dependent on translocation from vegetative structures with 52 to 100% of grain P at harvest originating in vegetative plant parts (Papakosta, 1994). Clarke et. al. (1990) found that more translocation occurs when growing conditions are not favorable to increased dry matter accumulation such as periods of reduced moisture availability. Dordas (2009) found the impact of P fertilization on translocation was very similar to N, with higher rates of translocation occurring in P fertilized treatments. This would imply that fertilization increases the plants uptake of P before grain filling to the point that it no longer needs to increase total plant P, it just needs to shift the P to the grain.

Potassium accumulates in the grain at a much lower percentage than N and P with less than 20% of total plant potassium occurring in the grain (Hocking, 1994), (Waldren and Flowerday, 1979). Rose et. al. found peak K accumulation to occur around heading (Feekes 10) Miller (1939) found that there was a drastic loss of K four to six weeks before harvest when there were significant rainfall events. Gregory et. al. (1979) also found this heavy loss of K from the wheat biomass to occur with almost 50% loss between anthesis (Feekes 10.5.1) and harvest.

Uptake of K is also highly influenced by the availability of N and P and the fertilization of these nutrients can greatly increase K uptake (Beaton & Sekhon, 1985).

Miller et. al. (1994) found that over 78% of total plant zinc was accumulated in the grain at maturity. Although micronutrients are required in lower amounts compared to the macronutrients, they are essential to plant health and overall production. It is just as important to understand the uptake trends of micronutrients in order to minimize yield and quality loss that otherwise may go unnoticed. A detailed evaluation of micronutrient uptake patterns can provide a better understanding of nutrient removal from the field through separate plant parts such as straw or grain. Understanding periods of rapid uptake and peak accumulation of micronutrients also helps to establish optimum time periods of fertilization.

The objective of this study was to assess wheat nutrient uptake and partitioning for different plant parts for N, P, K, S, Cu, Mn, and Zn, and verify potential nutrient remobilization with and without micronutrient fertilization.

MATERIALS AND METHODS

This study was conducted at two locations during the 2014-2015 growing season and one location during the 2015-2016 season. The experimental design of the study was a randomized complete block design with two treatments and four replications. Individual plot size was 55.7 square meters for all locations, 6.1 meters by 9.1 meters at locations 1 and 3 and 5.5 meters by 10.1 meters at location 2. All locations were non-irrigated and used conventional tillage.

Both treatments received an application of a broadcast blend of mono ammonium phosphate (MAP) [11-52-0 (N-P₂O₅-K₂O)] and potassium chloride (KCl) [0-0-62 (N-P₂O₅-K₂O)] for a total application rate of 12 kg ha⁻¹ of N, 56 kg ha⁻¹ of P₂O₅, and 56 kg ha⁻¹ of K₂O. The micronutrient (NPK+Micros) treatment received a broadcast blend of 17 kg ha⁻¹ of Zn, 11 kg ha⁻¹

of Mn, 11 kg ha⁻¹ of Cu, 3 kg ha⁻¹ of boron, and 45 kg ha⁻¹ of S in addition to the previously described N, P, and K fertilizer.

Location 1 was established in Manhattan, KS (Riley Co) (39°12'26"N; 96°35'46"W) (Table 2.1). A mixture of urea ammonium nitrate (UAN) 28% N and ammonium polyphosphate (APP) [10-34-0 (N-P₂O₅-K₂O)] containing 56 kg ha⁻¹ of N and 30 kg ha⁻¹ of P₂O₅ was applied pre-plant in late July, along with the previously mentioned broadcast blend applied after planting, for a total of 68 and 86 kg ha⁻¹ N and P applied during the fall. Spring top-dress of N was completed with 45 kg ha⁻¹ of N applied in the spring as UAN (28-0-0) to the entire study area. The total amount of N applied during the entire season was 113 kg ha⁻¹.

Location 2 was in Belleville, KS (Republic Co) (39°48'53"N; 97°40'22"W) (Table 2.1). An application of a liquid mixture of UAN (28-0-0) and APP (10-34-0) containing 90 kg ha⁻¹ of N and 34 kg ha⁻¹ of P₂O₅ was applied pre-plant, along with the previously mentioned broadcast blend applied after planting, for a total of 102 kg ha⁻¹ and 90 kg ha⁻¹ N and P applied in the fall. In the spring, an additional 17 kg ha⁻¹ of N was applied as broadcast urea. The total amount of N applied during the entire season was 119 kg ha⁻¹.

Location 3 was established in Ashland Bottoms (Riley Co) (39°8'45"N; 96°37'49"W) (Table 2.1). A liquid broadcast blend of UAN (28-0-0) and APP (10-34-0) was applied pre plant containing 56 kg ha⁻¹ of N and 34 kg ha⁻¹ of P₂O₅, along with the previously mentioned broadcast blend applied after planting, for a total of 68 kg ha⁻¹ and 90 kg ha⁻¹ N and P applied during the fall. In the spring, an additional 34 kg ha⁻¹ of N was applied as surface banded UAN (28-0-0). The total amount of N applied during the entire season was 102 kg ha⁻¹.

Soil Sampling and Analysis

Soil samples were collected from each plot at the time of planting at the 0-15 cm and 0-60 cm. Samples were dried at 40°C and ground to pass a 2mm sieve before analysis. The 0-15 cm samples were analyzed for pH with a 1:1 (soil:water) method (Watson and Brown, 1998), soil test P with the Mehlich-3 extraction (Frank et al., 1998), K by the ammonium acetate extraction (Warncke and Brown, 1998), organic matter by loss on ignition (Combs and Nathan, 1998), Cu, Mn, and Zn, with the DTPA extraction (Whitney, 1998). Samples collected at the 0-60 cm depth were analyzed for nitrate using the KCl extraction (Gelderman and Beegle, 1998), Cl with a calcium nitrate extraction (Gelderman et al., 1998), and S using a calcium phosphate extraction (Combs et. al.,1998). Soil test results are listed in Table 2.2.

Plant Tissue Sampling and Analysis

Above ground plant sampling started in the fall before wheat dormancy in the winter. One sampling was completed in the fall for locations 1 and 2, and two fall samplings for location 3. Sampling ceased throughout the winter and was reinitiated at spring green-up, with subsequent sampling once every 6 to 12 days depending on weather, for a total sampling number of 12 at location 1, 13 at location 2, and 15 at location 3. Plant samples were hand-clipped at ground level from two rows positioned roughly 1 m inside left and right plot edges, at a length of 76 cm. Total sampling area was .387 m² at locations 1 and 3 and .29 m² at location 2. Samples were taken from the front left corner of the plot at the first sampling time and then moved progressively up the plot with roughly 50 cm between sample locations. Once sampling position reached the end of the plot, the samples were taken from the right front corner of the plot and moved up the plot on that side. This allowed the central area of the plot to remain undisturbed for the purpose of grain harvest. Samples were then separated into plant fractions that include leaf, stem, spike and

grain depending on the growth stage. Samples were then dried at 60°C, weighed for biomass and ground to pass a 2mm mesh. They were then analyzed for total N using a sulfuric peroxide digest (Matsunaga & Shiozaki, 1987) and Zn, Cu, Mn, S, P, and K using a nitric perchloric digest (Giesecking et. al., 1935).

Statistical Analysis

Statistical analysis was performed by location using the GLIMMIX procedure in SAS 9.4 (SAS Institute Inc, 2012). Plant nutrient uptake was analyzed using sampling time as repeated measure in the model and blocks as random effect. A significance level of 0.10 was used for analysis.

RESULTS AND DISCUSSION

Biomass

At all locations leaf and stem fractions increase in biomass through the season until the time of anthesis (Feekes 10.5.1), at which point they decrease showing a remobilization of resources into the reproductive structures of the plant (Figures 3-1, 3-3, 3-5). Locations 1 and 2 showed the most biomass growth occurring during stem elongation, between Feekes 6 and Feekes 10. Location 3 accumulated biomass more rapidly during fall and early spring season.

Nitrogen uptake

Total N uptake at location 1 was not significantly different between treatments at any sampling date throughout the season (Table 3-4). Fall uptake was very rapid with a significant amount of total uptake occurring before winter dormancy (Figure 3-1). The most rapid period of uptake during spring occurred between Feekes 6 and Feekes 9. Accumulation of N in the leaf and stem fractions begins to decline after head formation and there is a rapid decline in leaf stem and spike fractions once grain production begins. Peak total uptake of N occurs at Feekes 11.2

and then declines slightly. At this stage grain N accounts for roughly 52 % of total N within the plant. At Feekes 11.3 shortly before harvest, grain N accounts for 72% of total plant N, although total N has declined a large portion has moved into the grain fraction. This result is very similar to the results presented by Waldren and Flowerday (1979).

At location 2 there was very little difference between total N uptake levels throughout the season (Table 3-5). Uptake patterns were very similar to location 1 although N levels in the leaves and stems stayed level longer into the season, not declining until well after anthesis (Feekes 10.5.1) occurred (Figure 3-3). N levels within the grain compared to the total plant were also much lower than location 1 with grain levels at roughly 40% and 54% at Feekes 11.2 and 11.3.

Total N uptake at location 3 was much more variable than locations 1 and 2 as well as much lower overall (Table 3-6). This is likely because of a higher sand content in the soil leading to a much lower water holding capacity. N accumulation was very rapid in the very early season, with well over half of total N being accumulated by Feekes 5, agreeing with the data presented by Holtz (2007). Total N accumulated in the leaf and stem fractions began to generally decline immediately after head differentiation occurred although the trend was inconsistent. The NPK+Micros treatment was significantly higher in total N uptake at 5 out of 6 sampling dates between Feekes 10 and Feekes 11.2. This is likely attributed to higher total biomass due to additional S which leads to higher total macronutrient uptake. Average N uptake across locations shows rapid increase beginning around Feekes 6 and continuing until anthesis (Feekes 10.5.4) (Figure 3-7). Nitrogen accumulation in leaves and stems decreases after anthesis while grain accumulation increases showing high amounts of nutrient remobilization.

Phosphorus uptake

Phosphorus uptake follows a very similar pattern to N at all locations (Figure 3-1, Figure 3-3, Figure 3-5). Soil test P levels were well above recommended sufficiency levels at all locations (Leikam et al., 2003). At location 1 there were no significant differences in total P uptake, between treatments, at any dates (Table 3-4). Phosphorus uptake increases consistently after green-up in the spring with a large portion of total uptake being distributed to the head immediately after they had been differentiated. During anthesis 40% to 50% of total plant P had already accumulated in the head. Phosphorus accumulation in the leaf, stem and spike follow a very similar pattern to N, decreasing rapidly during the middle and later periods of grain fill. Grain accumulation of P is roughly 67% and 80% of total plant P at Feekes 11.2 and 11.3. High amounts of P uptake also continue to occur well into the grain fill period with a 30% increase of total plant P between Feekes 11.1 and 11.2.

At location 2 only one sampling date, Feekes 10, showed a significant difference between treatments which can be attributed to higher total biomass collected at that sampling date. Total P uptake again follows a very similar trend to N. A much higher percentage of total plant P was accumulated in the leaf and stem fractions when compared to location 1. By anthesis only 28% of total plant P had accumulated in the head and roughly 85% of peak total P uptake had occurred. Grain accumulation of P was also much lower than location 1 with Feekes 11.2 and 11.3 having 50% and 65% of total plant P contained in the grain.

At location 3 the NPK+Micros treatment was significantly higher in total P uptake beginning at Feekes 10.5.4 and continuing all the way to the end of the season (Table 3-6). Phosphorus uptake was very inconsistent throughout the season due once again to the fluctuation of biomass levels (Figure 3-5). The grain contained 55% and 62% of total plant P, at Feekes 11.2

and Feekes 11.3, in the NPK treatment while in the NPK+Micros treatment grain contained 63% and 69% at the same time periods. Average P uptake and accumulation across locations shows very similar patterns to N (Figure 3-7).

Potassium uptake

Potassium uptake patterns were considerably different than N and P at all locations. Soil test K levels were well above sufficiency levels at all locations (Table 3-2, Leikam et al., 2003). Potassium uptake and accumulation at all locations was characterized by a high amount of total plant K accumulated in the stem fraction of the plant (Figures 3-1, 3-3, 3-5). This reflects the role of K in plant growth, maintaining stem strength and structure (Beaton & Sekhon, 1985). Potassium accumulation within the head, spike and grain fractions was much lower than the stem fraction while leaf accumulation levels were comparatively moderate except at location 3 where a high amount of K was accumulated in the leaves. This agrees with many previous studies that show low grain K accumulation (Waldren and Flowerday, 1979) (Hocking, 1994). The majority of total K uptake occurred early in the growing season with most treatments and locations reaching 100% of total K uptake at or before anthesis (Figure 3-1, Figure 3-3, Figure 3-5). At location 1 there were no significant differences of total K uptake, between treatments, at any sampling date (Table 3-4). Average K uptake across locations shows very rapid uptake between Feekes 5 and 10 before slowly decreasing (Figure 3-7). Potassium accumulation is highest in the stem fraction while very little K accumulates in the grain.

Sulfur uptake

Sulfur uptake patterns varied across locations. At location 1 two sampling times were significantly different in total S uptake, Feekes 10.5.4 and Feekes 11.2 (Table 3-4). At Feekes 10.5.4 the NPK treatment was significantly higher due to a very large and uncharacteristic spike

in S accumulation in the stem fraction (Figure 3-2). This large spike occurred a week after an unusually high, 122 mm, rainfall (Figure 3-9). The spike occurred in both treatments and can potentially be attributed to waterlogged conditions in the soil causing stress to the plant. Results at this location showed that tissue analysis and nutrient uptake evaluations can be affected significantly by environmental stress in the field. The NPK+Micros treatment was significantly higher in total S uptake at Feekes 11.2 with the largest difference occurring in the stem fraction again. This indicates that although the S difference did not increase grain yield, or grain S concentration, the peak total S uptake late in the growing season was pushed higher due to the added S. At location 2 S uptake patterns varied slightly between treatments although total S uptake was not significantly different at any sampling date. Both treatments followed very similar trends early in the season, until around Feekes 10, where the NPK treatment declined slightly in total S while the NPK+Micros treatment continued to increase, albeit at a much slower rate than early season uptake. Sulfur uptake late in the season, between Feekes 11.2 and Feekes 11.3, differed between treatments as well. In the NPK treatment total plant S as well as stem S accumulation and spike S accumulation all showed an increase in accumulation levels. The NPK+Micros treatment, declined in all three of the aforementioned areas although they were still higher than the NPK treatment. This may be because there was more S available to the plant due to added S fertilizer than available S due to mineralization, in the NPK+Micros treatment. On the contrary, in the NPK treatment late season S availability may have been increased due to the mineralization of S because of increasing soil temperatures, and the lack of the added fertilizer in the earlier stages. Location 3 was the location most expected to show differences in S uptake due to much lower soil test values than the other two locations as well as much higher sand content. Adding to these factors, precipitation totals were the highest of all three locations at location 3

which meant high possibility for S leaching from the soil profile (Schulte & Kelling, 1992). Total S uptake was significantly higher in the NPK+Micros treatment at 8 of the 12 sampling dates between Feekes 5 and Feekes 11.3, including all of the final 5 sampling dates of the season. Both treatments followed similar trends for total S uptake, increasing early in the season, decreasing during stem elongation, and increasing again after the heads had differentiated. Similar to location 2, the final two sampling dates differ between treatments. In the NPK treatment once again total S uptake increased while the NPK+Micros treatment decreased. This may, once again, be associated with late season mineralization of S creating more availability to the NPK treatment while the NPK+Micros treatment already had sufficient levels of available S to reach peak uptake levels. Average sulfur uptake across locations increases rapidly between Feekes 9 and 10.5.4 before decreasing in leaves and remobilizing to the grain (Figure 3-8).

Copper and Manganese uptake

Copper and manganese followed very similar uptake patterns at all locations and for that reason, are grouped together here. At location 1 both nutrients increase rapidly between Feekes 5 and Feekes 10.5.4 (Figure 3-2). Both nutrients show small spikes at Feekes 10.5.4, however not as large as S, due to the waterlogged soil conditions during that time. Once total accumulation of Cu and Mn drop after Feekes 10.5.4, they continue to increase at a slower rate than early season. The NPK+Micros treatment increases more rapidly than the NPK treatment leading to significantly higher peak levels at Feekes 11.2 in both nutrients as well as Feekes 11.3 for Mn. In the NPK treatment we see continued total nutrient uptake increase all the way to the final sampling date, whereas in the NPK+Micros treatment the total uptake declines after Feekes 11.2, because of declines in spike and stem. At location 2 both nutrients, again, increased rapidly until Feekes 10.5.3, where they dropped slightly before slowly increasing again (Figure 3-4). Both

nutrients decreased in total uptake amounts from Feekes 11.2 to Feekes 11.3. Higher amounts of Mn were accumulated in the leaf and stem fractions later in the season while Cu had more even distribution throughout the plant. At location 3 Cu uptake was very low in the NPK treatment throughout the entire season while the NPK+Micros treatment showed large spikes later in the season and was significantly higher in total uptake (Figure 3-6). The large spikes were mostly in the leaf fraction of the plant without a consistent trend of uptake. Manganese increased until Feekes 10.5.2 where it fluctuated around a fairly even level before declining late in the season. The NPK+Micros treatment was also significantly higher at many sampling dates later in the season. Copper and Mn uptake are most rapid between Feekes 8 and Feekes 10.5.4 (Figure 3-8).

Zinc uptake

Zinc uptake at location 1 was similar between treatments until Feekes 10.5.4 when total uptake dropped slightly before slowly increasing through grain fill in the NPK treatment and increasing rapidly from anthesis until the end of grain fill in the NPK+Micros treatment (Figure 3-2). Total Zn uptake was significantly higher in the NPK+Micros treatment at the final three sampling dates. Unlike many other nutrients, Zn uptake continued to increase in both treatments even at the final sampling date. At location 2 Zn uptake was rapid throughout stem elongation with the NPK+Micros treatment rising to significantly higher total uptake levels at Feekes 10 and 10.5.3 (Figure 3-4). Both treatments declined in total uptake around the time of anthesis, with the NPK treatment declining slightly earlier than the NPK+Micros treatment. In both treatments leaf, stem and spike fractions fell in total Zn levels while grain increased. Total Zn at Feekes 11.3 was higher in the NPK+Micros treatment because the NPK treatment declined in total Zn during the final week of sampling while the NPK+Micros treatment did not. Zinc uptake at location 3 followed very different patterns in the NPK and NPK+Micros treatments (Figure 3-6). Uptake in

the NPK treatment was fairly steady between stem elongation (Feekes 6) and early grain fill (Feekes 11.1). Total Zn peaked at Feekes 11.1 before declining which suggests all of the Zn accumulated in the grain was remobilized from other plant fractions. Contrasting the NPK treatment, the NPK+Micros treatment showed extremely rapid Zn uptake between flag leaf (Feekes 9) and flowering (Feekes 10.5.4). Roughly 60% of the total Zn accumulated during the season was taken up during this time period. After Feekes 10.5.4 further Zn uptake was minimal while grain Zn levels increased with leaf and spike levels declining and stem levels maintaining. Total Zn uptake was significantly higher in the NPK+Micros treatment at every sampling date from Feekes 10 until harvest. Average Zn uptake increases rapidly between Feekes 9 and 10.5.4 (Figure 3-8). In the NPK+Micros treatment Zn uptake continues to increase during grain fill showing that the additional Zn caused less remobilization and more direct uptake.

CONCLUSIONS

Total N, P, and K uptake was influenced by S and micronutrient fertilization at location 3. All three nutrients were significantly higher at many sampling dates during the late season due to increased biomass production in the NPK+Micros treatment due, most likely, to the additionally applied S. At location 1 and 2 N and P uptake occurred rapidly between Feekes 6 and Feekes 10.5 whereas rapid K uptake was highly concentrated into a two week period between Feekes 7 and Feekes 10. Location 3 accumulated all three nutrients most rapidly during fall and early spring before stem elongation, due to the high level of biomass accumulation during the fall. Nitrogen and P, compared to K, showed much higher amounts of remobilization from leaves and stems into the grain. Sulfur showed an uptake pattern similar to N except at location 1 during the time period where waterlogging of the soils most likely influenced S uptake. Copper and Mn uptake were variable, but rapid uptake occurred roughly between Feekes

6 and Feekes 10.5 much like N and P. Zinc uptake was rapid during the same time period, however there was not as much remobilization of Zn into the grain as N or P. Total Zn uptake was also significantly impacted by fertilization at all locations with many late season sampling dates being significantly higher in the NPK+Micros treatment.

REFERENCES

- Baethgen, W. E., and M. M. Alley. 1989. Optimizing soil and fertilizer nitrogen use by intensively managed winter wheat. I. Crop nitrogen uptake. P. 116-120. *Agronomy journal* 81.1.
- Bauer, A., A. B. Frank, and A. L. Black. 1987. Aerial parts of hard red spring wheat. II. Nitrogen and phosphorus concentration and content by plant development stage. P. 852-858. *Agronomy journal* 79.5.
- Beaton, J. D. & G. S. Sekhon. 1985. Potassium nutrition of wheat and other small grains. P. 701-752 *Potassium in agriculture*.
- Bender, R. R., J. W. Haegele, M. L. Ruffo, & F. E. Below, 2013. Modern corn hybrids' nutrient uptake patterns. *Better crops*, 97(1), 7-10.
- Boatwright, G. O., and H. J. Haas. 1961. Development and composition of spring wheat as influenced by nitrogen and phosphorus fertilization. P. 33-36 *Agronomy Journal* 53.1.
- Campbell, C. A., H. R. Davidson, & F. G. Warder. 1977. Effects of fertilizer N and soil moisture on yield, yield components, protein content and N accumulation in the aboveground parts of spring wheat. p. 311-327 *Can. J. Soil Sci.* 57
- Clarke, J. M., C. A. Campbell, H. W. Cutforth, R. M. Depauw & G. E. Winkleman. 1990. Nitrogen and phosphorus uptake, translocation, and utilization efficiency of wheat in

- relation to environment and cultivar yield and protein levels. P. 965-977 Canadian Journal of Plant Science 70.4
- Combs, S. M., J. L. Denning & K. D. Frank. 1998. Sulfate-sulfur. P. 35-40. In: J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Combs, S.M., & M.V. Nathan. 1998. Soil organic matter. P. 53–58. In: J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central 17 Reg. Res. Publ. 221 (Rev.). SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Dordas, C. 2009. Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source–sink relations. European Journal of Agronomy, 30(2), 129-139.
- Frank, K., D. Beegle, & J. Denning. 1998. Phosphorus. P. 21–26. In: J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Gelderman, R. H., & D. Beegle. 1998. Nitrate-nitrogen. P. 17-20. In: J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Reg. Res. Publ, 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Gieseking, J.E., Snider, H.J., and Getz,C.A. 1935. Destruction of organic matter in plant material by the use of nitric and perchloric acids. P. 185-186. Ind. and Eng. Chem.,Anal.Ed.,V.7,
- Gregory, P. J., D. V. Crawford, & M. McGowan. 1979. Nutrient relations of winter wheat: 1. Accumulation and distribution of Na, K, Ca, Mg, P, S and N. P. 485-494 The Journal of Agricultural Science 93.02

- Gregory, P.J., B. Marshall, & P.V. Biscoe. 1981. Nutrient relations of winter wheat:3. Nitrogen uptake, photosynthesis of flag leaves and translocation of nitrogen to grain, *The Journal of Agricultural Science*, 96(3), pp. 539–547. doi: 10.1017/S0021859600034493.
- Hocking, P. J. 1994. Dry-matter production, mineral nutrient concentrations, and nutrient distribution and redistribution in irrigated spring wheat. *Journal of Plant Nutrition* 17.8 : 1289-1308.
- Holtz, S. L. 2007. Above-ground Nitrogen Accumulation as a Function of Time in Corn and Winter Wheat. ProQuest.
- KSU Mesonet. 2016. Available at: <http://mesonet.k-state.edu>
- Karlen, D. L., & D. A. Whitney. 1980. Dry matter accumulation, mineral concentrations, and nutrient distribution in winter wheat. P. 281-288. *Agronomy Journal*, 72(2).
- Leikam, D.F., R.E. Lamond, & D.B. Mengel. 2003. Soil test interpretations and fertilizer Recommendations. MF-2586. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University.
- Mengel, D. 2016. Soil pH and liming in Kansas: Part 1- Basic Concepts. Agron. e-Update Kansas State University ext. No. 571.
- Mengel, D. & D.A. Ruiz Diaz. 2009. Plant analysis for wheat: Be sure it's done at the proper stage of growth. Agron. e-Update Kansas State University ext. No. 193.
- Miller, E. C. 1939. A physiological study of the winter wheat plant at different stages of its development. Kansas State University Agricultural Experiment Station. Rep. 47
- Lamond, R. E. 1997. Sulphur in Kansas: Plant, Soil, and Fertilizer Considerations. MF-2264 Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University.

- Leikam, D.F., R.E. Lamond, & D.B. Mengel. 2003. Soil test interpretations and fertilizer Recommendations. MF-2586. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University.
- Matsunaga, T., & Shiozaki, H. 1989. Sulfuric acid-hydrogen peroxide digestion for the determination of total nitrogen in plant material containing nitrate nitrogen. *Japanese Journal of Soil Science and Plant Nutrition (Japan)*.
- Meng, Q., S. Yue, X. Chen, Z. Cui, Y. Ye, W. Ma, & F. Zhang, 2013. Understanding dry matter and nitrogen accumulation with time-course for high-yielding wheat production in China. *PloS one*, 8(7), e68783.
- Papakosta, Despo K., and A. A. Gagianas. 1991. Nitrogen and dry matter accumulation, remobilization, and losses for Mediterranean wheat during grain filling. P. 864-870 *Agronomy Journal* 83.5.
- Papakosta, D. K. 1994. Phosphorus accumulation and translocation in wheat as affected by cultivar and nitrogen fertilization. P. 260-270 *Journal of Agronomy and Crop Science* 173.3-4:
- Parent, C., N. Capelli, A. Berger, M. Crèvecoeur, & J.F. Dat. 2008. An overview of plant responses to soil waterlogging. P. 20-27 *Plant Stress*, 2(1).
- Pezeshki, S. R., & R. D. DeLaune. 2012. Soil oxidation-reduction in wetlands and its impact on plant functioning. P. 196-221 *Biology* 1.2.
- Rennenberg, H. 1984. The fate of excess sulfur in higher plants. P. 121-153. *Annual Review of Plant Physiology*, 35(1).

- Rose, T. J., Rengel, Z., Ma, Q., & Bowden, J. W. (2007). Differential accumulation patterns of phosphorus and potassium by canola cultivars compared to wheat. *Journal of Plant Nutrition and Soil Science*, 170(3), 404-411.
- SAS Institute. 2013. The SAS system for Windows. Version 9.4. SAS Inst., Cary, CN.
- Schulte, E. E., & K. A. Kelling. 1992. Soil and applied sulphur. Understanding plant nutrients. A2525. University of Wisconsin-Madison and University of Wisconsin-Extension, Cooperative extension.
- Spiertz, J. H. J. & J. Ellen. 1978. Effects of nitrogen on crop development and grain growth of winter wheat in relation to assimilation and utilization of assimilates and nutrients. P. 210-231. *Neth. J. Agric. Sci* 26.2
- Stevenson, F. J., & M. A. Cole. 1994. Cycles of soil. Carbon, nitrogen, phosphorus, sulfur and micronutrients. John Wiley and Sons. Inc. New York
- Waldren, R. P., & A. D. Flowerday. 1979. Growth stages and distribution of dry matter, N, P, and K in winter wheat. P. 391-397. *Agronomy Journal* 71.3
- Warncke, D., & J.R. Brown. 1998. Potassium and other basic cations. P. 31-34. In J. R. Brown (Ed.), Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn., Columbia.
- Watson, M.E., & J.R. Brown. 1998. pH and lime requirement. P.13-16. In J. R. Brown (Ed.) Recommended chemical soil test procedures for the North Central Region. North Central Region Publ. 221 (rev.). Missouri Agric. Exp. Stn, Columbia.
- Whitney, D.A. 1998. Micronutrients: Zinc, Iron, Manganese and Copper. P. 41-44. In Recommended Chemical Soil Test procedures for North Central Region. North Central Regional Publ.221(Rev.) Missouri Agric. Exp. Stn. Columbia.

Wise, K., B. Johnson, C. Mansfield, & C. Krupke 2011. Managing wheat by growth stage. Purdue Extension ID-422

Zhan, A., X. Chen, S. Li, & Z. Cui. 2015. Changes in phosphorus requirement with increasing grain yield for winter wheat. P. 2003-2010 Agronomy Journal, 107(6),.

Table 3-1. Description of locations in 2014-2015 and 2015-2016.

Location	Year	County	Soil Series [†]	Soil Subgroup	Precipitation			Variety	Planting Rate	Planting Date
					30-yr	1-yr	Season			
					----- mm -----				kg ha ⁻¹	
1	2014-2015	Riley	Smolan ScL	Pachic Argiustolls	904	777	599	Hotrod	45	10/6/2014
2	2014-2015	Republic	Crete SL	Pachic Udertic Argiustolls	775	655	381	Everest	102	10/7/2014
3	2015-2016	Riley	Belvue SL	Typic Udifluvents	904	988	652	Everest	45	10/6/2015

[†] SCL, Silty clay loam; SL, Silty loam

Table 3-2. Initial soil test results from each location.

Soil parameter †	Location		
	1	2	3
pH	5.9	4.6	5.4
OM (g kg ⁻¹)	21.5	29.0	16.0
P (mg kg ⁻¹)	36	59	69
K (mg kg ⁻¹)	293	475	232
Cu (mg kg ⁻¹)	1.5	1.7	0.7
Mn (mg kg ⁻¹)	25.5	82.5	14.5
Zn (mg kg ⁻¹)	1.1	1.2	1.1
NO ₃ -N (mg kg ⁻¹)	13.0	21.5	21.0
Cl (mg kg ⁻¹)	2.8	6.2	4.5
S (mg kg ⁻¹)	9.8	13.8	1.9

† pH 1:1 soil:water, organic matter, loss on ignition, P, Mehlich-3, K, ammonium acetate, Cu, Mn, Zn, DTPA Extraction, NO₃-N, potassium chloride extractant, Cl, calcium nitrate extraction, S, calcium phosphate extraction. pH, organic matter, P, K, Cu, Mn, Zn were all sampled at 0-15 cm depth. NO₃-N, Cl, S were all sampled at 0-61 cm depth.

Table 3-3. Significance of F values for treatment, date, and treatment by sampling date effects on N, P, K, S, Cu, Mn, and Zn uptake values in leaf, stem, head, spike and grain fractions at all locations.

Nutrient	Leaf			Stem			Head			Spike			Grain		
	FT†	SD	FT x SD	FT	SD	FT x SD	FT	SD	FT x SD	FT	SD	FT x SD	FT	SD	FT x SD
----- P < F -----															
<u>Location 1</u>															
N	0.107	<0.001	0.530	0.783	<0.001	0.301	0.509	<0.001	0.780	0.809	0.028	0.637	0.518	0.042	0.953
P	0.146	0.002	0.678	0.422	<0.001	0.399	0.904	<0.001	0.424	0.954	0.200	0.118	0.429	0.449	0.812
K	0.228	<0.001	0.758	0.855	<0.001	0.910	0.810	<0.001	0.934	0.382	0.006	0.160	0.278	0.172	0.887
S	0.920	<0.001	0.771	0.653	<0.001	0.014	0.972	<0.001	0.693	0.463	0.099	0.211	0.328	0.081	0.820
Cu	0.073	<0.001	0.005	0.941	<0.001	0.653	0.250	<0.001	0.065	0.508	0.377	0.063	0.178	0.769	0.322
Mn	0.384	0.002	0.877	0.313	<0.001	0.310	0.186	<0.001	0.477	0.337	0.406	0.241	0.230	0.419	0.615
Zn	0.243	<0.001	0.456	0.085	<0.001	0.045	0.180	<0.001	0.673	0.109	0.332	0.652	0.028	0.102	0.624
<u>Location 2</u>															
N	0.363	<0.001	0.900	0.243	<0.001	0.333	0.116	<0.001	0.138	0.130	0.013	0.086	0.944	0.129	0.636
P	0.156	<0.001	0.714	0.229	<0.001	0.239	0.107	<0.001	0.105	0.282	0.239	0.172	0.871	0.190	0.807
K	0.210	<0.001	0.489	0.562	<0.001	0.109	0.105	<0.001	0.086	0.337	0.078	0.172	0.909	0.762	0.793
S	0.300	<0.001	0.939	0.055	<0.001	0.421	0.229	<0.001	0.119	0.905	0.008	0.230	0.346	0.756	0.679
Cu	0.000	<0.001	0.000	0.391	<0.001	0.781	0.322	<0.001	0.219	0.681	0.671	0.177	0.720	0.490	0.306
Mn	0.843	<0.001	0.997	0.271	<0.001	0.567	0.583	<0.001	0.036	0.882	0.390	0.771	0.784	0.203	0.613
Zn	0.022	<0.001	0.361	0.013	<0.001	0.139	0.658	<0.001	0.148	0.897	0.069	0.594	0.711	0.113	0.227
<u>Location 3</u>															
N	0.005	<0.001	0.763	0.005	<0.001	0.280	0.003	<0.001	0.687	0.380	0.112	0.061	0.038	0.319	0.299
P	0.965	<0.001	0.942	0.008	<0.001	0.171	0.003	<0.001	0.436	0.234	0.447	0.058	0.003	0.247	0.435
K	0.005	<0.001	0.534	<0.001	<0.001	0.126	0.001	<0.001	0.347	0.115	0.125	0.031	0.001	0.390	0.541
S	<0.001	<0.001	0.423	<0.001	0.011	0.175	0.002	<0.001	0.519	0.056	0.094	0.028	0.008	0.426	0.339
Cu	<0.001	<0.001	0.004	<0.001	<0.001	0.007	0.155	<0.001	0.715	0.012	0.292	0.968	0.018	0.271	0.677
Mn	<0.001	<0.001	0.916	0.000	<0.001	0.342	0.001	<0.001	0.035	0.076	0.113	0.099	0.011	0.240	0.528
Zn	<0.001	<0.001	0.080	<0.001	<0.001	0.068	0.001	<0.001	0.143	0.097	0.004	0.013	0.006	0.548	0.387

† FT, Fertilizer Treatment, SD, Sampling date

Table 3-4. P-Values for treatment effect on nutrient uptake levels for all nutrients within leaf, stem, head, spike, and grain fraction along with total uptake levels in the plant. Results show all sampling dates at location 1.

Date	Growth Stage	Nutrient						
		N	P	K	S	Cu	Mn	Zn
	Feekes	-----P>F-----						
		<u>Leaf</u>						
Dec. 3	2	0.620	0.631	0.622	0.826	<0.001	0.318	0.010
Mar. 26	4	0.119	0.280	0.278	0.788	0.084	0.879	0.586
Apr. 1	5	0.007	0.027	0.014	0.237	0.293	0.603	0.248
Apr. 9	6	0.459	0.590	0.524	0.752	0.777	0.872	0.984
Apr. 15	7	0.509	0.281	0.697	0.925	0.735	0.843	0.856
Apr. 22	8	0.486	0.128	0.719	0.817	0.831	0.689	0.728
Apr. 29	10	0.238	0.447	0.648	0.881	0.808	0.856	0.972
May 11	10.5.4	0.344	0.292	0.473	0.230	0.147	0.850	1.000
May 18	11.1	0.553	0.809	0.982	0.734	0.531	0.422	0.510
May 26	11.1	0.330	0.525	0.356	0.273	0.174	0.295	0.338
Jun. 4	11.2	0.357	0.359	0.561	0.160	0.236	0.049	0.163
Jun. 17	11.3	0.853	0.830	0.901	0.932	0.214	0.203	0.157
		<u>Stem</u>						
Apr. 9	6	0.719	0.705	0.807	0.894	0.927	0.816	0.903
Apr. 15	7	0.961	0.830	0.865	0.924	0.916	0.977	0.846
Apr. 22	8	0.598	0.340	0.752	0.890	0.870	0.641	0.744
Apr. 29	10	0.610	0.425	0.601	0.761	0.559	0.574	0.868
May 11	10.5.4	0.079	0.023	0.208	0.036	0.171	0.155	0.085
May 18	11.1	0.897	0.673	0.972	0.561	0.949	0.438	0.237
May 26	11.1	0.534	0.883	0.498	0.376	0.902	0.206	0.078
Jun. 4	11.2	0.761	0.815	0.579	0.061	0.188	0.048	0.002
Jun. 17	11.3	0.444	0.628	0.699	0.049	0.262	0.023	0.003
		<u>Head</u>						
Apr. 29	10	0.973	0.815	0.829	0.657	0.931	0.926	0.930
May 11	10.5.4	0.722	0.371	0.658	0.482	0.920	0.733	0.554
May 18	11.1	0.845	0.655	0.762	0.775	0.685	0.781	0.245
May 26	11.1	0.247	0.304	0.719	0.447	0.007	0.060	0.080
		<u>Spike</u>						
Jun. 4	11.2	0.703	0.275	0.128	0.156	0.057	0.152	0.090
Jun. 17	11.3	0.598	0.314	0.922	0.728	0.268	0.782	0.146
		<u>Grain</u>						
Jun. 4	11.2	0.572	0.448	0.360	0.357	0.088	0.208	0.129
Jun. 17	11.3	0.622	0.666	0.465	0.532	0.638	0.562	0.035
		<u>Total</u>						
Dec. 3	2	0.825	0.892	0.847	0.914	0.027	0.541	0.421
Mar. 26	4	0.480	0.756	0.669	0.894	0.443	0.926	0.872
Apr. 1	5	0.204	0.498	0.315	0.557	0.646	0.751	0.730
Apr. 9	6	0.631	0.758	0.668	0.824	0.929	0.866	0.952
Apr. 15	7	0.753	0.691	0.782	0.925	0.852	0.897	0.958
Apr. 22	8	0.596	0.402	0.709	0.854	0.878	0.700	0.940
Apr. 29	10	0.452	0.539	0.556	0.746	0.714	0.768	0.937
May 11	10.5.4	0.289	0.123	0.206	0.065	0.869	0.611	0.421
May 18	11.1	0.800	0.170	0.680	0.827	0.739	0.703	0.780
May 26	11.1	0.279	0.574	0.367	0.249	0.036	0.196	0.088
Jun. 4	11.2	0.276	0.112	0.349	0.013	0.001	0.001	<.001
Jun. 17	11.3	0.436	0.516	0.736	0.163	0.396	0.051	<.001

Table 3-5. P-Values for treatment effect on nutrient uptake levels for all nutrients within leaf, stem, head, spike, and grain fraction along with total uptake levels in the plant. Results show all sampling dates at location 2.

Date	Growth Stage	Nutrient						
		N	P	K	S	Cu	Mn	Zn
	Feekes	-----P>F-----						
		<u>Leaf</u>						
Dec. 3	2	0.945	0.845	0.953	0.822	0.377	0.984	0.337
Mar. 26	3	0.689	0.646	0.941	0.836	0.124	0.954	0.368
Apr. 1	4	0.959	0.928	0.637	0.520	0.324	0.705	0.241
Apr. 9	5	0.778	0.585	0.449	0.975	0.619	0.892	0.520
Apr. 16	6	0.207	0.227	0.079	0.890	0.878	0.878	0.710
Apr. 23	7	0.925	0.767	0.772	0.196	0.078	0.769	0.428
Apr. 30	8	0.764	0.051	0.079	0.743	0.959	0.910	0.978
May 11	10	0.082	0.061	0.028	0.949	0.381	0.792	0.692
May 18	10.5.3	0.994	0.906	0.999	0.258	<0.001	0.303	0.000
May 27	11.1	0.984	0.776	0.487	0.528	0.770	0.565	0.315
Jun. 2	11.1	0.528	0.325	0.938	0.535	0.898	0.518	0.713
Jun. 9	11.2	0.261	0.605	0.842	0.271	0.286	0.641	0.717
Jun. 16	11.3	0.956	0.766	0.978	0.983	0.403	0.882	0.585
		<u>Stem</u>						
Apr. 9	5	0.959	0.894	0.914	0.934	0.983	0.969	0.990
Apr. 16	6	0.233	0.388	0.450	0.648	0.613	0.805	0.648
Apr. 23	7	0.900	0.984	0.673	0.578	0.639	0.621	0.827
Apr. 30	8	0.188	0.431	0.524	0.797	0.860	0.742	0.605
May 11	10	0.198	0.048	0.024	0.614	0.750	0.784	0.062
May 18	10.5.3	0.109	0.599	0.760	0.082	0.260	0.020	0.001
May 27	11.1	0.812	0.288	0.831	0.061	0.907	0.172	0.011
Jun. 2	11.1	0.266	0.182	0.528	0.246	0.880	0.704	0.195
Jun. 9	11.2	0.347	0.908	0.476	0.019	0.076	0.822	0.551
Jun. 16	11.3	0.913	0.345	0.945	0.005	0.950	0.454	0.008
		<u>Head</u>						
Apr. 30	8	0.615	0.649	0.716	0.773	0.823	0.991	0.783
May 11	10	0.088	0.052	0.041	0.135	0.356	0.220	0.302
May 18	10.5.3	0.684	0.606	0.596	0.886	0.320	0.666	0.717
May 27	11.1	0.662	0.693	0.704	0.505	0.417	0.163	0.298
Jun. 2	11.1	0.493	0.559	0.680	0.779	0.437	0.189	0.596
		<u>Spike</u>						
Jun. 9	11.2	0.386	0.763	0.642	0.404	0.475	0.754	0.723
Jun. 16	11.3	0.025	0.136	0.084	0.320	0.197	0.932	0.903
		<u>Grain</u>						
Jun. 9	11.2	0.716	0.763	0.778	0.512	0.511	0.818	0.342
Jun. 16	11.3	0.657	0.917	0.902	0.888	0.286	0.562	0.204
		<u>Total</u>						
Dec. 3	2	0.975	0.954	0.984	0.923	0.778	0.991	0.846
Mar. 26	3	0.861	0.892	0.980	0.929	0.620	0.974	0.856
Apr. 1	4	0.982	0.978	0.875	0.781	0.752	0.832	0.812
Apr. 9	5	0.880	0.818	0.735	0.952	0.868	0.926	0.904
Apr. 16	6	0.243	0.421	0.226	0.846	0.891	0.848	0.792
Apr. 23	7	0.915	0.922	0.669	0.385	0.457	0.707	0.748
Apr. 30	8	0.305	0.236	0.235	0.902	0.996	0.940	0.769
May 11	10	0.024	0.009	0.004	0.405	0.777	0.293	0.353
May 18	10.5.3	0.314	0.643	0.732	0.162	0.001	0.599	0.001
May 27	11.1	0.750	0.640	0.637	0.110	0.742	0.236	0.017
Jun. 2	11.1	0.255	0.217	0.548	0.792	0.929	0.430	0.295
Jun. 9	11.2	0.394	0.928	0.534	0.112	0.852	0.703	0.984
Jun. 16	11.3	0.949	0.324	0.978	0.117	0.019	0.703	0.005

Table 3-6. P-Values for treatment effect on nutrient uptake levels for all nutrients within leaf, stem, head, spike, and grain fraction along with total uptake levels in the plant. Results show all sampling dates at location 3.

Date	Growth Stage	Nutrient						
		N	P	K	S	Cu	Mn	Zn
	Feekes	-----P>F-----						
				<u>Leaf</u>				
Nov. 9	2	0.323	0.447	0.543	0.199	0.476	0.702	0.479
Jan. 5	3	0.991	0.813	0.852	0.470	0.965	0.845	0.851
Mar. 10	4	0.034	0.583	0.147	0.010	0.762	0.216	0.181
Mar. 17	5	0.037	0.556	0.059	0.001	0.595	0.186	0.293
Mar. 25	6	0.053	0.581	0.001	<0.001	0.545	0.178	0.148
Mar. 31	7	0.325	0.369	0.206	0.008	0.763	0.373	0.792
Apr. 6	8	0.979	0.232	0.762	0.346	0.849	0.402	0.685
Apr. 14	9	0.242	0.531	0.854	0.041	0.763	0.197	0.613
Apr. 21	10	0.158	0.291	0.054	0.006	0.579	0.037	0.083
May 2	10.5.2	0.113	0.529	0.306	0.043	0.008	0.010	<0.001
May 10	10.5.4	0.035	0.267	0.026	0.004	0.045	0.005	<0.001
May 19	11.1	0.123	0.635	0.194	0.018	0.091	0.010	<0.001
May 27	11.1	0.701	0.978	0.720	0.006	<0.001	0.151	0.059
Jun. 3	11.2	0.642	0.965	0.430	0.228	0.273	0.087	0.179
Jun. 10	11.3	0.766	0.790	0.626	0.529	0.631	0.299	0.104
				<u>Stem</u>				
Mar. 17	5	0.322	0.313	0.331	0.087	0.360	0.637	0.489
Mar. 25	6	0.013	0.036	0.023	0.003	0.162	0.284	0.307
Mar. 31	7	0.382	0.516	0.357	0.094	0.698	0.535	0.361
Apr. 6	8	0.427	0.409	0.393	0.111	0.760	0.259	0.479
Apr. 14	9	0.056	0.188	0.180	0.055	0.416	0.289	0.418
Apr. 21	10	0.012	0.040	0.029	0.001	0.194	0.038	0.149
May 2	10.5.2	0.059	0.282	0.203	<0.001	<0.001	0.002	0.039
May 10	10.5.4	0.014	0.001	<0.001	<0.001	0.269	<0.001	<0.001
May 19	11.1	0.167	0.004	<0.001	<0.001	0.036	0.000	<0.001
May 27	11.1	0.325	0.729	0.050	0.004	0.931	0.007	0.046
Jun. 3	11.2	0.917	0.905	0.004	0.001	0.218	0.006	0.001
Jun. 10	11.3	0.825	0.792	0.505	0.045	0.330	0.125	<0.001
				<u>Head</u>				
Apr. 21	10	0.417	0.354	0.117	0.316	0.570	0.713	0.413
May 2	10.5.2	0.529	0.397	0.211	0.246	0.778	0.620	0.330
May 10	10.5.4	0.057	0.039	0.017	0.013	0.101	0.050	0.012
May 19	11.1	0.022	0.006	0.001	0.006	0.168	0.016	0.001
May 27	11.1	0.199	0.006	0.001	0.008	0.249	<0.001	<0.001
				<u>Spike</u>				
Jun. 3	11.2	0.079	0.032	0.014	0.004	0.020	0.015	0.038
Jun. 10	11.3	0.743	0.732	0.848	0.871	0.022	0.571	0.256
				<u>Grain</u>				
Jun. 3	11.2	0.032	0.018	0.015	0.013	0.050	0.025	0.007
Jun. 10	11.3	0.552	0.182	0.093	0.235	0.162	0.162	0.065
				<u>Total</u>				
Nov. 9	2	0.641	0.763	0.787	0.495	0.486	0.843	0.772
Jan. 5	3	0.996	0.925	0.934	0.703	0.966	0.920	0.939
Mar. 10	4	0.313	0.828	0.517	0.166	0.767	0.522	0.581
Mar. 17	5	0.547	0.534	0.590	0.071	0.626	0.689	0.593
Mar. 25	6	0.289	0.905	0.085	0.021	0.520	0.644	0.392
Mar. 31	7	0.700	0.648	0.608	0.157	0.804	0.741	0.741
Apr. 6	8	0.917	0.727	0.795	0.396	0.868	0.629	0.734
Apr. 14	9	0.311	0.832	0.600	0.140	0.689	0.313	0.591
Apr. 21	10	0.047	0.118	0.043	0.004	0.410	0.071	0.088
May 2	10.5.2	0.022	0.824	0.905	0.294	0.039	0.278	0.057
May 10	10.5.4	0.003	0.010	0.003	<0.001	0.021	0.002	<0.001
May 19	11.1	0.007	0.007	0.005	<0.001	0.033	0.004	<0.001
May 27	11.1	0.436	0.086	0.106	<0.001	<0.001	0.014	0.001
Jun. 3	11.2	0.025	<0.001	0.002	<0.001	0.019	<0.001	<0.001
Jun. 10	11.3	0.872	0.044	0.098	0.009	0.141	0.011	<0.001

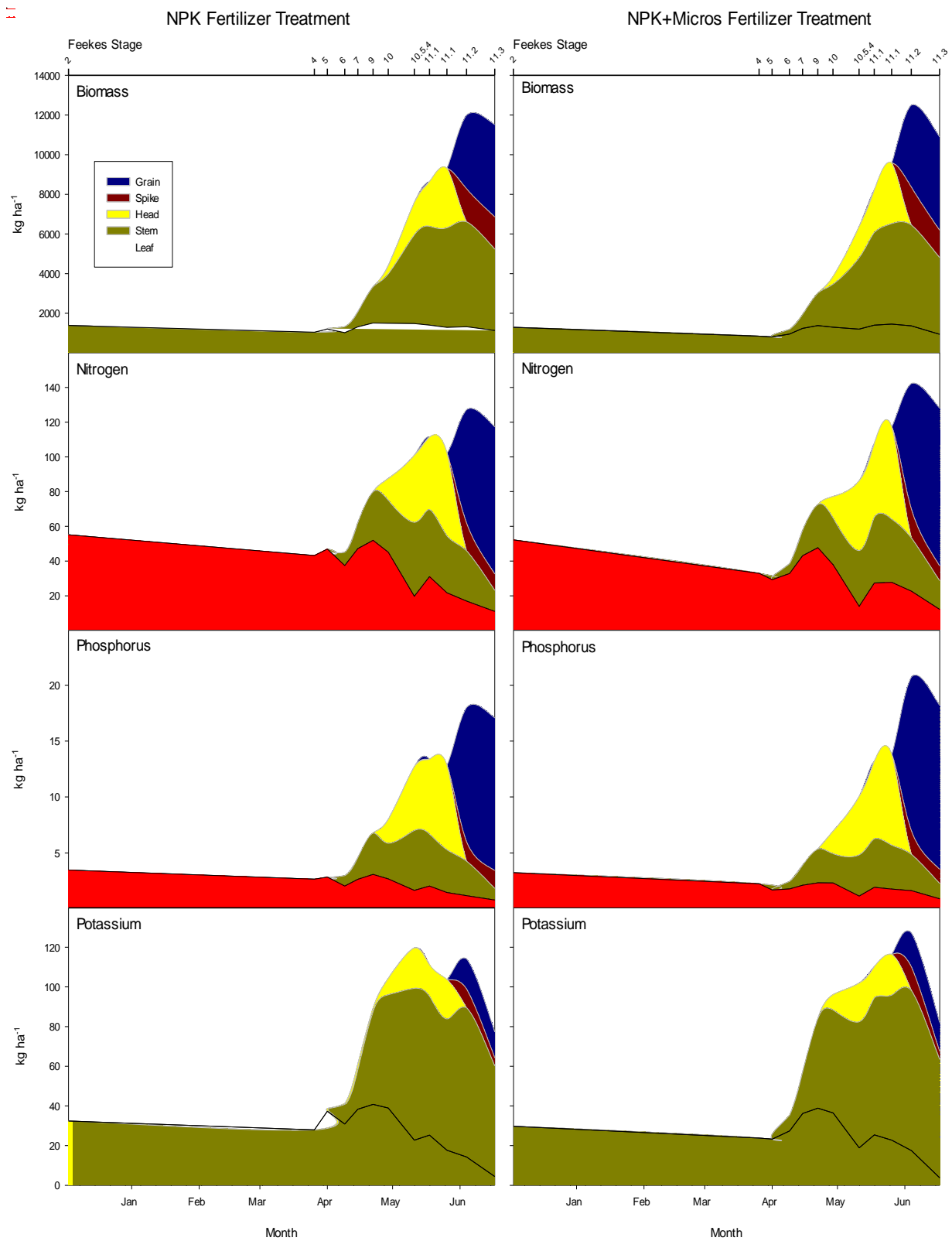


Figure 3-1. Total dry matter accumulation and macronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #1.

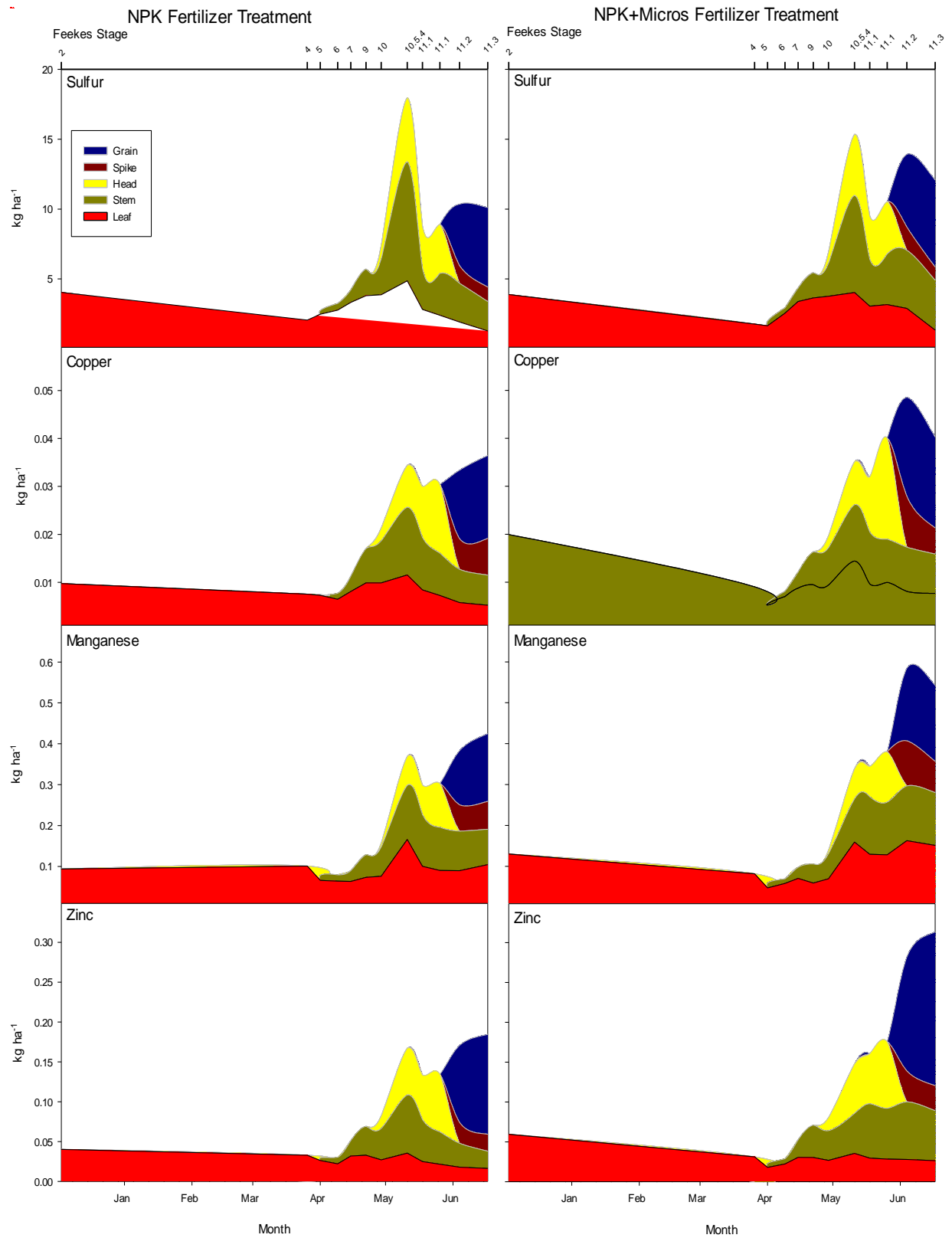


Figure 3-2. Total micronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #1.

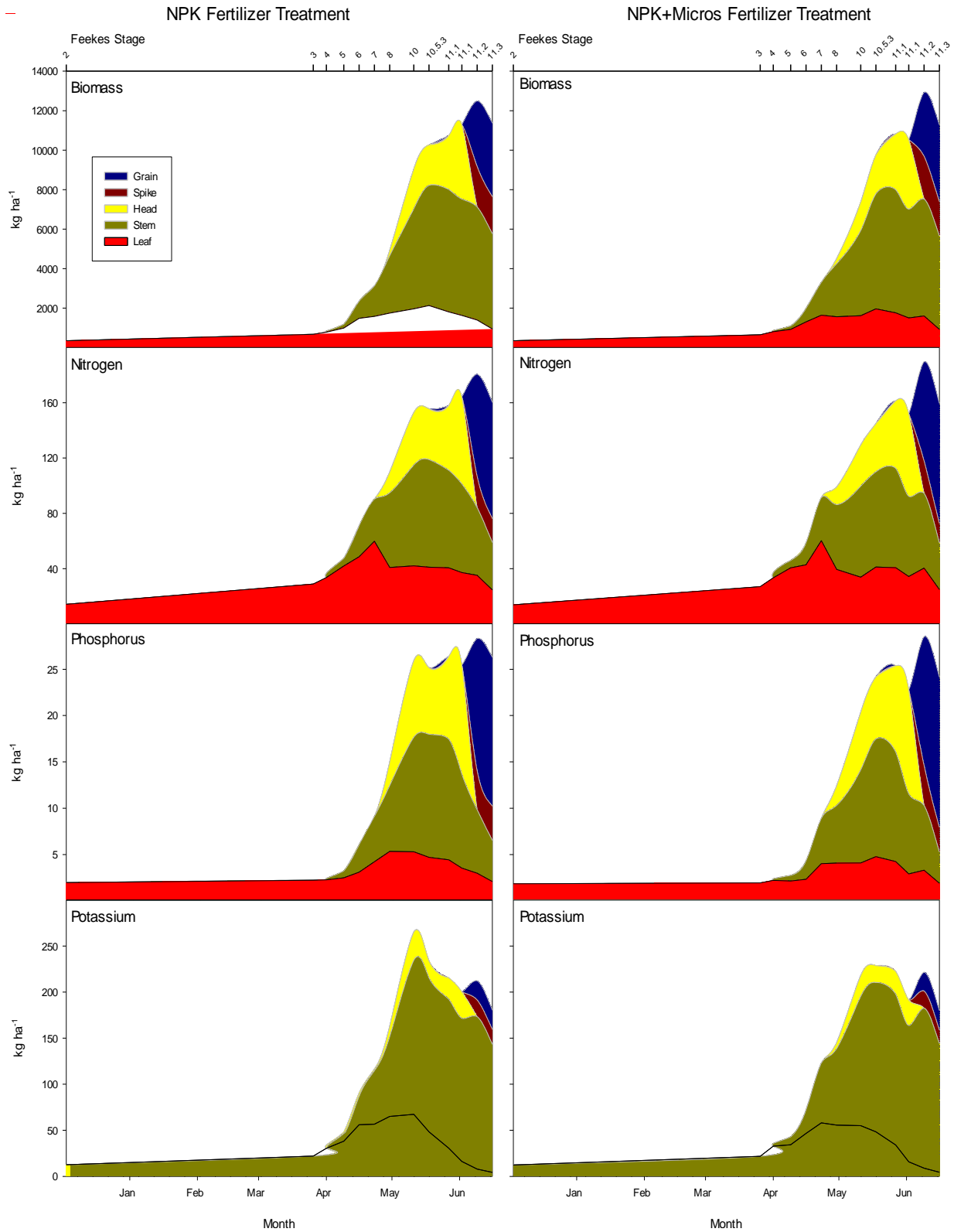


Figure 3-3. Total macronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #2.

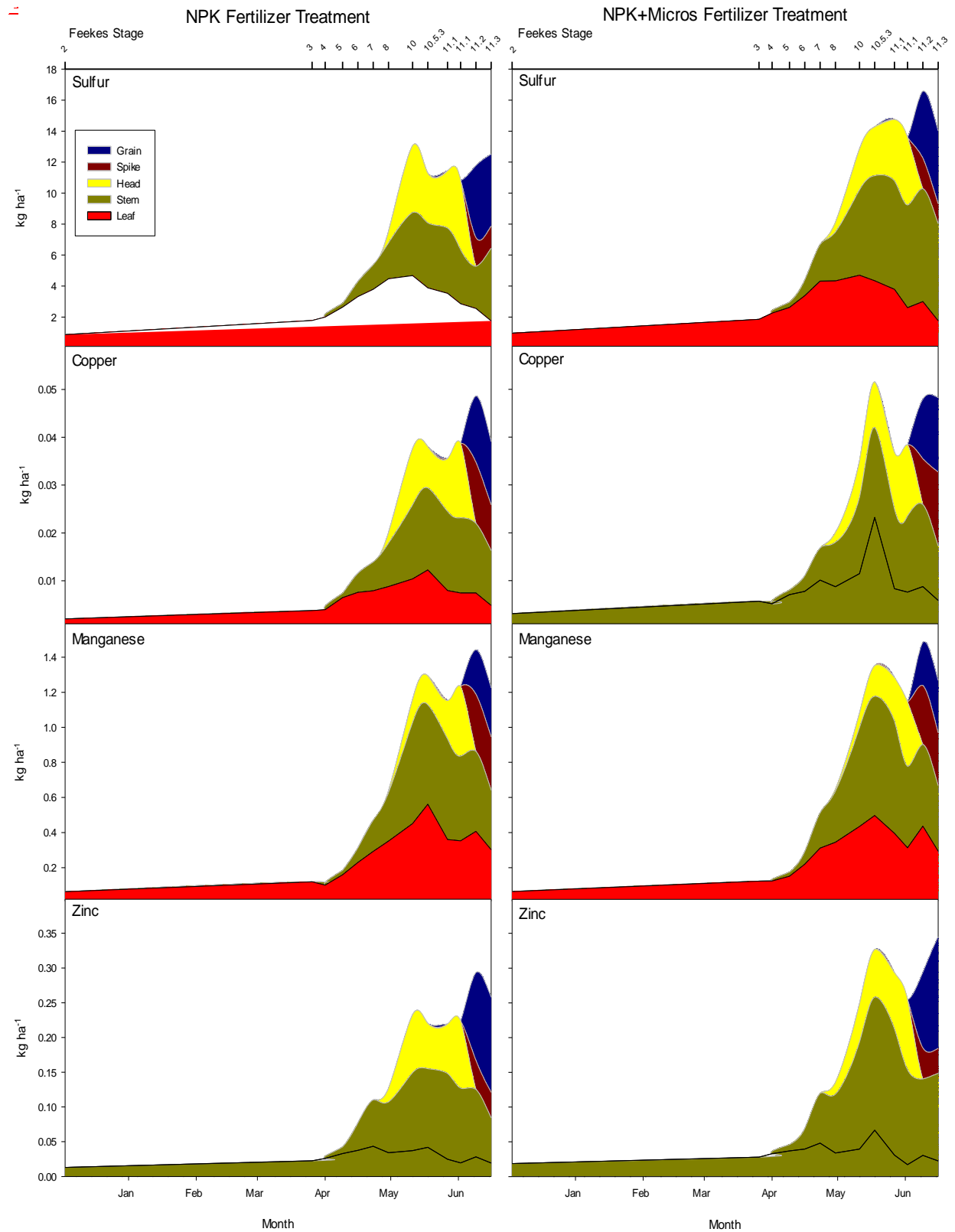


Figure 3-4. Total micronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #2.

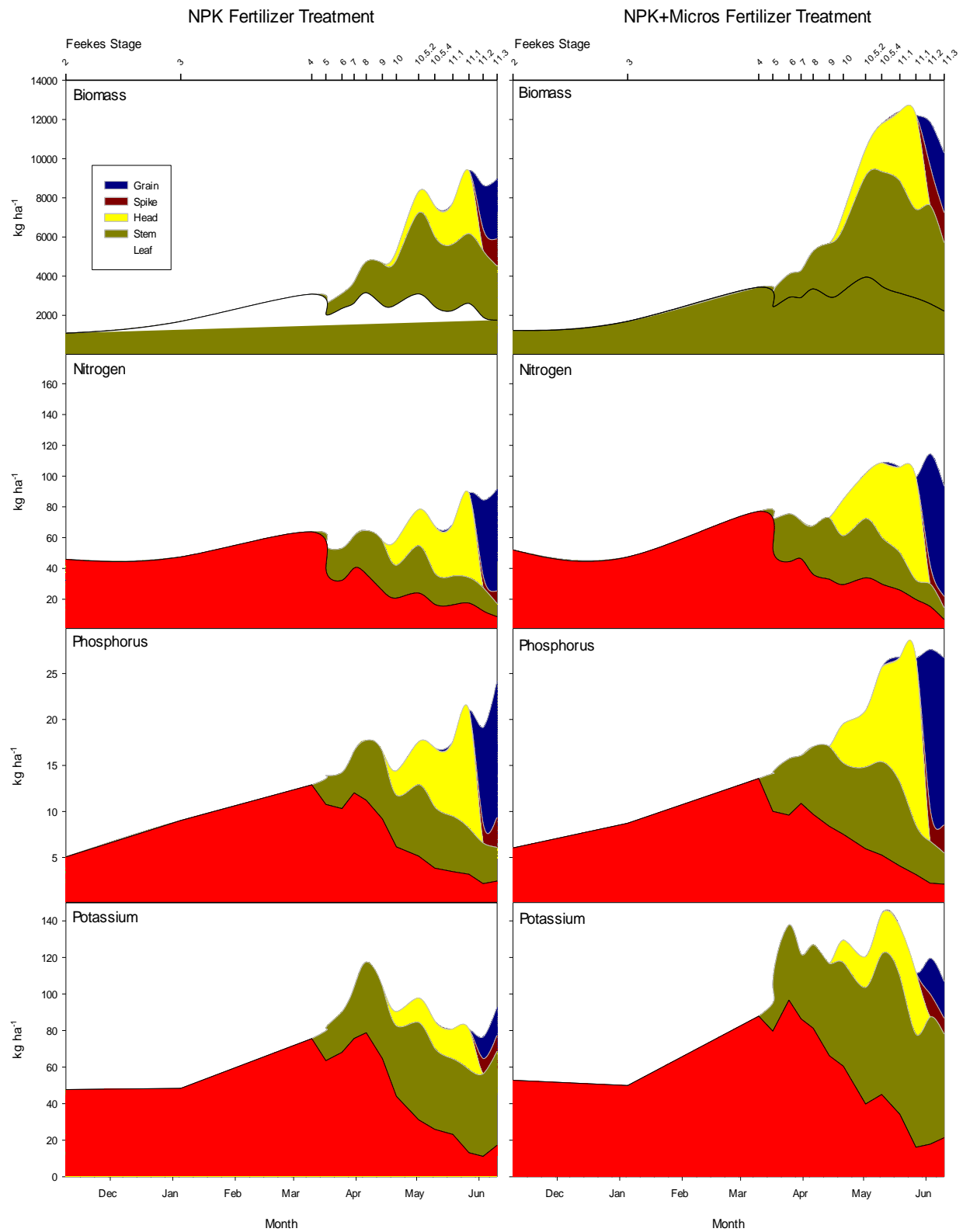


Figure 3-5. Total dry matter accumulation and macronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #3.

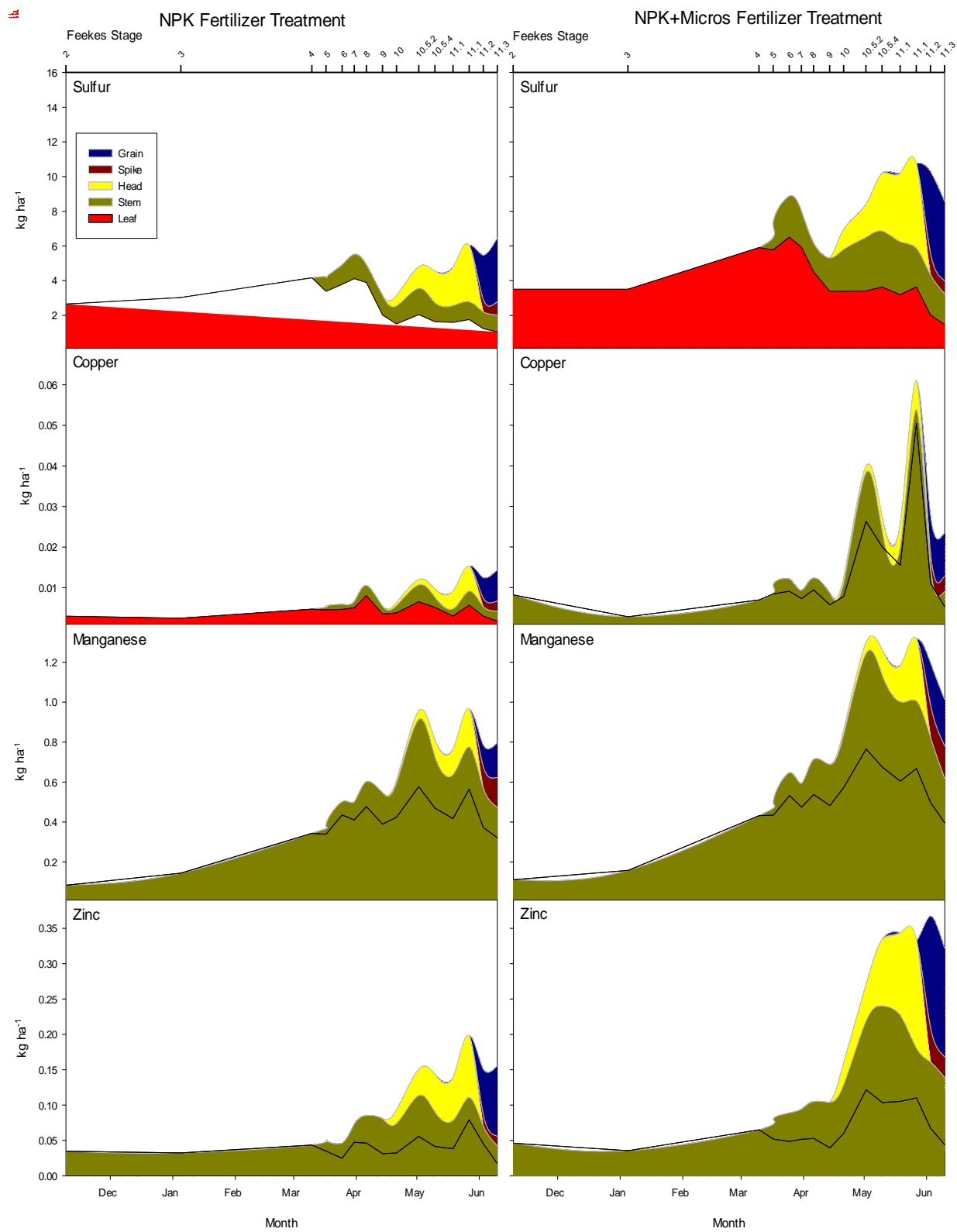


Figure 3-6. Total micronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment at Location #3.

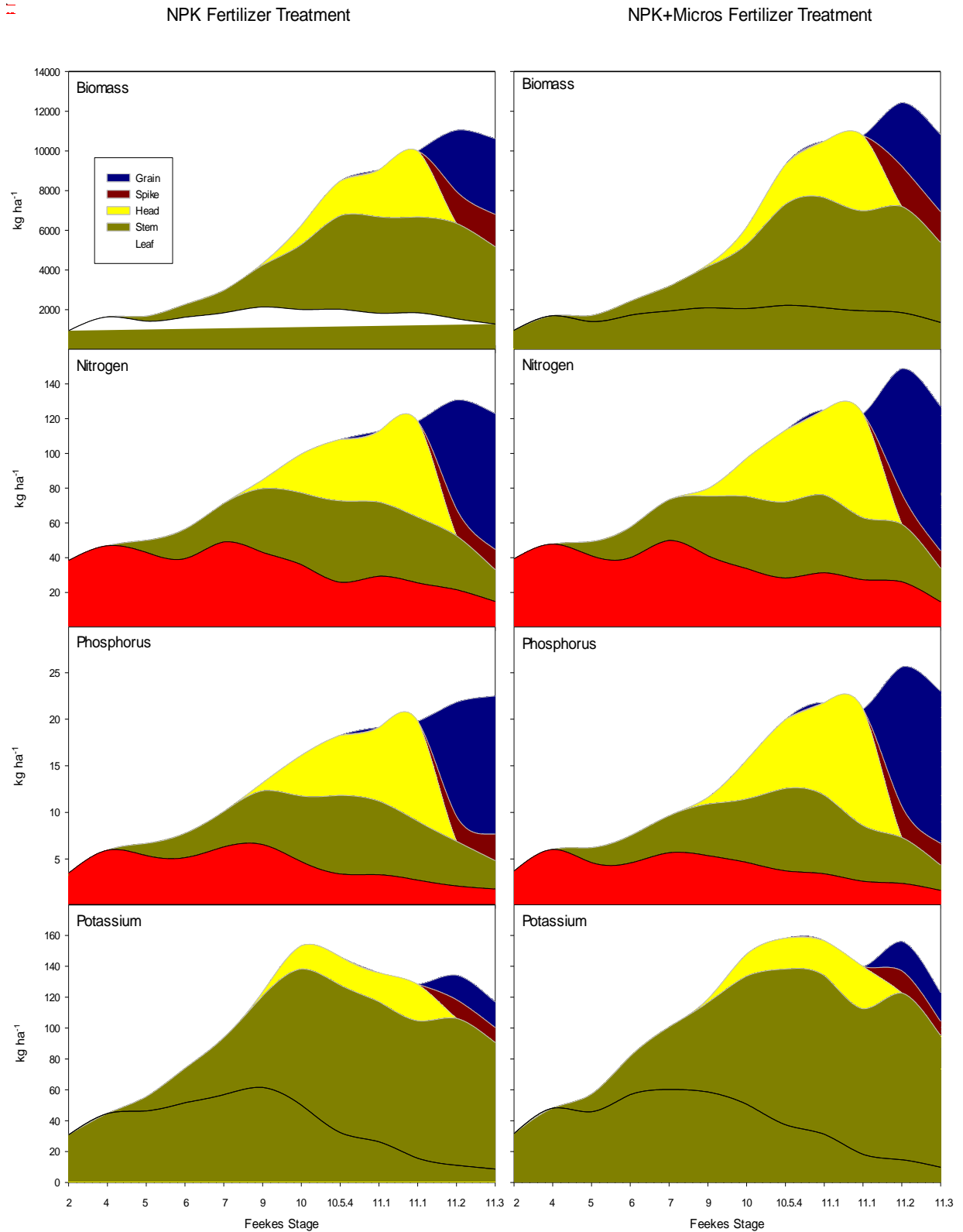


Figure 3-7. Total macronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment averaged across all three locations.

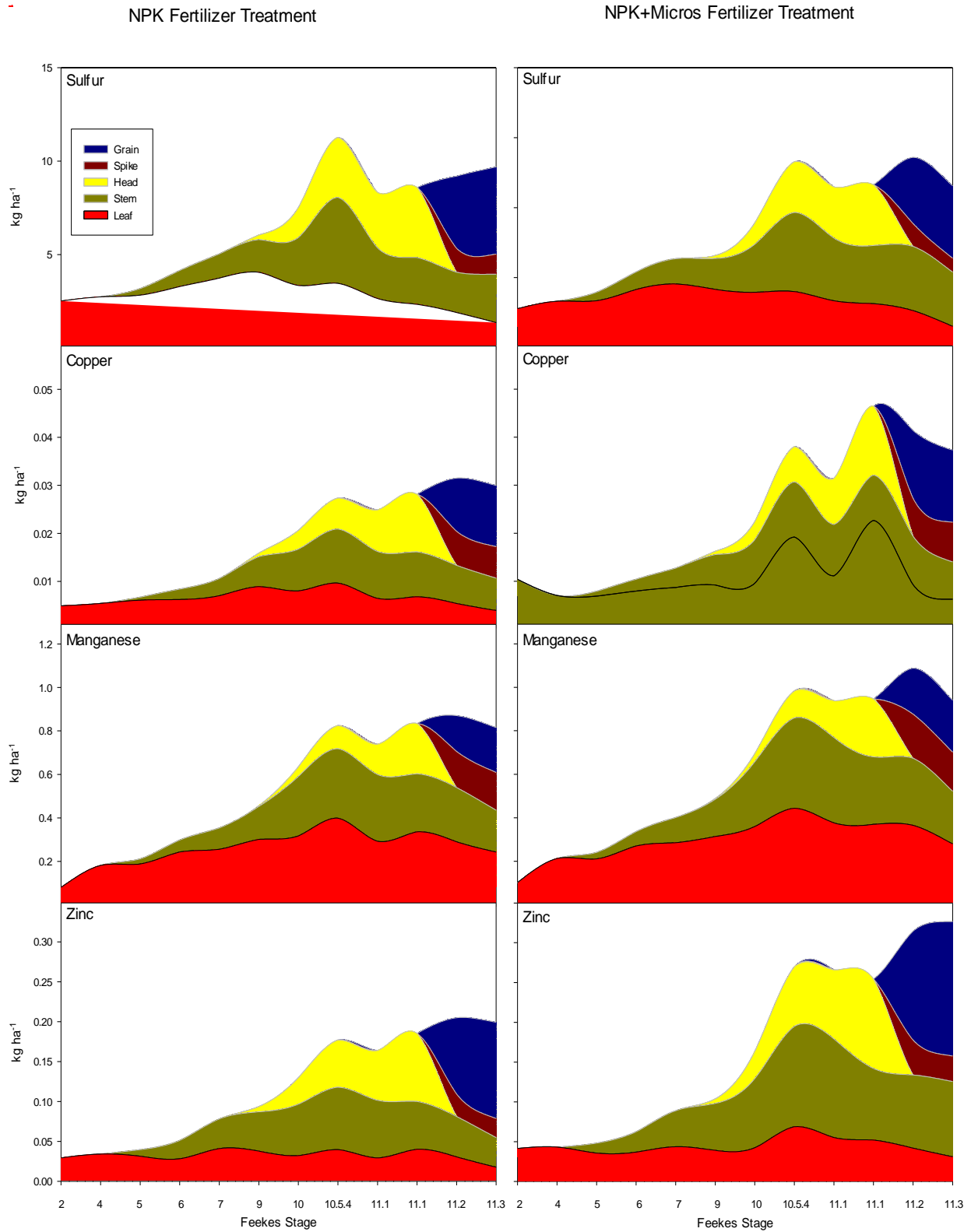


Figure 3-8. Total micronutrient uptake and partitioning into different fractions of the plant as the growing season progresses. Left and right columns compare NPK fertilizer treatment to the NPK+Micros treatment averaged across all three locations.

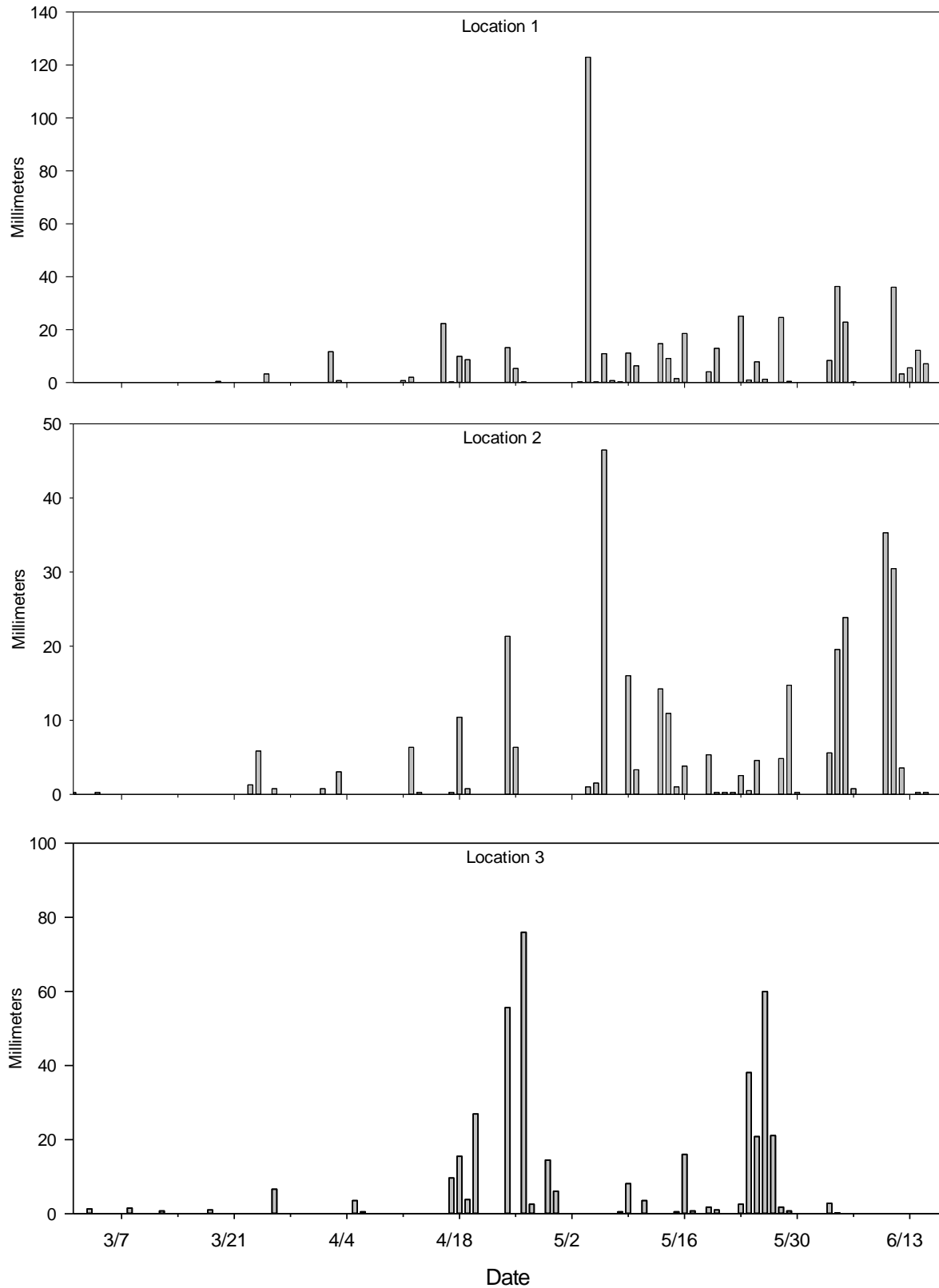


Figure 3-9. Daily precipitation amounts at each location beginning March 1st and ending June 17th.

Chapter 4 - Nitrogen fertilizer management for winter wheat under dual purpose grazing and grain production

ABSTRACT

Dual purpose winter wheat (*Triticum aestivum*) is a common system in the Southern Great Plains of the USA. The objectives of this study were to: i) evaluate the interaction of wheat grazing management and fertilizer nitrogen (N) requirements with emphasis on dual purpose wheat, ii) assess the use of normalized difference vegetation index (NDVI) sensors for N management and forage quantity assessment in wheat grazing conditions, and iii) evaluate forage quality based on N content and quantity interactions with N management. This study was conducted at 3 locations during the 2015-2016 season. . Experimental design was a randomized split block design with 16 treatments including simulated grazing and grain only treatments along with fall N fertilizer rates of 0, 34, 67, and 101 kg ha⁻¹. Simulated grazing was performed with a self-propelled bagging lawn mower and was initiated at a growth threshold of 12.5 centimeters above ground. Clippings were removed from the study area and weighed for dry matter estimation and analyzed for total N. NDVI sensor readings were taken before each simulated grazing to be used to estimate total forage and N requirements. Spring N rates were 0, 101 kg ha⁻¹ and an application rate based on NDVI sensor readings. Grain was harvested and collected for yield, test weight, moisture and total N analysis. Results showed increases in both forage quantity and N concentration with increased N fertilizer all the way up to the highest rate of 101 kg ha⁻¹. NDVI based spring N rates were much lower than our 101 kg ha⁻¹ and produced similar yields between fall N rates of 67 and 101 kg ha⁻¹ although N concentration of the grain was lower in the NDVI treatments.

INTRODUCTION

The use of winter wheat as both forage and grain crop in a dual-purpose system has been used profitably in the Southern Great Plains for many years. Dual purpose systems can be more profitable than a grain only system in many situations (Epplin et. al., 2001). Wheat provides a high protein forage source for cattle, with crude protein levels as high as 25 to 30 %, that can promote high gains at times when there are few other forage options (Shroyer et al., 1993). Wheat that has been grazed can also be harvested for a grain crop in many cases with minimal yield loss, and under some circumstances yield gain, as long as proper cultural practices are followed (Edwards et al., 2014).

The effectiveness of a dual-purpose wheat system depends on the management decisions of the producer. Early planting date is important to the establishment of an ample amount of forage in the fall and winter. Early planting allows the plant to produce more tillers and increase plant height before dormancy in the winter months. Along with early planting, increased seeding rate is also essential with about 50-100% increases above grain only rates (Shroyer et. al., 1993). Removing cattle from wheat before first hollow stem (Feekes 6) (Wise et. al., 2011) occurs is perhaps the most important management practice to maintain high grain yields. Grazing past first hollow stem can reduce grain yields by up to 5% each day (Edwards and Horn, 2010).

In addition to these cropping practices, fertilization is a key factor when managing a productive dual purpose system. Nitrogen management is of particular importance as N is typically the most limiting nutrient to forage yield and quality as well as grain yield (Shroyer et al., 1993). Optimum N fertilization within a dual-purpose system can differ when compared to a grain only system. Higher levels of available N in the fall are required by the plant to support additional biomass needed for grazing. The removal of high amounts of N-rich biomass along

with harvesting grain creates a much higher depletion of N within the field. Exact N requirements can vary year to year depending on moisture availability, but typical recommendations are an additional 34 to 56 kg above a grain only situation (Shroyer et. al., 1993). Manandhar (2008) found 90 kg ha⁻¹ to be the optimum rate for sufficient fall forage production. Sij et. al. (2016) found that forage production increases linearly with N rate before planting during years with high precipitation. However, there is little difference in forage production during years of low rainfall. They also showed a linear increase in forage protein with increased pre-plant N rate. Naveed et. al. (2013) reported that at a total rate of 150 kg ha⁻¹ of N applied at planting and after grazing, forage dry matter was highest when 75% of N was applied at planting. They also showed grain yield was highest when 25% of N was applied at planting and 75% after grazing. Sij et. al. (2016) showed pre-plant N rate up to 101 kg ha⁻¹ had little effect on grain yield when 50 kg ha⁻¹ N was applied as top-dress.

The use of NDVI (normalized difference vegetation index) sensors to make more accurate and efficient N applications in the spring has become increasingly popular in recent years. Raun et. al. (2005) found they could increase N use efficiency by 15% with sensor based spring N applications, compared to conventional applications. Raun et. al. (2002) also found they could increase profitability from N applications using sensor-based variable rate applications. NDVI values have also been used to estimate vegetation coverage, dry matter, and N uptake. Lukina et. al. (2000) found correlation coefficients between 0.81 and 0.98 between NDVI and vegetative coverage however, they also found NDVI values to be impacted by growth stage.

Although there is a large amount of research being done on NDVI sensors and their use for top-dress N applications, much of this research is focused on grain only wheat systems. Higher N removal rates and increased plant stress due to grazing can potentially cause a change

in the interaction of N applied as fertilizer and the effect it has on grain yield. It is important to understand this impact so that optimum N fertilizer applications can be made to dual-purpose wheat systems just as they are to grain only systems.

Much of the available research on dual purpose wheat production has been conducted in Oklahoma and Texas. Although dual purpose wheat is not as popular in Kansas as these other areas, the system can still be utilized with productive results. It is beneficial to conduct research on the production system in all environments where it can be effectively utilized in order to both increase the general understanding of the interactions within the system as well as better implement the system with proper management decisions specific to this area.

The objectives of this study were to: i) evaluate the interaction of wheat grazing management and fertilizer N requirements with emphasis on dual-purpose wheat, ii) assess the use of sensors for N management and forage quantity assessment in wheat grazing conditions, and iii) evaluate forage quality and quantity interactions with N management.

MATERIALS AND METHODS

This study was conducted at six locations during the 2014-2015 and 2015-2016 growing seasons. However, only three locations were included due to crops failures at three locations, related to environmental conditions. A description of locations can be found in table 4-1. The experimental design was a randomized split block design with 16 treatments and a reference strip. Treatments included 12 grazed treatments and 4 grain only treatments. Grazing treatments included a combination of four fall N rates combined with three top-dress N rates for a total of 12 treatment combinations. The four fall N application rates were 0, 34, 67, and 101 kg ha⁻¹. Fertilizer was applied as broadcast urea within one week of planting. Each fall rate was

accompanied by three rates of spring topdress N of 0, 101 kg ha⁻¹ and a sensor-based N rate, applied after simulated grazing termination. The sensor-based N rate used an N rate algorithm developed for grain wheat production (Asebedo, 2015). Grain only plots received a fall rate of 0, 34, 34, and 101 kg ha⁻¹. Spring topdress of these plots was 101, 67, sensor based application, and 0 kg ha⁻¹ respectively. Spring N fertilizer treatments were applied at first hollow stem (Feekes 6) using urea broadcast. Plot size 1.8 meters by 9.1 meters.

Soil samples were collected from each block, before fertilization, at depths of 0-15 cm and 0-60 cm. Samples were dried at 40°C and then ground to pass a 2mm mesh before being submitted for analysis. The 0-15 cm samples were analyzed for pH with a 1:1 (soil:water) method (Peters et al., 2012), P with Mehlich-3 extraction (Frank et al., 1998), K by ammonium acetate (Warncke and Brown, 1998), and organic matter by loss on ignition (Combs and Nathan, 1998). The 0-60 cm samples were analyzed for nitrate using a KCl extractant (Gelderman and Beegle, 1998).

NDVI values were collected for each plot using a Holland rapid scan sensor before each simulated grazing. Simulated grazing was performed in-season using a Honda self-propelled bagging lawnmower. Individual plots were mowed and then all clippings in the bag were weighed for biomass estimation. Simulated grazing was initiated once plants had reached a height threshold of 12.7 cm and were mowed to a height of 5 cm. Subsamples from each plot were hand clipped from two rows and 76 cm in length, and at 5 cm from the ground. Subsamples were then weighed, dried at 60°C, and reweighed for moisture estimation before being ground to pass a 2 mm mesh. Tissue samples were submitted for analysis for total N content using the sulfuric peroxide digest (Matsunaga & Shiozaki, 1987). Simulated grazing was terminated at the first hollow stem growth stage as defined by Edwards and Horn (2010). Grain was harvested

using a plot combine and tested for moisture and test weight. Grain was then ground using a burr coffee grinder and analyzed for total N content using the sulfuric peroxide digestion.

RESULTS AND DISCUSSION

Forage Production

Dry matter production was heavily influenced by fall N application rates as was expected. Regression data shows total dry matter produced at locations 1 and 2 increased without indication of plateauing at the highest rate of fall N application (Figure 4-1). This increase suggests more dry matter production may have been possible at higher rates of N than was applied. Location 3 showed a plateauing level of dry matter between rates of 67 kg ha⁻¹ and 101 kg ha⁻¹. Location 1 was only mowed one time, in the spring, because of poor fall stand establishment and short plant height. Total dry matter production at this location was much lower than locations 2 and 3. Locations 2 and 3 had similar levels of total dry matter production although location 3 was mowed 3 times, 2 in the fall and once in the spring, and location 2 was only mowed twice, once in the fall and once in the spring. The extra fall mowing at location 3 can be attributed to a different variety and much higher seeding rate at this location.

Forage N concentration showed positive correlation with increasing fall N application rates at every sampling time and location (Figure 4-2). Nitrogen concentration showed a greater response to N rates for spring samplings, however overall N concentration levels were higher for fall sampling times. N concentrations of first fall clippings and spring clippings at locations 2 and 3 were very similar with ranges from 46 to 48 g kg⁻¹ for fall and 27 to 35 g kg⁻¹ for spring. The second fall clipping at location 3, the only location to receive a second fall clipping, occurred in mid-December and had N concentration levels that were 5 to 7 g kg⁻¹ lower than the first clipping. This is a good indication that N concentration decreases throughout the season.

Location 1, which only received one clipping, had lower concentration levels than similarly timed clippings at the other locations. Decreased early spring growth could have attributed to less opportunity for the plants at location 1 to accumulate the same levels of N as the other locations.

Dry matter levels showed high correlation with NDVI values at locations 1 and 2 with R^2 values of 0.77 and 0.91 respectively (Figure 4-3). At location 3, there was poor correlation as the first sampling time had much higher dry matter levels compared to the NDVI readings as the other two sample times. This lack of correlation may be partly attributed to a higher leaf area index from prostrate growth at the two later sampling times (Aparicio et. al. 2002). Other contributing factors may be low precipitation prior to the first sampling time followed by higher precipitation amounts between the first and second cutting, promoting the greenness of the plant but during low temperature where growth is slowed.

Sensor-based Spring Topdress N Application

N was applied in the spring after termination of simulated grazing based on sensor NDVI readings at each of four fall N rates. Average rates of spring applied N were much higher at location 1 compared to locations 2 and 3 (Figure 4-4). This can be attributed to much lower growth during the fall and early spring at this location causing lower NDVI that triggered higher N recommendation rates. The difference between spring N applied on the 0 kg ha⁻¹ fall treatment and 101 kg ha⁻¹ fall treatment was much wider at location 1 compared to 2 and 3 as well. Spring rates of 105 kg ha⁻¹ and 50 kg ha⁻¹ were applied to the respective fall N levels. Spring rates of 24 and 14 kg ha⁻¹ at location 2 and 25 and 11 kg ha⁻¹ at location 3 were applied to these same fall rates.

Grain yield and N concentration

Grain yields varied widely across locations as well as treatments. At location 1 grain yields of all three spring rates increased as fall rates increased (Figure 4-5). Yields at this location were also much lower than the other two locations. Yields of the spring sensor based treatment were very close to the yields of the 101 kg ha⁻¹ treatment. Yields of the 0 kg ha⁻¹ were much lower than both the sensor and 101 kg ha⁻¹ treatments and even at the 101 kg ha⁻¹ fall application rate the 0 kg ha⁻¹ spring rate is not higher than the 0 kg ha⁻¹ fall rate of either the sensor or 101 kg ha⁻¹ spring rates. Grain only treatment yields show that at no fall applied N and high spring applied N dual-purpose wheat yields are higher than grain only. On the other hand, high fall applied N and no spring applied N grain yields are better than the dual-purpose system. Sensor-based applied N rates for grain only treatments are very similar to the dual-purpose sensor treatment.

At location 2 there was a very low coefficient of determination value for the 101 kg ha⁻¹ spring rate (Figure 4-5). The spring sensor rate and the 101 kg ha⁻¹ spring rate were very similar at higher rates of fall N application. The 0 kg ha⁻¹ spring rate was again consistently lower than both the sensor and 101 kg ha⁻¹ spring applications. Grain only treatments were higher in grain yield in every situation when compared to equally fertilized dual-purpose treatments at location 2.

At location 3 there was a weak correlation between the 101 kg ha⁻¹ spring N application and fall N rates. All three spring application rates were very similar at the 101 kg ha⁻¹ fall N rate. Grain only treatment yields were lower than dual-purpose yields fertilized at the same rates. This could be due to increased early season growth in the grain only treatments using higher amounts of moisture than the dual-purpose treatments (Edwards et al., 2014). Across all locations there

was very good correlation between all three spring applications and fall rate. The 0 kg ha⁻¹ spring application was much lower than the other two spring applications across all fall N rates. The sensor spring application was lower than the 101 kg ha⁻¹ spring application at the 0 kg ha⁻¹ fall rate, however the two trendlines are much closer at higher fall N rates.

Grain N concentration was widely variable across locations. At location 1 the 101 kg ha⁻¹ spring application was consistent across all fall N rates while the sensor spring application fell in concentration as rates increased (Figure 4-6). Decreased spring N application rates of the sensor treatment were most likely the cause of this decrease in concentration. The 0 kg ha⁻¹ spring application was much lower than the other spring application treatments and actually decreased as fall rates increased.

At location 2 the 101 kg ha⁻¹ spring application was much higher than the other spring applications. The sensor spring application was fairly consistent across all fall N rates whereas the 0 kg ha⁻¹ spring application increased drastically as fall rate increased. The sensor application showed very low correlation and overall the correlation at location 2 was much lower than at location 1. At location 3 the 101 kg ha⁻¹ spring application is much higher than both of the other spring applications across all fall N rates. The sensor spring application and the 0 kg ha⁻¹ application are very similar across all fall rates. Sensor applied N rates were very low at this location, which contributed to the low concentration levels. Across all locations, the 101 kg ha⁻¹ had higher N concentration levels than both the sensor application and 0 kg ha⁻¹. The sensor spring application and 101 kg ha⁻¹ were more similar at higher rates of fall N. The 0 kg ha⁻¹ spring application was consistently much lower than the other spring applications which promotes the idea that higher spring topdress N rates are critical for maintaining high N levels in the grain.

CONCLUSIONS

We found fall N application rates to impact total forage dry matter up to the maximum applied N rate of 101 kg ha⁻¹. The dry matter increase was much lower between 67 and 101 kg ha⁻¹ at location 3 which had the higher planting rate. This suggests further research is needed to determine the optimum combination of planting rate and fall N rate to realize peak dry matter yields. Higher fall N rates also contributed to increased N concentration levels in the forage, which translates to increased protein content and higher quality forage. NDVI readings showed a high correlation with total dry matter levels at two of three locations. Grain yields were higher with increased fall and spring N rates and sensor based spring N applications were very similar in yield to a high rate of spring N if higher rates of N were used in the fall. Grain yields of the sensor-based N rate treatments in both grazed and non-grazed treatments were very similar, justifying that a sensor-based N application in a dual purpose wheat system is a very suitable management decision. Grain N content was heavily influenced by a high rate of spring applied N. Using NDVI sensors to apply N can slightly decrease grain N levels if the recommended rate is very low.

REFERENCES

- Alley M.M., P. Scharf, D. E. Brann, W. E. Baethgen & J. L. Hammons 1996. Nitrogen management for winter wheat: principles and recommendations
www.ext.vt.edu/pubs/grains/424-026, publication number 424–026.
- Aparicio, N., D. Villegas, J. L. Araus, J. Casadesus, & C. Royo. 2002. Relationship between growth traits and spectral vegetation indices in durum wheat. P. 1547-1555 *Crop science*, 42(5).

- Asebedo, A. R. 2015. Development of sensor-based nitrogen recommendation algorithms for cereal crops (Doctoral dissertation, Kansas State University).
- Combs, S.M. and M. V. Nathan. 1998. Soil Organic Matter. P. 53-58. . In: J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Edwards, J., B. Carver, G. Horn, 2014. Impact of Grazing on Wheat Grain Yield Fact Sheet PSS-2157. Okla. State Univ. Coop. Ext. Serv., Stillwater, OK.
- Edwards, J.T., and G.W. Horn. 2010. First hollow stem: A critical growth stage for dual-purpose producers. Fact Sheet PSS-2147. Okla. State Univ. Coop. Ext. Serv., Stillwater, OK.
- Epplin, F. M., E. G. Krenzer Jr, & G. Horn. 2001. Net returns from dual-purpose wheat and grain-only wheat. P. 8-14 Journal of the ASFMRA, 64(1).
- Frank, K., D. Beegle, and J. Denning 1998. Phosphorus. P.21-26. In: J.R. Brown (ed.) Recommended chemical soil test procedures for North Central Region. North Central Reg. Res. Publ. 221 (Rev.). SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Freeman, K. W., K. Girma, D. B. Arnall, R. W. Mullen, K. L. Martin, R. K. Teal, & W. R. Raun. 2007. By-plant prediction of corn forage biomass and nitrogen uptake at various growth stages using remote sensing and plant height. P. 530-536 Agronomy Journal, 99(2).
- Gelderman, R. H. & D. Beegle. 1998. Nitrate-Nitrogen. P. 17-20. In: : J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Govaerts, B., & N. Verhulst. The normalized difference vegetation index (NDVI) Greenseeker (TM) handheld sensor: toward the integrated evaluation of crop management. Part A- Concepts and case studies." (2010).

- Holman, J. D., C. R. Thompson, R. L. Hale, & A. J. Schlegel. 2010. Forage yield and nutritive value of hard red and hard white winter wheat. P. 759-773 *Agronomy journal*, 102(2).
- Lukina, E. V. W. R. Raun, M. L. Stone, J. B. Solie, G. V. Johnson, H. L. Lees, J. M. LaRuffa & S. B. Phillips 2000. P. 103-122. Effect of row spacing, growth stage, and nitrogen rate on spectral irradiance in winter wheat, *Journal of Plant Nutrition*, 23:1.
- Manandhar, R. Application of Nitrogen Fertilizer in Dual-purpose Wheat (*Triticum Aestivum* L.). 2008. ProQuest,
- Matsunaga, T., & Shiozaki, H. 1989. Sulfuric acid-hydrogen peroxide digestion for the determination of total nitrogen in plant material containing nitrate nitrogen. *Japanese Journal of Soil Science and Plant Nutrition (Japan)*.
- Maloney, T. S., E. S. Oplinger, & K. A. Albrecht. 1999. Small grains for fall and spring forage. P. 488-494. *Journal of production agriculture*, 12(3).
- Naveed, K., M. A. Khan, M. S. Baloch, N. Khan, & M. A. Nadim. 2013. Effect of time of nitrogen application on morphological and physiological attributes of dual-purpose wheat. P. 1299-1305. *Pakistan Journal of Botany*, 45(4),
- Raun, W. R., & G. V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. P. 357-363. *Agronomy journal*, 91(3).
- Raun, W. R., J. B. Solie, G. V. Johnson, M. L. Stone, R. W. Mullen, K. W. Freeman, & E. V. Lukina. 2002. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. P. 815-820 *Agronomy Journal*, 94(4).
- Raun, W. R., J. B. Solie, M. L. Stone, K. L. Martin, K. W. Freeman, R. W. Mullen, & G. V. Johnson. 2005. Optical sensor-based algorithm for crop nitrogen fertilization. P. 2759-2781. *Communications in Soil Science and Plant Analysis*, 36(19-20).

- Sembiring, H., H.L. Lees, W.R. Raun, G.V. Johnson, J.B. Solie, M.L. Stone, & C.W. Woolfolk, C. W. 2000. Effect of growth stage and variety on spectral radiance in winter wheat. P. 141-149. *Journal of plant nutrition*, 23(1),
- Shroyer, J. R., K. C. Dhuyvetter, G. L. Kuhl, D.L. Fjell, L. N. Langemeier, & J. O. Fritz. 1993. *Wheat pasture in Kansas*. C-Kansas State University, Cooperative Extension Service (USA).
- Sij, J., Belew, M., & W. Pinchak. 2016. Nitrogen management in no-till and conventional-till dual-use wheat/stocker systems. P. 38-49 *Texas Journal of Agriculture and Natural Resources*, 24.
- Thoele, H., & D. Ehlert. 2010. Biomass related nitrogen fertilization with a crop sensor. P. 769-775 *Applied Engineering in Agriculture*, 26(5).
- Warncke, D. & J.R. Brown, 1998. Potassium and other cations. P. 31–33. In: J.R. Brown (ed.) *Recommended chemical soil test procedures for the North Central Region*. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.
- Watson, M.E. & Brown, J.R. 1998. pH and Lime Requirement. P. 13-16. In: J.R. Brown (ed.) *Recommended chemical soil test procedures for the North Central Region*. North Central Reg. Res. Publ. 221 (Rev.) SB 1001. Missouri Agric. Exp. Stn. Columbia.

Table 4-1. Description of locations used for data, all during the 2015-2016 season.

Location	County	Soil		Wheat Variety	Planting Date	Planting Rate	Tillage†
		Series	Subgroup				
1	Marion	Wells Loam	Udic Argiustolls	Iba	9/17/2015	70 kg/ha	NT
2	Reno	Taver loam	Udertic Argiustolls	Iba	9/24/2015	70 kg/ha	CT
3	Riley	Smolan silt loam	Pachic Argiustolls	Everest	10/1/2015	136 kg/ha	CT

† CT, Conventional Till; NT, No Till

Table 4-2. Initial soil test results from each location.

Soil parameter †	Location		
	1	2	3
pH	6.56	7.32	5.79
OM (g kg ⁻¹)	3.55	2.22	3.00
P (mg kg ⁻¹)	86.3	38.1	12.1
K (mg kg ⁻¹)	430	350	309
NO ₃ -N (mg kg ⁻¹)	1.5	11.6	7.0

† pH 1:1 soil:water, organic matter, loss on ignition, P, Mehlich-3, K, ammonium acetate, NO₃-N, potassium chloride extractant, pH, organic matter, P, K, were all sampled at 0-15 cm depth. NO₃-N, was sampled at 0-61 cm depth.

Table 4-3. Date of simulated grazing sampling at each location. Locations were mowed when plants reached a growth threshold of 12.5cm.

Location	Clipping Timing		
	First	Second	Third
1	3/17/2016		
2	11/12/2015	3/10/2016	
3	11/10/2015	12/11/2015	3/8/2016

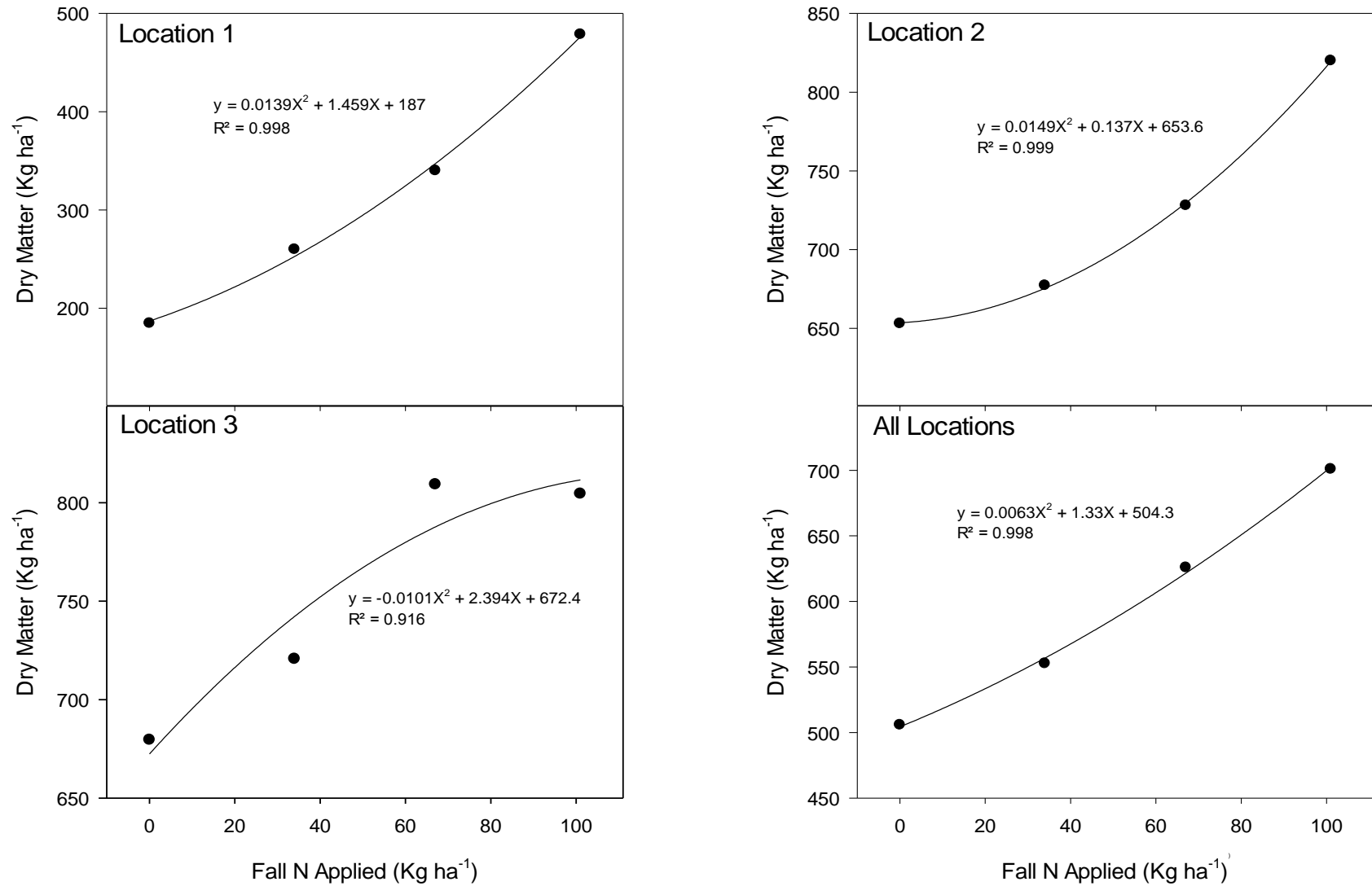


Figure 4-1. Total dry matter produced, all simulated grazing weights were added for each location, at fall N fertilizer rates of 0, 34, 67 and 101 kg ha⁻¹.

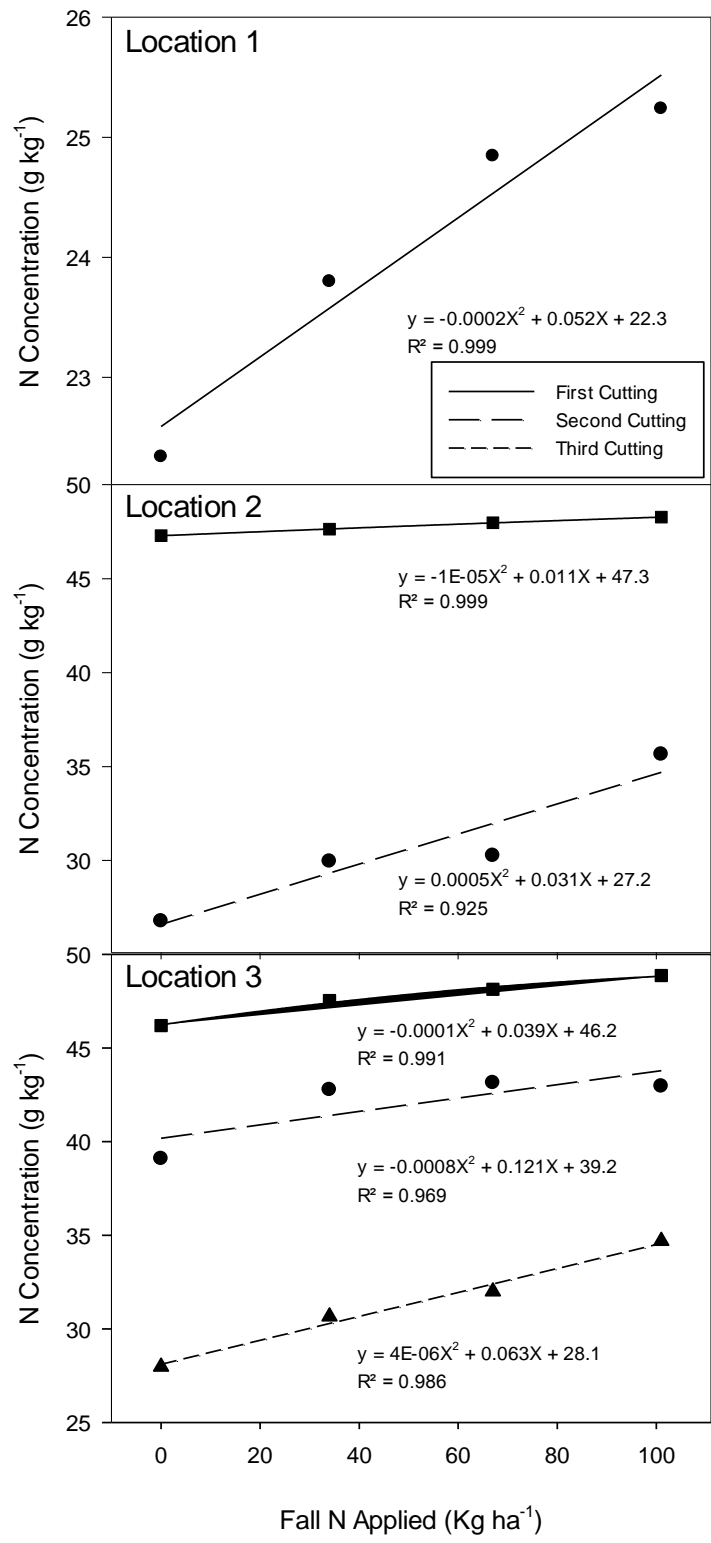


Figure 4-2. Forage N concentration levels at fall applied N fertilizer rates of 0, 34, 67, and 101 kg ha⁻¹. Cuttings occurred on 3/17 at location 1, 11/12 and 3/10 at location 2, 11/10, 12/11, and 3/8 at location 3.

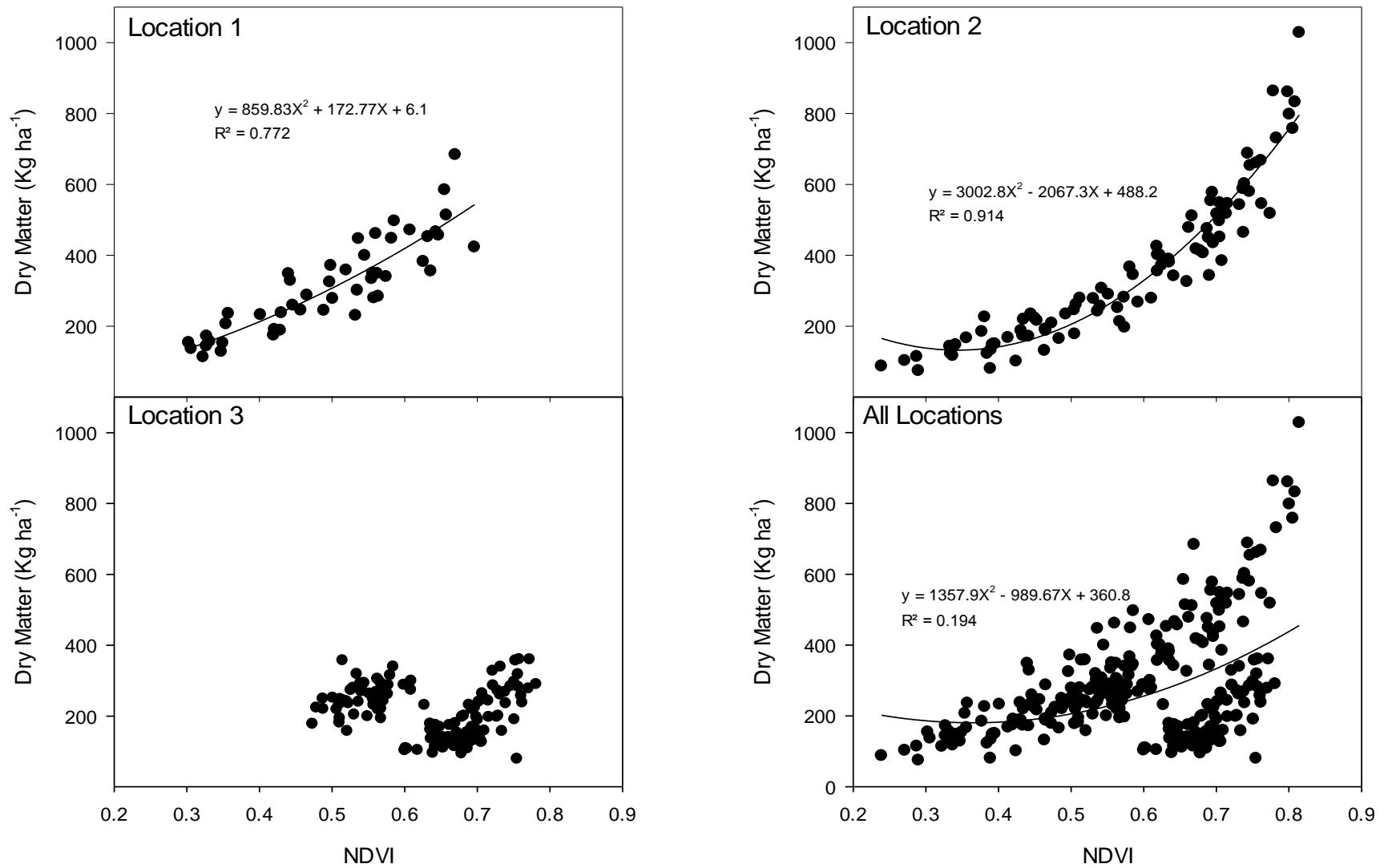


Figure 4-3. Dry matter weights correlated with individual NDVI readings for each plot at a location. One sampling time at location 1, two at location 2 and three at location 3.

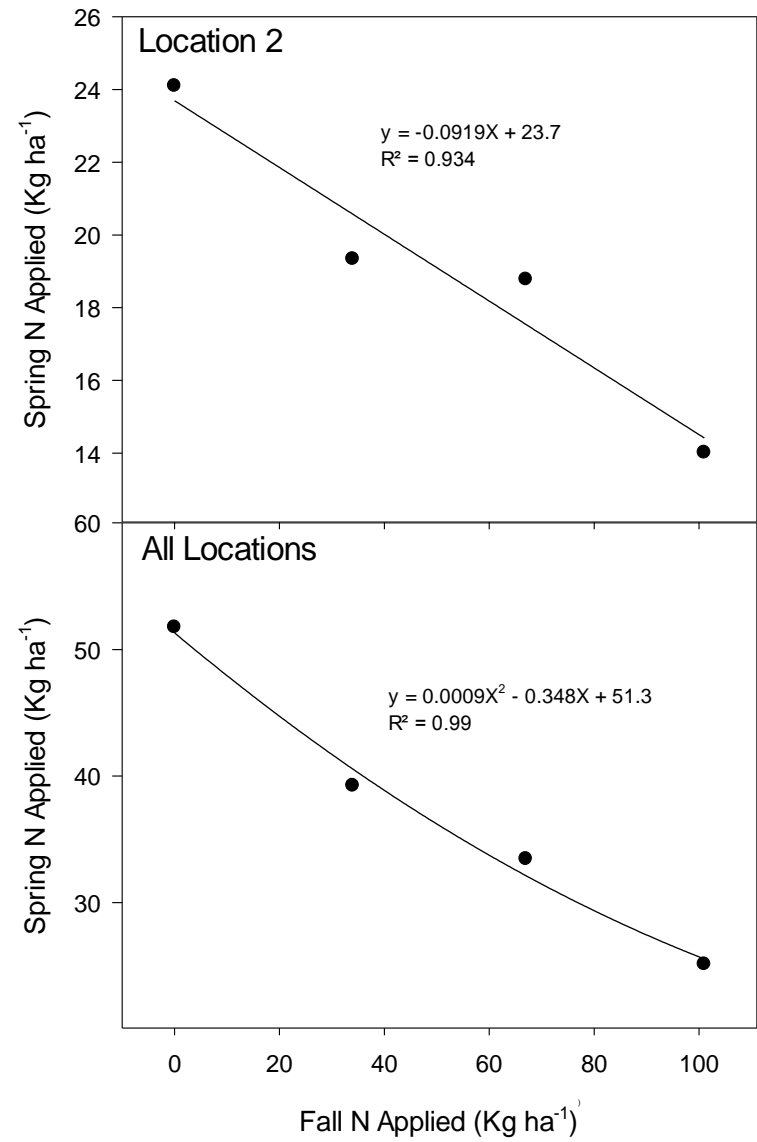
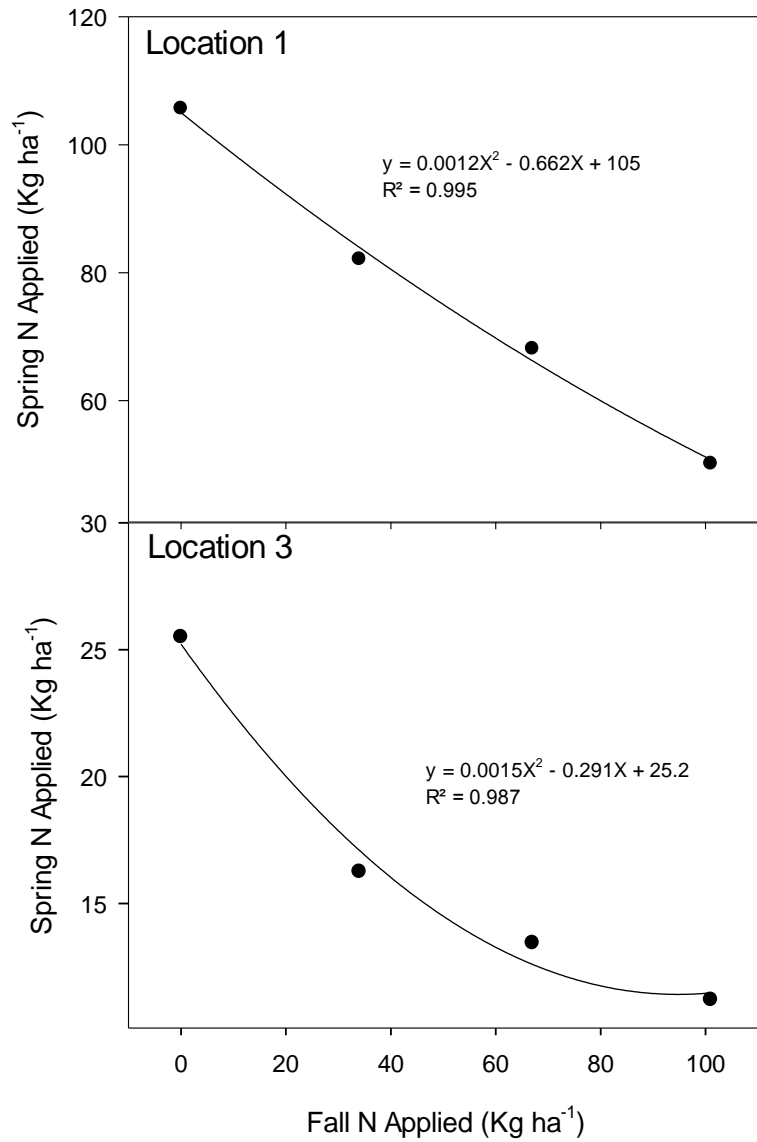


Figure 4-4. Spring top-dress N rates applied to the sensor treatments at 0, 34, 67, and 101 kg ha⁻¹.

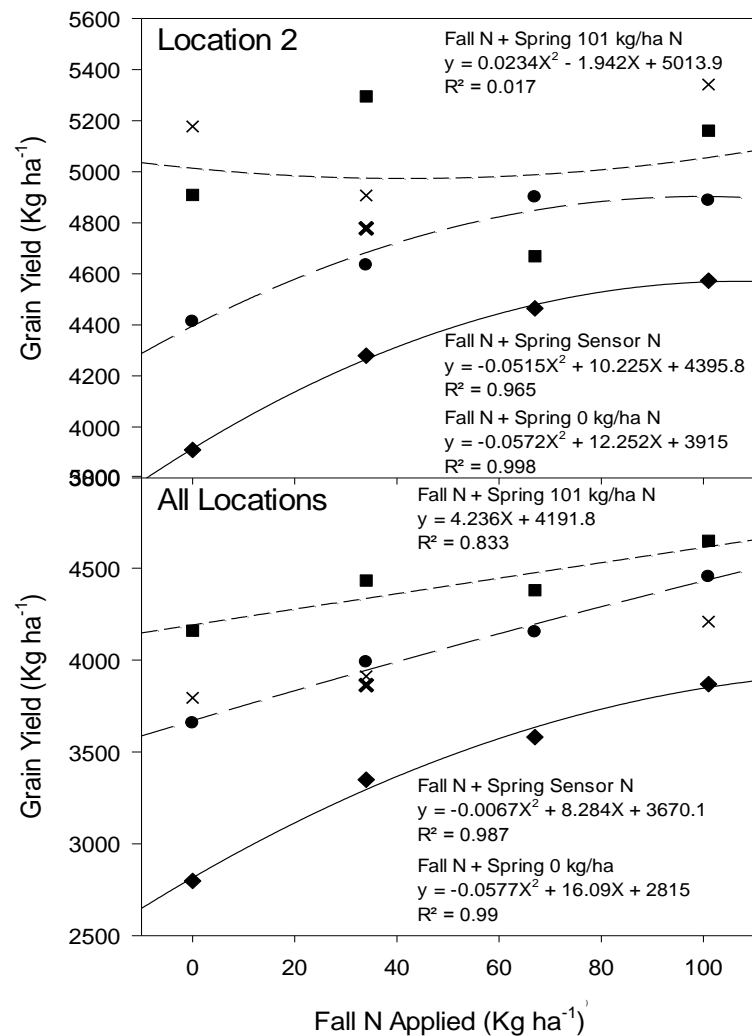
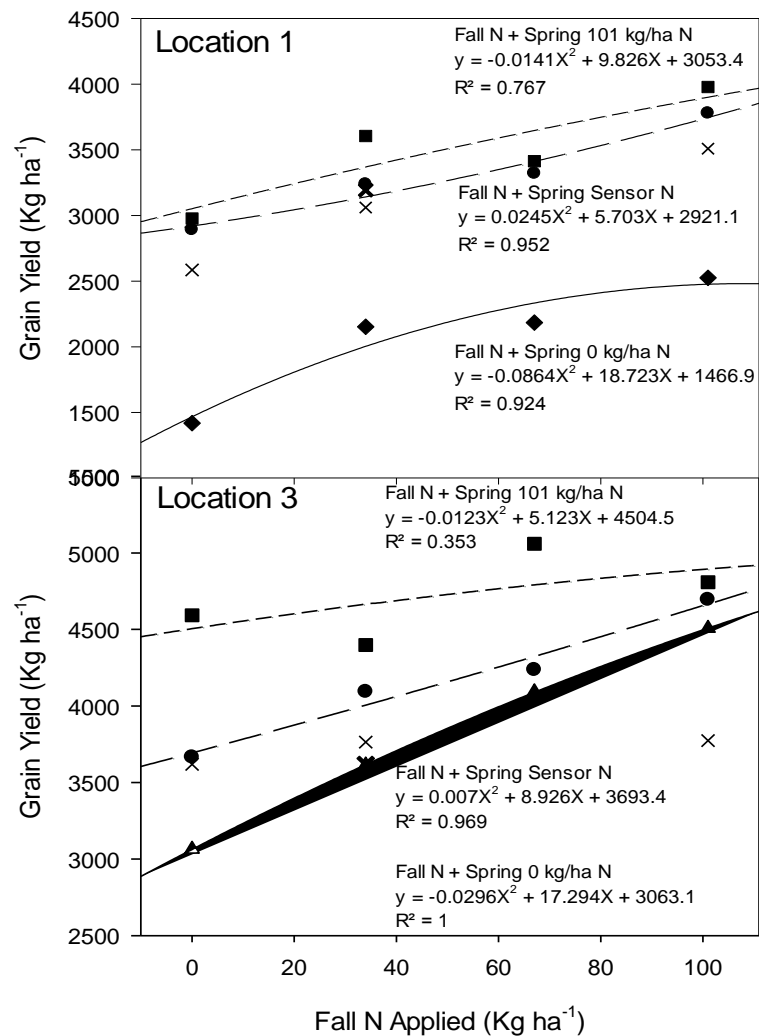


Figure 4-5. Grain yield of three spring topdress N applications, 101 kg ha⁻¹ (top trendline), 0 kg ha⁻¹ (bottom trendline), and a sensor based N application with actual rates depending on NDVI values (center trendline). X's represent grain only treatments and the bold X is the sensor grain only treatment.

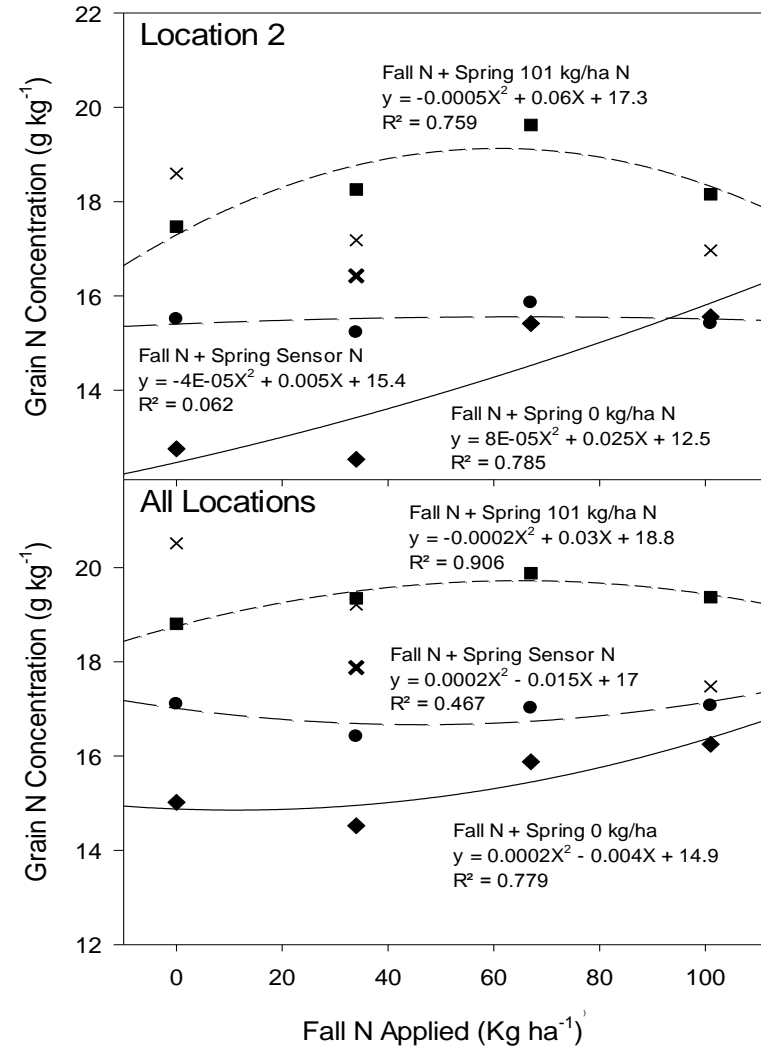
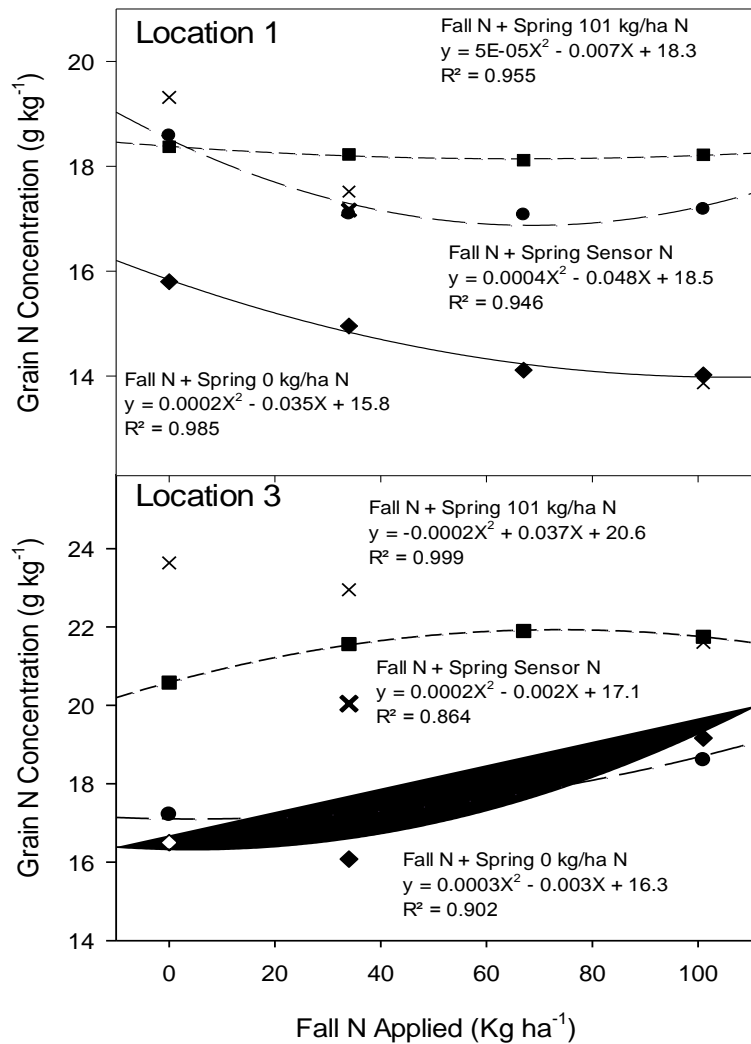


Figure 4-6. Grain N content of three spring topdress N applications, 101 kg ha⁻¹ (short dash trendline), 0 kg ha⁻¹ (solid trendline), and a sensor based N application with actual rates depending on NDVI values (long dash trendline). X's represent grain only treatments and the bold X is the sensor grain only treatment.

Chapter 5 - General Conclusions

Understanding changes in nutrient concentration levels and uptake and remobilization patterns can help predict proper nutrient application timing, nutrient removal, and optimal nutrient levels for plant health, contributing to a more productive nutrient management strategy. Results from our study showed that N, P, K and S tend to decrease in concentration throughout the season in leaves, stems, and spike tissue. Grain concentration levels tend to maintain or decrease slightly. Cu, Mn and Zn tend to show more variability in concentration during the growing season. The most rapid period of nutrient uptake is generally during stem elongation, between Feekes 6 and Feekes 10. K showed a shorter window of rapid uptake occurring during the final two weeks of stem elongation. Zn showed the most response to Zn fertilization, with higher total uptake and grain Zn concentration occurring in response to applied Zn fertilizer.

Dual purpose grazing and grain production of wheat stands as a viable option for increasing profitability especially to producers in the southern area of the state. Higher rates of fall N increased total forage production and seemed to slightly increase forage quality, especially during the later fall and early spring sampling times. Results from this study also showed that NDVI sensors can be used for biomass estimation, however environmental factors and growth stage may affect values. Grain yields produced using NDVI recommended top-dress N rates were similar to a standard application of 101 kg ha⁻¹ when fall N applications were between 67 kg ha⁻¹ and 101 kg ha⁻¹. Top-dress N rates based on NDVI values were much lower than the high rate of 101 kg ha⁻¹. This suggests that NDVI based top-dress N applications could be a viable option to optimize N application rates for producers using a dual purpose system.