INFLUENCE OF BEDS AND ROW SPACING IN WINTER WHEAT, AND BY-PLANT PREDICTION OF CORN FORAGE YIELD.

By

KYLE WAYNE FREEMAN

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
1999

Master of Science
Oklahoma State University
Stillwater, Oklahoma
2002

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Thesis Approved:

Dr. William Raun
Thesis Advisor

Dr. Art Klatt

Dr. Gordon Johnson

Dr. John Solie

Dr. A. Gordon Emslie
Dean of the Graduate College

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BEDDED AND CONVENTIONALLY PLANTED DRYLAND WINTER WHEAT AS INFLUENCED BY ROW SPACING.

ABSTRACT

Traditionally hard red winter wheat in Oklahoma is grown under conventional tillage and planted on the flat with row spacing ranging from 15 cm to 25 cm. Bed planted wheat systems offer a new alternative for the traditional wheat producer to provide opportunities for crop rotation, more efficient use of water, and new techniques of nutrient management. This study was conducted to determine if planting winter wheat in Oklahoma using alternative planting methods can maintain grain yields while providing more options in the cropping system. Two experiments were initiated in the fall of 2002 at Hennessey and Lake Carl Blackwell, Oklahoma and were repeated in 2003-04 and 2004-05 crop cycles. In the bedded system and conventional systems, 8 and 12 treatments were evaluated that included a factorial combination of varieties, nitrogen rates and planting configurations. The two winter wheat varieties were Jagalene and 2174, both commonly grown in Oklahoma. Nitrogen rates were 0 and 100 kg ha^{-1}. The planting configurations included wheat planted on beds with two and three rows on a 75 cm bed. With three and two rows per bed, 15 cm and 30 cm row spacing were used, respectively. These row spacing configurations were

evaluated with wheat planted on a conventional seedbed. In addition the traditional configuration of a solid stand with 15 cm row spacing was evaluated in the conventional system. In four of six site years, bedded wheat (either 2 or 3 rows per bed) resulted in yields equal to conventionally planted wheat (15 cm row spacing). No differences in wheat grain yield were found when planting either 2 or 3 rows per bed, or on the flat. However, both 2 and 3 rows per bed resulted in increased yields when compared to 2 and 3 row configurations without beds.

INTRODUCTION

Bed Planting Systems

Bed planting systems have been used in cultivation for centuries. The origin of raised bed cultivation has traditionally been associated with water management issues either by providing opportunities to reduce the impact of excess water in rainfed conditions or to more efficiently deliver irrigation water in high production irrigated systems (Sayre, 2003). Sayre goes on to state that the opportunities for raised bed systems are endless. In dryland agriculture, bed planting systems are used with small dykes to trap water after a rain so the fields are able to retain more water and store moisture for future crops versus letting it run off.

Iragavarapu and Randall (1997) stated that spring wheat performance was affected by the position of the row in a ridge-till system. On poorly drained soils that tend to be cooler in the spring, wheat rows planted on the ridge tops and shoulders had greater grain and straw yield and total nitrogen (N) uptake than those rows planted in the furrows. They explained that this variation is due to better drainage and warmer soil conditions on the ridge tops and shoulders than in the furrows.

Limon-Ortega and Sayre (2003) noted that an important field-access advantage of bed-planting is the flexibility it allows to apply fertilizer when and where it can be most efficiently used. Fertilizer can be applied by direct placement in bands between the wheat beds or rows when the wheat plant can make the most efficient use without trampling the crop. The bulk of fertilizer application can be delayed in a bed-planted system until the crop requirements are greater.

Hobbs et al (1998) explained that bed-planted systems have several important advantages. These advantages included:

1. Improved water distribution and efficiency
2. Provided an alternative for weed control with the ability to cultivate the furrows
3. Reduced lodging because the wheat plants are not exposed to soft soil conditions and more light can penetrate the canopy, resulting in stronger plants
4. Allowed for dramatic reductions in seeding rates

In 1998, Sayre stated that the crucial first step in initiating research on bed-planting wheat is to test a wide spectrum of varieties with differing heights, tillering abilities, phenologies, and canopy architectures. Close cooperation between wheat breeders and agronomists to jointly identify and understand the proper plant type needed for optimum performance on beds is highly recommended.

Irrigated Systems

The system of bed-planting wheat for irrigated conditions that has been widely adopted by farmers in northwest Mexico offers an innovative option for diversifying wheat production practices. The Yaqui Valley in Sonora, Mexico, already recognized for its importance as the birth place of the Green Revolution wheat varieties, may again make important contributions to world wheat production if bed-planting of wheat is widely adopted. The great benefit of bed-planting for wheat production is the enhanced field access, which facilitates controlling weeds and other pests, handling nutrients, reducing tillage, and managing crop residues (Sayre and Ramos, 1997).

Fahong et al. (2004) found that nitrogen use efficiency (NUE) could be improved by 10% or more in furrow irrigated bed-planting systems because of improved N placement possibilities. Also, the microclimate within the field was changed to the orientation of the wheat plants in rows on the beds, which reduced crop lodging and decreased the incidence of some wheat diseases. This was explained by the reduction in canopy humidity that is conducive to reduced disease pressure and enhanced healthy wheat growth. These advantages of increased NUE and decreased disease pressure improved grain quality and increased grain yield by more than 10%.

Dryland Systems

Some previous research work has been reported from rainfed experiments with wheat drilled on raised beds ranging from 1.2 to 2 m spacing (Morrison and Gerik, 1983, and Gerik and Morrison, 1985). These reports consistently showed that wheat rows next to the furrow produced more heads per square meter and grains per spike than wheat rows in the center of the bed, in the furrow, or to wheat rows flat-planted. Consequently, the grain yield average of wheat rows planted on beds has been lower than grain yield from wheat planted on the flat. However, grain yield measured individually from rows next to the furrow has been greater than yield from rows on the flat. On the other hand, work by Sayre and Ramos (1997) has shown that decreasing bed width to 75-80 cm can be used in rainfed conditions with two to three rows drilled 15-20 cm apart on top of those beds.

Mascagni and Sabbe (1990) attributed higher yields on wide beds (193 cm) to greater soil aeration and temperature as well as higher soil temperatures on top of the bed. This experiment investigated crowned beds, flat beds, and a conventional seedbed. There were no significant differences between seedbed types, but there was a definite trend for the crowned beds to have higher yields, NUE, and N uptake. They also stated that one possible benefit of the wide-bed planting system beyond the obvious drainage aspect was that the furrow provides controlled traffic lanes. This may be an advantage in certain production systems and in soils that tend to have compaction problems.

Mascagni et al. (1991) noted that for grain sorghum there was an increase in grain yield, dry weight, and N uptake on crowned beds as compared to the flat seedbed. They concluded that the rows in the center of the crowned beds were where the major differences occurred. This suggested that growing conditions were more ideal on top of the crowned beds versus on the edges. Further research also showed that N uptake was higher on the crowned beds than the flat seedbed.

Bed-planting can be very effective for drainage where water tables result in excess surface moisture, especially after rain or even with irrigation. Under low rainfall conditions where moisture is limiting, initial results demonstrated that moisture can be effectively conserved with proper residue retention and management on permanent beds. Sweeney and Sisson (1988) reported that on poorly drained soils, wheat yields increased when grown on 75 cm raised beds. These researchers also found that soil temperature tended to be higher on the raised beds early in the growing season. Mascagni et al., (1995) observed that wheat produced on raised, wide beds may increase production efficiency and overall profitability. The raised, wide bed system may also integrate well with other crops in a rotation. While finding no grain yield advantage for raised bed wheat production, it was noted that in a situation where the field slope does not provide adequate surface drainage, bedding may be a viable management option. Also, since the use of raised beds did not significantly reduce yields, this practice may integrate into an overall production system including crop rotations and permanent beds.

Row Spacing

In Canada, researchers found that among yield components investigated, heads per unit area decreased as row spacing increased. Similar trends were noted for the number of plants per unit area described above. Plants with wider row spacing produced more kernels per head than plants with narrow row spacing, compensating for the lower number of heads per unit area. For example, plants with 30 cm row spacing produced 34% more kernels than plants in the 10 cm spacing. Row spacing did not have an impact on kernel weight. It was also observed that wide row spacing increased plant height. Higher N concentration available to the plants in the widely spaced rows than those in narrow rows might explain the increase in plant height and more kernels per head. The results of their studies show that a decrease in yield did not occur up to a row spacing of 30 cm (Lafond and Gan, 1999).

Cutforth and Selles (1992) noted that paired rows of spring wheat had no agronomic advantage over equidistance row seeding. These pair rows were spaced 10cm apart and 40cm between pairs. However, earlier work by Papendick et al. (1985) explained that paired rows in winter wheat appeared to yield as well as, or slightly greater than conventionally seeded winter wheat. Porter and Khalilian (1995) noted that in a relay cropping system with skipped row wheat, there was no significant yield loss from the conventional system wheat.

HYPOTHESES AND OBJECTIVES

The hypotheses for this study were: (1) winter wheat planted on beds will not yield significantly less than the traditional method currently used by producers; and (2) narrow row spacing will result in higher yields on both bedded and conventional planting systems. The objectives of the experiment were: (1) to determine if wheat planted with skipped rows will yield higher on raised beds than the wheat with the same skipped rows planted on the flat; and (2) to determine if 3-rows (15cm spacing) seeded on a bed will yield more than 2-rows (30cm spacing) on the beds versus the same configurations in a flat seedbed.

MATERIALS AND METHODS

Two dryland field experiments were conducted in the fall of 2002 in bedded and conventionally planted systems at two locations in Oklahoma. The first location was Hennessey with a soil classification Shellabarger sandy loam (fine-loamy, mixed, thermic Udic Argiustioll). The second location was Lake Carl Blackwell with a soil classification Pulaski fine sandy loam (coarse-loamy, mixed Thermic Typic Ustifluvent).

The bedded and conventionally planted systems were treated as separate environments (Table 1). These environments were kept separate because in a bedded system the beds must be continuous across the extent of the experiment to allow for drainage of excess water. This bedded system would be more representative of how a producer field would be constructed. Due to the importance of continuous beds, the mixing of conventionally planted plots in the same area was not implemented.

Figure 1 illustrates the details of treatment combination for the experiment. In the bedded system eight treatments comprised a complete factorial combination of varieties, N rates, and planting configurations each at two N levels. In the conventional planting system, the variety and N levels remained the same but the planting configurations included one additional level (Table 1). The two varieties were Jagalene and 2174; two commonly planted varieties in Oklahoma. Nitrogen rates were 0 and 100 kg ha^{-1}. In the bedded system the planting configurations were winter wheat planted on beds with two and three rows of winter wheat on 75 cm beds, furrow to furrow. The three and two rows per bed configurations were spaced 15 cm and 30 cm apart, respectively. The additional configuration in conventionally planted wheat was solid seeding with 15 cm row spacing. The experimental design was a Randomized Complete Block with three replications. Plot sizes were 3.0 x 6.1 m.

The seeding rate in both systems was 88 kg ha^{-1}. This resulted in placing more seeds per meter of row on the beds due to the fewer number of rows planted. Beds were formed in early August with a 4 row lister set up on 75 cm centers and reshaped just prior to planting in October. Nitrogen was applied as ammonium nitrate (NH_3NO_3) and incorporated with the reshaping operation prior to planting. Winter wheat was planted with a 3 m AGCO drill set up on 15 cm spacing. All non-experimental plot management activities were accomplished as per Oklahoma State University Extension Service recommendation for the respective sites.

Plots were harvested using a self-propelled Massey Ferguson 8XP combine. The harvested area was 1.5 x 6.1 m for the bedded plots and skipped row plots planted on the flat. An area of 2 x 6.1 m was harvested for the conventionally planted plots. A Harvest Master yield-monitoring computer installed on the combine was used to record yield and grain moisture data. Grain yield from each plot was determined and a sub-sample was collected for total N analyses. Grain samples were dried in a forced air oven at 66 ^{o}C, ground to pass a 140 mesh sieve (100 um), and analyzed for total N content using a Carlo-Erba NA 1500 automated dry combustion analyzer (Schepers et al., 1989). Statistical evaluation and analysis of variance were performed using SAS (SAS Inst., 1989).

RESULTS

At each location, analysis was performed by year due to contrasting environmental conditions encountered over the length of this study. Thus interactions by year were not investigated.

Grain Yield

For the analysis of variance performed by site and year, two way interactions including system by variety, system by row, system by N rate, variety by row and variety by N rate, were significant in at least one site year. There were no significant three or four way interactions (Table 2). Although there were significant interactions for each site year, there were definite main effects trends (Table 3). The effect of system showed that across the three years of this study, the bedded system had a grain yield advantage over the flat system of 170 and 237 kg ha^{-1} at Hennessey and LCB, respectively. However, this trend was only observed when comparing the 2 and 3 row planting treatments on the bed and the flat. The conventional planting system (solid stand) was superior to the bed and flat rowed planting in 5 of 6 site years. This trend for greater yield was evidenced by an increase of 316 and 78 kg ha^{-1} in the bed system and 486 and

315 kg ha^{-1} in the flat system at Hennessey and LCB averaged over the length of this study. Jagalene was the superior variety in the experiment with yields exceeding '2174' by 125 and 357 kg ha^{-1} at Hennessey and LCB, respectively. There was no response to applied N at Hennessey, and a response of over 1000 kg ha^{-1} of increased grain yield to added N fertilizer at LCB. The conventional planting system produced higher yields than the 2 row and 3 row planting configurations in all site years (Table 3).

In 2003 at LCB, there was a significant system by variety interaction. Jagalene produced similar yields to '2174' in the bedded system while yielding over 1000 kg ha^{-1} more grain on the flat. At Hennessey in 2003, grain yield of '2174' in the bed system was significantly higher than grain yield of '2174' in the flat system. Jagalene recorded higher grain yields than '2174' in both systems at Hennessey and LCB in 2004. No differences were noted between systems or varieties at Hennessey in 2005. However, grain yield of Jagalene was significantly higher than '2174' in the bed and flat systems at LCB in 2005(Table 4). Averaged across years at Hennessey and LCB, Jagalene produced higher grain yield in the bed and flat system than '2174'.

Simple effects of planting system by row spacing on wheat grain yield are reported in Table 5. This interaction was significant at LCB in 2003. The interaction occurred due to no differences between 2 and 3 row planting configurations in the bed system versus a significant increase in grain yield of 500 kg ha^{-1} of 3 row compared to the 2 row treatment in the flat system. At Hennessey in 2003, the 3 row planting configuration on the bed yielded similar to the solid stand, however, both of these treatments yielded significantly greater than 2 rows on the bed and flat and 3 rows on the flat. The solid stand was significantly higher than all other treatments at Hennessey in 2004. Also, the 3 row planting on beds was significantly better than the 2 row bed or either planting on the flat. Similarly at LCB in 2004, the solid stand was the highest yielding, yet both row planting configurations were significantly higher in the bed system than on the flat. No differences were noted among system or planting structure including the solid stand at both locations in 2005. Across years and locations, there was a distinct advantage of the solid stand over the 2 and 3 row planting structure in both the bed and flat systems. This trend was clearly established since the solid stand produced superior grain yield to the 2 and 3 row planting structures in bed and flat systems at six site years. Finally, 2 and 3 row planting structures were higher yielding in the bed system when compared to the flat (Table 5).

There was a significant interaction of system and N rate at Hennessey in 2003. The incidence and severity of lodging increased with added N fertilizer in the bed system, however, reduced lodging was observed in the flat system. The increase in lodging resulted in a reduction in wheat grain yield for the bed system and allowed for grain yield of the flat system to exceed that of the bed system. Another significant interaction of system and N rate occurred at LCB in 2004. This can be explained by an increase in grain yield produced in the bed system 0 N treatments, significantly yielding more grain than the 0 N treatments in the flat system. It is hypothesized that there was possibly increased moisture conservation in the bedded system compared to the flat. In 2004 and 2005 at Hennessey, there was no response to added N fertilizer. However, the LCB site proved to be very responsive with 919 and 1298 kg ha^{-1} increase in grain yield in the bed and flat systems, respectively (Table 6).

In 2003 and 2004, significant variety by row interactions were observed. The 2003 crop year resulted in no differences between 2 and 3 row planting configurations with the variety ‘2174’, however there was an increase in grain yield of nearly 500 kg ha^{-1} from 2 to 3 row planting configurations in the variety Jagalene (Table 7). In 2004, 2 row planting was significantly higher than 3 row planting in ‘2174’, whereas in Jagalene, 3 row posted greater grain yield than 2 row planting. At LCB in 2005, no differences were recorded between 2 and 3 row planting configurations in either variety. Varieties and row configurations gave similar yields at Hennessey in 2003 and 2005. Alternatively, in 2004, grain yield of 2 row ‘2174’ was significantly lower than 3 row ‘2174’ and both plantings of Jagalene. Across years and locations, the variety Jagalene proved to be higher yielding in both 2 and 3 row planting configurations (Table 7).

Significant variety by N rate interactions were observed in 2003 and 2005 at Hennessey. In 2003, there was no response to added N fertilizer with Jagalene, conversely a grain yield increase of 499 kg ha^{-1} in response to added N fertilization occurred for ‘2174’. On the other hand in 2005, no differences in grain yield were noted in ‘2174’ with added N and Jagalene showed a significant depression in grain yield with added N fertilizer. At LCB, both varieties showed a significant response to added N throughout the length of the study (Table 8).

Grain N Concentration

For the analysis of variance performed for grain N concentration, variety by row configuration and system by N rate were the only two-way interactions that were significant in more than one site year. Two interaction exceptions were noted in addition to the two-way interactions noted above, but both were only slightly significant and inconsistent across years and locations. Variety and N rate were highly significant in all six site years. Planting system recorded significant differences in 2 out of 6 site years (Table 9). The main effects of system, variety, N rate, and row configurations are reported in Table 9.

The variety '2174' recorded significantly higher grain N concentrations that Jagalene across years and locations. Averaged over the duration of the study, the grain N concentration of '2174' was 2.1 and 1.6 g kg^{-1} greater that Jagalene at Hennessey and LCB respectively. There was also a highly significant ($p< 0.001$) increase in grain N in response to the addition of N fertilizer. The grain N concentration of the fertilized treatments over the 3 years of the study increased by 5.1 and 4.2 g kg^{-1} N in the grain over that of treatments not receiving fertilizer nitrogen, at Hennessey and LCB, respectively. The effect of planting system was inconsistent across locations. At Hennessey, there was a trend for higher concentration of N in the grain in the flat system compared to the bed (> 1 g kg^{-1} averaged over 3 years). Conversely, the bed system at LCB produced higher amounts of N in the grain for the length of the study. There was no effect of row configuration on grain N concentration at either location for the duration of the study (Table 10).

At Hennessey in 2004 and 2005 and at LCB in 2004, a significant variety by row interaction was reported in Table 11. This interaction can be explained in all three instances by the 2 row planting configurations having higher grain N concentration in the beds system, whereas in the flat system 3 row planting configurations posted higher grain nitrogen.

Across the three years of the study, a significant system by N rate interaction was observed at Hennessey. This interaction was also observed at LCB in 2003. In all cases a synergistic interaction took place where there was a larger increase in grain N in response to added N fertilizer in the bed system than in the flat system (Table 12).

DISCUSSION

Grain Yield

The locations in this study greatly differed in relation to growing conditions and soil characteristics. The Hennessey site would be representative of the central Oklahoma wheat belt. This location had been in continuous wheat production for several years prior to the initiation of this experiment. The use of excess fertilizer at this location explains the lack of response to added N fertilizer

(Table 2). Lake Carl Blackwell is located in a low lying area near a water body and is prone to frequent flooding and water logging conditions. Lake Carl Blackwell was not in intensive agriculture production prior to the start of the experiment and received no fertilizer. However, there was greater rainfall and with added N fertilizer this location proved to provide an environment with greater yield potential than Hennessey.

The bed system gave similar yields to that of the solid stand at LCB. The extended periods of water logging conditions offered a more favorable growing environment for the bed planting system. At Hennessey, excess water in the field was not a problem. Therefore the solid stand consistently outperformed the bed system. The varieties selected for this study were also quite different. Jagalene is a newly released variety with a higher yield potential than ‘2174’. This higher yield potential is realized due to improved genetics and more resistance to plant pathogens. Both varieties are commonly grown across the region. In the lower yielding Hennessey location, ‘2174’ and Jagalene performed equally. Alternatively, at LCB, Jagalene proved to be a superior variety with 357 kg ha^{-1} additional grain yield over ‘2174’ over the 3 years of this study (Table 3). It is important to note that there was an increased incidence of lodging of Jagalene at Hennessey with the addition of N fertilizer. This is reflected by a reduction of wheat grain yield shown in Table 8. Jagalene did not show this susceptibility to lodging at Lake Carl Blackwell.

The conventional solid stand of winter wheat achieved greater grain yield than the bed and flat rowed configurations. Although there was a distinct trend for increased grain yield in the solid stand configuration, the yield difference was significant in only 2 site years compared to the bed system. However, the yield advantage of the solid stand was considerably greater compared to grain yield of the 2 and 3 row configurations in the flat system. The solid stand wheat yields were significantly higher than the grain yield of the flat system in 4 out of 6 site years. The major objective of this study was to explore if winter wheat planted on beds would yield similar to winter wheat planted in a conventional solid stand. The results of the study showed that in 4 out of 6 site years the bed system did record similar grain yield to that of the solid stand, but with an average difference was 316 and 78 kg ha^{-1}at Hennessey and LCB, respectively.

An alternative objective of this study was determining if 2 or 3 row configurations performed differently in the bed and flat planting systems. At Hennessey there was a tendency for higher grain yield with the 3 row configuration compared to the 2 row configuration in both planting systems. However, this trend for increased grain yield with a 3 row configuration was only significant in 2003 in the bed system. Conversely, at LCB, 2 and 3 row configurations performed equally when compared to each other in the same system. A trend for increased grain yield shows an advantage for the bed system over the flat system when the crop production system requires wheat that is planted with skipped rows. It should be noted that both 2 and 3 row configurations consistently produced higher yields in the bed system compared to the flat system.

With no significant reduction in grain yield using a 2 row planting configuration, it could be easily implemented into a relay cropping system. Relay cropping is a system that implements planting configurations where skipped rows are used to provide more timely and efficient planting and harvesting of crops in the system. This study would support the use of bed planting with 2 or 3 row planting configurations in these relay cropping systems with their advantage in grain yield versus that of the flat system. Additionally, these row configurations offer other management opportunities to the cropping system. Skipped rowed wheat will allow for accessible controlled traffic lanes that can be used during the entire crop season.

Grain N Concentration

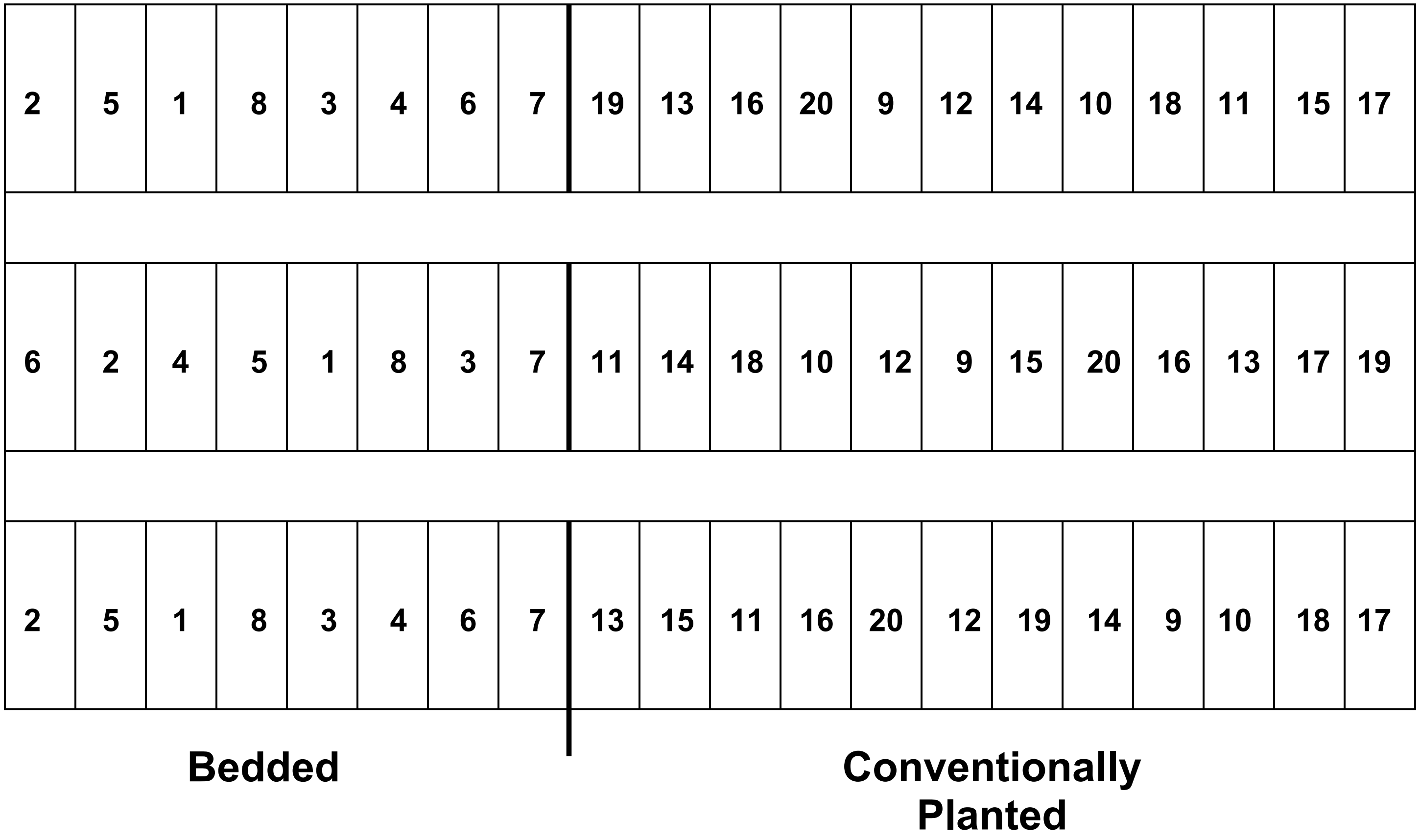
The Hennessey location assimilated higher amounts of N in the grain than LCB. The difference in grain N concentrations can be attributed to the differences in grain yield that were observed. Lake Carl Blackwell was consistently a higher yielding environment, thus more N was utilized for grain yield resulting in lower concentration of N in the grain. Alternatively, varieties and response to N fertilizer acted similarly across locations. The variety ‘2174’ had higher N concentrations in the grain compared to Jagalene, and the fertilized treatments produced higher N concentration than unfertilized treatments.

The results of the study indicate that the bed system provided an environment that more efficiently utilized N fertilizer. This is supported by Table 12, which illustrates a greater difference between grain N concentration in the fertilized and check plots across years and locations. At the N responsive site (LCB), the increase in grain yield and greater difference in N concentration reveals that the bed system more efficiently utilized the added N fertilizer than the flat system. At Hennessey where no grain yield response to N was recorded, nitrogen use efficiency was not influenced by planting system. However, the difference in N concentration between fertilized and check plots was still greater in the bed system, likely due to improved moisture conservation.

CONCLUSION

In summary, the first hypothesis of this study was that winter wheat planted on beds will not yield significantly less than traditional methods currently used by producers. Results reported here support this hypothesis by finding similar grain yields in the bed system and the conventional solid stand in 4 out of 6 site years, but with an average difference was 316 and 78 kg ha^{-1}at Hennessey and LCB, respectively. The second hypothesis was that narrow row spacing will result in higher yields on both bedded and conventional planting systems. Data from this study does not support this hypothesis in that 2 and 3 row planting configurations performed equally in the bed and flat systems. A larger increase in grain N concentration was found between the fertilized and check plots in the bed system compared to the flat system. Finally, this study showed a trend for increased grain yield in the bed system over the flat when cropping systems call for skipped row configurations that accommodate controlled traffic lanes or relay cropping.

Figure 1. Plot plan for bedded and conventionally planted winter wheat.



2	5	1	8	3	4	6	7	19	13	16	20	9	12	14	10	18	11	15	17
6	2	4	5	1	8	3	7	11	14	18	10	12	9	15	20	16	13	17	19
2	5	1	8	3	4	6	7	13	15	11	16	20	12	19	14	9	10	18	17

Bedded

Conventionally Planted

Table 1. Treatment structure for bedded wheat and conventional wheat.

Trt	Variety	N rate kg ha^{-1}	Planting configuration	System
1	Jagalene	0	3 rows	Bedded
2	Jagalene	100	3 rows	Bedded
3	Jagalene	0	2 rows	Bedded
4	Jagalene	100	2 rows	Bedded
5	2174	0	3 rows	Bedded
6	2174	100	3 rows	Bedded
7	2174	0	2 rows	Bedded
8	2174	100	2 rows	Bedded
9	Jagalene	0	3 rows	Flat
10	Jagalene	100	3 rows	Flat
11	Jagalene	0	2 rows	Flat
12	Jagalene	100	2 rows	Flat
13	Jagalene	0	Solid	Flat
14	Jagalene	100	Solid	Flat
15	2174	0	3 rows	Flat
16	2174	100	3 rows	Flat
17	2174	0	2 rows	Flat
18	2174	100	2 rows	Flat
18	2174	0	Solid	Flat
20	2174	100	Solid	Flat

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips
between configurations
Flat (solid) = Solid stand with row spacing of 15 cm
Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene
N Rate, plots received 0 or 100 kg N ha^{-1}
Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 2. Significance of main effects and interactions at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

	2003		2004		2005	
Variable	Henn	LCB	Henn	LCB	Henn	LCB
Sys	**	*	NS	**	NS	NS
Variety	NS	***	**	NS	NS	***
Sys*Var	NS	***	NS	NS	NS	NS
Row	NS	*	*	NS	NS	NS
Sys*Row	NS	*	NS	NS	NS	NS
Var*Row	NS	*	NS	*	NS	NS
Sys*Var*Row	NS	NS	NS	NS	NS	NS
N rate	NS	***	NS	***	**	***
Sys*N rate	***	NS	NS	*	NS	NS
Var*N rate	*	NS	NS	NS	*	NS
Sys*Var*N rate	NS	NS	NS	NS	NS	NS
N rate*Row	NS	NS	NS	NS	NS	NS
Sys*N rate*Row	NS	NS	NS	NS	NS	NS
Var*N rate*Row	NS	NS	NS	NS	NS	NS
Sys*Var*N rate*Row	NS	NS	NS	NS	NS	NS

*, **, and ***; significant at the 0.05, 0.01, & 0.001 probability levels, respectively

NS not significant at 0.05 level

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Flat (solid) = Solid stand with row spacing of 15 cm

Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene

N Rate, plots received 0 or 100 kg N ha^{-1}

Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 3. Main effects of planting system, variety, N rate, and row spacing on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

	Hennessey				Lake Carl Blackwell			
System	2003	2004	2005	Avg.	2003	2004	2005	Avg.
	---------------------------------Grain Yield, kg ha^{-1}---------------------------------							
Bed	3486	2881	2883	3083	3488	3832	2959	3426
Flat (rows)	3104	2855	2779	2913	3193	3462	2912	3189
Flat (solid)	3826	3435	2935	3399	3595	3827	3091	3504
Variety								
2174	3267	2681	2846	2931	3017	3578	2792	3129
Jagalene	3323	3055	2817	3065	3664	3716	3079	3486
N rate								
0 N	3205	2903	2987	3032	2697	3051	2512	2753
100 N	3384	2833	2676	2964	3984	4243	3360	3862
Row								
2 row	3256	2702	2834	2931	3211	3681	2950	3281
3 row	3334	3034	2828	3065	3470	3613	2921	3334
Solid	3826	3435	2935	3399	3595	3827	3091	3504

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Flat (solid) = Solid stand with row spacing of 15 cm
Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene
N Rate, plots received 0 or 100 kg N ha^{-1}
Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 4. Simple effects of planting system and variety on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
System	Variety	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		---------------------------Grain Yield, kg ha^{-1}---------------------------							
Bed	2174	3504	2724	2952	3060	3366	3797	2792	3318
Bed	Jagalene	3468	3038	2814	3107	3610	3867	3126	3534
Flat	2174	3029	2637	2739	2802	2669	3356	2792	2939
Flat	Jagalene	3179	3072	2820	3024	3717	3566	3032	3438
LSD		359	345	248		301	372	172	

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene

Table 5. Simple effects of planting system and row spacing on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
System	Row	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		----------------------------Grain Yield, kg ha^{-1}----------------------------							
Bed	2 row	3331	2662	2876	2956	3483	3808	3004	3432
Bed	3 row	3618	3101	2822	3180	3492	3784	2915	3397
Flat	2 row	3158	2744	2771	2891	2939	3483	2897	3106
Flat	3 row	3050	2939	2821	2937	3439	3441	2927	3269
Flat	Solid	3827	3435	2935	3399	3595	3827	3090	3504
LSD		375	334	283		292	369	232	

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Flat (solid) = Solid stand with row spacing of 15 cm
Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 6. Simple effects of planting system and N rate on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
System	N rate	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		----------------------------Grain Yield, kg ha^{-1}------------------------------							
Bed	0 N	3675	2958	3056	3230	2908	3404	2588	2967
Bed	100 N	3297	2805	2711	2938	4068	4260	3330	3886
Flat	0 N	2736	2849	2918	2834	2487	2698	2435	2540
Flat	100 N	3472	2861	2641	2991	3899	4227	3389	3838
LSD		359	345	248		301	372	172	

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
N Rate, plots received 0 or 100 kg N ha^{-1}

Table 7. Simple effects of variety and row spacing on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
Variety	Row	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		----------------------------Grain Yield, kg ha^{-1}----------------------------							
2174	2 row	3264	2429	2759	2817	3008	3768	2807	3194
2174	3 row	3269	2933	2932	3045	3027	3387	2777	3064
Jagalene	2 row	3248	2976	2910	3045	3415	3594	3094	3368
Jagalene	3 row	3398	3134	2724	3085	3912	3839	3064	3605
LSD		359	345	248		301	372	172	

Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene
Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 8. Simple effects of variety and N rate on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
Variety	N rate	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		----------------------------Grain Yield, kg ha^{-1}----------------------------							
2174	0 N	3017	2624	2815	2819	2304	2916	2339	2520
2174	100 N	3516	2738	2877	3044	3730	4239	3245	3738
Jagalene	0 N	3394	3183	3159	3245	3090	3186	2684	2987
Jagalene	100 N	3252	2928	2475	2885	4237	4247	3474	3986
LSD		359	345	248		301	372	172	

Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene
N Rate, plots received 0 or 100 kg N ha^{-1}

Table 9. Significance of main effects and interactions of wheat grain N concentration at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

	2003		2004		2005	
Variable	Henn	LCB	Henn	LCB	Henn	LCB
Sys	NS	***	NS	NS	*	NS
Variety	*	***	***	**	**	**
Sys*Var	NS	NS	NS	NS	NS	NS
Row	NS	NS	NS	NS	NS	NS
Sys*Row	NS	NS	NS	NS	NS	NS
Var*Row	NS	NS	*	*	*	NS
Sys*Var*Row	NS	NS	NS	NS	NS	NS
N rate	***	***	***	***	***	***
Sys*N rate	*	**	*	NS	*	NS
Var*N rate	NS	NS	NS	NS	NS	*
Sys*Var*N rate	NS	NS	NS	NS	*	NS
N rate*Row	NS	NS	NS	NS	NS	NS
Sys*N rate*Row	NS	NS	NS	NS	NS	NS
Var*N rate*Row	NS	NS	NS	NS	NS	NS
Sys*Var*N rate*Row	NS	NS	NS	NS	NS	NS

*, **, and ***; significant at the 0.05, 0.01, & 0.001 probability levels, respectively
NS not significant at 0.05 level

Table 10. Main effects of planting system, variety, N rate, and row spacing on wheat grain N concentration at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

	Hennessey				Lake Carl Blackwell			
System	2003	2004	2005	Avg.	2003	2004	2005	Avg.
	Grain N, g kg^{-1}							
Bed	24.9	24.5	24.0	24.5	21.3	22.3	20.3	21.3
Flat (rows)	25.9	26.0	25.5	25.8	19.1	21.8	19.7	20.0
Flat (solid)	25.6	25.7	25.0	25.4	18.8	20.7	18.1	18.9
Variety								
2174	26.0	26.7	25.8	26.2	21.1	22.9	20.7	21.6
Jagalene	24.8	23.9	23.7	24.1	19.3	21.2	19.4	20.0
N rate								
0 N	23.4	22.7	21.7	22.6	17.8	20.0	18.2	18.7
100 N	27.4	27.9	27.7	27.7	22.7	24.1	21.9	22.9
Row								
2 row	25.5	25.5	24.8	25.4	20.4	22.2	20.0	20.9
3 row	25.4	25.1	24.7	25.1	20.0	21.9	20.0	20.6
Solid	25.6	25.7	25.0	25.4	18.8	20.7	18.1	18.9

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Flat (solid) = Solid stand with row spacing of 15 cm
Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene
N Rate, plots received 0 or 100 kg N ha^{-1}
Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems
Solid = Solid stand at 15 cm spacing placed in flat systems only

Table 11. Simple effects of variety and row spacing on wheat grain N concentration at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
Variety	Row	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		Grain N, g kg^{-1}							
2174	2 row	26.4	27.5	26.7	26.9	21.6	23.8	21.0	22.1
2174	3 row	25.7	25.8	25.2	25.6	20.6	22.3	20.3	21.1
Jagalene	2 row	24.5	23.4	23.3	23.7	19.2	20.6	19.1	19.6
Jagalene	3 row	24.9	24.4	24.1	24.5	19.4	21.7	19.7	20.3
LSD		1.2	1.6	1.7		1.3	1.3	1.2	

Variety, 2 common varieties to Oklahoma were used, 2174 and Jagalene

Planting configurations, 2 row = 2 rows, 30 cm spacing with 45 cm skip placed on beds and flat systems
3 row = 3 rows, 15 cm spacing with 45 cm skip placed on beds and flat systems

Table 12. Simple effects of planting system and N rate on wheat grain yield at Hennessey and Lake Carl Blackwell in 2003, 2004, and 2005.

		Hennessey				Lake Carl Blackwell			
System	N rate	2003	2004	2005	Avg.	2003	2004	2005	Avg.
		Grain N, g kg^{-1}							
Bed	0 N	22.5	21.2	20.4	21.4	18.3	20.2	18.2	18.9
Bed	100 N	27.4	27.9	27.6	27.5	24.4	24.4	22.4	23.7
Flat	0 N	24.7	23.7	22.2	23.5	17.3	19.5	17.8	18.2
Flat	100 N	26.8	28.1	28.3	27.7	20.6	23.3	20.6	21.5
LSD		1.0	1.3	1.4		1.0	1.1	1.0	

Planting system, Bed and Flat (rows) = 2 row (30 cm spacing) and 3 row (15 cm spacing) configurations with 45 cm skips between configurations
Flat (solid) = Solid stand with row spacing of 15 cm

N Rate, plots received 0 or 100 kg N ha^{-1}

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BY-PLANT PREDICTION OF CORN FORAGE BIOMASS AND NITROGEN UPTAKE AT VARIOUS GROWTH STAGES USING REMOTE SENSING AND PLANT HEIGHT MEASURES.

ABSTRACT

As research intensifies on developing precision agricultural practices for corn production, one main component will be identifying the scale at which these practices should be implemented. This two year study was conducted to determine if corn forage biomass and nitrogen uptake could be determined on a by-plant basis. Further study focused on the use of by-plant height measurements for improved prediction of plant biomass and nitrogen uptake. Current strategies focus on obtaining information and applying crop inputs to specific areas or zones of fields. These areas/zones could range from a square meter to many hectares. However, differences in corn production exist on a by-plant basis. Identifying the difference in biomass and nitrogen uptake between neighboring plants will be crucial for developing algorithms which can adjust crop inputs by-plant. Experimental locations were Efaw research farm, Stillwater, OK, Perkins research station, Perkins, OK, and Lake Carl Blackwell irrigated research station. Optical sensor readings were collected on corn plants at various growth stages ranging from V8 to VT. The average NDVI for each plant was calculated

over the area occupied by the plant and correlated with plant biomass, forage yield based on the area occupied by the plant, and nitrogen uptake of that plant. Plant height alone proved to be an excellent predictor of plant biomass without accounting for area for all stages of growth. The index of NDVI x height provided the highest correlation with by-plant forage yield on an area basis. Forage N uptake was most accurately predicted using NDVI alone. The area occupied by each plant was not found to be related to plant height or plant biomass.

INTRODUCTION

In 2002, there were 80,000 harvested acres of dryland corn for grain production in Oklahoma with an average yield of 85 bushels per acre (National Ag Statistical Service). Increased pressure for no-till production systems, which will almost certainly include crop rotations, will result in increased dryland corn production in Oklahoma. As corn acreage increases the need to develop better strategies for nutrient management will arise. Norwood and Currie (1996) stated that zero tillage systems for corn production were essential for adequate yields in dry years and will usually result in yield increases in years with more favorable climatic conditions. They went on to state that no-till is not just a better management practice, but a requirement, because very low yields will occur with conventional tillage in dry years.

Prediction of Forage Biomass and N Uptake

Araus (1996) reported that methods based on red/near infrared ratios can yield estimates of leaf area index (LAI), green biomass, crop yield, and canopy photosynthetic capacity. As noted by Filella et al. (1995), remote sensing could provide inexpensive, large-area estimates of nitrogen (N) status in wheat. They further reported that the use of reflectance at 430, 550, 680 nm, and red edge wavelengths offers potential for assessing N status of wheat. Stone et al. (1996) demonstrated that N uptake of winter wheat and the normalized difference vegetative index (NDVI) are highly correlated. Fox et al. (2001) compared late-season diagnostic tests for predicting N status of corn. Their work showed that the stalk NO_3^- test was an excellent predictor of corn N status when samples are collected from one-fourth milk line growth stage (MLGS) to a few weeks after black-layer formation. They also noted that chlorophyll meter (CM) readings are an accurate predictor of N sufficiency if drought-stressed fields are not included, and they added that the advantage of the CM test is that it gives on-site results. GopalaPillai and Tian (1999) used high-resolution color infrared (CIR) images collected from an airborne digital camera to detect spatial variability of crop nutrient stress and spatial variability of grain yield. These CIR images could easily delineate levels of nitrogen stress in poor areas of the field 75 days after planting, however, they could not differentiate between N levels in the areas of the field with higher fertility. They also concluded that NDVI was a better indicator of N stress than uncalibrated image gray level values.

Plant Height and Yield Components

Katsvairo et al. (2003) studied how biomass, N concentrations, and N uptake could be used to facilitate variable rate N management. They found that these factors had no spatial variability at V6, R1, and R6 growth stages. However, they did state that plant height showed significant spatial variability but did not consistently correlate with corn yields in a dry year, but they recognized that more research should be conducted on plant height measurements. A study by Muchado et al. (2002) revealed that by using plant height, 90 and 61% of the variation in total dry matter and grain yield, respectively, could be explained in a dry year. These data are supported by Sadler et al. (1995), who reported that differences in phenology, biomass, leaf area, and yield components were most pronounced under drought.

Spatial Variability

As precision farming becomes accepted and adopted, delineating the proper field element size becomes more important. Sadler et al. (2000) studied the effects of soil variation on crop phenology, biomass, and yield components of corn under drought. Their experiment analyzed detailed soil maps at a scale of 1:1200 and extensive sampling of crop characteristics across an eight hectare field. The results proved that grain yield variation within a soil map unit was too large for the soil survey alone to be used to create homogenous soil management zones for use in precision farming. Sadler et al. (2000) went on to state that these results supported the need for on-the-go measurements of soil properties and plant response that could be used in conjunction with soil surveys to create management zones that can be used in models, or by themselves, to predict grain yield.

Solie et al. (1996) defined field element size as the area that provides the most precise measure of the available nutrient and where the level of that nutrient changes with distance. This work went on to say that the fundamental field element size averages 1.5 m^2. A microvariability study by Raun et al. (1998) found significant differences in surface soil test analyses when samples were <1m apart for both mobile and immobile nutrients. Solie et al. (1999) stated that in order to describe the variability encountered in field experiments, soil, plant, and indirect measurements should be made at the meter or submeter level.

Identifying and understanding the variability among plant-to-plant spacings within the row is also crucial for precision farming techniques. This variability is usually due to the combination of crowded plants (doubles, triples, etc.) and long gaps or skips. It is possible that plants next to gaps can compensate and produce larger ears, but they generally cannot compensate enough for the smaller ears of the crowded plants that are competing for sunlight, water and nutrients. A growth stage difference of two leaves or greater between adjacent plants in a row will almost always result in the later developing plant being barren at harvest (Nielson, 2001). Nielson went on to quantify the variability between plants in a row by using plant spacing variability (PSV). The PSV is simply the standard deviation of the plant spacing within a representative row in a field. Nielson noted that in 350 production corn fields in Indiana and Ohio, 16% had a PSV of three inches or less, 60% had a PSV of three to five inches, and 24% of the fields had a PSV of six inches or greater. Further research showed that for every one inch in PSV about 157 kg ha^{-1} of yield loss occurred.

Current Strategies for Measuring N status and N Fertilization

The use of chlorophyll meters to measure N status in corn has been a very successful technique. The success of this technique is due primarily to the high correlation between chlorophyll content and leaf N concentration (Schepers et al. 1992). Nitrogen fertilization strategies using chlorophyll meters are now implemented in the corn belt. Varvel et al. (1997) discussed the use of reference strips of nitrogen in corn fields. They implemented the sufficiency index concept and used chlorophyll meters to measure crop health. They applied nitrogen fertilizer when the crop had a chlorophyll meter reading less than 95% of the reference strip. They stated that this concept of using chlorophyll meters and sufficiency index should result in greater N use efficiency and less N being available for leaching to the groundwater, since these applications are made when N uptake by corn is greatest.

In 1996, Stone et al. investigated the use of hand-held sensors to detect and predict forage N uptake and grain yields in winter wheat. These sensors measured red and near infrared irradiance from the crop. These irradiance measurements were then used to calculate NDVI. They found NDVI to be highly correlated with forage N uptake and grain yields of winter wheat. Johnson and Raun (2001) developed a fertilizer response index (RI) that was calculated by dividing the average NDVI from a non-N limiting strip (created in each field by fertilizing a strip at a rate where N would not be limiting throughout the season) by the average NDVI in a parallel strip that was representative of the N availability across the field as affected by N fertilizer applied by the farmer. This RI would then suggest how responsive the crop would be to added N fertilization in a given year. Similarly, Raun et al. (2002) showed that their methods recognize that each 1m^2 area in wheat fields need to be sensed and managed independently and that the need for fertilizer N is temporally dependent.

HYPOTHESIS

The hypothesis of this study is that corn forage biomass, corn forage yield, and corn forage N uptake can be accurately predicted using by-plant sensor data and plant height collected by-plant at various stages of corn development.

MATERIALS AND METHODS

Two dryland field experiments were initiated in the spring of 2003 to evaluate the use of sensor readings for predicting by-plant total biomass and N uptake. The locations included Efaw and Perkins research stations in 2003 and 2004. In 2005, experiments were located at the Efaw research station and at the Lake Carl Blackwell (LCB) irrigated research farm. All locations were planted with a row spacing of 0.76 m. The soil at Efaw is classified as Easpur loam (fine-loamy, mixed superactive thermic Fluventic Haplustoll). Perkins is classified as Teller sandy loam (fine, mixed, thermic Udic Argiustolls). Soil classification of the Lake Carl Blackwell experiment is Pulaski fine sandy loam (coarse/loamy, mixed nonacid, thermic, Typic, Ustifluvent).

For each site and forage harvest, 13 to 17 m of row were identified that included exactly 50 corn plants. Three forage harvests of 50 individual plants were taken at each location at various growth stages (Table 1). Each plant was sensed using a GreenSeeker active, optical sensor that was mounted to a bicycle with a shaft encoder to log distance (1 reading per cm of linear distance traveled) with each NDVI reading collected.

The GreenSeeker™ Hand Held Optical Sensor Unit (NTech Industries, Inc.) was used to collect normalized difference vegetative index (NDVI) measurements. This device uses a patented technique to measure crop reflectance and to calculate NDVI. The unit senses a 0.6 x 0.01 m spot when held at a distance of approximately 0.6 to 1.0 m from the illuminated surface. The sensed dimensions remain approximately constant over the height range of the sensor. The sensor unit has self-contained illumination in both the red (650 ± 10 nm full width half magnitude (FWHM)) and NIR (770 ± 15 nm FWHM) bands. The device measures the fraction of the emitted light in the sensed area that is returned to the sensor (reflectance or ρ). These fractions are used within the sensor to compute NDVI according to the following formula:

$$NDVI = \frac{\rho_{NIR} - \rho_{\mathrm{Re}\,d}}{\rho_{NIR} + \rho_{\mathrm{Re}\,d}}$$

Where:

ρ_{NIR} – Fraction of emitted NIR radiation returned from the sensed area(reflectance)
ρ_{Red} – Fraction of emitted red radiation returned from the sensed area (reflectance)

The sensor samples at a very high rate (approximately 1000 measurements per second) and averages measurements between outputs (each cm). The sensor was passed over the crop at a height of approximately 0.9 m above the crop canopy and oriented so that the 0.6 m sensed width was perpendicular to the row and centered over the row. With advancing stage of growth, sensor height above the ground increased proportionally. The mean NDVI was computed for each plant across growth stages and sensing dates. Growth stages in corn were identified using the terminology developed at Iowa State University (1993).

Immediately after sensing, each plant was cut at ground level and wet weights recorded by plant. Each plant was then dried at 75 °C for 4 days and dry weights subsequently recorded. Dry plant material was then ground to pass a 240 mesh screen and analyzed for total N using a Carlo-Erba dry combustion unit (Schepers et al., 1989).

To determine corn forage yield it was imperative to determine the area that each individual plant occupied. Prior to sensing, the distance between each plant was measured at each site and harvest. The area each plant occupied was calculated by taking the distance half way to the plant in front and behind it. This determined the linear dimension and was then multiplied by the row width of 0.76 m to calculate the area for a given plant. This process allowed us to determine a forage yield per unit area as a function of the linear distance between plants within a row. Consistent with the method used to obtain by-plant forage yields, NDVI readings for each plant were determined in the same fashion whereby sensor readings ½ the distance to the neighboring plant in front and behind of the plant in question were averaged and subsequently paired with the dry matter data. This was accomplished by employing the shaft encoder since distance and NDVI were written to the data file. Because total distances and distances between plants were recorded previously, sensor data could be partitioned accordingly.

Plant heights were also recorded for each individual plant prior to harvest. Plant height was determined by extending the last collared leaf upright. For the 3rd cutting the corn height was measured to the top of the tassel.

Sensor NDVI readings were multiplied by plant height in order to assess a pseudo three dimensional image of total biomass. Earlier work by Stone et al., (1996) showed that NDVI alone was an excellent predictor of wet and/or dry biomass. Simple correlation of NDVI, height, and the index NDVI x height were evaluated with wet and dry biomass, forage yields, N uptake, and tissue N concentration.

RESULTS AND DISCUSSION

In an attempt to more accurately predict corn forage biomass, the data were divided into two groups based on growth stage. The first group consisted of corn harvested between the V8 and V10 growth stages (less than 65 days from planting to harvest). The second group consisted of corn harvested between growth stages V11 and R1 (greater that 65 days from planting). Table 2 describes growth stage and days from planting to harvest. As mentioned earlier, each harvest consisted of fifty successive plants within a row. Plant populations were variable across harvest, locations and years (Table 3). The Efaw location had consistently higher populations than the Perkins locations in 2003 and 2004. In 2005, the LCB site was under sprinkler irrigation.

Plant height, NDVI, and NDVI x height index (the product of NDVI and plant height) were used as independent variables to predict corn forage biomass (g per plant not accounting for area occupied by the plant), corn forage yield (g of biomass accounting for area occupied by plant), corn forage N uptake (forage yield*N concentration of forage), and tissue N concentration. Over years, locations, stages of growth, the correlation of NDVI and height with wet biomass (either determined using determinate area, or not) was far improved when compared to dry biomass. However, for purposes of reporting the findings of this work, the focus has remained on dry biomass, despite the lower resultant correlation due to the errors associated with moisture determination (wet weights, dry weights, etc.).

Biomass

Across years and locations, NDVI proved to be a poor predictor of dry plant biomass. NDVI was calculated and measured for each corn plant by averaging sensor readings from half the distance to the preceding plant and half the distance to the following plant in a row. With unequal spacing often incurred by mechanized corn planting, the area occupied by individual corn plants varied. This variation in plant spacing affected the ability of NDVI alone to predict dry corn biomass at early and late stages of growth. In Figures 1 and 2, NDVI versus dry plant biomass is plotted for early and advanced growth stages, respectively. There was a slight relationship between NDVI and plant biomass, however among individual site years, the ability of NDVI to predict plant biomass was reduced.

Height and biomass were highly correlated independent of the area the plant occupied (Figures 3 and 4), and the correlation with forage biomass was much better at earlier stages than later stages. This is important because it indicates that height can be used by itself to estimate plant biomass without having to compensate for the area occupied by the plant. Using data from the V8-V10 growth stages, the area occupied per plant and dry biomass per plant were found to be unrelated (Figures 5 and 6). Similarly, plant area was not correlated with plant height (Figures 7 and 8). These combined results (no correlation of area with either height or biomass) indicate that area was not an important variable in the prediction of dry biomass using the populations and hybrids employed in this trial. When areas were partitioned into the following categories (area <0.2 m^2 or >0.2 m^2), the resultant correlations were nearly identical, again suggesting the independence of these relationships as a function of area (graphs not reported).

The index of NDVI x height proved to be a better predictor of plant biomass compared to NDVI alone. However, plant height by itself was more accurate in predicting dry plant biomass (Figures 9 and 10). A linear regression was performed between the NDVI x height index and plant biomass at early growth stages and resulted in an r^2 value of 0.66. At the later growth stage the NDVI x height index was not as good in predicting plant biomass compared to early growth stages.

Forage Yield

Forage yields were determined by dividing the dry plant biomass by the area each plant occupied (g m^{-2}). Yields were converted to Mg ha^{-1} by dividing g m^{-2} by a factor of 100. Across years and locations, NDVI more accurately predicted forage yields accounting for area at earlier stages of growth (Figures 11 and 12). This improved relationship between NDVI and corn forage yield at earlier growth stages is explained by increased sensitivity of NDVI. When corn is younger and smaller, the sensor has the ability to detect more soil area of lower yielding plants compared to higher yielding plants. Conversely, at later stages of growth, corn plants were taller which required increased elevation of the sensor and subsequently soil background had a diminished influence on NDVI. The lower plant populations and poor growing conditions at Perkins consistently produced lower yielding plants and lower NDVI values than the Efaw location.

Plant height measurements were also used to predict corn forage yield accounting for area. At growth stages ranging from V8 to V10, plant height predicted forage yield similarly to NDVI. However, at later growth stages, plant height was a better predictor of forage yield than NDVI (Figures 13 and 14). For the duration of this experiment, location, growth stage, and year tended to produce distinct data clusters when plant height and forage yield were plotted. This observation was not noted when plant height was correlated with by-plant dry biomass at the early growth stages (Figure 3). This further explains the ability of plant height to predict biomass, and the finding that there is little benefit in considering the area that the plant occupies across locations and growth stages of this experiment (Figure 3).

The product of NDVI and plant height was also correlated with corn forage yield accounting for area. This index proved to be a better predictor of corn forage yield than either NDVI or plant height alone (Figures 15 and 16). Further investigations showed that this index performed similarly at early and later stages of growth.

The relationship between forage yield and NDVI, plant height, and their product was investigated across all years, locations, and growth stages. When growth stages were combined, there was an improved correlation between plant height and the NDVI x height index and by-plant forage yields (data not reported). Alternatively, NDVI was a much poorer predictor of corn forage biomass across all growth stages compared to separate evaluation of NDVI and corn forage yield by two growth stage ranges (V8-V10, and V11-R1). Although there was an increase in the ability of plant height and the NDVI x height index to predict forage yield when plotted across all stages of growth, they were partitioned separately to better understand if forage yields could be predicted at early stages of growth.

N uptake

The amount of N taken up in corn forage was highly correlated with NDVI (Figures 17 and 18). At early stages of growth, NDVI explained 64% of the variation in N uptake. This correlation was slightly lower at later growth stages. In both cases, NDVI proved to be a better predictor of N uptake than forage yield or plant biomass (data not shown). This increase in correlation with N uptake could be explained by the ability of NDVI to detect differences in red absorption and variation in chlorophyll content. Thomas and Oernther (1972) noted similar finding in sweet peppers, as N-deficiency symptoms became more pronounced reflectance in the visible portion of the spectrum (500 to 700 nm) increased.

At early and later stages of growth, plant height was not as accurate a predictor of N uptake in the forage as NDVI (Figures 19 and 20). At later growth stages, there was a much higher correlation between plant height and N uptake than earlier growth stages. A relationship was present between plant height and N uptake at early growth stages, however this relationship differed based on growth stage and location. Forage harvested between V8 and V9 at Efaw in 2004 and LCB in 2005 took place following early irrigations. This may have allowed for favorable growing conditions that led to increased N uptake compared to the other locations that were harvested at early growth stages, but where moisture was limiting. This difference in growing conditions resulted in decreased correlation between plant height and N uptake at growth stages V8 to V10. At later growth stages, the relationship of plant height and NDVI was much improved over the relationship at earlier growth stages.

The NDVI x height index was also a good predictor of N uptake in corn forage. Similar to plant height, this index had a much stronger relationship with N uptake at later growth stages compared to earlier stages of growth. The V8-V10 growth stages did show a correlation with N uptake, but this relationship was not consistent across locations (Figure 21). The NDVI x height index expressed a strong relationship with N uptake ($r^2 = 0.77$) using an exponential model for corn forage harvested from V11-R1 growth stages (Figure 22).

Nitrogen concentration

No relationship was noted between NDVI and tissue N concentration in corn forage across years, locations, and growth stages (Figure 23).

CONCLUSIONS

The objective of this experiment was to determine if corn forage biomass, corn forage yield, and corn forage N uptake could be accurately predicted using by-plant sensor data and plant height collected at various stages of corn development. Results showed that forage biomass, forage yield, and forage N uptake could be accurately predicted using indirect measures. By-plant forage yields, accounting for area occupied by the plant, were accurately predicted using the index NDVI x height. Forage yields were also correlated with NDVI and plant height individually. These relationships with forage yields were consistently better at early stages of growth. The best predictor of forage N uptake was NDVI alone when compared to plant height and the index of NDVI x height at early growth stages. Plant height, NDVI and their product had no relationship with tissue N concentration for corn forage. Sensor NDVI was not as good a predictor of plant biomass as was plant height alone, without accounting for the area the plant occupied. There was a better relationship with plant height and plant biomass, without accounting for the area occupied by the plant than when forage yield was calculated using the plants area. This implies that plant height was independent of the area occupied by the plant. Area occupied by a corn plant was shown to be unrelated to plant height or plant biomass for the in-row variability encountered in these experiments.

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Table 1. Planting and harvest dates for corn forage biomass experiments at Efaw, Perkins, and Lake Carl Blackwell from 2003-2005.

2003	Planted	1st harvest Date	2nd harvest Date	3rd harvest Date
Efaw	3-31-03	5-22-03	6-02-03	6-18-03
Perkins	4-02-03	5-23-03	6-02-03	6-18-03
2004				
Efaw	4-07-04	6-02-04	6-14-04	7-08-04
Perkins	4-02-04	6-02-04	6-14-04	7-08-04
2005				
Efaw	4-07-05	6-08-05		
LCB	4-26-05	6-17-05		

Table 2. Growth stages of corn at time of harvest and days from planting to forage harvest at Efaw, Perkins and Lake Carl Blackwell in 2003-2005.

	Growth Stage and DFP*		
2003	1st harvest	2nd harvest	3rd harvest
Efaw	V8 (52)	V10 (63)	VT (79)
Perkins	V8 (51)	V10 (61)	VT (77)
2004			
Efaw	V8 (56)	V11 (68)	R1 (92)
Perkins	V8 (61)	V11 (73)	R1 (97)
2005			
Efaw	V9 (61)		
LCB	V9 (52)		

* DFP = days from planting to sensing

Table 3. Population of rows used for by plant corn forage harvest at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

	1st harvest	2nd harvest	3rd harvest
2003		Plants ha^{-1}	
Efaw	49,524	49,602	53,017
Perkins	41,968	43,122	45,670
2004			
Efaw	68,377	66,151	70,462
Perkins	48,028	49,379	43,506
2005			
Efaw	51,127		
LCB	63,400		

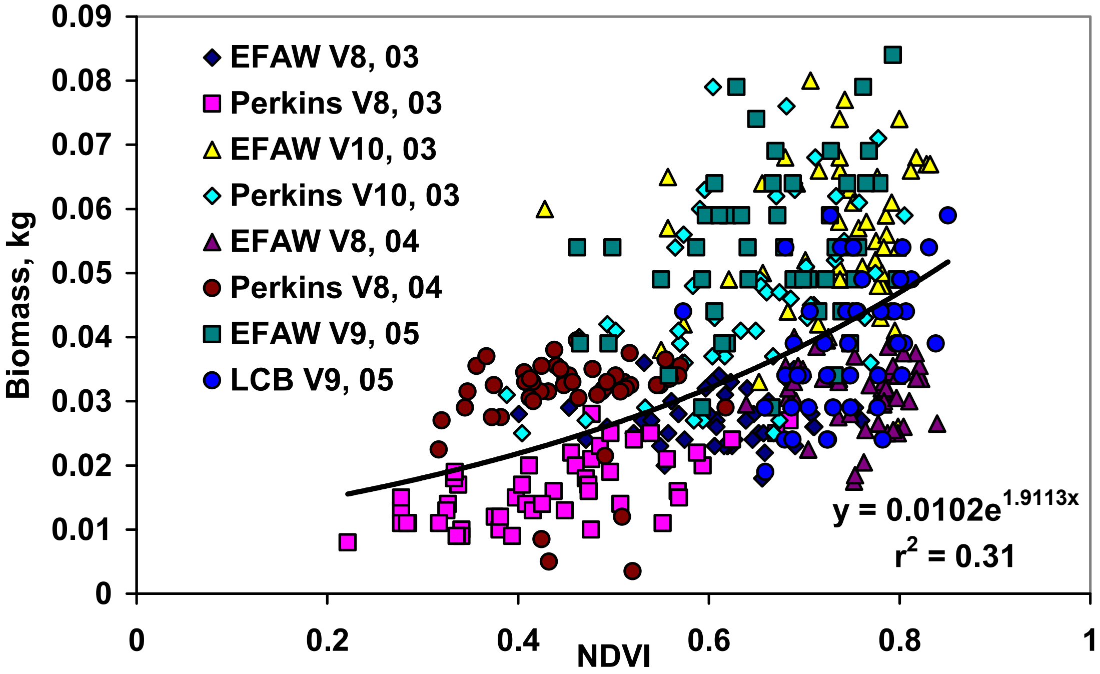

Figure 1. Relationship of NDVI and dry plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

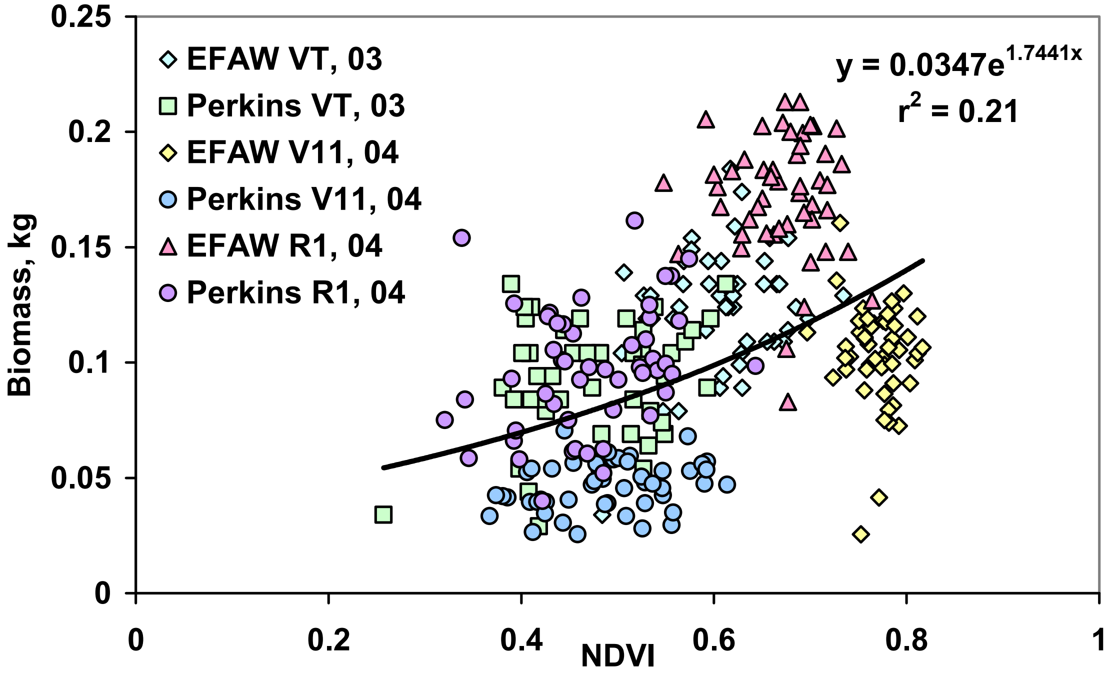

Figure 2. Relationship of NDVI and dry plant biomass at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

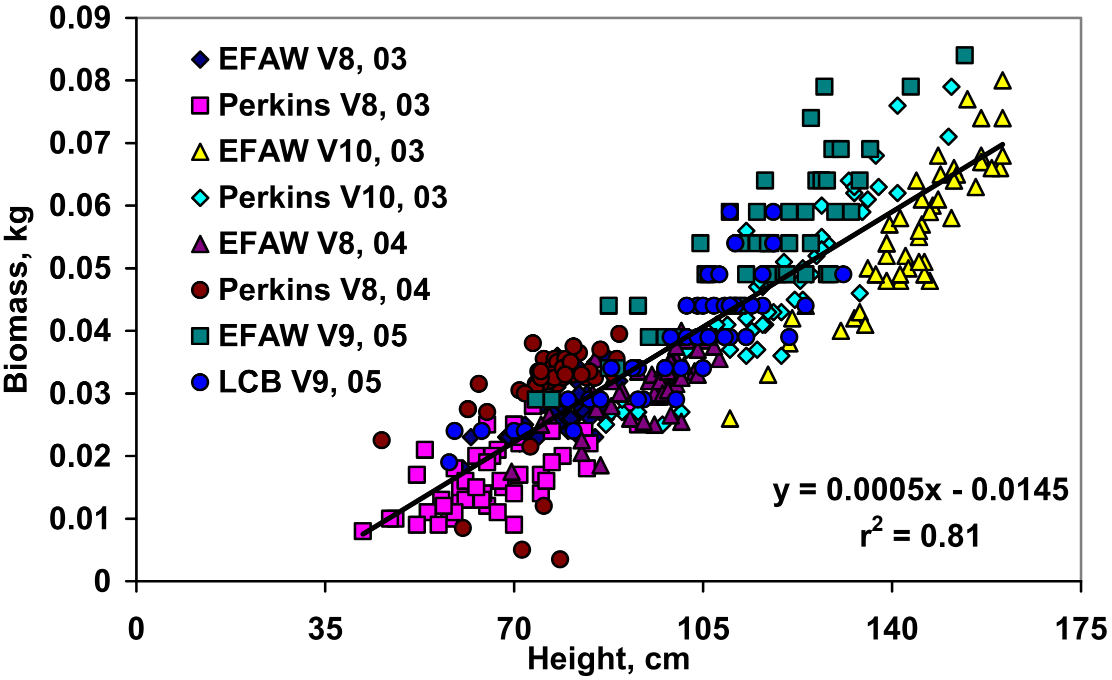

Figure 3. Relationship of plant height and dry plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

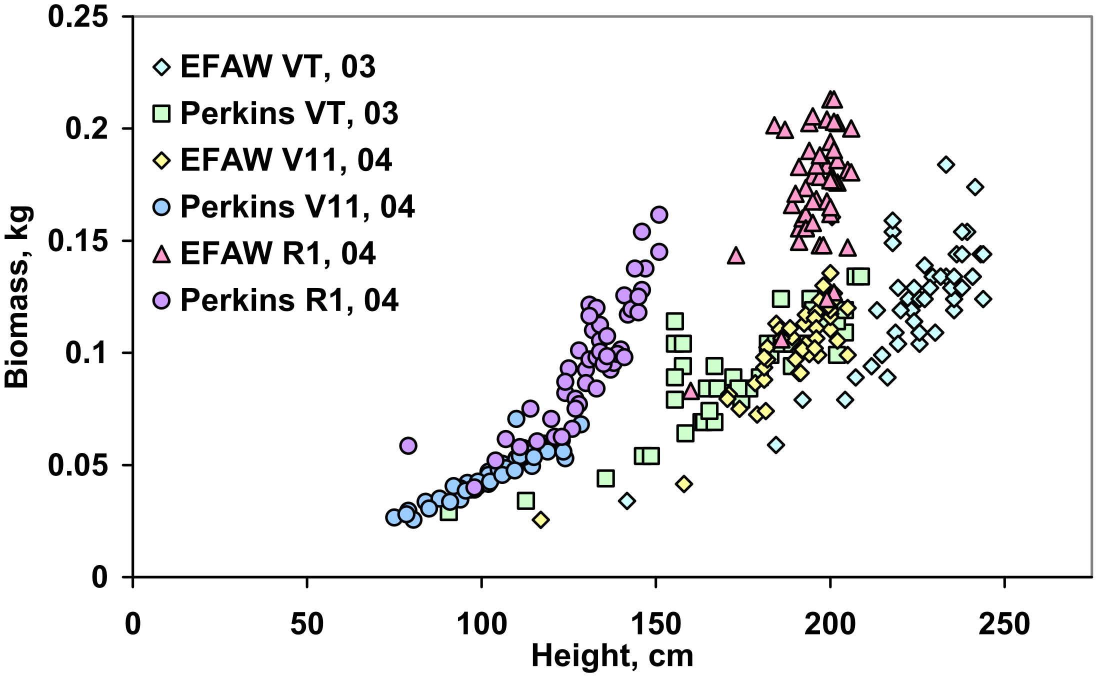

Figure 4. Relationship of plant height and dry plant biomass at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

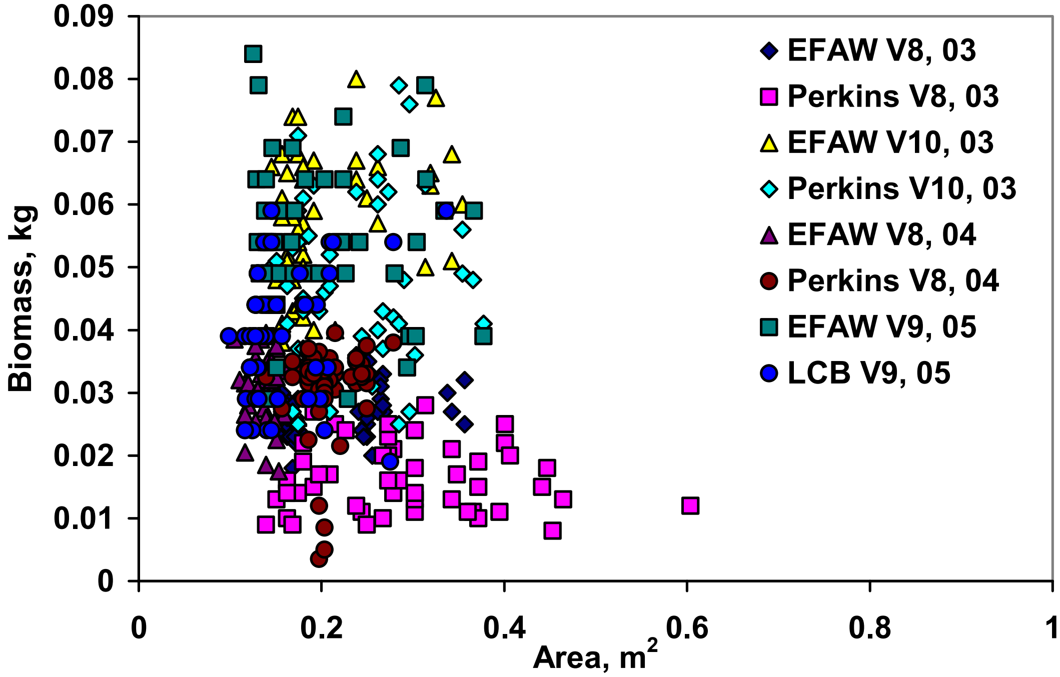

Figure 5. Relationship of plant area and dry plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

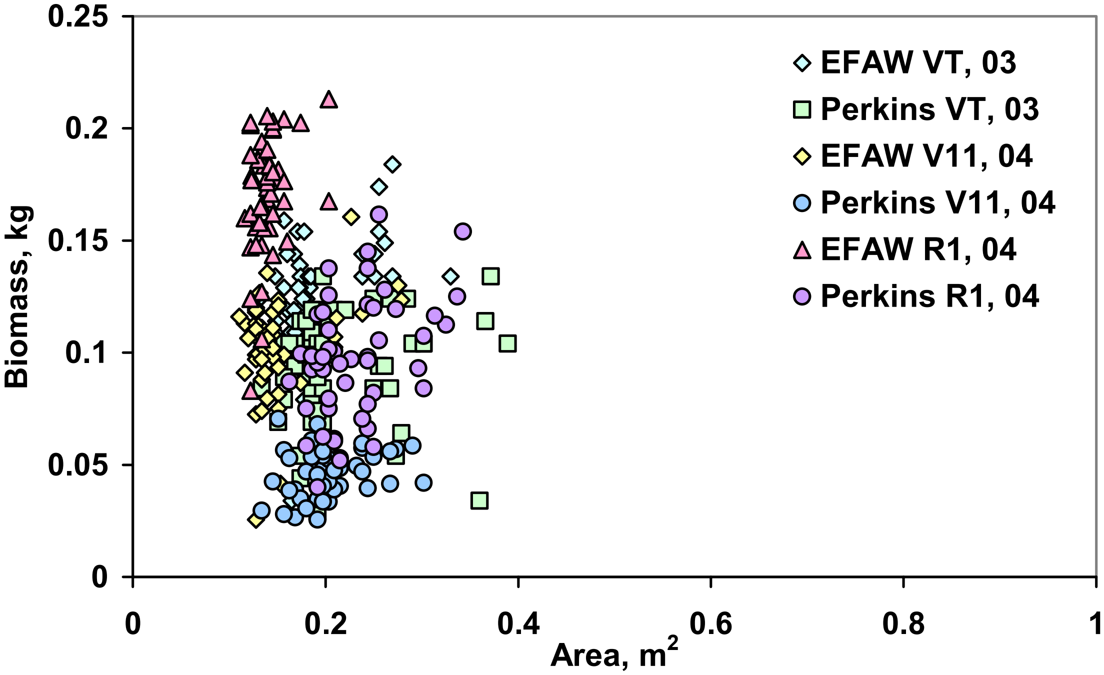

Figure 6. Relationship of the plant area and dry plant biomass at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

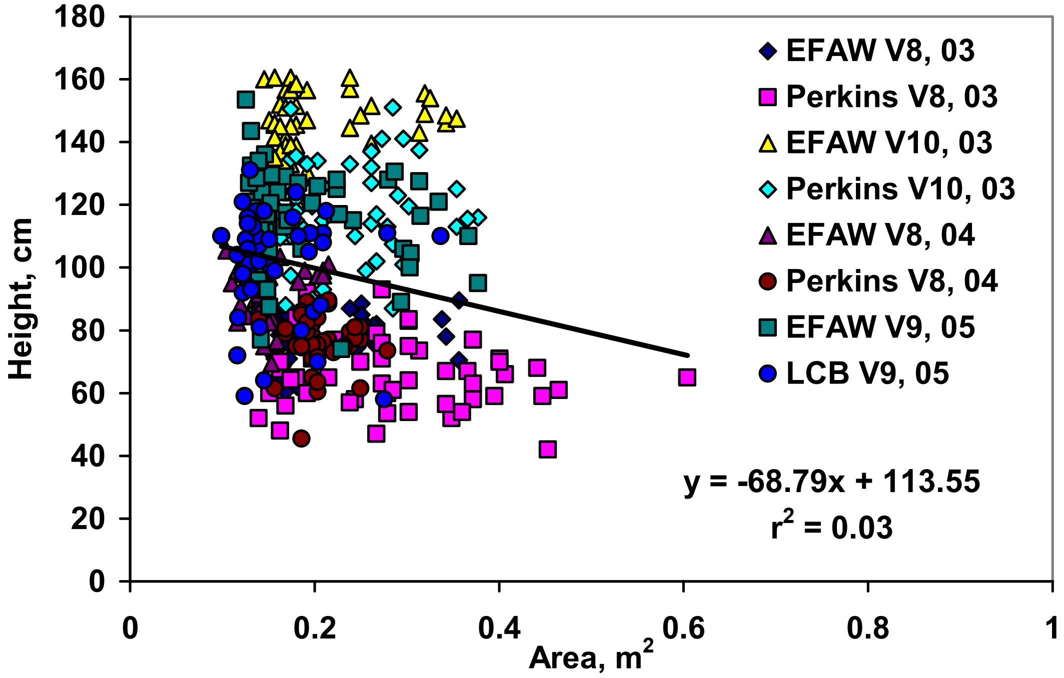

Figure 7. Relationship of plant area and plant height at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

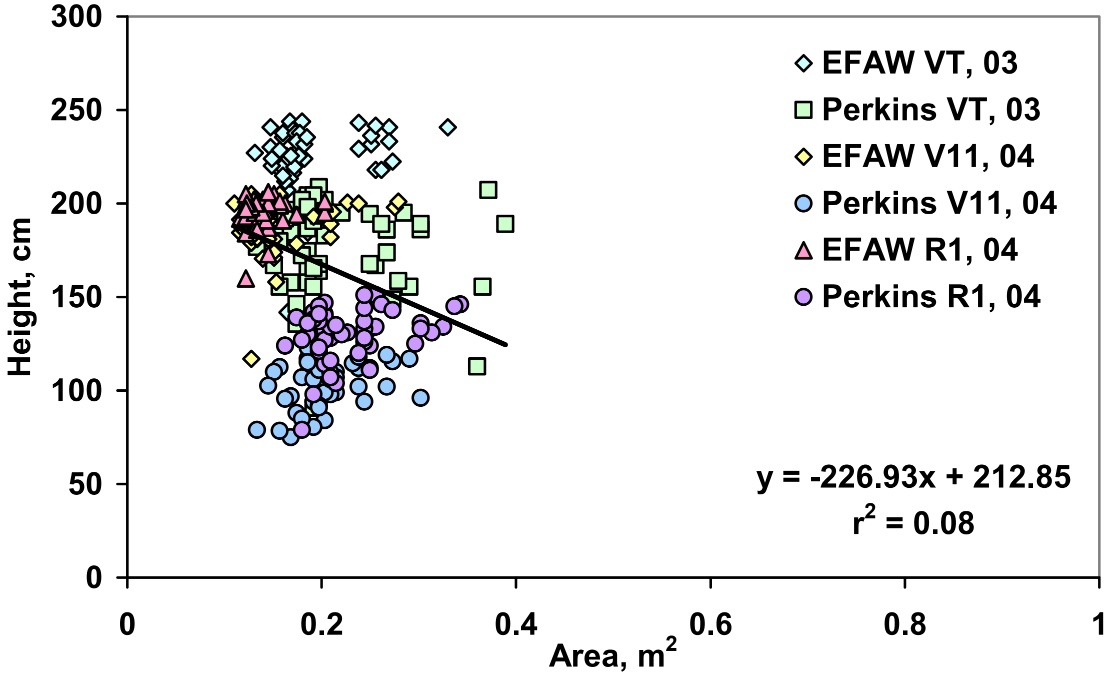

Figure 8. Relationship of the plant area and plant height at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

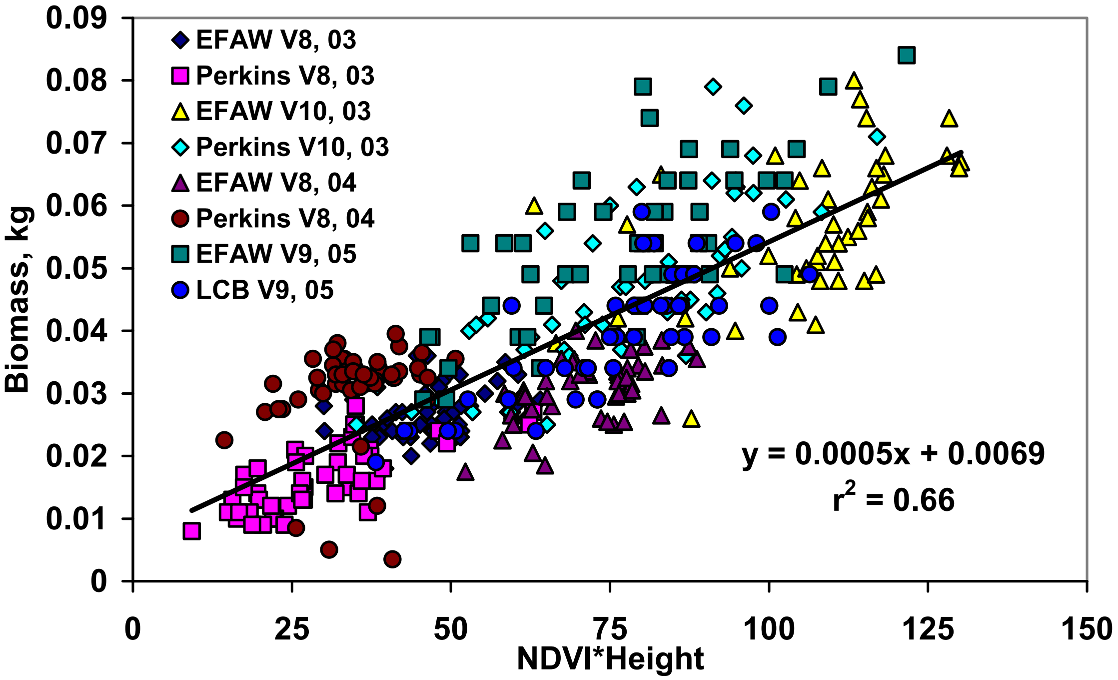

Figure 9. Relationship of the product of NDVI and plant height and dry plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

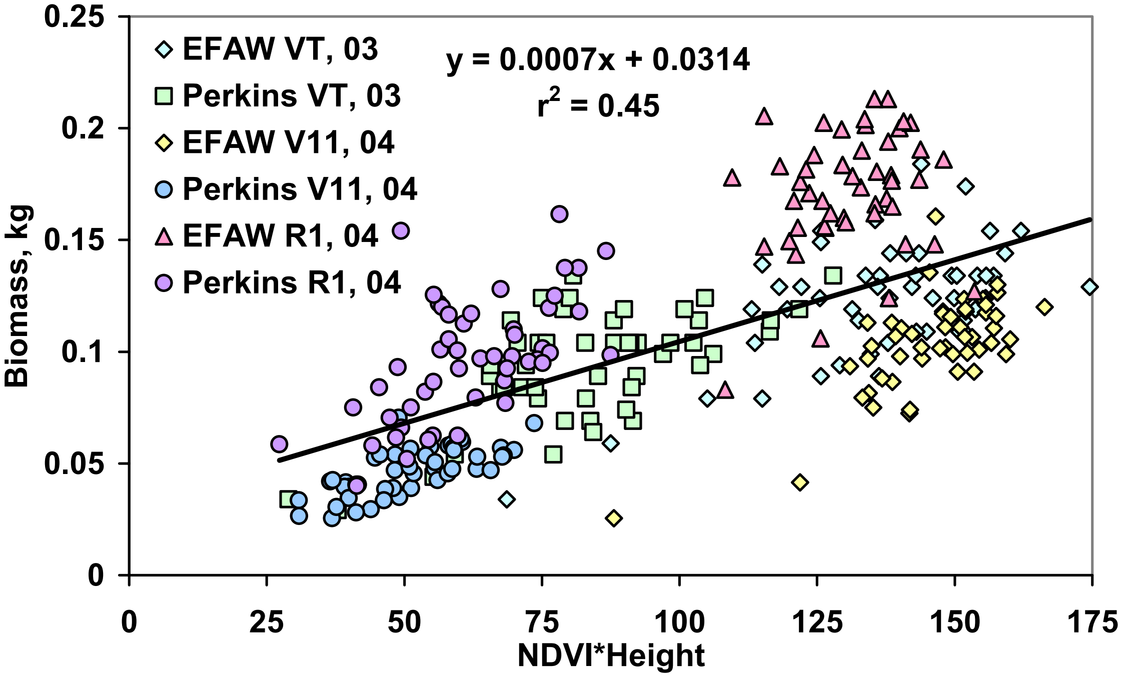

Figure 10. Relationship of the product of NDVI and plant height and dry plant biomass at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

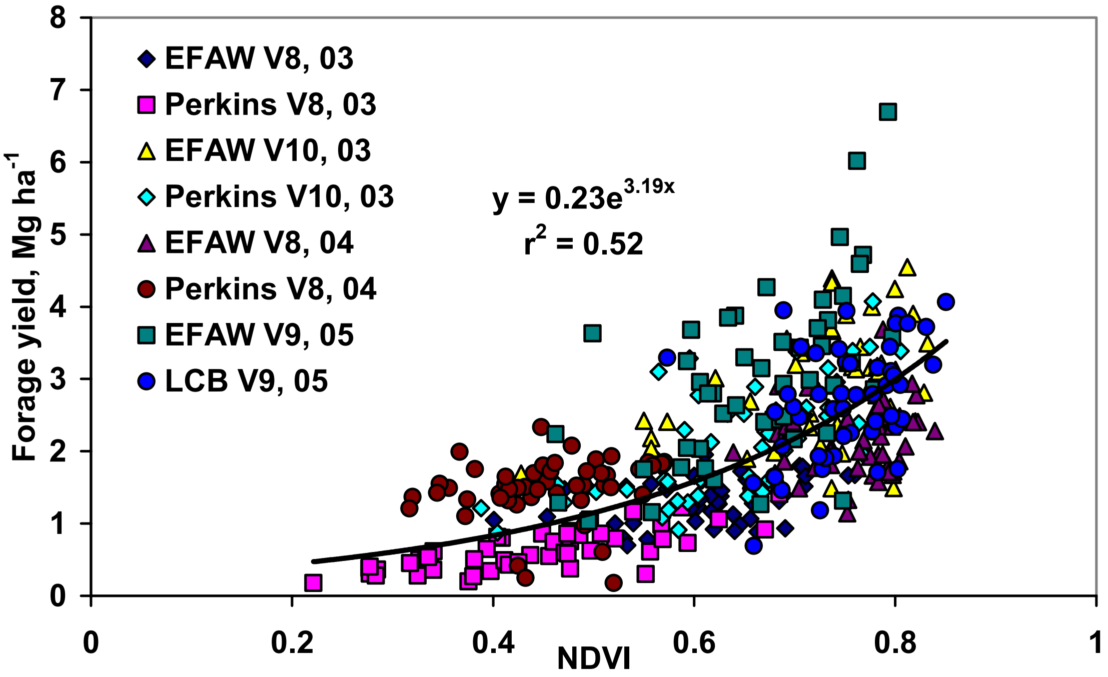

Figure 11. Relationship of NDVI and dry biomass yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

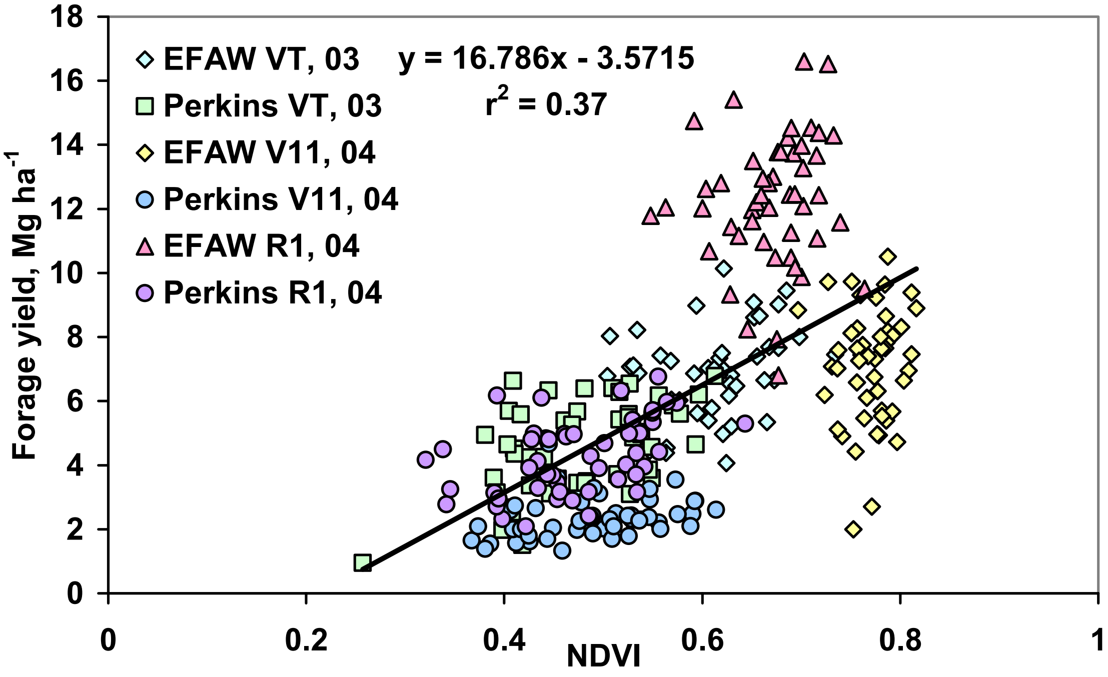

Figure 12. Relationship of NDVI and dry biomass yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

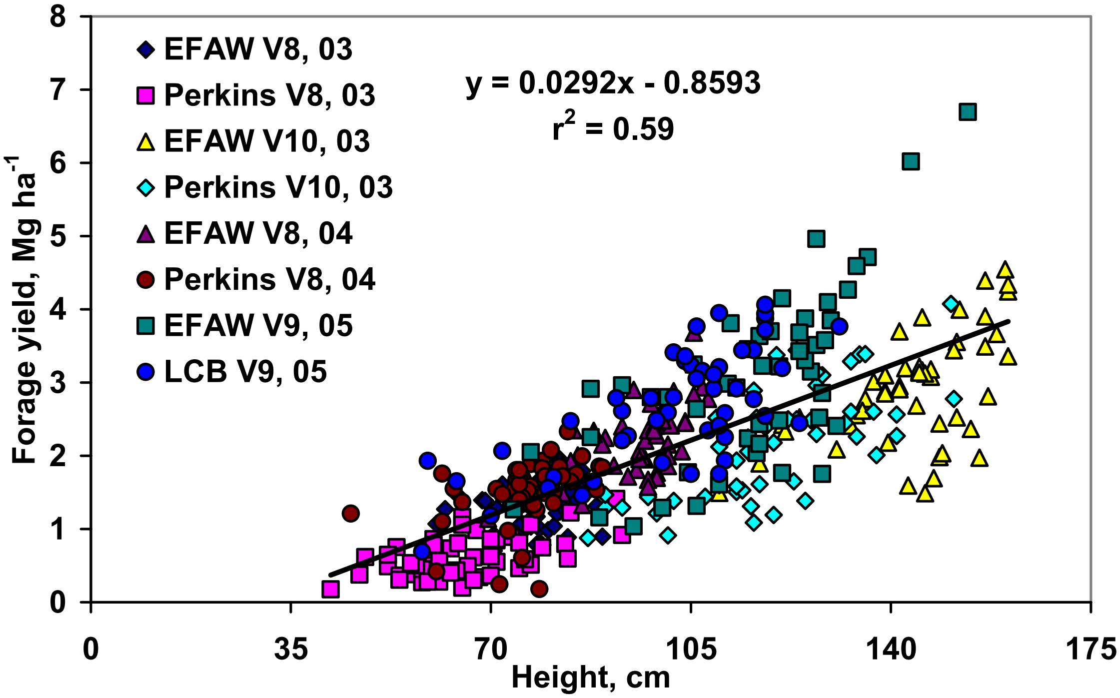

Figure 13. Relationship of plant height and dry biomass yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

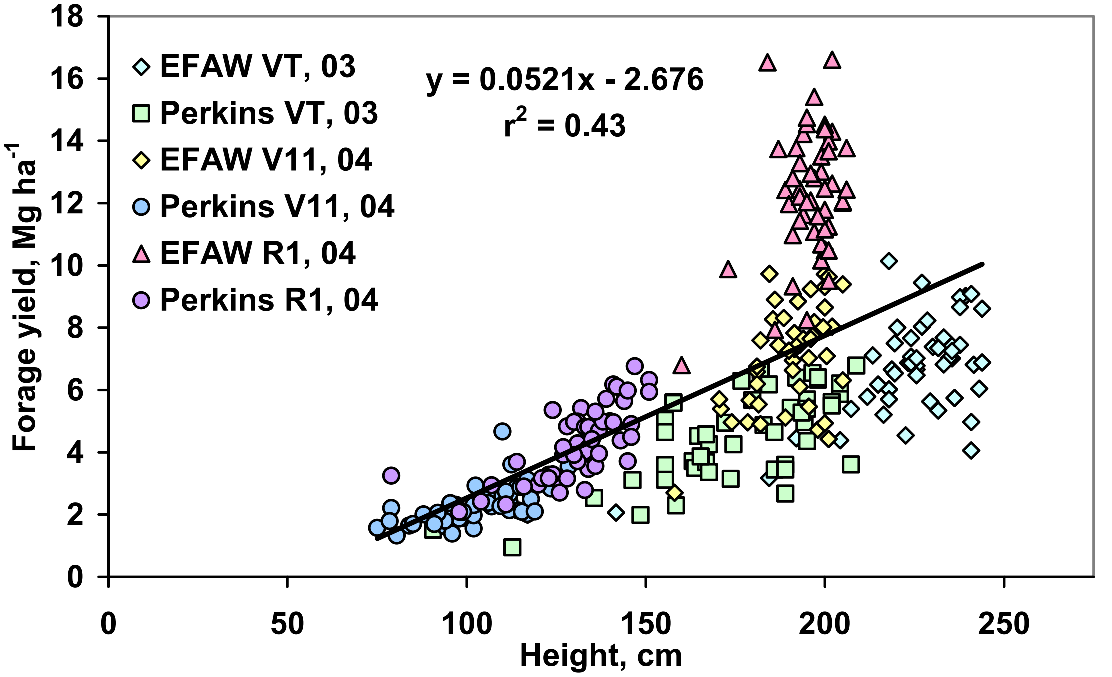

Figure 14. Relationship of plant height and dry biomass yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

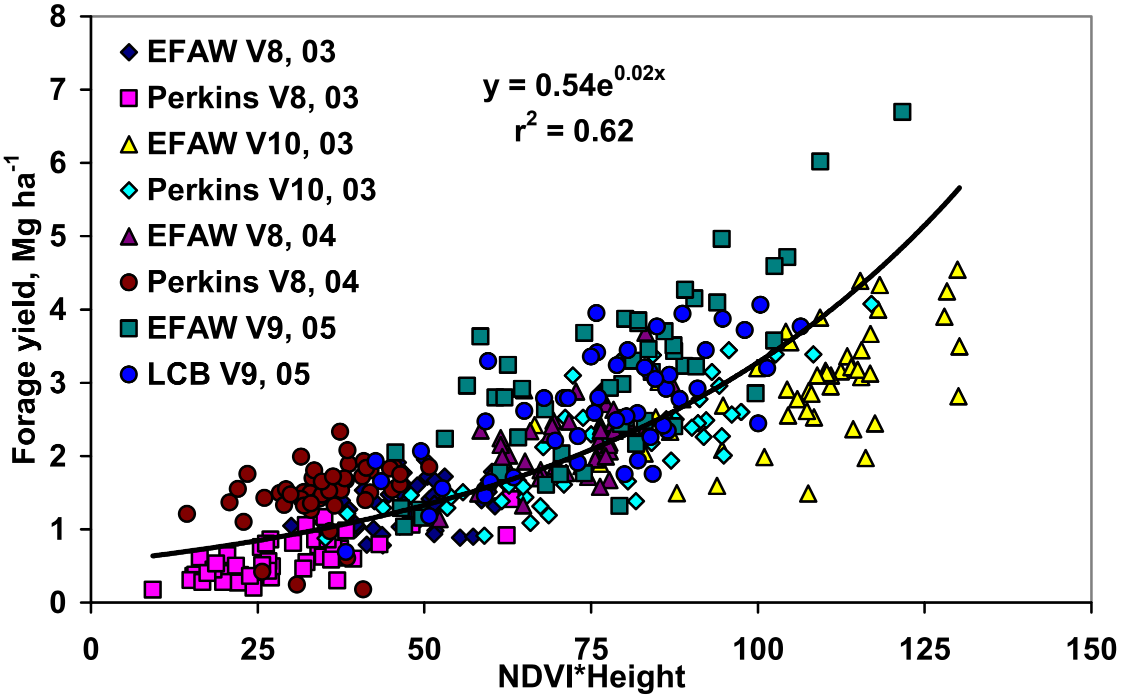

Figure 15. Relationship of the product of NDVI and plant height and dry biomass yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

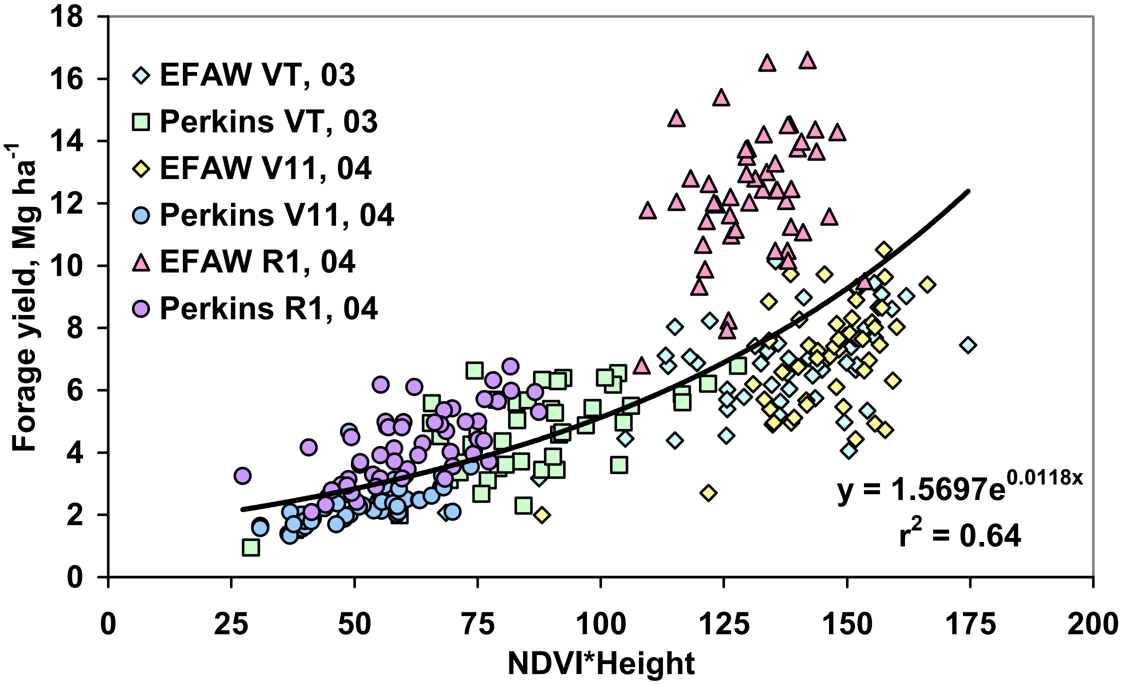

Figure 16. Relationship of the product of NDVI and plant height and dry biomass yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

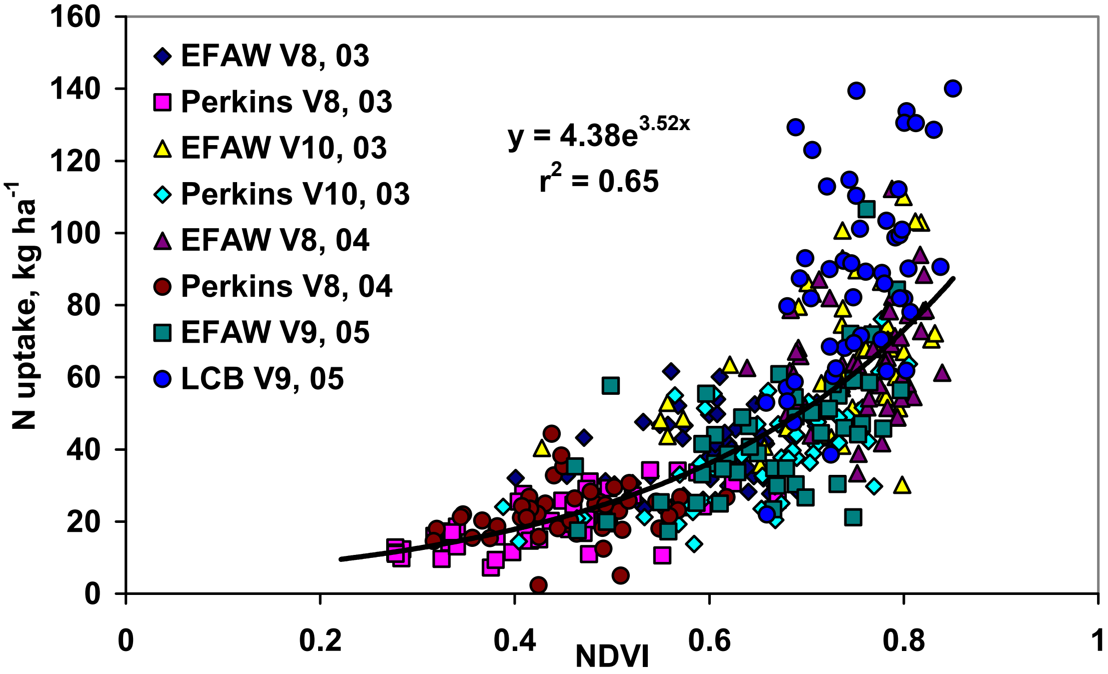

Figure 17. Relationship of NDVI and forage N uptake at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

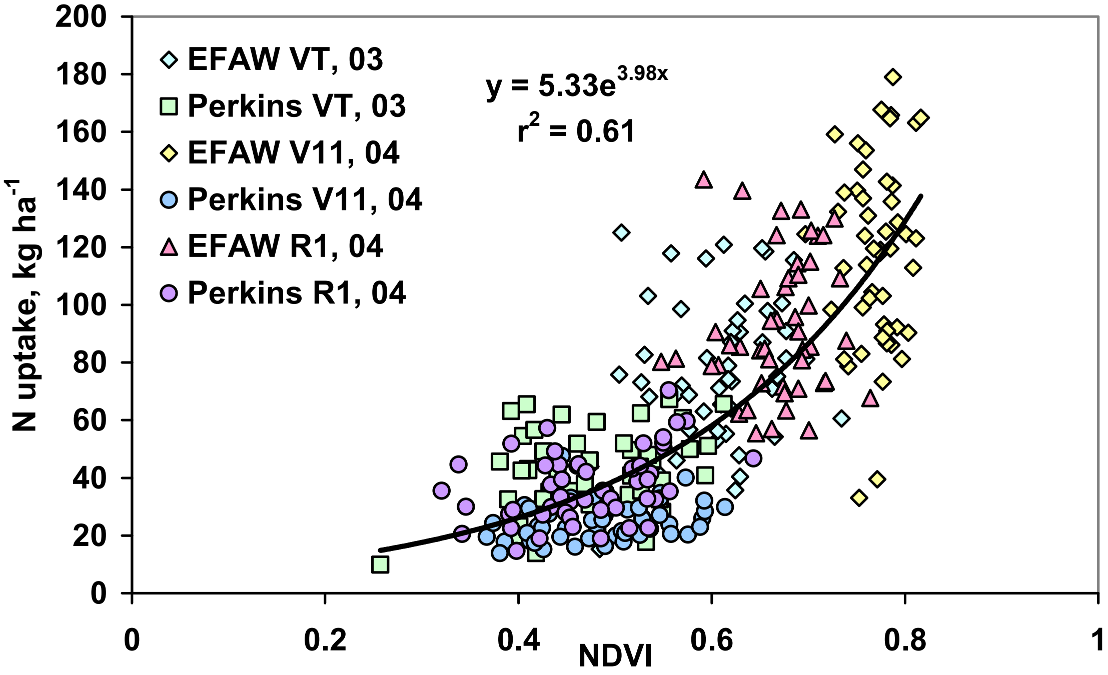

Figure 18. Relationship of NDVI and corn forage N uptake at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

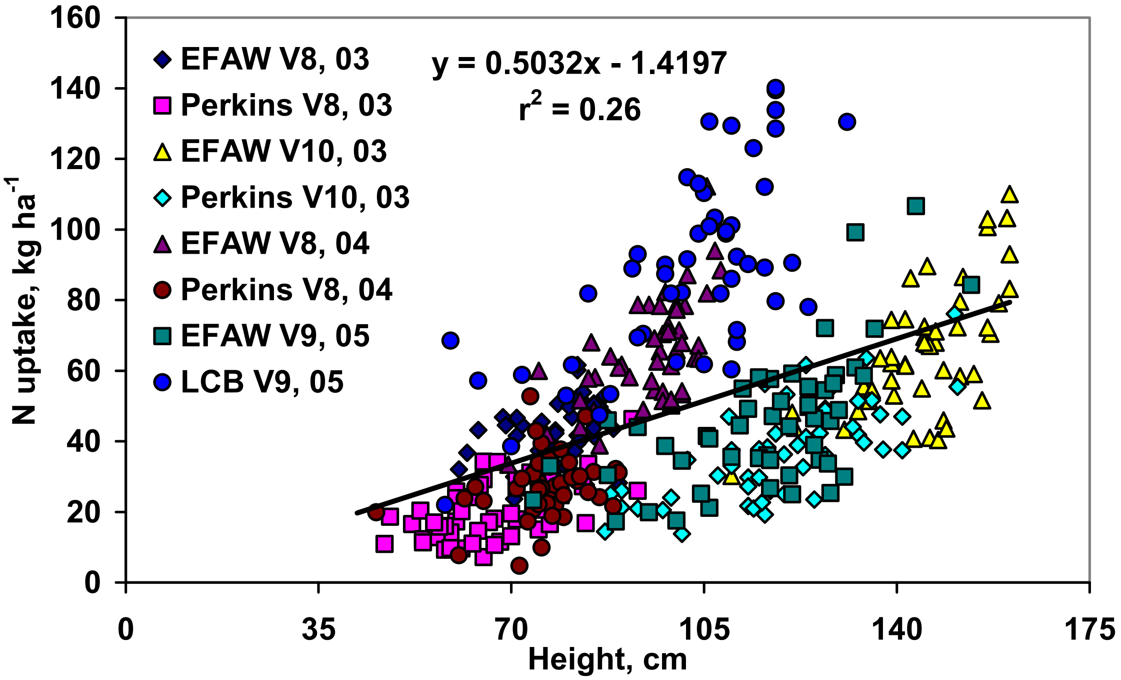

Figure 19. Relationship of plant height and corn forage N uptake at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

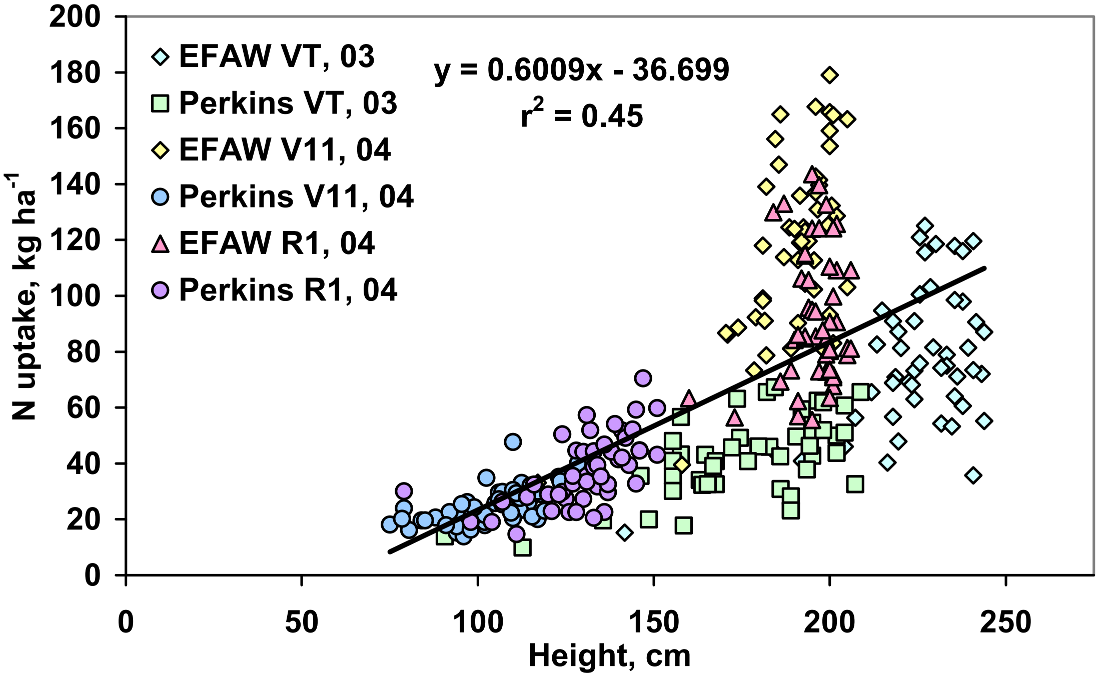

Figure 20. Relationship of plant height and corn forage N uptake at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

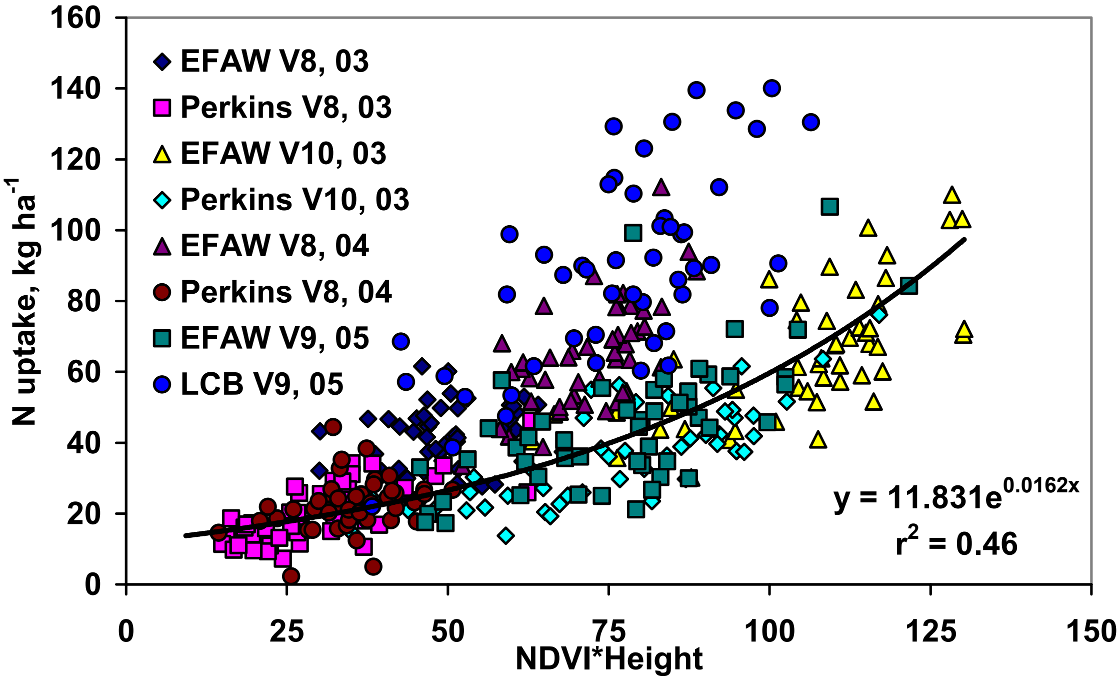

Figure 21. Relationship of the product of NDVI and plant height and corn forage N uptake at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

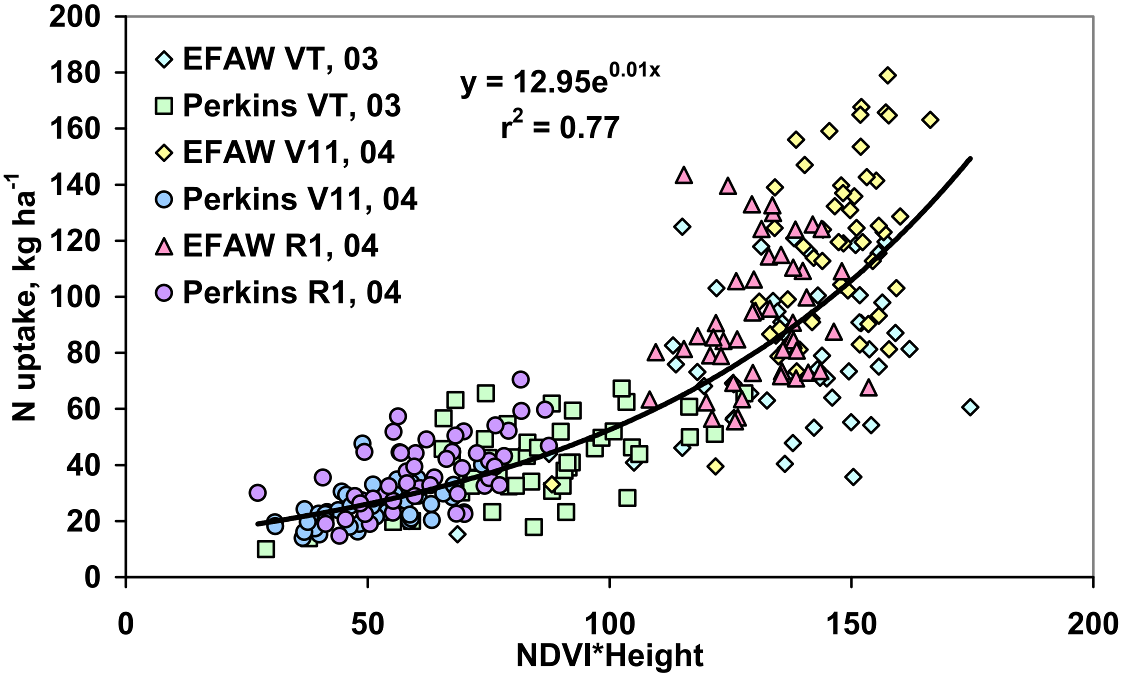

Figure 22. Relationship of the product of NDVI and plant height and corn forage N uptake at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

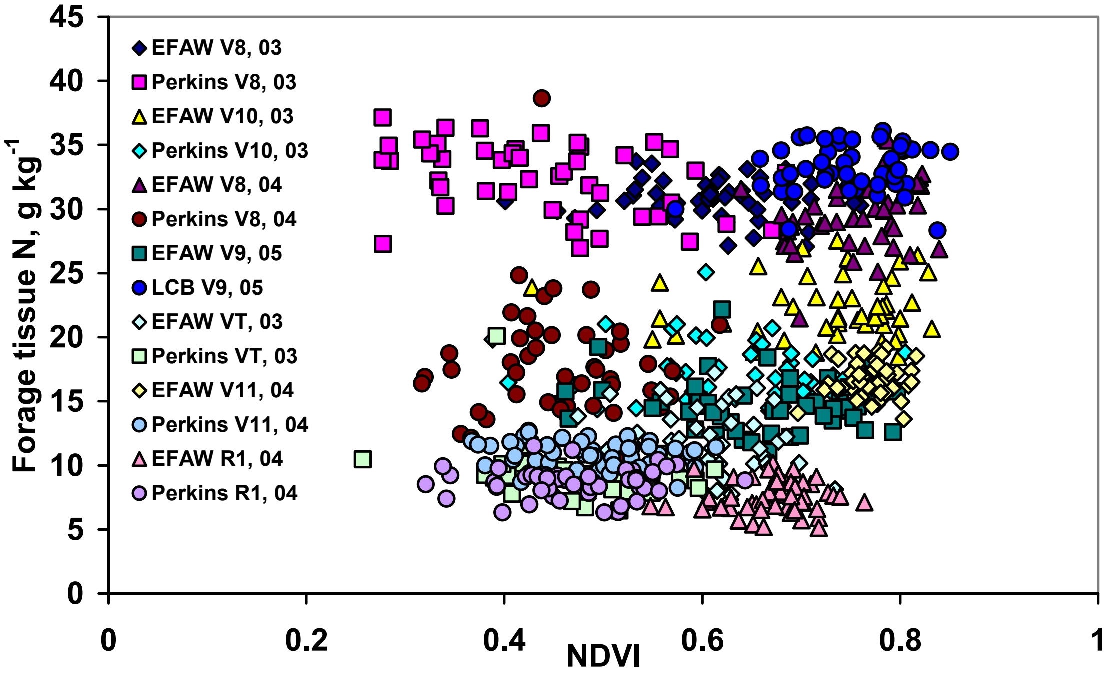

Figure 23. Relationship of NDVI and forage tissue N concentration at growth stages ranging between V8-R1 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

APPENDIX

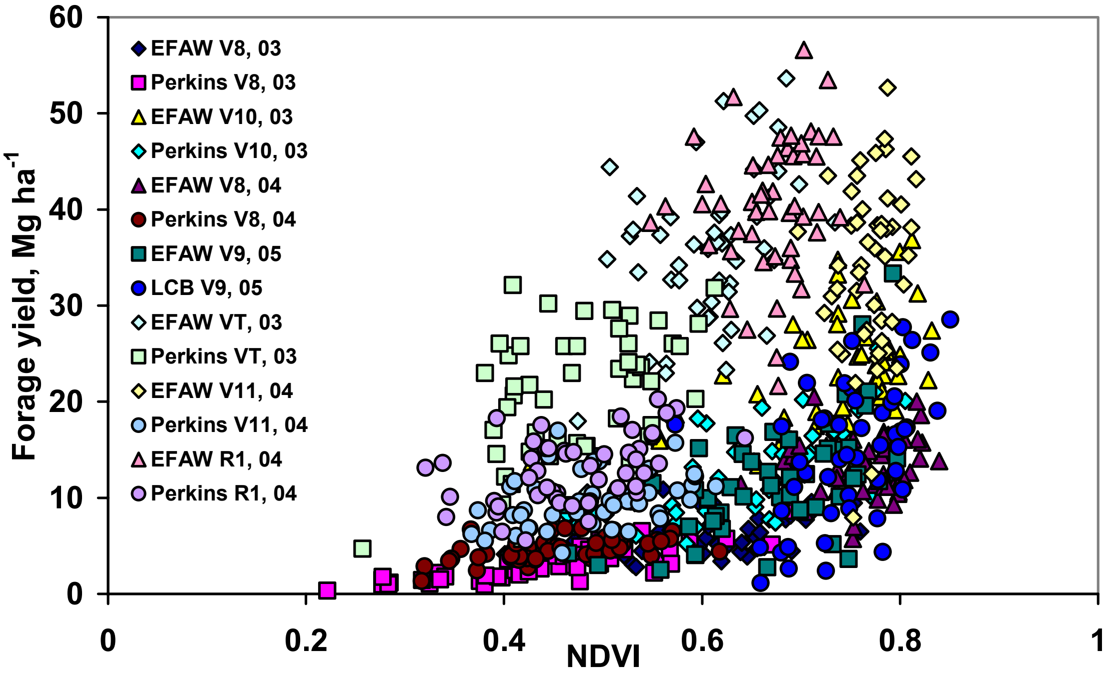

Figure A.1. Relationship of NDVI and wet forage yield at V8-R1 growth stages at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

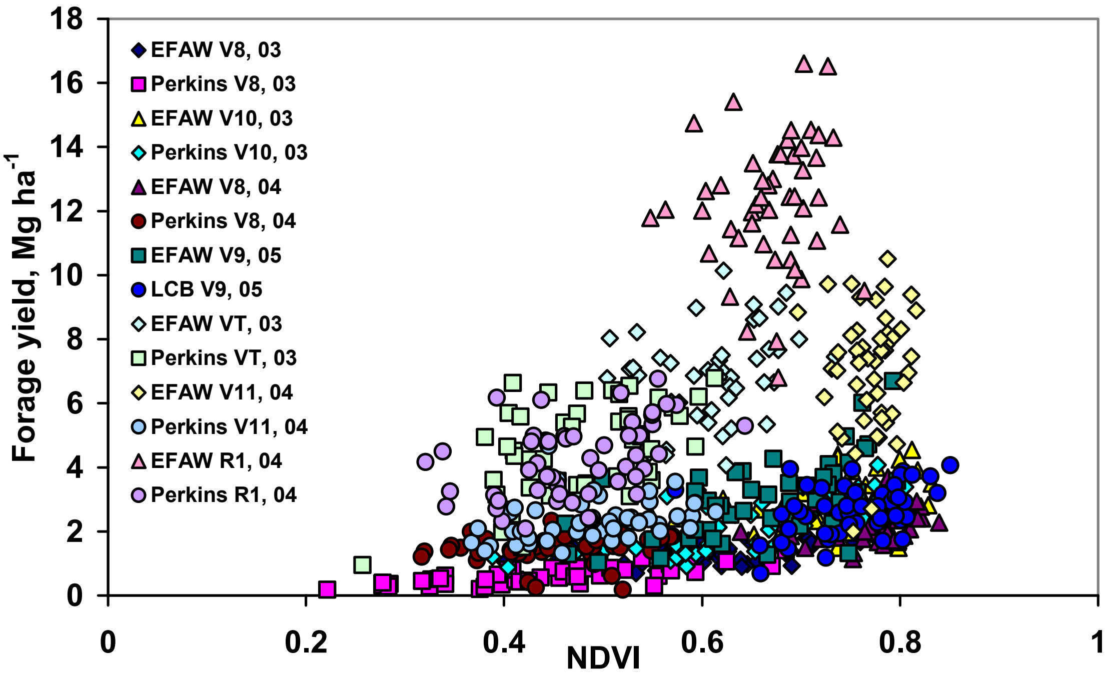

Figure A.2. Relationship of NDVI and dry forage yield at V8-R1 growth stages at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

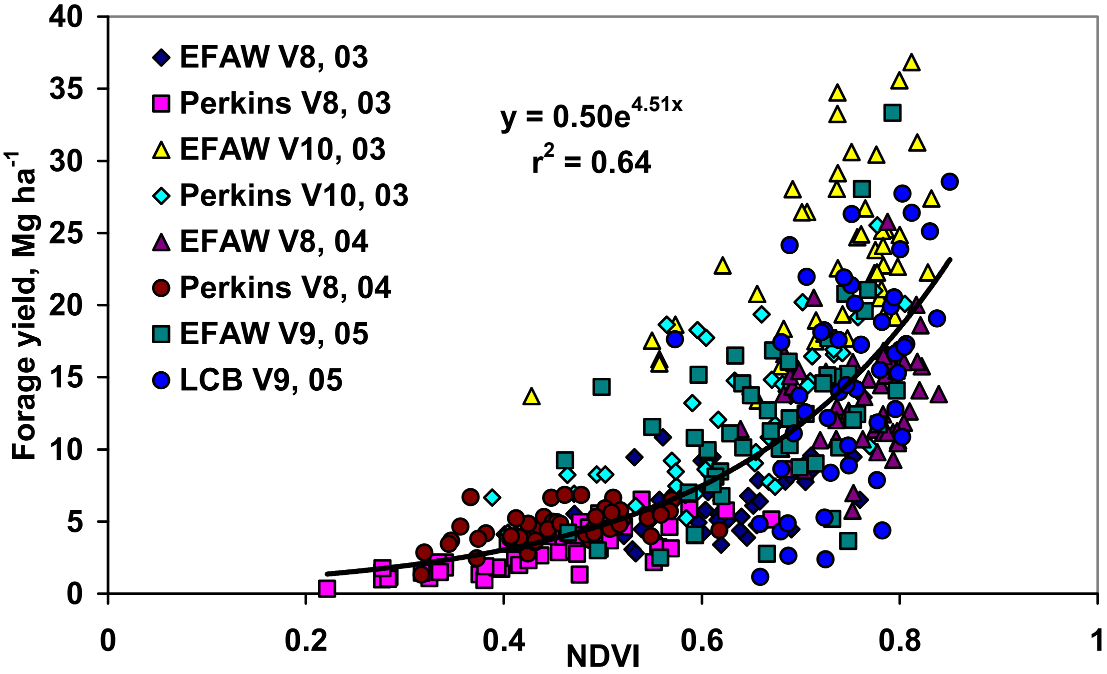

Figure A.3. Relationship of NDVI and wet forage yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

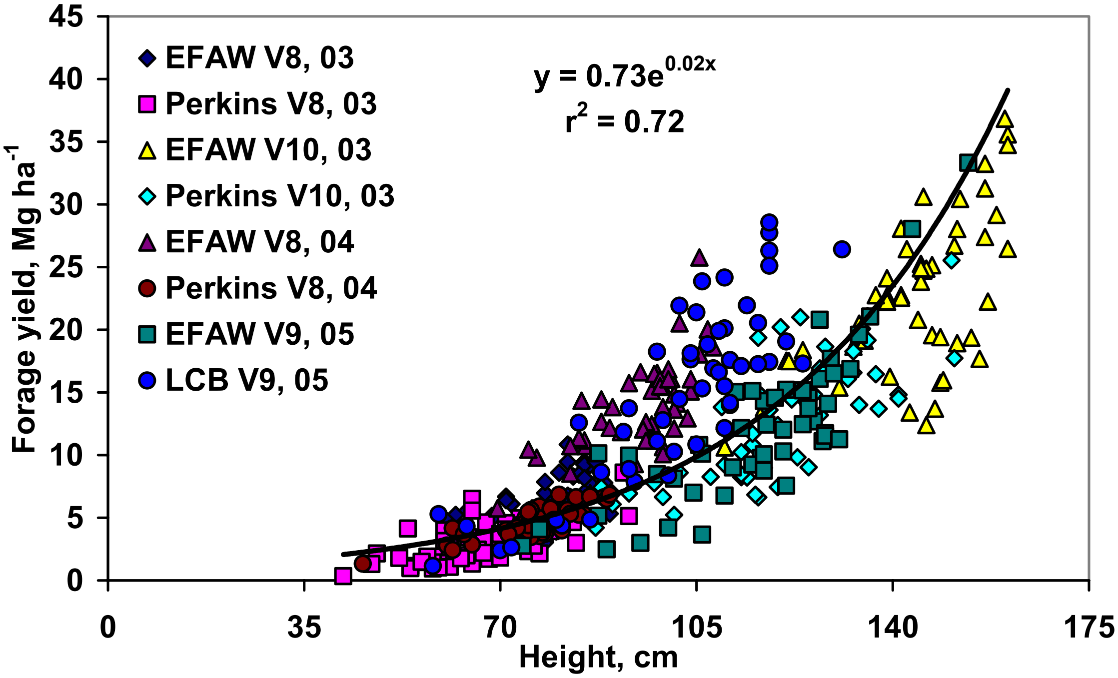

Figure A.4. Relationship of plant height and wet forage yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

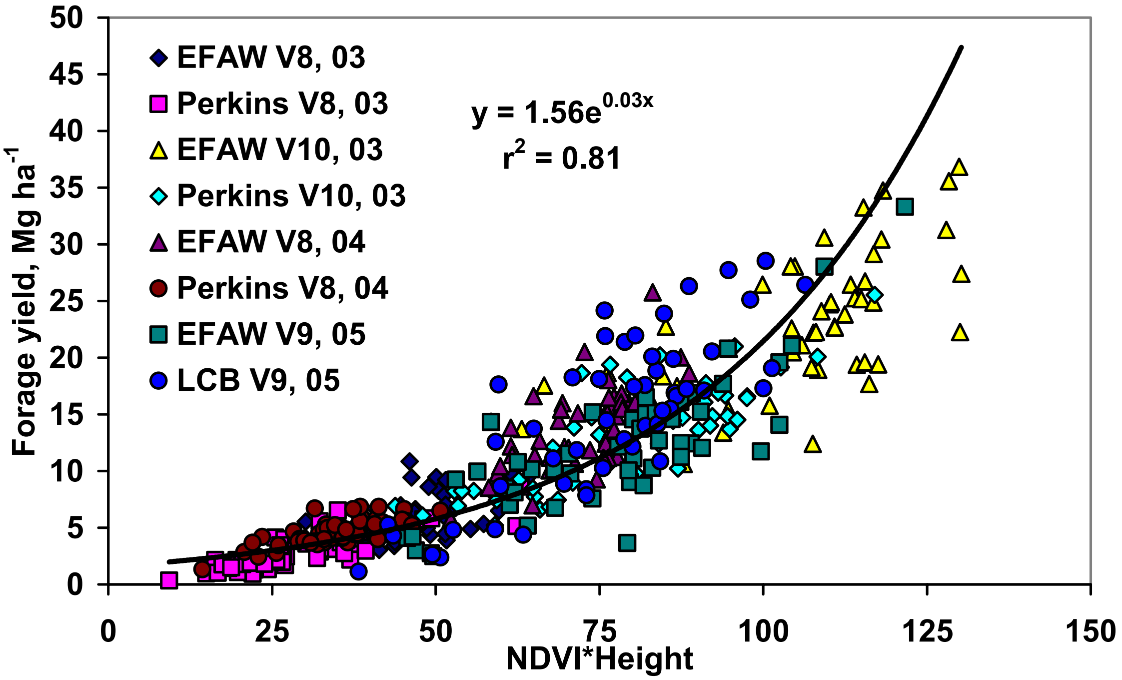

Figure A.5. Relationship of the product of NDVI and plant height and wet forage yield at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

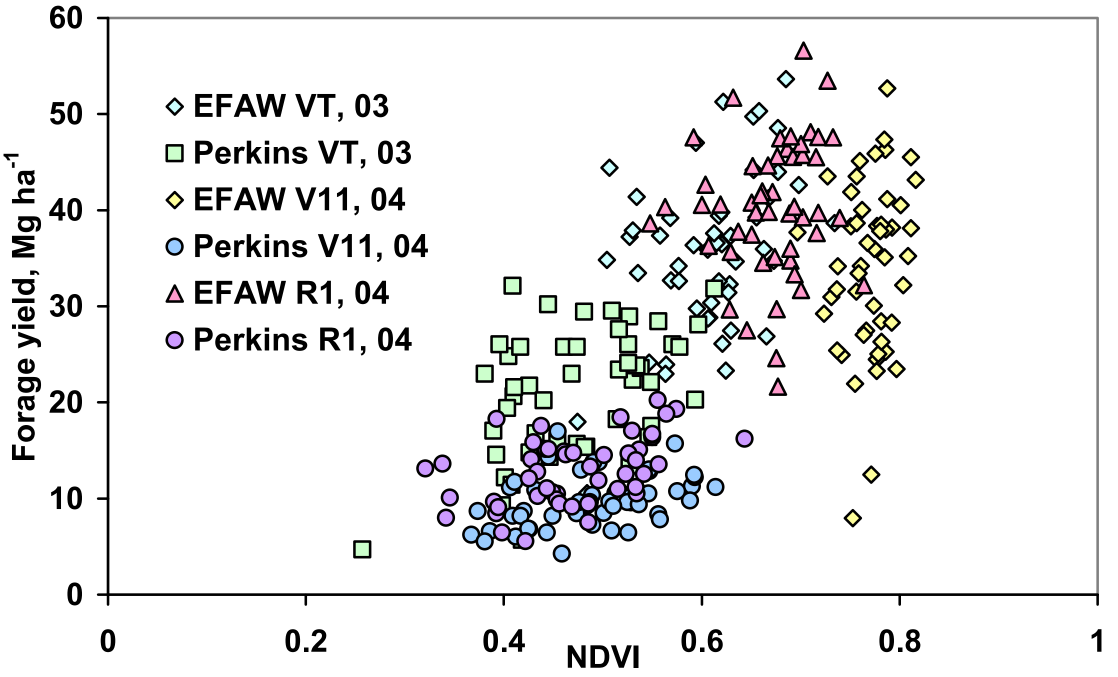

Figure A.6. Relationship of NDVI and wet forage yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

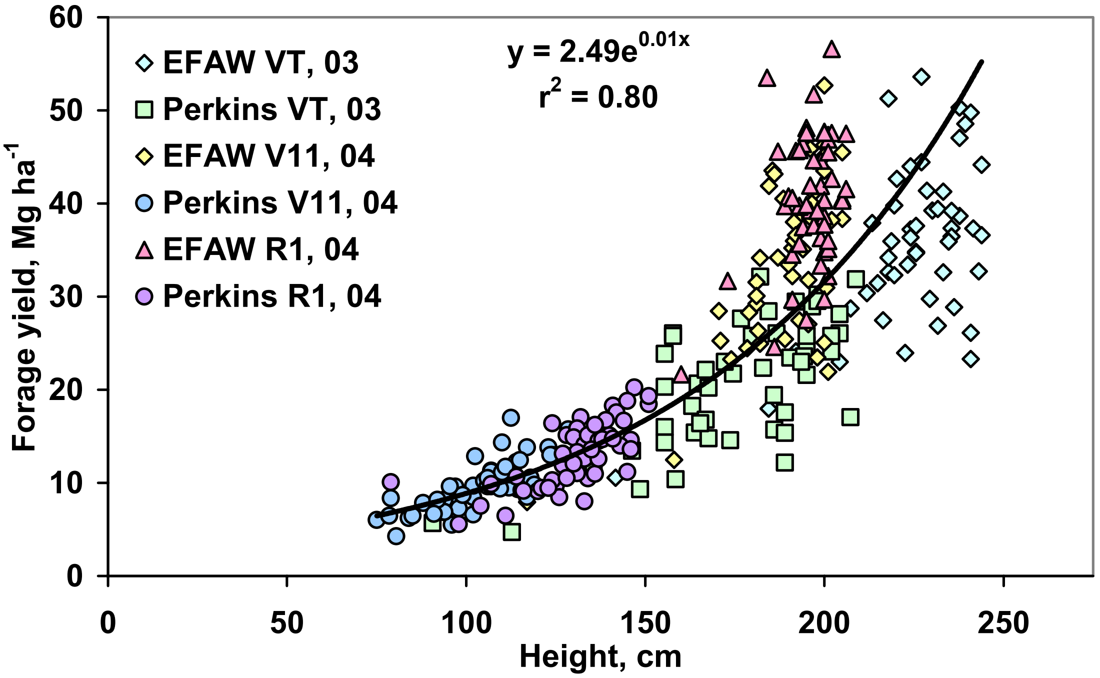

Figure A.7. Relationship of plant height and wet forage yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

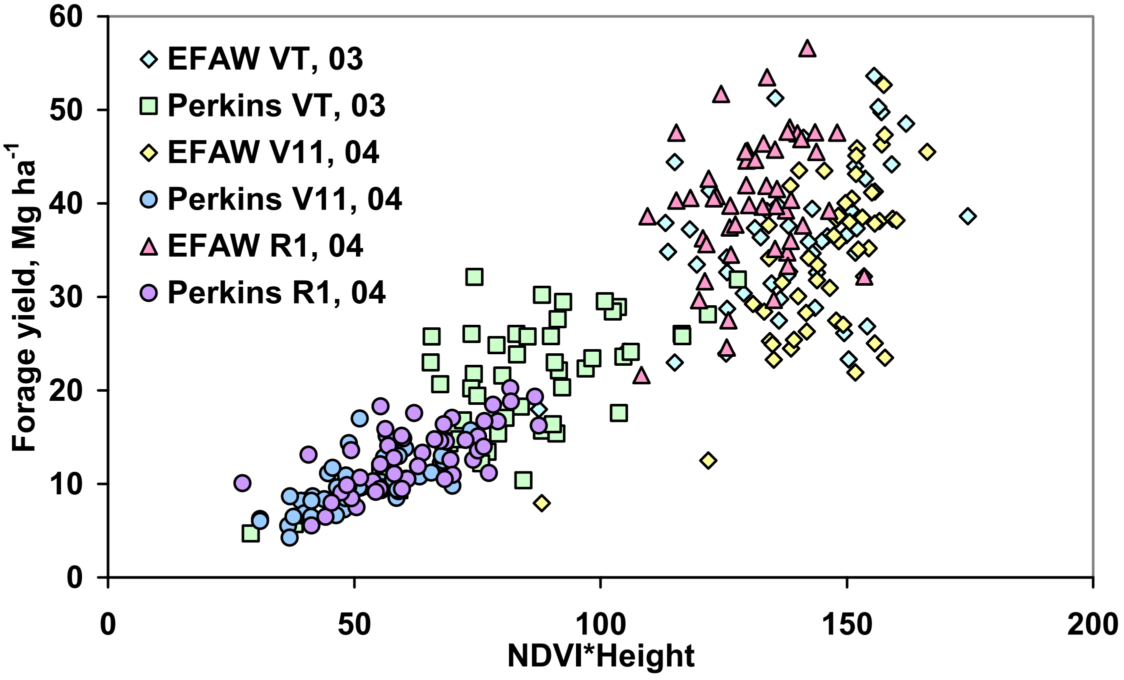

Figure A.8. Relationship of the product of NDVI and plant height and wet biomass yield at growth stages ranging between V11-R1 at Efaw and Perkins in 2003-2004.

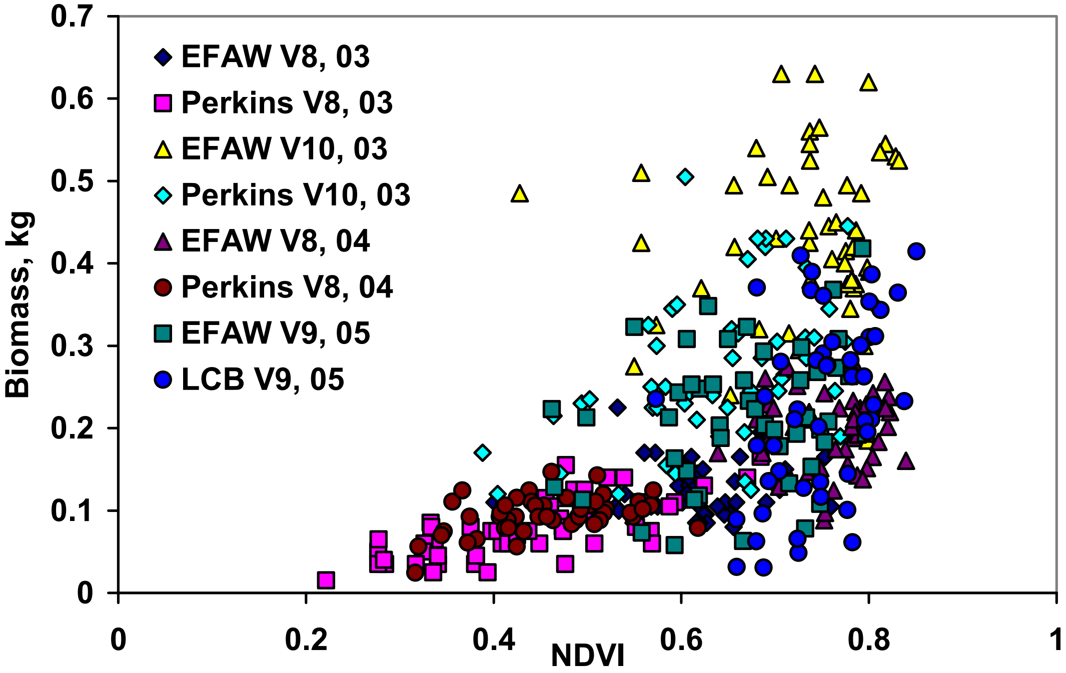

Figure A.10. Relationship of NDVI and wet plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

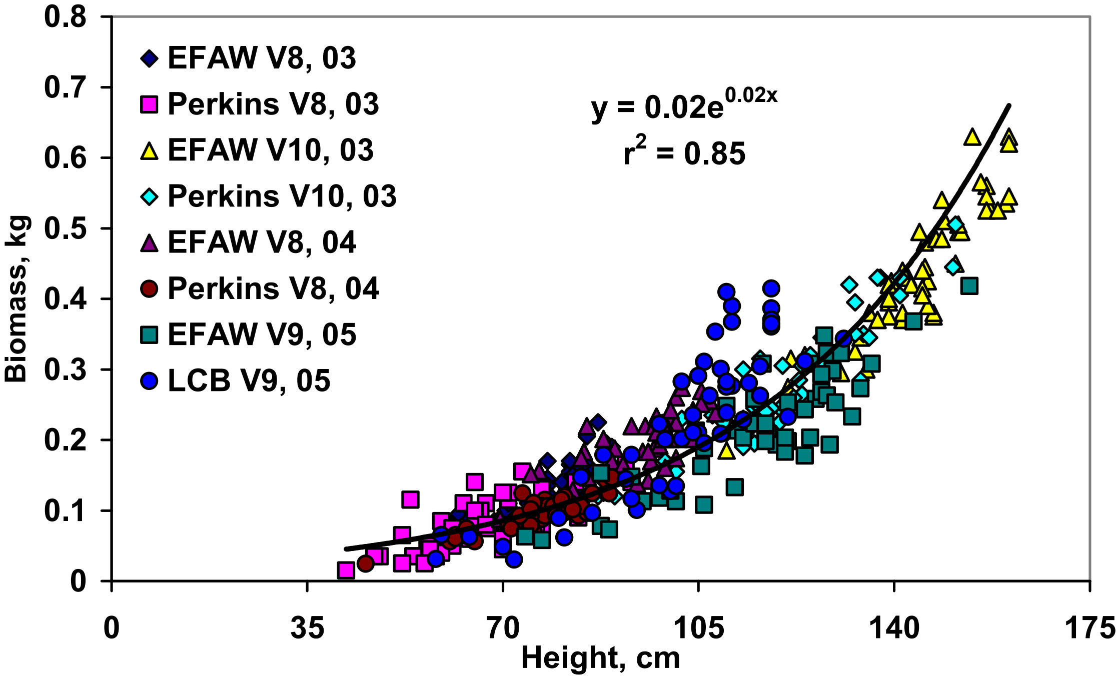

Figure A.9. Relationship of plant height and wet plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

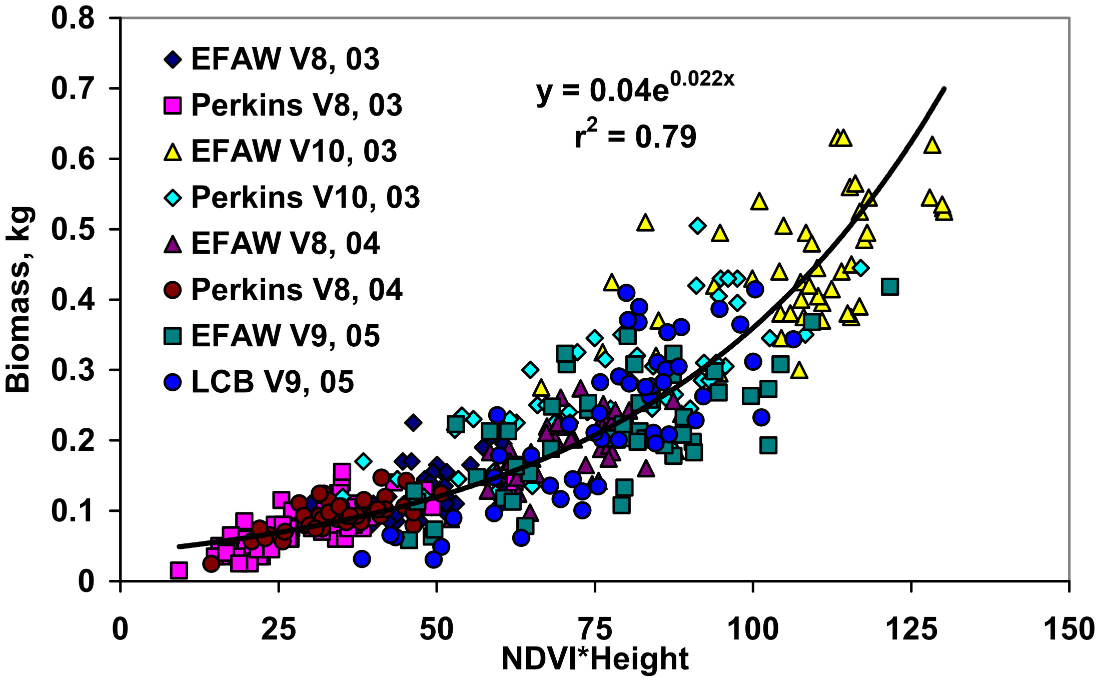

Figure A.9. Relationship of plant height and wet plant biomass at growth stages ranging between V8-V10 at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

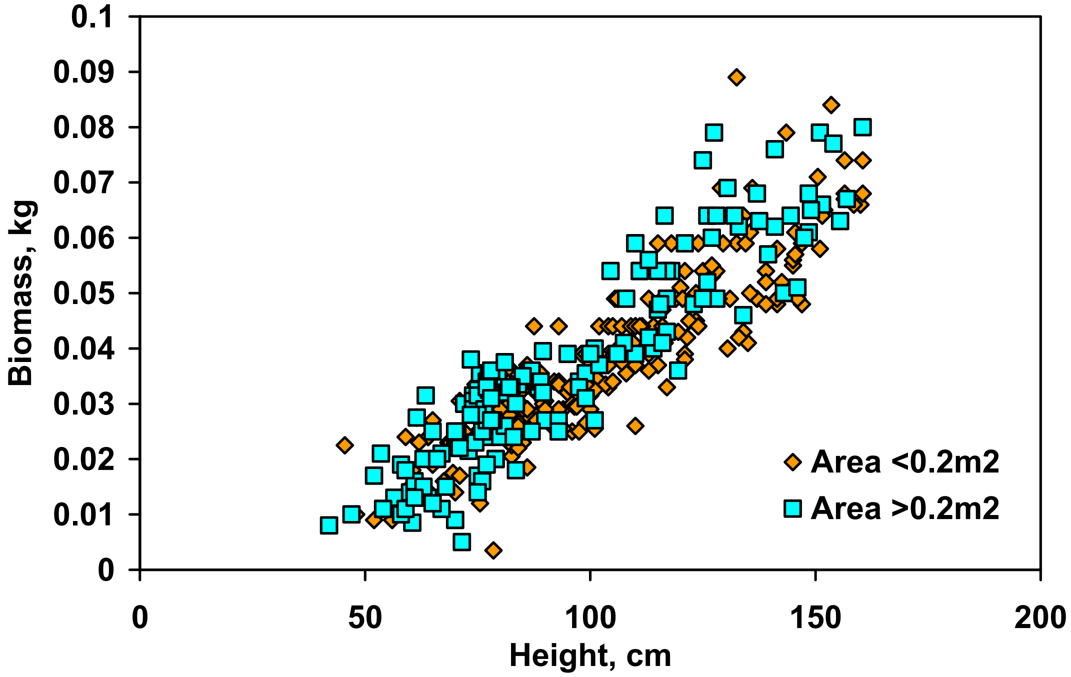

Figure A.11. Relationship of plant height and dry plant biomass with respect to area occupied by the plant at V8-V10 growth stages at Efaw, Perkins, and Lake Carl Blackwell in 2003-2005.

VITA

Kyle Wayne Freeman

Candidate for the Degree of

Doctor of Philosophy

Dissertation: INFLUENCE OF BEDS AND ROW SPACING IN WINTER WHEAT, AND BY-PLANT PREDICTION OF CORN FORAGE YIELD

Major Field: Soil Science

Biographical:

Personal Data: Born in Chickasha, Oklahoma, on April 7, 1977.

Education: Graduated from Tuttle High School, Tuttle, Oklahoma in May 1995; received Associate of Science degree in Agriculture from Connors State College, Warner, Oklahoma in May 1997; received Bachelors of Science degree in Agronomy from Oklahoma State University, Stillwater, Oklahoma in December 1999. Completed the requirements for the Master of Science degree with a major in Plant and Soil Science at Oklahoma State University in May 2002. Completed the requirements for the Doctor of Philosophy degree with a major in Soil Science at Oklahoma State University in December 2005.

Experience: Employed as a laborer for Tuttle Grain & Supply, 1993-1996,Tuttle, Oklahoma; summer intern for Crop Quest, 1997-1998, Montezuma,Kansas; summer intern for Zeneca Ag Products, 1999, Vernon, Texas;employed by Connors State College as a laboratory assistant, 1995-1997;employed by Oklahoma State University, Department of Plant and Soil Sciences as field assistant for the forage weed control and soil fertility projects, 1997-1999; employed by Oklahoma State University,Department of Plant and Soil Sciences as a graduate research assistant, 2000-2001; employed by Oklahoma State University, Department of Plant and Soil Sciences as a senior agriculturist, 2001-present.

Professional Memberships: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Name: Kyle Wayne Freeman Date of Degree: December, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INFLUENCE OF BEDS AND ROW SPACING IN WINTER WHEAT, AND BY-PLANT PREDICTION OF CORN FORAGE YIELD

Pages in Study: 76 Candidate for the Degree of Doctor of Philosophy

Major Field: Soil Science

Scope and Method of Study: For chapter one, Hard red winter wheat (Triticum aestivum L.) experiments were conducted to evaluate varieties, N rate, and row spacing in bedded and conventional planting systems. A factorial arrangement of treatments with 2 varieties (‘2174’, Jagalene), 2 N rates (0, 100), and 3 row spacings (6 & 15 cm with skipped rows, and 6 cm solid stand) were placed in the conventional planting system, while the bedded system consisted of 2 varieties, 2 N rates, and 2 row spacings. For chapter two, Corn (Zea mays L.) experiments were conducted to evaluate if spectral reflectance and plant height measurements could predict corn forage biomass on a by-plant basis. The normalized difference vegetation index (NDVI) for each plant was collected with a GreenSeeker™ Hand Held optical reflectance sensor mounted to a bicycle with a shaft encoding device to record distance. Plant height measurements were collected by extending the last collar leaf of each plant upward and recording the distance from the tip of the leaf to the ground.

Findings and Conclusions: For chapter one, in 4 out of 6 years grain yields in the bed planting systems were similar to grain yield of the conventional planting system. Grain yield was not affected by row spacing. At Hennessey, no consistent differences were recorded among varieties and N rate; however LCB posted significant differences across the 3 years of the study. There was a significant trend for increased grain yield with the solid stand compared to the skipped row treatments. This study showed a trend for increased grain yield of the bed system over the flat when cropping systems call for skipped row configurations that accommodate controlled traffic lane or relay cropping. For chapter two, over sites and years by-plant forage yield was predicted using the multiple of NDVI and plant height from growth stages ranging from V8 to V10. The combined use of plant height and NDVI better predicted forage yield than when using either plant height or NDVI alone. These results are encouraging since the ideal time to top-dress fertilize corn is at the V8-V10 growth stages and when biomass can be accurately predicted.

ADVISER’S APPROVAL: Dr. William Raun