NITROGEN USE EFFICIENCY IN HARD RED WINTER WHEAT

By

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ABSTRACT

Winter wheat varieties with improved N-use efficiency (NUE) have not been identified in the Great Plains. Research is also lacking which documents the components of NUE related to genetic variation for grain yield under limited N. One experiment was initiated to evaluate the difference in NUE among several cultivars and among experimental lines divergently selected for grain yield under limiting N. Seventeen experimental lines and 13 cultivars of hard red winter wheat were evaluated at the Agronomy Research Station at Perkins, OK in 1992-1993. Two levels of N (45 and 134 kg ha^{-1}) were applied within a split-plot randomized complete block design. Dry matter yield and percent plant N were determined at Feekes stage 8, anthesis, and maturity. At maturity, dry matter of grain, straw, and leaf components, as well as NUE parameters were determined. Partitioning the main effects of genotype shown large differences among cultivars and experimental lines in NUE components, grain yield, harvest index, and grain protein concentration. In a breeding program, consideration of growth stages is essential to successfully select improved genotypes based on N utilization. Any effort to genetically improve NUE in wheat should consider N-uptake efficiency

and N-utilization efficiency. To assess the overall importance of NUE, the cultivars that presented high yield potential and NUE should be evaluated under low N fertilizer and different locations to obtain a precise estimation of parameters in study. Nitrogen use efficiency was linearly correlated with N-uptake efficiency (0.75^{**} and 0.87^{**}), N-utilization efficiency (0.81^{**} and 0.89^{**}), translocation efficiency (0.81^{**} and 0.90^{**}), in the low and high N rates. A late planting was in part responsible for the extremely low grain yields and poor N use efficiency observed in the materials evaluated.

CHAPTER I

INTRODUCTION

Nitrogen (N) plays a central role in crop production because it is an essential element for plant growth and a major limiting nutrient in most U.S. agricultural soils. Nitrogen fertilizer is the most costly input used to produce crops. Nitrogen fertilizer use has increased greatly during the past three decades (Cerrato and Blackmer, 1990). An increased demand for N fertilizer in areas where production is most intensive has resulted in a rise in the cost of farm inputs. At the same time, public awareness of the possible contamination of water supplies by N fertilizer has placed more pressure on the agriculture industry to use applied N efficiently. Therefore, a real need exists to use N fertilizer as efficiently as possible in crop production and to determine what soil and plant genetic factors limit crop productivity in environments where N supply is limited. Breeders' awareness has recently increased for developing cultivars which more efficiently absorb N from the soil and/or more efficiently partition N to the grain. Such cultivars could minimize loss of N from the soil and make more economic use of applied N (Dhugga and Waines, 1989).

Nitrogen is the most limiting nutrient in winter wheat yields in the Great Plains (Nielsen and Halvorson, 1991), particularly Oklahoma. Initial interest in N utilization in wheat was prompted by the desire to increase protein content in the grain (McNeal et al., 1971). Some studies have focused on N accumulation in certain parts of the wheat plant which correlate with different degrees of deficiency at certain growth stages (Engel and Zubriski, 1982; Baker and Tucker, 1973; Vaughan et al., 1990a). Others studies have showed the importance to determine genotypic variation in N use efficiency in wheat cultivars. Van Sanford and Mackown (1986) found significant genotypic variation in soft red winter wheat for NUE, N harvest index and grain yield. They stated that N uptake would be a better criterion than N harvest index for identifying genotypes which use N most efficiently in producing protein.

Breeding for "Nitrogen-use efficiency" (NUE) in a crop depends on the presence of genetic variability in the species for traits that determine NUE, and also on the development of procedures to accurately measure NUE (Sisson et al., 1991). Utilization of N in grain production is associated with absorption, redistribution, translocation, and assimilation of N to produce grain. More studies are required to identify wheat genotypes which maintain high yield potential with lower N fertilizer requirements.

CHAPTER II

LITERATURE REVIEW

Nitrogen use efficiency is defined in many crops as grain production per unit of N available in soils (Moll et al., 1982; Van Sanford and Mackown, 1986; De Datta and Broadbent, 1988; Youngquist et al., 1992). Nitrogen use efficiency was defined as Gw/Ns, where Gw is grain weight per unit area and Ns is the N supply per unit area. NUE consists of two primary components: (1) the efficiency of absorption (uptake), and (2) the efficiency with which N absorbed is utilized to produce grain. Moll et al. (1982), working with maize (*Zea mays* L.), developed conceptual tools for evaluating the contribution of N uptake and utilization to variation in NUE. These were defined as uptake efficiency (Nt/Ns) and utilization efficiency (Gw/Nt), where Nt is total N in the plant at maturity. It follows that:

$$NUE = Gw/Ns = (Nt/Ns)(Gw/Nt).$$

This expression can be expanded to account for N partitioning to the grain vs. vegetative matter.

The utilization efficiency, Gw/Nt, can be expressed as:

$Gw/Nt = (Gw/Ng)(Ng/Nt)$, and $Ng/Nt = (Na/Nt)(Ng/Na)$, where

Gw/Ng = grain produced per unit of grain N, Ng/Nt = fraction of total N that is translocated to grain (translocation efficiency),

Na/Nt = fraction of total N that is accumulated after anthesis,

Ng/Na = ratio of N translocated to grain to N accumulated after anthesis

NUE can be defined in a more expanded form as

Gw/Ns = (Nt/Ns)(Gw/Ng)(Na/Nt)(Ng/Na)

Moll et al. (1982) found an interaction between maize hybrids and N treatments for all traits, except grain yield. The relative contribution of the two components (N uptake and utilization efficiency) to variation in NUE among hybrids was considerably different for the two levels of N applied. Variation in N uptake efficiency contributed relatively little to variation in NUE among hybrids under low N. Under high N, uptake efficiency contributed substantially to variation in NUE among hybrids. They concluded that the cause of variation in NUE appears to be a result of differences between levels of N supplied and differences among genotypes of diverse origin.

Sisson et al. (1991) evaluated NUE and its component parts, N uptake and N utilization for 12 tobacco cultivars. Significant differences were found among cultivars due to both N uptake and utilization efficiency. They indicated that any effort to genetically improve NUE should consider uptake efficiency and utilization efficiency equally.

Moll et al. (1987) developed single-cross maize hybrids with high grain yield, high levels of prolificacy, and high values for the components of NUE: N uptake efficiency and efficiency of utilization of accumulation N. Hybrid and S_1 progenies were developed from reciprocal crosses and self-pollinated of paired plants. Nitrogen uptake and utilization contributed equally to variation in NUE, suggesting that breeding for improved NUE was possible in maize by selecting among hybrid S_1 x S_1 progenies for NUE, expressed as grain weight to N supply averaged over N rates.

Chevalier and Schrander (1977) working with corn inbreds and their F_1 hybrids showed genetic variation in NO_3-uptake and partitioning of absorbed N. They observed genotypic differences in reduced N in all plant parts except ears, total NO_3-N uptake among inbreds, and accumulation in some plant tissues. These results demonstrated the potential for genetic improvement of NO_3-uptake and N utilization in maize.

Elbehri et al. (1993) noted that N uptake efficiency in grain amaranth plays a fundamental role in NUE variation. They observed that NUE decreased with increased soil N because of decreasing N uptake efficiency. Similar findings were found by Moll et al. (1982) working with maize. Grain amaranth is relatively inefficient in N use because of its low harvest index (9-15%) and N harvest index (12-26%). These values are low relative to a harvest index of about 45% for oats and corn (Brinkman and Rho, 1984; Ottman and Welch, 1989) and from 30-45% for wheat (Austin et al., 1977; Sharma et al., 1987; Entz and Fowler, 1991).

Van Sanford and Mackown (1986) determined the importance of N-uptake vs. utilization to variation in NUE and grain protein levels in soft red winter wheat. Cultivars showed differences for components of NUE under nonlimiting conditions: total plant N/nitrogen supplied to the plant (Nt/Ns), total plant dry weight/total plant N (Gw/Nt) and total plant dry weight/total grain N (Gw/Ng), N harvest index, and grain yield. Nitrogen-uptake efficiency constituted a significant proportion of the variation in NUE for yield (54%) and protein content (72%). There was a strong association between the amount of N absorbed and the plant's capacity to produce grain and protein. They concluded that under non-limiting N conditions, N uptake is strongly associated with grain yield and protein per unit area. Therefore, N uptake would be a better criterion for identifying genotypes which use nitrogen most efficiently in producing protein under high N conditions. They also recognized that strong environmental effects may be a hindrance to selection for NUE and its components (Teyker et al., 1989; Sisson et al., 1991).

May et al. (1991) reported findings similar to Van Sanford and Mackown (1986). Significant differences were obtained between NUE for protein and NUE for yield in the F_4 generation of each wheat population evaluated. Nitrogen uptake efficiency was associated with most of the variation in NUE-yield (91%) and NUE-protein (88%) in all populations.

Simultaneous increases in grain protein content and grain yield of spring wheat have been obtained by genetic improvement and from late applications of fertilizer N (Miezan et al., 1977; Loffler et al., 1985). Higher wheat grain yields in response to applied N have been explained by a greater capacity to convert dry matter into grain yield (Gehl et al., 1990). Those workers noted that a specific grain yield of any cultivar was not associated with a particular harvest index due to the differences in growing conditions, especially moisture that influenced the proportion of plant weight harvest in the grain.

Nitrogen accumulation in the production of dry matter has been extensively reviewed for various cereal crops (Denmead et al., 1974; Daigger et al., 1976; cited by Papakosta and Gagianas, 1991). Research has shown that N accumulation is maximized by heading and subsequently decreases to maturity, with final N contents at 60 to 80% of that found at heading. It is necessary to study accumulation of both dry matter and N at various growth stages in order to understand the processes of assimilation and partitioning of N in the context of plant growth and development. Cox et al. (1985a) found that increased accumulation of N between anthesis and maturity was associated with continued uptake of N from the soil, although translocation from roots may also have been involved. Indirect evidence showed that genetic differences in N assimilation from the soil could exist. Cox et al. (1985b) observed significant differences for N accumulation and genetic variation in N assimilation before and after anthesis in 95 F_5 bread wheat lines derived from a single cross. Papakosta and Gagianas (1991) and Dhugga and Wainess (1989) also found differences in N accumulation prior to anthesis. Harper et al. (1987) observed that plant N measurements after anthesis showed that about half of the grain N was from N redistribution within the plant, with the balance assimilated directly from the soil.

Work by Wuest and Cassman (1992) showed that fertilizer N applied at anthesis increased the amount of N taken up by the plants from 38 to 48% the first year, and from 49 to 61% the second year. Therefore, the amount of fertilizer N applied at anthesis had the greatest influence on postanthesis N-uptake, which ranged from 17 to 77 kg N ha^{-1}. Without supplemental N applied at anthesis, postanthesis N uptake only provided from 12 to 18% of the total grain N demand, and postanthesis N uptake was not increased by greater preplant N rates.

Investigations by Van Sanford and Mackown (1987) emphasized the importance of evaluating N differences at anthesis and maturity. They demonstrated that approximately 83% of N at maturity in soft red winter wheat was present in the plant at anthesis, and that higher grain N concentration was associated with postanthesis N-uptake. Postanthesis N uptake was associated with lower N utilization efficiency, higher grain N concentration, and lower grain yield. Based on their final analyses, they noted that nitrogen deficiency had a strong impact on grain N concentration and it could vary among cultivars.

Critical N levels at different growth stages has been recently evaluated, and results for wheat have been reported by several authors (Baker and Tucker, 1973; Vaughan et al., 1990b). Papastylianou et al. (1982) noted that the concentration of NO_3 at three stages of growth i.e. tillering, jointing and anthesis were related both to rates of applied nitrogen and to shoot dry matter yield at time of sampling. Total N in the whole plant was correlated with grain yield of winter wheat at Feekes 7 growth stage (Vaughan et al., 1990a). Total N in the leaves, NO_3-N in the whole plant, and stem NO_3-N were correlated with grain yield at Feekes stage 5. They indicated that nitrogen recommendations could be made from tissue N taken at Feekes 5.

Similar results were obtained by Papastylianou (1984), who established that NO_3-N concentration in the stem of wheat plants at tillering was associated with 79% of the total variation in grain yield. Baker and Tucker (1973) reported a critical N level at Feekes 7 and 7-8 in the whole plant (total N and NO_3-N, respectively). Donohue and Brann (1984) found a critical N level at Feekes 10.5 in the flag leaf (total N). In a later study Engel and Zubriski (1982) found a critical N level at Feekes 10.5 in the whole plant and top two leaves (total N). Roth et al. (1989), using two years of combined data, observed a critical level at Feekes 5-6 growth stages in the whole plant (total N) and at Feekes 5-6 in the stem (NO_3-N).

Raun and Westerman (1991) determined that crown and leaf NO_3-N at growth stages 4 and 5 were significantly correlated with grain yield, and that yield prediction models were reliable at or before Feekes stage 5. More recently, Kelly et al. (1993) working with soft red winter wheat, found that N-uptake was highest during stages 10.5 (sheath of last leaf completely emerged, spike swollen but not yet visible) and 11.1 (flowering complete, kernel milky ripe, Large, 1954), because the N absorbed at those growth stages was transported to the developing grain.

These studies indicate that the concentration of N varies with growth stage of the plant and the plant part sampled. Therefore, a successful breeding program must consider growth stage when selecting improved genotypes based on N utilization (Kelly et al., 1993). Proper interpretation of plant analysis requires that the critical concentration be established for a specific plant part at a specific stage of growth.

Further field studies are needed to determine genetic variation in hard red winter wheat under low N conditions. It is known that grain yield responds to increasing levels of N at very low fertility. Increasing grain yield potential is a major goal in most breeding programs (Ketata et al., 1976). There is a need to better understand the nature of NUE and its potential use in wheat breeding. The objectives of this research were: to (1) identify wheat cultivars which might be used in a breeding program for improving N-use efficiency, (2) identify NUE components which account for grain yield variation under low N and high N conditions, and (3) quantify the genetic relationship between yield potential (optimum N) and yield expression under low N.

CHAPTER III

MATERIALS AND METHODS

Development and Evaluation of Materials

A field experiment with 30 hard red winter wheat genotypes was established at the Agronomy Research Station, Perkins, OK in the fall of 1992. The 30 genotypes were comprised of 2 groups of different origin. Sixteen genotypes were experimental lines selected for either high or low grain yield under low N (one-half the recommended rate). Selection was initiated in 1991 at Perkins by testing 120 $S_{0:2}$ lines from a broad-based random-mated population in a replicates-in-sets design (4 sets and 2 replicates per set). The top and bottom one third of each set was selected for grain yield. These 80 $S_{0:2}$ lines were evaluated again in 1992 near Perkins under low N using the same replicates-in-sets design, except with 3 replicates. The two highest and two lowest yielding lines were selected in each set for further study, with the restriction that selections in each set showed similar maturity and stature in an observation nursery planted at the Agronomy Research Station at Stillwater, OK. The final set of selected lines were in the S_3 generation during evaluation of NUE. An S_3 unselected bulk of the original random-mated population was also included in the NUE evaluation as a control.

The remaining 13 genotypes constituted adapted cultivars previously or currently grown in the Great Plains. They were chosen not for their prior record of response to N but for their past performance record in Oklahoma or potential contribution to hard red winter wheat breeding programs.

The genotypes were arranged in a split-plot design with four replications, during the 1992-1993 growing season. Each plot consisted of four rows spaced 0.3 m apart and 3 m in length. Nitrogen levels were assigned to whole-plots and genotypes were assigned to sub-plots. Two levels of nitrogen were selected representing suboptimal and optimal levels of applied N rates: a low level of 45 kg ha^{-1} and a high level of 134 kg ha^{-1}. The high rate was the recommended rate for a yield goal of 3450 kg ha^{-1}, and is commonly used in the wheat breeding at Oklahoma State University. Traditionally, genetic improvement has been accomplished under that level of soil N.

NUE Data Analysis

Nitrogen-use efficiency was analyzed according to an expanded model of Moll et al. (1982). Nitrogen-use efficiency for grain yield was partitioned into various components as follows:

Gw/Ns = grain weight/N supply (applied N to the plant),

Gw/Ns = (Nt/Ns)(Gw/Nt), where

Nt/Ns = uptake efficiency = ratio of total plant N to N supply per unit area,

Nt = (grain yield)(grain N) + (dry wt of stem and leaves)

(N in stem and leaves)

Gw/Nt = utilization efficiency = (Gw/Ng)(Ng/Nt), where

Gw/Ng = grain weight/grain N and

Ng/Nt = translocation efficiency = proportion of total plant N in the grain = (Na/Nt)(Ng/Na), where

Na/Nt = proportion of total plant N accumulated after anthesis, i.e.,

Na = Nt-Nv, where

Nv = total above ground plant N at anthesis = (dry wt at anthesis) (N at anthesis),

Ng/Na = proportion of N accumulated after anthesis translocated to the grain.

One row was harvested over two developmental periods; i.e., one half of the row at Feekes 8 (second node visible) and the other half at anthesis. At maturity, a complete row was harvested for grain, leaf, and stem samples. For each harvest (Feekes 8, anthesis and maturity) all plots were harvested on the same day. Differences in physiological growth stage among the cultivars evaluated were generally small. Samples were dried and weighed. All vegetative samples were first ground in a large Wiley mill (Taylor et al., 1993), and later in an automated grinding unit to obtain finely ground plant tissue samples (>100 mesh), after which they were analyzed for total N.

Two center rows were harvested at maturity with a binder at ground level. Bundles were threshed and plot grain yield was recorded. Grain weight was taken for 1000-kernel samples. Grain yield and test weight was determined at 12% moisture. Heading date, plant height (cm), and harvest index (grain yield/total dry weight including the grain) were also recorded.

Nitrogen was analyzed by dry combustion using a Carlo-Erba NA 1500 analyzer, designed to determinate total N present in a wide range of organic and inorganic samples (Jojola et al., 1993).

Statistical Analyses

Analysis of variance was performed on N-use efficiency components, grain yield, yield at Feekes 8 and anthesis, harvest index, and protein (SAS Institute Inc., 1985). The data were analyzed as a split-plot design with N rate as the main plot treatment, and genotypes as the sub-plot treatment (Snedecor and Cochran, 1980; Gomez and Gomez, 1984).

The variation among genotypes was further partitioned among cultivars and among experimental lines. The latter source was partitioned among high-yield selections (HY), low yield selections (LY), HY vs. LY, and S_3 Bulk vs. selections. These analyses were made for N-use efficiency (Gw/Ns), N-uptake efficiency (Nt/Ns), N-utilization efficiency (Gw/Nt), translocation efficiency (Ng/Nt), N harvest index (Ng/Nt), proportion of total plant N accumulated after anthesis (Na/Nt), grain yield/grain N (Gw/Ng), harvest index, grain yield, and N in the grain (Ng). In general genotype x N rate interactions were not significant for the variables evaluated in this study. However, genotype x N rate was highly significant for N use efficiency (Gw/Ns), utilization efficiency (Gw/Nt), translocation efficiency (Ng/Nt), and harvest index (HI). Correlation coefficients based on genotype means in each N treatment were determined.

CHAPTER IV

RESULTS AND DISCUSSION

Cultivars evaluated showed genetic diversity for N-use efficiency (Gw/Ns), N-uptake efficiency (Nt/Ns), N-utilization efficiency (Gw/Nt), fraction of total N translocated to the grain (Ng/Nt), fraction of total N accumulated after anthesis (Na/Nt), grain yield/Ng (Gw/Ng), grain yield and harvest index, which impacted on the partitioning analysis (Tables 1 and 2).

Significant genotypic differences were observed for all NUE components, grain yield, and harvest index (HI). These results indicate that the varieties and experimental lines studied had substantial genetic diversity, which impacted on the partitioning analysis and those cultivars could be used to improve NUE in a wheat breeding program. These findings regarding NUE and grain yield are in general agreement with those of Van Sanford and Mackown (1986). Others authors have reported significant genotypic variation in wheat and those genotypic differences have been associated primarily with variation in dry matter at anthesis (MacNeal et al., 1966; Austin, et al., 1977) and maturity (Loffler, et al., 1985; Cox et al., 1985b).

A significant genotype x N rate interaction was observed for NUE (Gw/Ns), utilization efficiency (Gw/Nt) and fraction of total N translocated to the grain (Ng/Nt), thus limiting interpretation of main effects. Significant genotype x N rate interactions indicates wide fluctuations in the ranking of genotypes across N rates.

Significant differences among high-yield (HY) and among low-yield (LY) selections were observed for all NUE components, except for N-uptake efficiency (Nt/Ns) and total plant N accumulated after anthesis/total plant N (Na/Nt) that did not exhibit significant differences, therefore genotypes performed consistently at both N rates evaluated.

Significant differences between HY vs. LY were observable in all NUE components, grain yield and HI, except Gw/Ng which was not significant indicating that genetic differences were relatively consistency among HY and LY (Tables 1 and 2). Differences in NUE were more attributable to Gw/Nt than Nt/Ns which did not present significant differences among HY and LY.

Mean values

Increased applied N significantly decreased N use efficiency, N-uptake efficiency, N-utilization efficiency, fraction of total N translocated to the grain (Ng/Nt), grain yield/total grain N (Gw/Ng), and grain yield (Table 3). Nitrogen use efficiency components could be satisfactorily evaluated without the use of fertilizer, or possibly under limited N conditions. Those results agree with those reported by De Datta and Broadbent (1988). They noted that the better genotypes are sufficiently consistent to be used in a breeding program to improve N utilization efficiency at suboptimal fertilizer N levels. Engel and Zubriski

(1982) reported that high rates of applied N would not have significantly improved growth.

Differences between varieties were found at the low and high N rates for NUE, Nt/Ns, Gw/Nt, Ng/Nt, Na/Nt, Ng/Na, Gw/Ng and HI, grain yield, and protein (Table 4). Mean expression at the low and high N levels was highest for N-utilization efficiency (15.9 and 11.8 kg ha^{-1}) than for N-uptake efficiency (1.3 and 0.5 kg ha^{-1})(Table 3). According to those results, N-utilization is relatively more important than N-uptake efficiency. There were relatively much smaller differences in N utilization efficiency than N use efficiency between varieties. Similar results were reported for maize (Moll et al., 1982) and wheat (Dhugga and Waines, 1989; Huggins and Pan, 1993). Elberhi et al. (1993) noted that NUE decreased in amaranth with increased soil N because of decreasing N-uptake efficiency. In soils with limited available N, utilization efficiency has been found to be more important than N-uptake when considering genotypic differences in grain production (Moll et al., 1982; Van Sanford and MacKown, 1986, cited by Youngquist et al., 1992). In other studies, Moll et al. (1987) and Sisson et al. (1991) found that variation in Nt/Ns and Gw/Nt contribute equally to the prediction of mean yield of selected genotypes. They suggested that any effort to genetically improve N-use efficiency should consider both components, N-uptake and N-utilization efficiency, at the same time.

The varieties Longhorn, 2163, AGSECO 7853, Triumph 64, and 2180 had significantly higher NUE compared with some varieties evaluated (Table 4). The same varieties had improved values for Nt/Ns (except 2180) and Gw/Nt. These genotypes may be used in a breeding program to improve N utilization efficiency at low fertilizer N rates.

The fraction of total N translocated to the grain was low for both N rates. Reports by Terman et al. (1969) and Cox et al. (1986) showed increases of N translocation due to N fertilizer. Others authors have noted differences in translocation efficiency during the grain filling period, when the plant retains a specific amount of dry matter at anthesis that is essential for survival (biological functions), while the remainder is available for translocation (Papakosta and Gagianas, 1991). In this study, maximum dry matter accumulation was present at anthesis (not shown).

Maximum yields were obtained at the low N rate, except for Longhorn, 2163, 2180, Karl, and TAM 200 that exhibited highest mean values of yield at the high N rate (Table 4). Most of the genotypes with high grain yield had increased N use and translocation efficiency. Campbell et al. (1993) noted that grain yield response to fertilizer N increased more steeply at low than at higher N levels. Studies by Gehl et al. (1990) showed that higher grain yield responses to applied N in wheat cultivars have been explained by a greater capacity to convert dry matter into grain yield. The variety Longhorn had the highest grain yield at both low and high N rates (1585 kg ha^{-1} and 1734 kg ha^{-1}). Under low and high N rates, 2163, AGSECO 7853, Triumph 64, 2180, Karl, Mesa, and Siouxland showed the highest grain yield (Table 4). The same varieties also performed well respective to N use efficiency parameters Gw/Ns, Nt/Ns, Gw/Nt, and Ng/Nt.

The HY experimental lines 1-6, 1-25, 2-2, 2-24, and 4-6 had relatively high N use efficiencies with higher grain yields at the low and high N rates (Table 5). In contrast, no LY experimental lines performed well in terms of grain yield or N use efficiency components when compared with varieties and HY entries. Those results indicate the selection process was successful for grain yield.

Mean protein values in the varieties ranged from 10.9 (TAM W-101) to 12.9% (2180) at the low N rate and from 12.0 (Triumph 64 and TAM W-101) to 13.5% (Longhorn) at the high N rate, respectively, with somewhat lower grain yields and N-use efficiency.

High harvest index (HI) levels suggest an increased capacity to translocate photosynthates to the grain. Mean HI values in the varieties ranged from 24% (TAM-101) to 34% (2163) at the low N rate and from 21% (TAM 200 and 2158) to 32% (2180) at the high N rate (Table 4). Note that HI decreased with increased N rate. Kramer (1979); Dhuga and Waines (1989); and Gehl et al. (1990) found that HI decreased with increased N applied. This trend was more evident in the LY experimental lines that showed higher grain yield means under low N inputs (335 to 745 kg ha^{-1}), than at high N rates (217 to 629 kg ha^{-1}). Additionally, environment and late planting influences on HI. The low HI values observed can be attributed to a late planting, environmental conditions present during vegetative growth, followed by low soil moisture and high temperatures. Sharma et al. (1991); and Howell (1990) noted that variation on HI may be induced by environmental factors, but can also be attributed to genetic differences (Kramer, 1986). Sharma and Smith, (1986); Sharma et al. (1987); and Howell, (1990) found that high temperatures and dry winds during the grain-filling period decreased HI, condition similar to what was found in this study.

Correlation

Nitrogen use efficiency was positively correlated with Nt/Ns (0.75** and 0.87**), Gw/Nt (0.81** and 0.89**), Ng/Nt (and 0.81** and 0.90**), Na/Nt (0.55** and 0.63**), and harvest index (0.71** and 0.63**) at low and high N rates, respectively (Table 6). The positive correlation found in this study is corroborated by similar findings of others workers (Moll et al., 1982; Van sanford and MacKown, 1986; Moll et al., 1987).

A commonly used measure of N partitioning is the N harvest index (NHI), defined by Austin et al. (1977) as grain N/total N (or fraction of total N that is translocated to the grain, Ng/Nt). In this study, low values were found for NHI. A very low and nonsignificant correlation between protein content and NHI was observed (0.11 and -0.14) at low and high N rates. The very low and nonsignificant correlation between NHI and protein content found in this study, has also been reported by Desai and Bathia (1978); Cox et al. (1986); and Van Sanford and Mackown (1986). Those findings differed from results by May et al. (1991) who found highly significant correlation between NHI and protein content.

Harvest index and NHI were positively correlated at the low and high N rates. These results agree with those reported by Austin et al. (1977) and Desai and Bhatia (1978) who observed a similar positive correlation. Their work indicated that mobilization and translocation of N compounds from foliage to grain are closely associated but not entirely identical. However, they emphasized that N partitioning is considerably influenced by environmental conditions.

Grain yield was positively correlated with Nt/Ns, Gw/Nt, Ng/Nt and Na/Nt, test weight, and HI at the low and high N rates. Grain yield and grain protein were negatively correlated at the low N rate, and moderate and negatively correlated at the high N rate. These results agree with those reported by Terman et al. (1969); Hunter and Stanford (1973); and Loeffler et al. (1985). The negative correlation between grain yield and protein content, arises from higher energy costs associated with protein synthesis as compared to carbohydrate synthesis. Guthrie et al. (1984) and Cox et al. (1985a) noted that a low to moderate correlation allows for selecting lines with high grain yield and high protein concentration and that this could aid in the development of high grain protein content, high-yielding soft red winter wheat cultivars (May et al., 1991). Nevertheless, it is recognized by plant breeders that protein content is not constant even for a particular genotype (Johnson et al., 1968, cited by Desai and Bhatia, 1977). Differences in protein contents among cultivars can be shown more clearly under conditions where applied N results in increased yields rather than where protein content increases (Terman et al., 1969).

Grain yield was negatively correlated with stem and leaf total N, and heading date at the low and high N rates, respectively (Table 7). This would appear that those genotypes that were the highest yielding also had the ability to deplete N in the stem and leaves. This finding is consistent with these of Francis et al. (1993). The negative and statistically significant correlation between grain yield and heading date is more attributable to environmental influences. Those results are corroborated by similar finding reported by Ketata et al. (1976). A consistently positive correlation between grain yield and total N at maturity (0.75^{**}, 0.87^{**} and 0.72^{**}) at the low, high and combined N rates, reflects the importance of total N accumulation on breeding techniques for N use efficiency.

Grain yield and N accumulated from Feekes 8 growth stage to maturity (0.39^{**} and 0.40^{**}) and from anthesis to maturity (0.57^{**} and 0.59^{**}) were positively correlated at the low and high N rates, respectively (not shown). These results corroborate findings reported by Cox et al. (1985a).

CHAPTER V

CONCLUSIONS

Genetic variation was found among varieties and experimental lines for N use efficiency and its components. The contribution of N-utilization efficiency to variation in NUE was more pronounced particularly between experimental lines divergently selected for yield. Any effort to genetically improve NUE should focus on N-utilization efficiency.

Nitrogen use efficiency was highly correlated with grain yield at both N rates. The quantity of fertilizer N required to produce maximum grain yield varied among wheat cultivars. Differences among varieties and experimental lines in NUE components at the low and high N rates, suggest that cultivars should be selected for improved N use efficiency under N limiting conditions.

This study suggests that the varieties Longhorn, 2163, AGSECO 7853, Triumph 64, 2180, Karl, and experimental lines 4-6, 1-25, 2-24, 2-2, and 1-6 HY could be beneficial in a breeding program designed to improve N use efficiency.

Although no data was collected to indicate as much, alternative planting dates and environmental conditions could alter N use efficiency. Those findings support future efforts for genetic improvement of NUE and improvement of grain expression under limited N supply.

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TABLE 1. Mean squares for N-use efficiency components of 30 genotypes at two N rates measured at Perkins, OK 1992-1993.

Source	df	N-use trait†					
		N-use efficiency (Gw/Ns)	N-uptake efficiency (Nt/Ns)	N-utilization efficiency (Gw/Nt)	Fraction of total N translocated to the grain (Ng/Nt)	Fraction of total N accumulated after anthesis (Na/Nt)	Grain yield/ grain N (Gw/Ng)
Replicate (R)	3	79	0.21	15	0.003	0.22	26
N Rate	1	12496**	35.00**	1049**	0.330**	1.25*	881*
R*N Rate	3	42	0.140	12	0.001	0.014	84
Genotype (G)	29	228**	0.160**	137**	0.081**	0.57**	40**
Among Varieties	12	112**	0.160**	33**	0.029**	0.40**	42**
Among Experimentals	16	188**	0.084**	149**	0.088**	0.48**	32**
Among high-yield (HY)	7	52**	0.030	32**	0.012**	0.07	43**
Among low-yield (LY)	7	26**	0.040	36**	0.016**	0.25	28*
HY vs LY	1	2458**	0.88**	1903**	1.210**	5.22**	0.36
S_3 Bulk vs others	1	0.82	0.001	3	0.004	0.29	7
G*N Rate	29	52**	0.026	6*	0.004**	0.13	9
Error	174	7	0.031	3	0.002	0.15	9

*,**Significant at the 0.05 and 0.01 probability levels, respectively.
† N-use efficiency = grain yield/N supply (Gw/Ns); N-uptake efficiency = total plant N/N supply (Nt/Ns); N-utilization efficiency = grain yield/total plant N (Gw/Nt); fraction of total N that is translocated to the grain = N-translocation efficiency (N harvest index,Ng/Nt); fraction of total N that is accumulated after anthesis (Na/Nt); grain yield/total grain N(Gw/Ng)

TABLE 2. Mean squares for yield and harvest index of 30 genotypes at two N rates measured at Perkins, OK 1992-1993.

Source	df	Grain yield	Harvest index
		kg/ha	%
Replicate (R)	3	271625	0.003
N Rate	1	400359	0.05**
R*N Rate	3	46416	0.001
Genotype (G)	29	1090601**	0.03**
Among Varieties	12	590655**	0.01**
Among Experimentals	16	823273**	0.03**
Among high-yield (HY)	7	244393**	0.004**
Among low-yield (LY)	7	109887**	0.008**
HY vs LY	1	1069231**	0.38**
S3 Bulk vs others	1	99	0.0003
G*N Rate	29	29257	0.001**
Error	174	24671	0.001

*,**Significant at the 0.05 and 0.01 probability levels, respectively.

TABLE 3. Means for grain yield, N-use efficiency and components, and harvest index of 30 genotypes at two N rates measured at Perkins, OK 1992-1993.

Source	Grain yield	N-use efficiency (Gw/Ns)	N-uptake efficiency (Nt/Ns)	N-utilization efficiency (Gw/Nt)	Fraction of total N translocated to the grain (Ng/Nt)	grain yield/ grain N (Gw/Ng)	Harvest index
	N-use trait†						
	kg/ha						%
Low N rate							
Mean	930	20.7	1.3	15.9	0.4	42.2	24.0
Varieties	1154	25.7	1.4	18.5	0.4	42.7	28.2
Experimental lines	758	16.9	1.2	14.0	0.3	39.2	20.5
High-yield selection	1062	23.6	1.3	18.3	0.5	41.2	26.1
Low-yield selection	461	10.3	1.1	9.6	0.2	37.0	14.9
S_3 Bulk (unselected)	713	15.9	1.1	14.0	0.4	41.3	20.0
LSD (0.05)	211	3.7	0.2	2.3	0.1	4.1	0.03
High N rate							
Mean	848	6.3	0.5	11.8	0.3	38.4	21.0
Varieties	1122	8.3	0.6	14.3	0.4	39.7	25.9
Experimental lines	639	4.8	0.5	9.8	0.3	37.4	17.4
High-yield selection	915	6.8	0.5	13.1	0.3	38.1	22.5
Low-yield selection	359	2.7	0.4	6.5	0.2	36.8	12.0
S_3 Bulk (unselected)	691	5.1	0.5	10.7	0.3	36.2	19.0
LSD(0.05)	211	3.7	0.2	2.3	0.1	4.1	0.03

† N-use efficiency = grain yield/N supply (Gw/Ns); N-uptake efficiency = total plant N/N supply (Nt/Ns)
N-utilization efficiency = grain yield/total plant N (Gw/Nt); fraction of total N that is translocated to the grain = N-translocation efficiency (N harvest index,Ng/Nt); grain yield/total grain N (Gw/Ng)

TABLE 4. Means for grain yield, N-use efficiency and components, harvest index, and protein of 13 varieties at two N rates measured at Perkins, OK 1992-1993.

Genotype	Grain yield	N-use efficiency (Gw/Ns)	N-uptake efficiency (Nt/Ns)	N-utilization efficiency (Gw/Nt)	Fraction of total N transloca-ted to the grain (Ng/Nt)	Fraction of total N accumulated after anthe-sis (Na/Nt)	Ratio of N translocated to grain to N accumulated after anthesis (Ng/Na)	Grain yield/ Grain N (Gw/Ng)	Harvest index	Protein content
	N-use trait†									
	kg/ha								%	
Low N rate										
Longhorn	1585	35.3	1.7	20.6	0.5	0.29	-1.6	40.8	28	12.7
2163	1584	35.3	1.7	20.9	0.5	0.23	10.7	43.1	34	11.7
AGSECO 7853	1327	29.5	1.5	20.0	0.4	0.03	-0.04	45.7	29	12.2
Triumph 64	1326	29.6	1.5	19.7	0.5	0.00	29.0	40.7	31	11.2
2180	1125	25.1	1.2	20.6	0.5	-0.35	-6.7	42.3	32	12.9
Chisholm	1098	24.5	1.3	18.7	0.4	-0.09	-2.8	45.4	29	11.6
Siouxland	1080	24.1	1.5	16.1	0.4	0.09	-4.7	39.0	24	12.7
Karl	1075	24.0	1.3	19.6	0.5	-0.27	-0.6	39.4	30	12.7
Cimarron	1035	23.1	1.2	19.1	0.5	-0.29	-3.4	43.0	30	11.9
Mesa	1033	23.0	1.3	17.2	0.4	-0.04	-0.2	44.0	29	12.1
TAM 200	987	22.0	1.4	15.3	0.4	-0.01	-1.9	42.8	22	12.2
2158	894	19.9	1.2	16.4	0.4	-0.37	11.3	42.2	25	12.6
TAM W-101	860	19.2	1.2	15.8	0.3	0.25	0.1	46.1	24	10.9
High N rate										
Longhorn	1734	12.9	0.8	16.2	0.5	0.3	1.8	35.8	28	13.5
2163	1687	12.5	0.8	16.9	0.4	0.0	-0.03	39.0	31	13.2
Agseco 7853	1318	9.8	0.7	13.8	0.4	0.1	-11.7	39.4	26	13.2
Triumph 64	1289	9.6	0.5	17.7	0.4	-0.1	4.2	41.3	30	12.0
2180	1172	8.7	0.5	17.3	0.5	-0.5	-1.6	37.8	32	13.2
Karl	1111	8.3	0.6	14.8	0.4	-0.1	-2.0	35.5	28	13.7
TAM 200	1030	7.7	0.6	11.9	0.3	0.1	1.2	39.5	21	13.0
Cimarron	1009	7.5	0.5	14.7	0.4	-0.4	-1.1	41.7	27	12.9
Mesa	972	7.2	0.5	13.6	0.3	-0.2	-1.5	41.7	25	12.9
Siouxland	930	6.9	0.6	12.2	0.3	-0.2	1.0	37.7	22	13.3
TAM W-101	800	6.0	0.5	11.7	0.3	-0.6	-1.8	44.1	22	12.0
Chisholm	787	5.9	0.4	13.4	0.3	-0.6	0.1	43.3	24	12.8
2158	740	5.5	0.5	11.6	0.3	-0.2	-0.7	39.0	21	13.4

† N-use efficiency = grain yield/N supply (Gw/Ns); N-uptake efficiency = total plant N/N supply (Nt/Ns); N-utilization efficiency = grain yield/totalplant N (Gw/Nt); fraction of total N that is translocated to the grain = translocation eficiency (N harvest index,Ng/Nt) fraction of total N that is accumulated after anthesis = total plant N accumulated after anthesis/total plant N (Na/Nt); ratio of N translocated to the grain to N accumulated after anthesis = total plant N accumulated after anthesis to grain (Ng/Na); grain yield/total grain N (Gw/Ng)

TABLE 5. Mean for grain yield, N-use efficiency and components, harvest index, and protein of the 8 high-yield and 8 low-yield selection and one unselected control at two N rates measured at Perkins, OK 1992-1993.

Genotype	Grain yield	N-use efficiency (Gw/Ns)	N-uptake efficiency (Nt/Ns)	N-utilization efficiency (Gw/Nt)	Fraction of total N transloca-ted to the grain (Ng/Nt)	Fraction of total N accumulated after anthe-sis (Na/Nt)	Ratio of N translocated to grain to N accumulated after anthesis (Ng/Na)	Grain yield/ Grain N (Gw/Ng)	Harvest index	Protein content
		N-use trait†								
	kg/ha								%	
Low N rate										
4-6-HIGRP	1282	28.6	1.4	20.8	0.5	0.1	-0.1	43.4	26	11.8
1-25-HIGRP	1207	26.9	1.3	20.1	0.5	-0.2	-4.9	43.7	27	12.1
2-24-HIGRP	1204	26.9	1.4	19.5	0.6	-0.1	7.6	43.8	28	11.9
2-2-HIGRP	1105	24.6	1.4	17.6	0.4	-0.2	0.6	41.1	27	12.5
1-6-HIGRP	1076	24.0	1.1	22.3	0.6	-0.4	-5.2	39.6	30	13.3
3-9-HIGRP	894	19.9	1.2	16.0	0.4	-0.2	-0.5	39.6	24	12.4
3-24-HIGRP	885	19.7	1.2	16.8	0.4	-0.2	-1.3	39.9	25	12.4
4-11-HIGRP	841	18.7	1.3	14.2	0.4	-0.1	0.5	38.3	22	13.1
4-23-LOGRP	745	16.6	1.1	14.7	0.3	-0.2	-0.7	45.4	21	11.3
S3 BULK	713	15.9	1.1	14.3	0.4	-0.2	-0.7	41.3	20	13.0
1-28-LOGRP	507	11.3	1.0	11.9	0.3	-0.4	-1.3	41.2	16	12.5
4-4-LOGRP	505	11.3	1.1	10.1	0.2	-1.0	-0.5	44.2	16	12.6
3-18-LOGRP	465	10.4	1.0	10.2	0.2	-0.1	-0.7	45.8	16	13.2
2-28-LOGRP	428	9.5	1.0	9.0	0.2	-0.5	-0.7	42.6	15	12.4
1-9-LOGRP	364	8.1	1.1	7.6	0.2	-0.5	-0.7	39.9	13	13.3
3-29-LOGRP	338	7.5	1.0	7.3	0.2	-0.4	-12.2	41.2	12	13.1
2-8-LOGRP	335	7.5	1.3	5.7	0.1	-0.5	2.7	40.9	10	14.7
High N rate										
4-6-HIGRP	1202	8.9	0.6	14.6	0.4	-0.18	34.1	41.7	24	12.1
1-25-HIGRP	1089	8.1	0.6	14.2	0.4	-0.04	-2.7	38.5	23	12.9
2-24-HIGRP	1024	7.6	0.5	14.7	0.4	-0.34	-2.2	39.3	25	12.4
1-6-HIGRP	947	7.0	0.5	12.9	0.4	-0.12	1.4	35.7	23	14.3
3-24-HIGRP	883	6.6	0.5	13.0	0.4	-0.21	0.7	37.2	23	13.3
2-2-HIGRP	820	6.1	0.5	13.3	0.3	-0.42	-1.5	40.4	22	13.4
S3 BULK	691	5.1	0.5	10.7	0.3	-0.18	7.2	36.2	19	14.3
3-9-HIGRP	676	5.0	0.4	11.7	0.3	-0.41	-0.9	39.1	21	13.2
4-11-HIGRP	667	5.0	0.5	10.0	0.3	-0.21	-2.7	32.7	19	14.3
3-18-LOGRP	629	4.7	0.5	10.1	0.3	-0.39	-0.8	37.4	20	14.1
4-23-LOGRP	464	3.5	0.4	8.0	0.2	-0.83	-0.4	39.4	14	13.0
4-4-LOGRP	396	2.9	0.4	6.8	0.9	-0.58	-2.9	37.7	12	13.3
1-28-LOGRP	337	2.5	0.4	6.3	0.2	-0.62	-0.5	37.2	11	14.3
1-9-LOGRP	296	2.2	0.4	5.4	0.2	-0.74	-0.2	35.4	11	14.5
3-29-LOGRP	274	2.0	0.4	5.4	0.2	-0.93	-0.3	36.0	10	13.5
2-8-LOGRP	257	1.9	0.4	4.3	0.1	-0.78	-0.2	33.4	8	15.6
2-28-LOGRP	217	1.6	0.3	5.4	0.1	-1.11	-0.2	38.1	10	13.6

† N-use efficiency = grain yield/N supply (Gw/Ns); N-uptake efficiency = total plant N/N supply (Nt/Ns); N-utilization efficiency = grain yield/totalplant N (Gw/Nt); fraction of total n that is translocated to the grain = translocation eficiency (N harvest index,Ng/Nt) fraction of total N that is accumulated after anthesis = total plant N accumulated after anthesis/total plant N (Na/Nt); ratio of N translocated to the grain to N accumulated after anthesis = total plant N accumulated after anthesis to grain (Ng/Na); grain yield/total grain N (Gw/Ng)

TABLE 6. Phenotypic correlation for N-use efficiency (NUE), grain yield, harvest index, protein and NUE components for 30 genotypes at two N rates measured at Perkins, OK 1992-1993.

	N-use trait†								
	Grain yield	Harvest index	Protein content	N-uptake efficiency (Nt/Ns)	N-utilization efficiency (Gw/Nt)	Fraction of total N trans-located to the grain (Ng/Nt)	Fraction of total N accumulated after anthesis (Na/Nt)	Ratio of N translocated to grain to N accumulated after anthesis (Ng/Na)	Grainyiel/ grain N Gw/Ng)
N-use efficiency (Gw/Ns)	‡0.99** 0.99** 0.66**	0.71** 0.63** 0.66**	-0.02 -0.21 -0.38**	0.75** 0.87** 0.90**	0.81** 0.89** 0.79**	0.81** 0.90** 0.73**	0.55** 0.63** 0.45**	0.16 0.02 0.07	0.002 0.22** 0.37**
Grain yield		0.63** 0.71** 0.88**	-0.02 -0.21* -0.15	0.75** 0.87** 0.45**	0.81** 0.89** 0.80**	0.81** 0.90** 0.83**	0.55** 0.63** 0.59**	0.16 0.02 0.08	0.001 0.22* 0.13*
Harvest index			0.13 -0.03 -0.26**	0.83** 0.89** 0.40**	0.21* 0.42** 0.92**	0.24* 0.44** 0.93**	0.56** 0.65** 0.45**	0.17 0.07 0.04	0.18 0.04 0.24**
Protein content				0.26** -0.008* -0.32*	-0.20* -0.38** -0.42**	0.11 -0.14 -0.15*	0.14 0.01 0.07	0.02 -0.05 -0.02	-0.99** -0.99** -0.99**
N-uptake efficiency (Nt/Ns)					0.25** 0.59** 0.51**	0.33** 0.63** 0.47**	0.63** 0.70** 0.43**	0.21** 0.04 0.07	-0.27** 0.01 0.31**
N-utilization efficiency (Gw/Nt)						0.95** 0.97** 0.96**	0.25** 0.49** 0.39**	0.07 -0.004 0.03	0.18* 0.38** 0.40**
Fraction of total N translocated to the grain (Ng/Nt)							0.28** 0.54** 0.42**	0.09 0.02 0.03	-0.12 0.14 0.13**
Fraction of total N accumulated after anthesis (Na/Nt)								0.08 0.06 0.07	0.13 -0.01 0.005
Ratio of N translocated to grain to N accumulated after anthesis (Ng/Na)									-0.03 0.06 0.01

*, **,Significantly different from zero correlations at the 0.05 and 0.01 levels of probability, respectively;

† N-use efficiency = grain yield/N supply(Gw/Ns); N-uptake efficiency = total plant N/N supply (Nt/Ns); N-utilization efficiency = grain yield/total plant N (Gw/Nt);fraction of total N that is translocated to the grain = translocation efficiency (Ng/Nt);fraction of total N that is accumulated after anthesis = total plant N accumulated after anthesis/total plant N (Na/Nt); ratio of N translocated to grain to N accumulated after anthesis(Ng/Na); grain yield/grain N (Gw/Ng)

‡ low,high and combined over N rates, respectively.

TABLE 7. Phenotypic correlation for Yield with selected characters at two N rates and combined over and 30 genotypes measured at Perkins, OK 1992-1993.

	N level		
	Low	High	Combined
Test weight	0.78**	0.75**	0.76**
Dry matter at Feekes 8	0.20*	0.31**	0.24**
Dry matter at anthesis	0.10	0.23**	0.13*
Dry matter, stem plus leaves	0.63**	0.71**	0.65**
Nitrogen total	0.75**	0.87**	0.72**
N at Feekes 8	0.05	0.18*	0.08
N at anthesis	-0.15	-0.05	-0.14*
Grain N	0.97**	0.98**	0.97**
Stem N	-0.57**	-0.53**	-0.50**
Leaves N	-0.30**	-0.22*	-0.27**
Heading date	-0.68**	-0.66**	-0.67**
Plant Height	0.31**	0.24**	0.27**

*, ** Significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.

APPENDIX A

NITROGEN ACCUMULATION BEFORE,

DURING AND AFTER ANTHESIS

APPENDIX TABLE A-1 . Mean values for N accumulated at two N rates of 30 genotypes measured at Perkins, 1992-1993.

	Nt	NF8	Nv	Ng	Nl	Ns	Nsla
	kg/ha				%		
Low N rate							
General mean	57.4	60.3	65.5	22.2	1.9	1.0	35.2
Varieties	62.6	64.1	64.8	27.4	1.9	1.0	35.2
Experimental lines	53.4	57.5	66.1	18.3	1.9	1.0	35.1
High-yield (HY)	58.5	57.3	63.9	25.7	1.7	1.0	32.8
Low-yield(LY)	48.6	56.3	69.0	10.9	2.2	1.1	37.7
S_3 Bulk	50.4	68.0	60.2	17.3	1.7	1.0	33.1
High N rate							
General mean	68.9	74.1	87.6	22.1	2.4	1.2	46.8
Varieties	78.0	79.2	87.6	28.7	2.4	1.2	49.3
Experimental lines	61.9	70.1	87.6	17.0	2.4	1.3	45.0
High-yield (HY)	69.3	69.8	84.4	24.0	2.3	1.1	45.3
Low-yield (LY)	54.3	70.0	92.3	9.7	2.4	1.4	44.5
S_3 Bulk	64.4	74.1	74.7	19.2	2.2	1.2	45.3

†Nt = total plant N at maturity; NF8 = total N at Feekes 8
Nv = total plant N at anthesis; Nl = N leaves at harvest
Ns = N stem at harvest; Ng = total N grain at harvest
Nsla = N accumulated in the straw (stem and leaves)

APPENDIX TABLE A-2. Mean for Nitrogen of 13 varieties at two N rates measured at Perkins, OK 1992-1993.

Genotype	Nt†	NF8	Nv	Ng	Nl	Ns	Nsla	NF8_Nv	NF8_M	Nv_M
		kg/ha		%	%	%	%	%	%	%
Low N rate										
Longhorn	77.5	57.0	54.6	29.3	1.2	0.8	38.5	-2.4	20.5	22.9
2163	75.7	69.7	58.5	36.9	2.4	0.7	38.8	-11.2	5.9	17.2
Agseco 7853	66.3	44.9	61.4	29.6	1.7	0.9	36.7	16.2	21.3	4.9
Triumph 64	67.6	68.4	66.8	32.7	2.0	0.7	34.9	-1.7	-0.8	0.8
2180	55.4	64.9	73.1	27.2	1.9	0.8	28.3	8.1	-9.5	-17.6
Chisholm	58.7	54.3	63.5	24.3	2.0	1.0	34.4	9.1	4.4	-4.8
Siouxland	67.3	65.3	61.2	27.8	1.9	0.8	39.5	-4.1	2.0	6.1
Karl	57.2	62.3	67.4	27.8	1.9	0.8	29.4	5.1	-5.1	-10.2
Cimarron	54.3	74.1	69.0	24.4	1.9	0.9	29.9	-5.1	-19.8	-14.7
Mesa	60.2	66.5	62.3	23.4	2.4	1.0	36.8	-4.2	-6.3	-2.1
TAM 200	64.6	77.0	65.3	23.4	1.7	1.0	41.2	-11.7	-12.4	-0.8
2158	54.7	71.0	72.9	21.4	2.0	0.9	33.3	1.9	-16.3	-18.2
TAM W-101	54.3	58.1	66.8	18.6	2.2	0.9	35.7	8.6	-3.8	-12.5
High N rate										
Longhorn	108.0	77.4	70.9	49.1	1.7	1.1	58.8	-6.5	30.6	37.1
2163	100.6	88.3	100.3	100.2	2.4	1.1	57.0	12.0	12.3	0.3
Agseco 7853	95.5	79.9	85.0	33.5	2.4	1.3	61.9	5.1	15.6	10.5
Triumph 64	72.9	74.0	80.4	31.2	2.4	0.9	41.7	6.4	-1.1	-7.5
2180	68.4	82.9	101.4	30.8	2.3	1.1	37.2	18.5	-14.5	-32.9
Chisholm	58.0	67.6	90.4	18.1	2.4	1.3	39.9	22.9	-9.5	-32.4
Siouxland	76.8	64.3	88.9	24.6	2.4	1.1	52.2	24.6	12.5	-12.1
Karl	75.4	79.4	81.4	31.4	2.2	1.2	44.0	1.9	-4.1	-6.0
Cimarron	68.3	93.2	92.8	24.2	2.5	1.2	44.1	-0.4	-24.9	-24.5
Mesa	71.4	76.2	87.0	23.4	2.7	1.2	48.0	10.8	-4.8	-15.6
TAM 200	86.3	79.7	80.8	26.0	2.1	1.3	60.2	1.1	6.6	5.5
2158	63.8	61.3	73.0	10.3	2.4	1.3	44.8	11.7	2.5	-9.2
TAM W-101	69.1	105.3	106.3	18.2	2.7	1.3	50.9	1.0	-36.2	7.2

†Nt = total plant N at maturity; NF8 = total N at feekes 8 growth stage
Nv = total N at anthesis; Ng = total N grain at harvest
Nl = N leaves at harvest; Ns = N stem at harvest
Nsla = N accumulated in the straw (stem and leaves)
NF8_Nv = N accumulated/lost from Feekes 8 to anthesis
NF8_M = N accumulated/lost from Feekes 8 to maturity
Nv_M = N accumulated/lost from anthesis to maturity

APPENDIX TABLE A-3. Mean for Nitrogen of 8 high-yield and 8 low-yield selection and one control at two N rates measured at Perkins, OK 1992-1993.

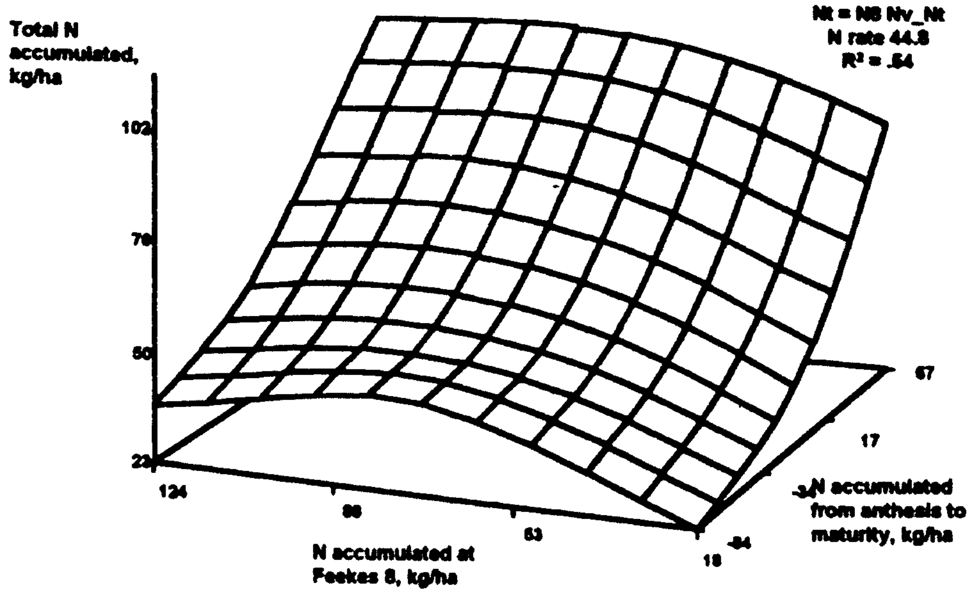
Genotype	Nt†	NF8	Nv	Ng	Nl	Ns	Nsla	NF8_Nv	NF8_M	Nv_M
	kg/ha			%	%	%	%	%	%	%
Low N rate										
4-6-HIGRP	62.3	39.8	51.1	29.3	1.3	0.7	33.1	11.3	22.6	11.2
1-25-HIGRP	59.6	54.8	68.5	27.4	1.4	0.8	32.3	13.8	4.9	-8.9
2-24-HIGRP	62.3	58.6	67.4	27.9	1.8	0.8	34.4	8.7	3.7	-5.1
2-2-HIGRP	63.0	65.6	69.6	26.8	1.9	0.8	36.2	4.0	-2.6	-6.6
1-6-HIGRP	50.7	66.1	63.6	27.5	1.4	0.7	23.2	-2.5	-15.4	-12.9
3-9-HIGRP	55.8	60.7	64.6	22.6	2.0	0.8	33.3	3.8	-4.9	-8.8
3-24-HIGRP	54.5	48.2	62.9	22.4	2.0	0.8	32.1	14.7	6.3	-8.3
4-11-HIGRP	60.1	65.0	63.9	22.2	1.9	0.9	37.9	-1.0	-4.9	-3.9
4-23-LOGRP	50.9	36.2	57.9	16.7	1.9	0.9	34.3	21.7	14.8	-7.0
S3 BULK	50.4	68.0	60.2	17.3	1.7	0.9	33.1	-7.8	-17.7	-9.9
1-28-LOGRP	43.2	39.3	60.5	12.6	1.8	0.8	30.6	21.2	3.9	-17.3
4-4-LOGRP	50.3	67.8	94.3	11.4	2.0	1.2	38.8	26.5	-17.6	-44.1
3-18-LOGRP	45.3	48.1	48.7	10.6	2.5	1.0	34.8	0.6	-2.8	-3.3
2-28-LOGRP	46.7	65.9	68.2	10.1	2.4	1.1	36.5	2.4	-19.2	-21.6
1-9-LOGRP	48.5	55.4	73.2	9.5	2.2	1.3	39.0	17.8	-6.9	-24.8
3-29-LOGRP	45.6	68.2	65.9	8.1	2.4	1.1	37.5	-2.4	-22.6	-20.3
2-8-LOGRP	58.7	69.3	83.3	8.4	2.5	1.4	50.3	14.0	-10.6	-24.6
High N rate										
4-6-HIGRP	82.3	65.8	96.8	28.9	2.3	1.0	53.4	31.0	16.5	-14.5
1-25-HIGRP	76.5	68.0	77.7	28.3	2.0	1.0	48.2	9.8	8.5	-1.3
2-24-HIGRP	69.3	72.5	90.0	26.3	2.2	1.1	43.0	17.5	-3.2	-20.7
2-2-HIGRP	61.6	74.6	87.2	20.4	2.2	1.1	41.2	12.5	-13.0	-25.5
1-6-HIGRP	71.8	79.3	79.6	26.3	2.5	1.0	45.5	0.2	-7.5	-7.8
3-9-HIGRP	57.9	63.5	82.4	17.4	2.4	1.2	40.5	18.9	-5.6	-24.5
3-24-HIGRP	68.4	65.6	81.7	23.8	2.4	1.1	44.6	16.1	2.8	-13.3
4-11-HIGRP	66.7	68.8	79.9	20.4	2.2	1.3	46.3	11.1	-2.1	-13.3
4-23-LOGRP	58.2	82.3	105.7	11.8	2.3	1.3	46.4	23.5	-24.1	-47.5
S3 BULK	64.4	74.1	74.7	19.2	2.2	1.2	45.3	0.6	-9.7	-10.3
1-28-LOGRP	53.6	70.5	87.1	9.0	2.2	1.3	44.6	16.6	-16.9	-33.4
4-4-LOGRP	57.9	67.1	88.1	10.6	2.3	1.4	47.3	20.9	-9.3	-30.2
3-18-LOGRP	60.4	60.0	83.3	17.1	2.7	1.2	43.3	23.3	0.4	-23.0
2-28-LOGRP	39.5	58.2	80.4	5.7	2.4	1.4	33.8	22.2	-18.7	-41.0
1-9-LOGRP	54.6	65.0	95.1	8.4	2.7	1.7	46.2	30.1	-10.4	-40.5
3-29-LOGRP	50.2	70.0	95.3	7.7	2.7	1.3	42.6	25.3	-19.8	-45.1
2-8-LOGRP	59.8	86.8	103.8	7.7	2.2	1.6	52.1	17.0	-27.0	-44.0

†Nt = total plant N at maturity; NF8 = total N at feekes 8 growth stage
Nv = total N at anthesis; Ng = total N grain at harvest
Nl = N leaves at harvest; Ns = N stem at harvest
Nsla = N accumulated in the straw (stem and leaves)
NF8_Nv = N accumulated/lost from Feekes 8 to anthesis
NF8_M = N accumulated/lost from Feekes 8 to maturity
Nv_v = N accumulated/lost from anthesis to maturity

APPENDIX TABLE A-4. Mean values for N accumulated at two N rates of 30 genotypes measured at Perkins, 1992-1993.

	F8_NV	NF8_M	NV_M
	kg/ha		
Low N rate			
General mean	5.2	-3.0	-8.2
Varieties	0.7	-1.5	-3.4
Experimental lines	8.6	-4.2	-12.7
High-yield (HY)	6.6	1.0	-5.4
Low-yield(LY)	12.7	-7.6	-20.4
S_3 Bulk	-7.8	-17.7	-9.9
High N rate			
General mean	13.5	-5.1	-18.7
Varieties	8.4	-1.2	-9.5
Experimental lines	17.4	-8.2	-25.6
High-yield (HY)	14.6	-0.5	-15.1
Low-yield (LY)	22.4	-15.7	-38.1
S_3 Bulk	0.6	-9.7	-10.3

†NF8_Nv = N accumulated/lost from Feekes 8 to anthesis
NF8_M = N accumulated/lost from Feekes 8 to maturity
Nv_M = N accumulated/lost from anthesis to maturity



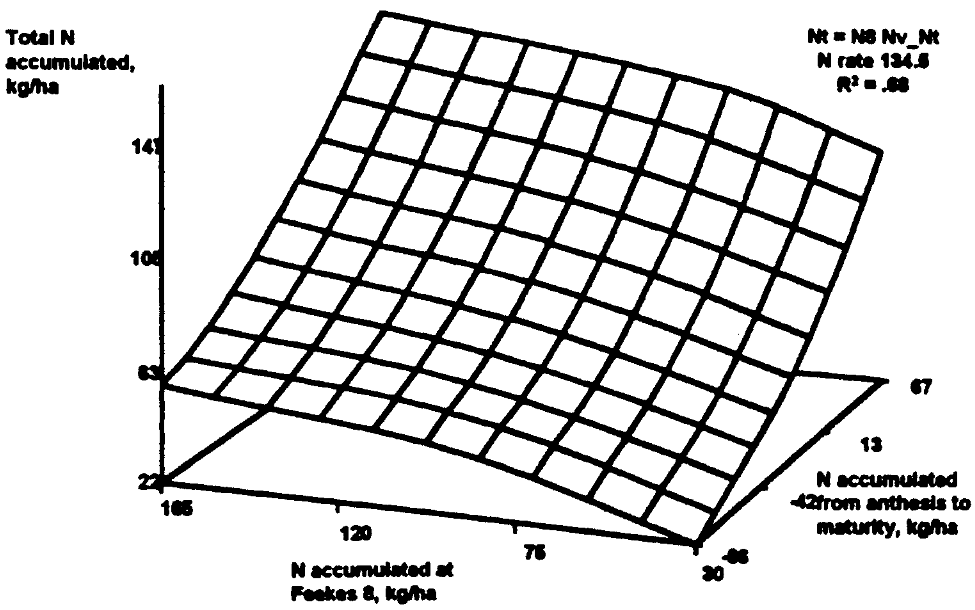


FIGURE A-1. Surface of response model of total N accumulated versus N accumulated at Feekes 8 and N accumulated from anthesis to maturity at the low and high N rate.

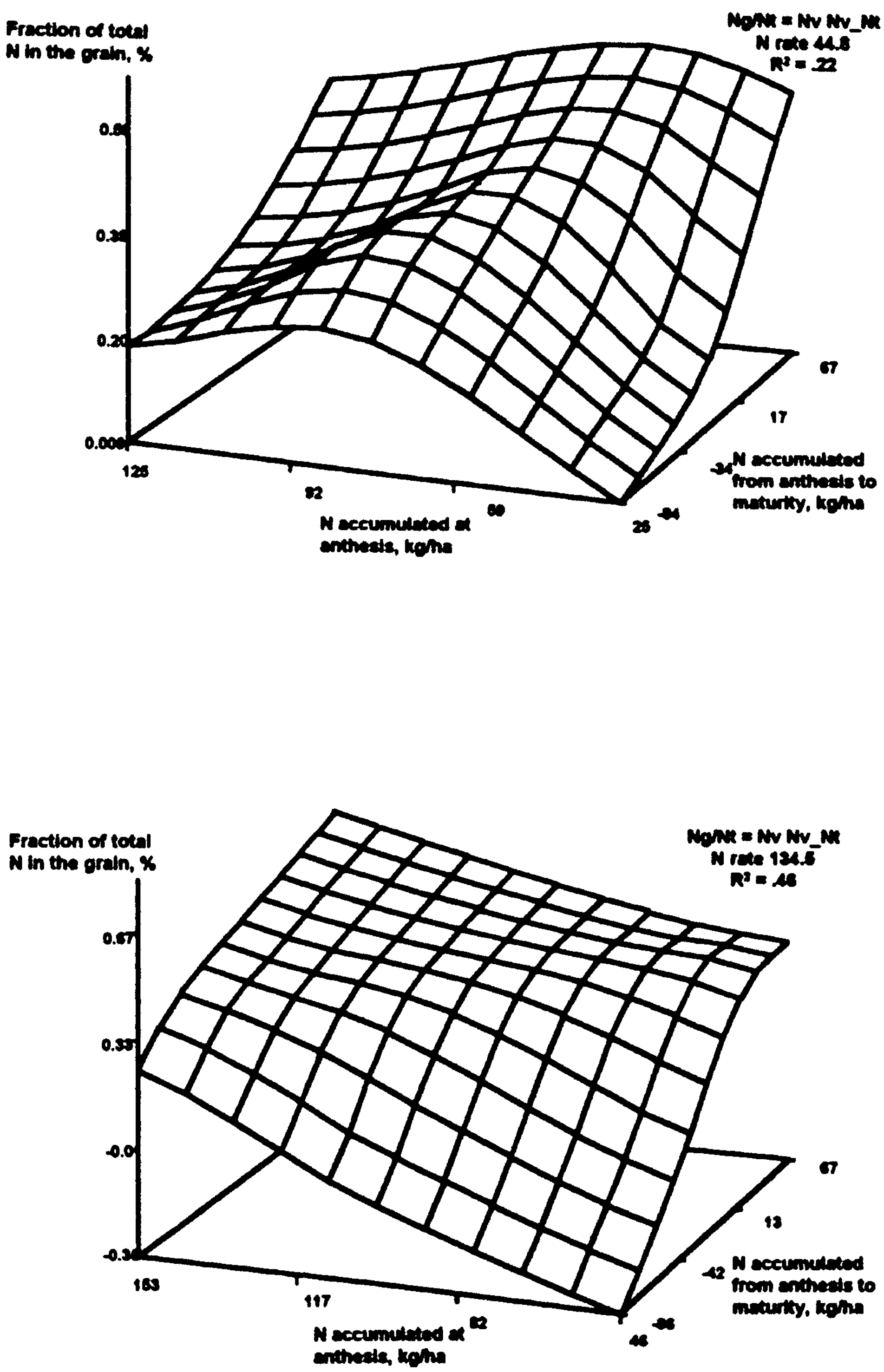


FIGURE A-2. Surface of response model of fraction of total N in the gr versus N accumulated at anthesis and from anthesis to maturity at the low and high N rate.

APPENDIX B

ACCUMULATION PATTERNS OF NITROGEN TOTAL

AND NITROGEN AT STRAW (LEAVES+STEM)

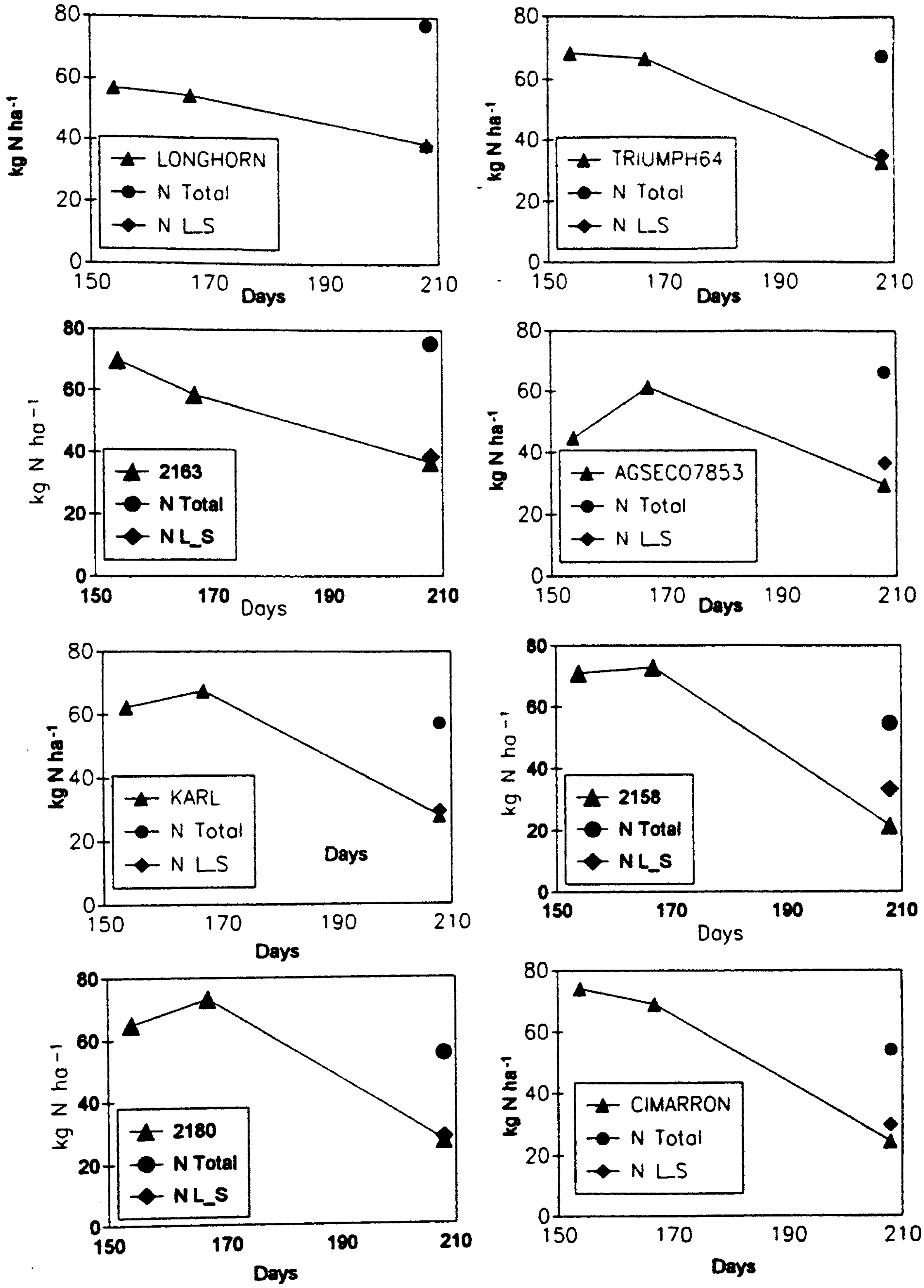


FIGURE. B-1. Accumulation patterns of N total and N at leaves + stem at the low N rate.

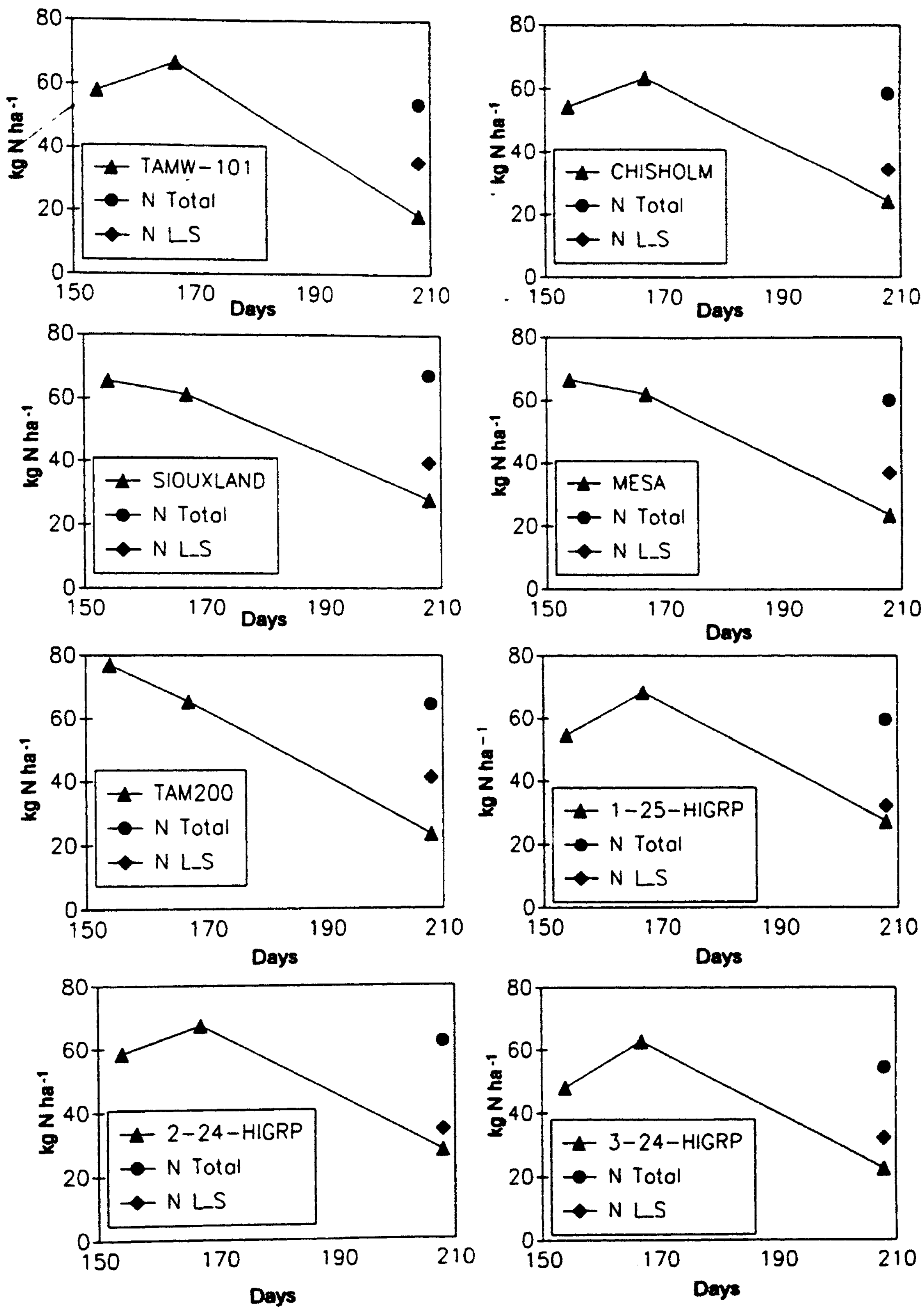


FIGURE B-1. Accumulation patterns of N total and N at leaves + stem at the low N rate.

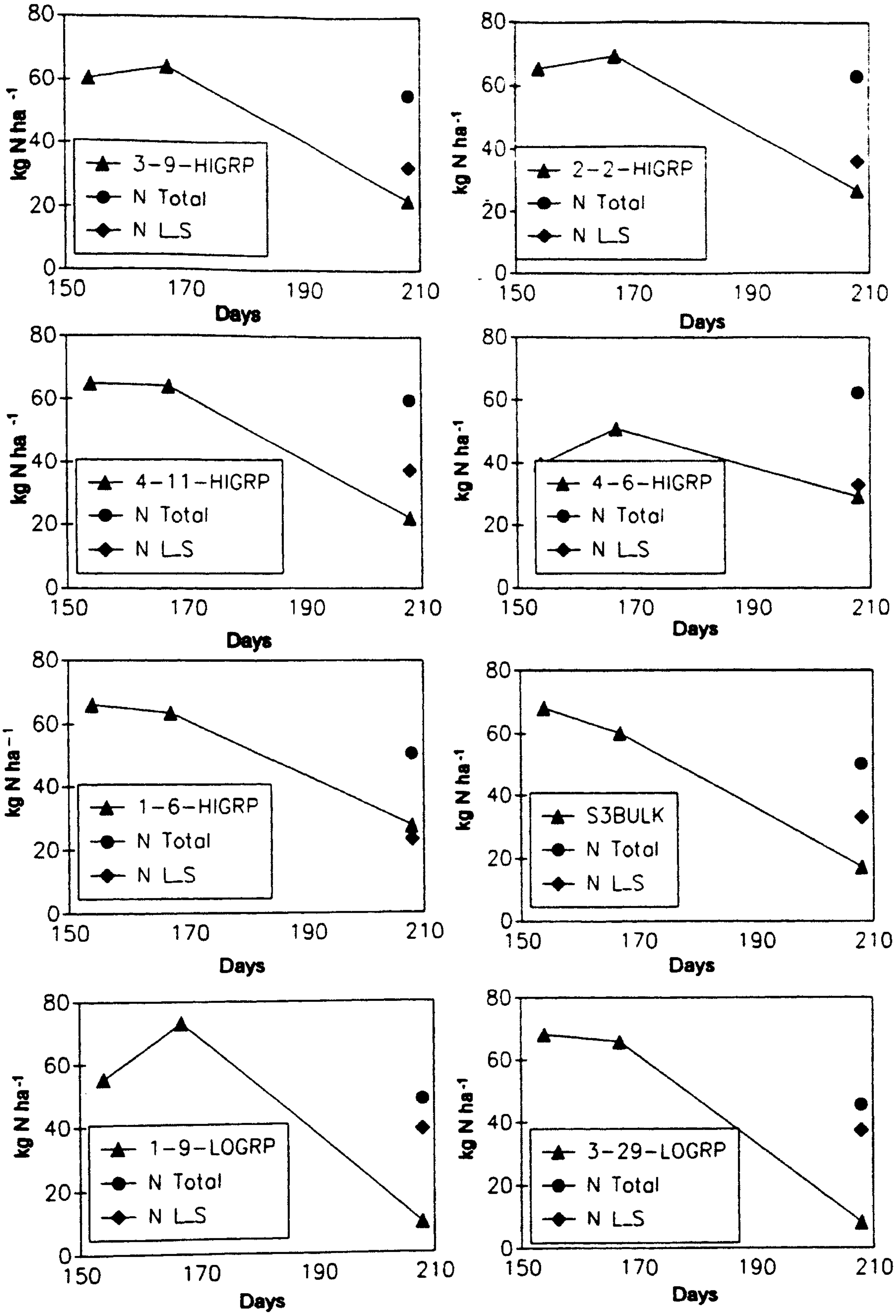


FIGURE B-1. Accumulation patterns of N total and N at leaves + stem at the low N rate.

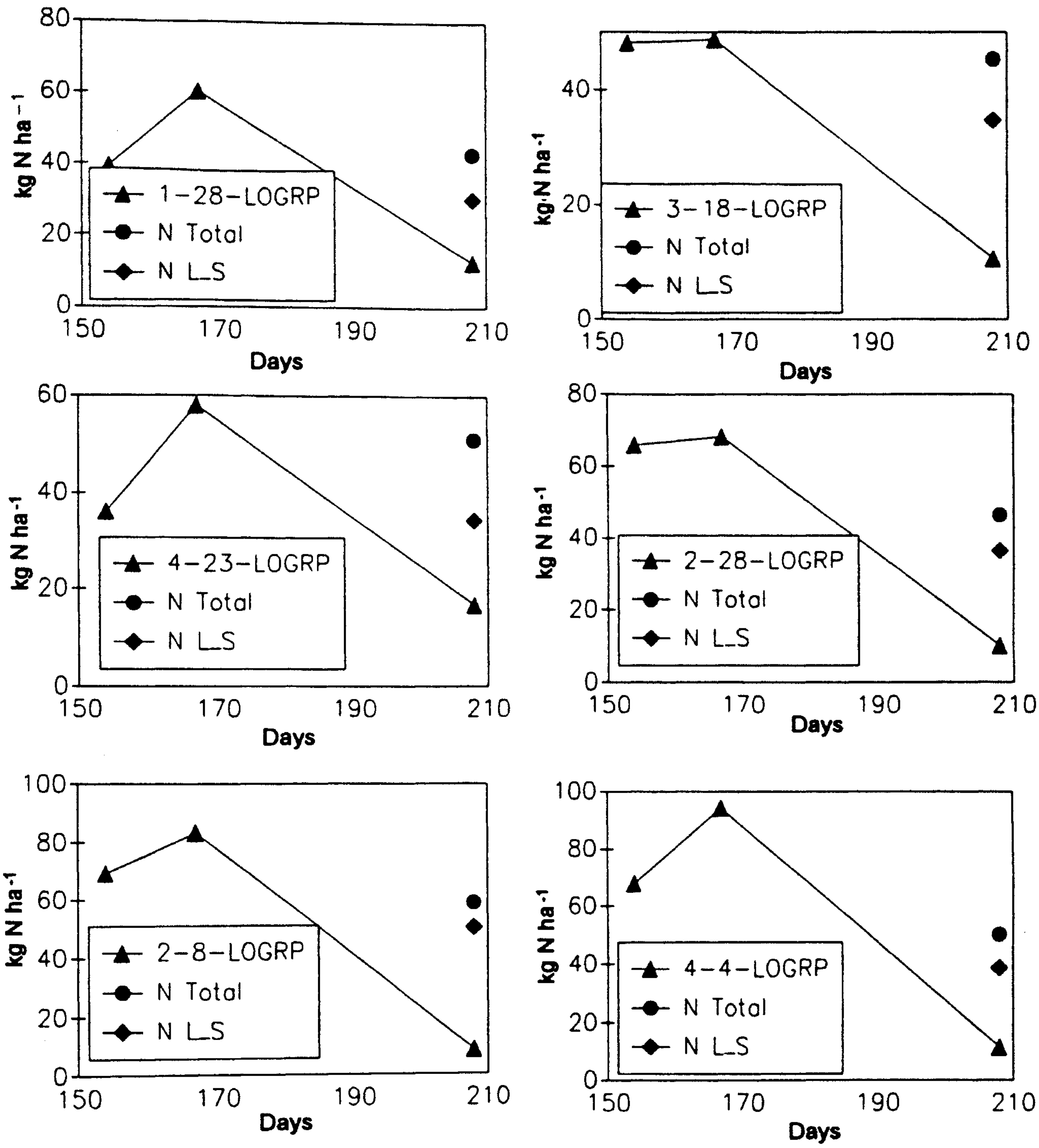


FIGURE B-1. Accumulation patterns of N total and N at leaves + stem at the low N rate.

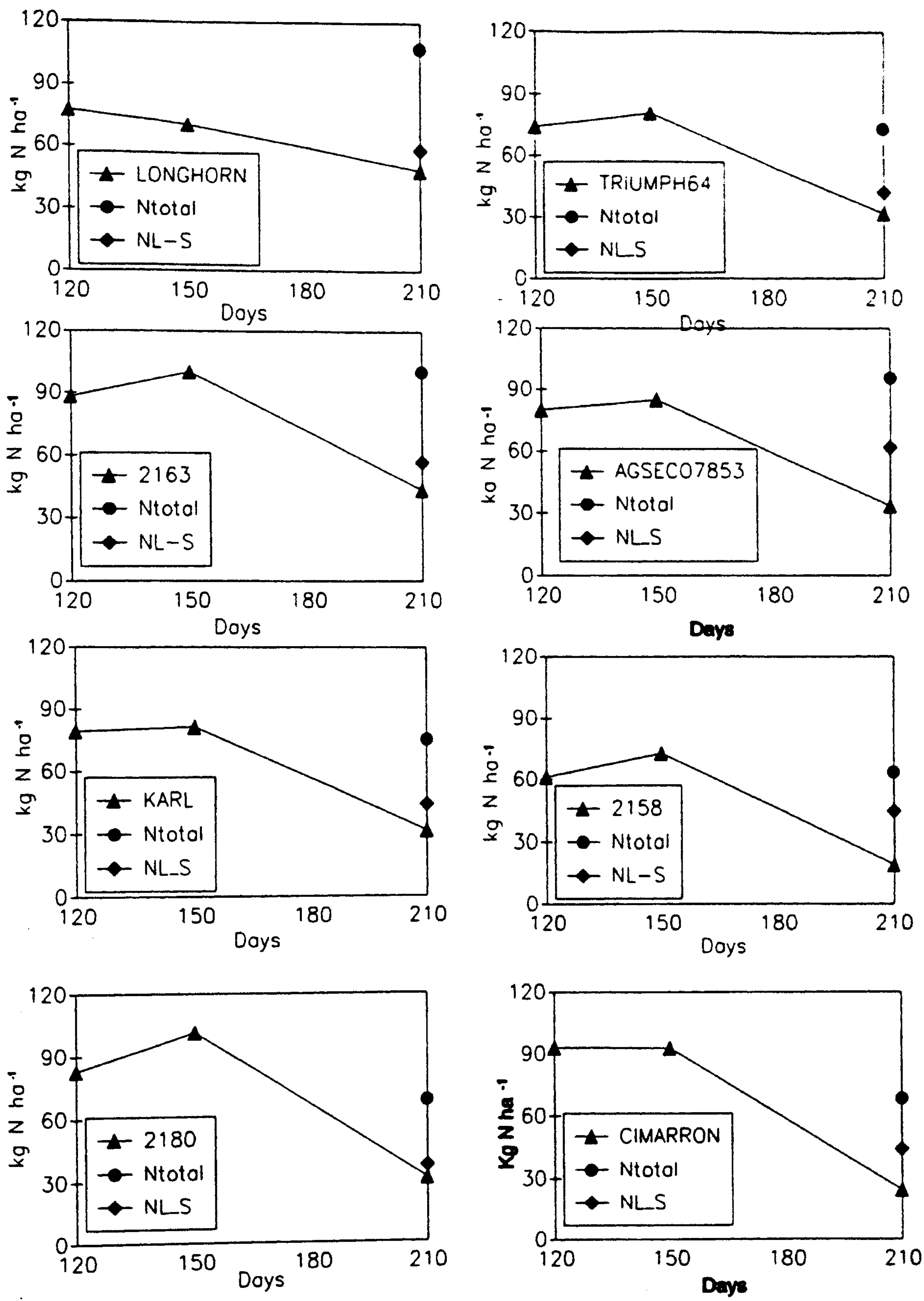


FIGURE B-2. Accumulation patterns of N total and N at leaves+stem at the high N rate.

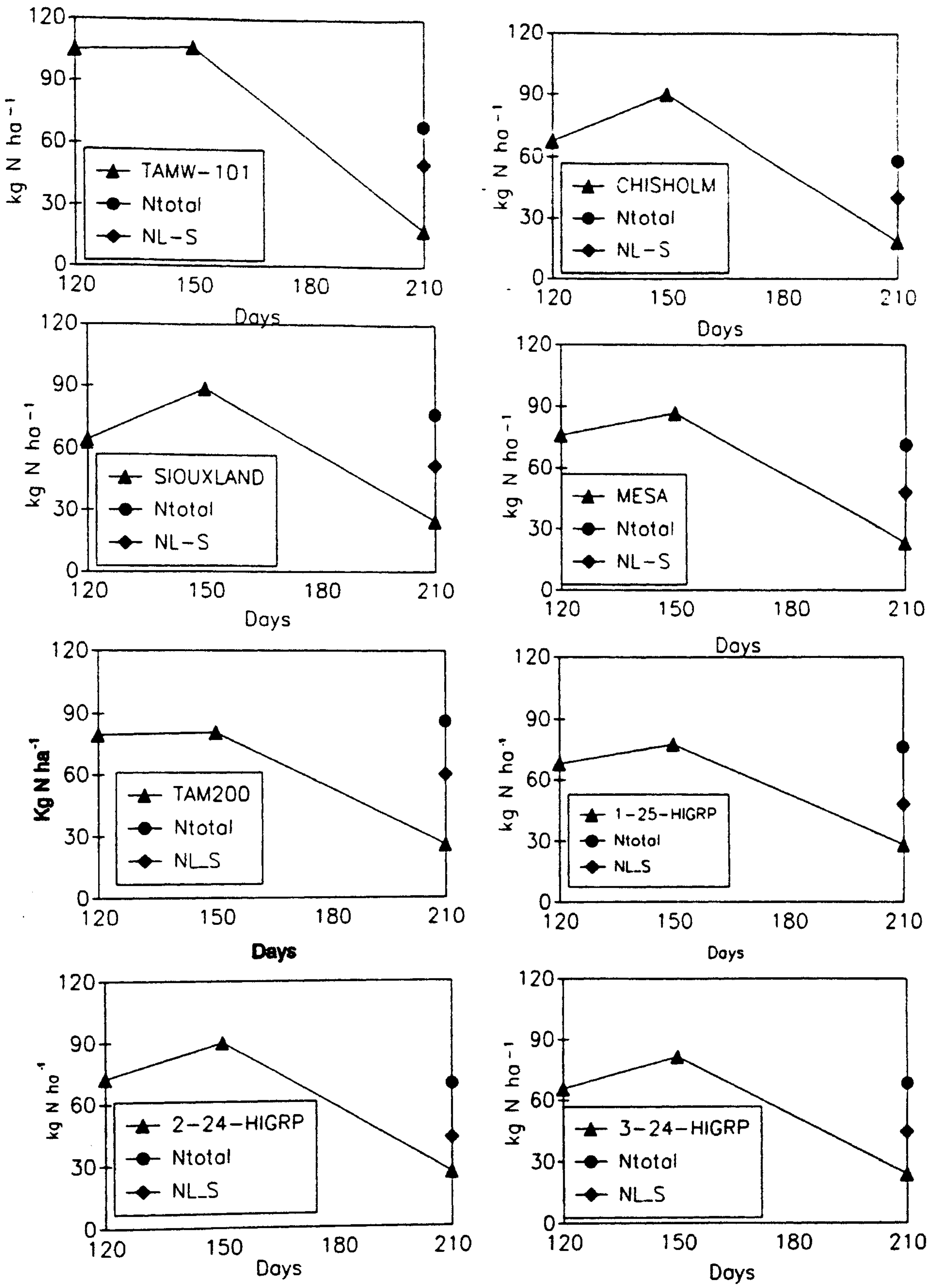


FIGURE B-2. Accumulation patterns of N total and N at leaves+stem at the high N rate.

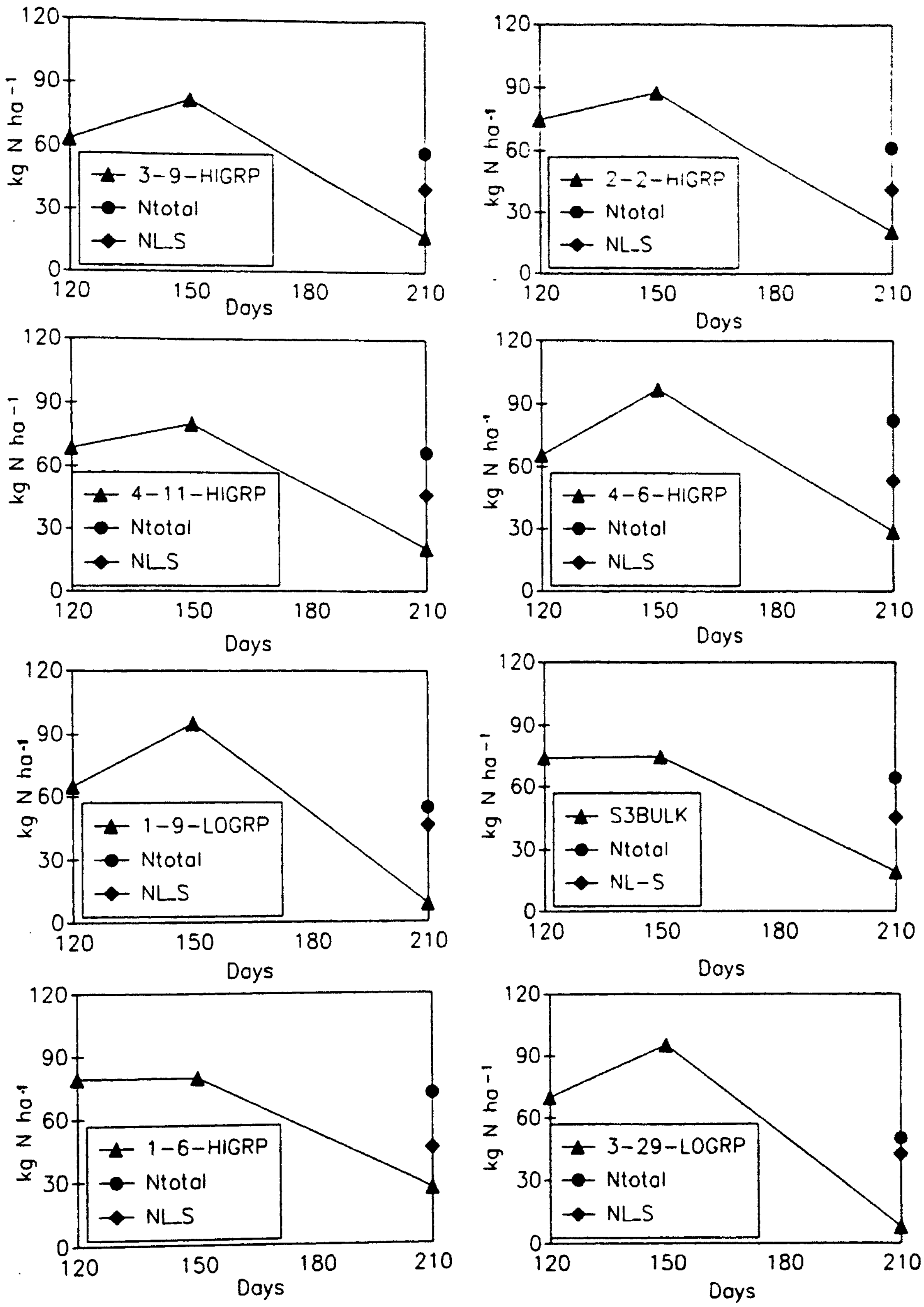


FIGURE B-2. Accumulation patterns of N total and N at leaves+stem at the high N rate.

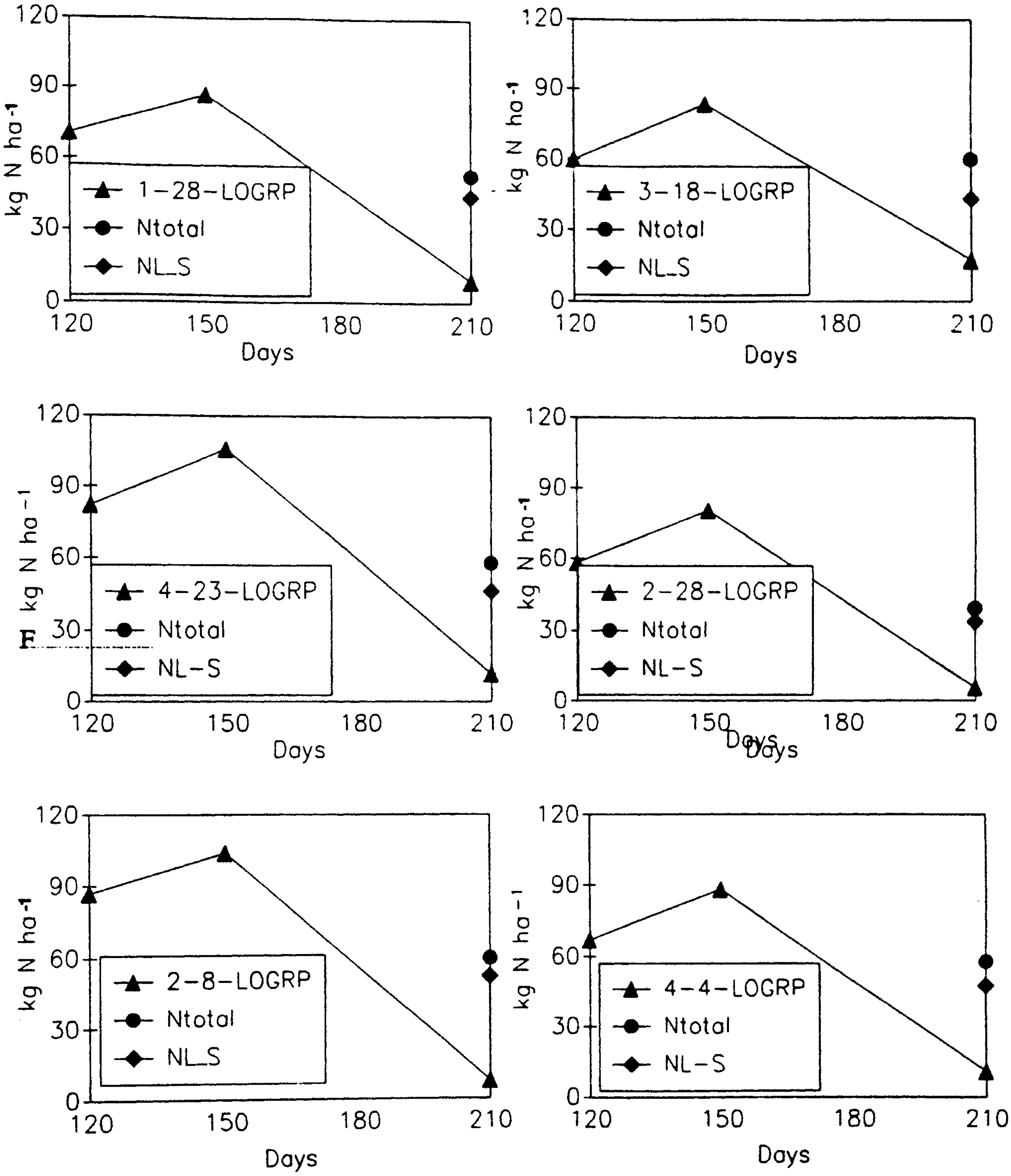


FIGURE B-2. Accumulation patterns of N total and N at leaves+stem at the high N rate.

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VITA 2

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