# EFFECT OF N FERTILITY AND SOIL MOISTURE ON YIELD AND NITROGEN ACCUMULATION IN MANITOU WHEAT

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## INTRODUCTION

The effect of N fertility and soil moisture on the growth and yield of spring wheat, and the disposition of N in the soil-plant system were investigated. In the present paper the effect of moisture and N fertility on N accumulation in the plant tops, and grain yield will be discussed.

## MATERIALS AND METHODS

Manitou wheat was grown in 15-cm diameter, 120-cm deep galvanized iron lysimeters which were pushed into a Wood Mountain loam by means of the soil-coring device already described by Dyck et al. (1976). The stubble field contained 18 kg $NO_3$-N/ha in the top 60 cm of soil at seeding.

Two soil moisture regimes [natural rainfall (dry) and irrigated (wet)], seven rates of nitrogen [0, 28, 56, 84, 112, 168 and 224 kg/ha $NO_3$-N as $Ca(NO_3)_2$], and five sampling times (3 leaf, tillering, shot blade, late anthesis, and maturity) were combined factorially and their influence on N accumulation and grain yield determined. There were two replicates. All lysimeters received 112 kg/ha $P_2O_5$ as superphosphate. Three seeds were planted in each lysimeter; this was the rate of seeding calculated to be equivalent to that generally used in southwestern Saskatchewan.

Destructive sampling was employed. At each sampling date plant samples were taken and the number of tillers, leaves, the leaf area, dry matter and Kjeldahl N determined. Also, the soil was cut into 2.5- and 5-cm segments; odd-numbered segments were used for moisture and chemical analyses and even-numbered segments for root determinations. All pertinent meteorological data were collected. Only data pertinent to this paper will be discussed here.

## RESULTS

### Growing Season Conditions

Because of abundant autumn and early spring precipitation the stubble field was moist to about 150 cm at seeding time. As will be shown later, this moisture provided good growing conditions until between shot blade and anthesis when a hot dry spell during the first three weeks in July (Fig. 1) caused incipient wilting on several occasions. However, timely rains fell in late July and early August thus alleviating the moisture stress problem, although this also tended to extend the period of maturation. Consequently, samples taken at maturity were harvested over a period from about day 75 to day 95 after emergence.

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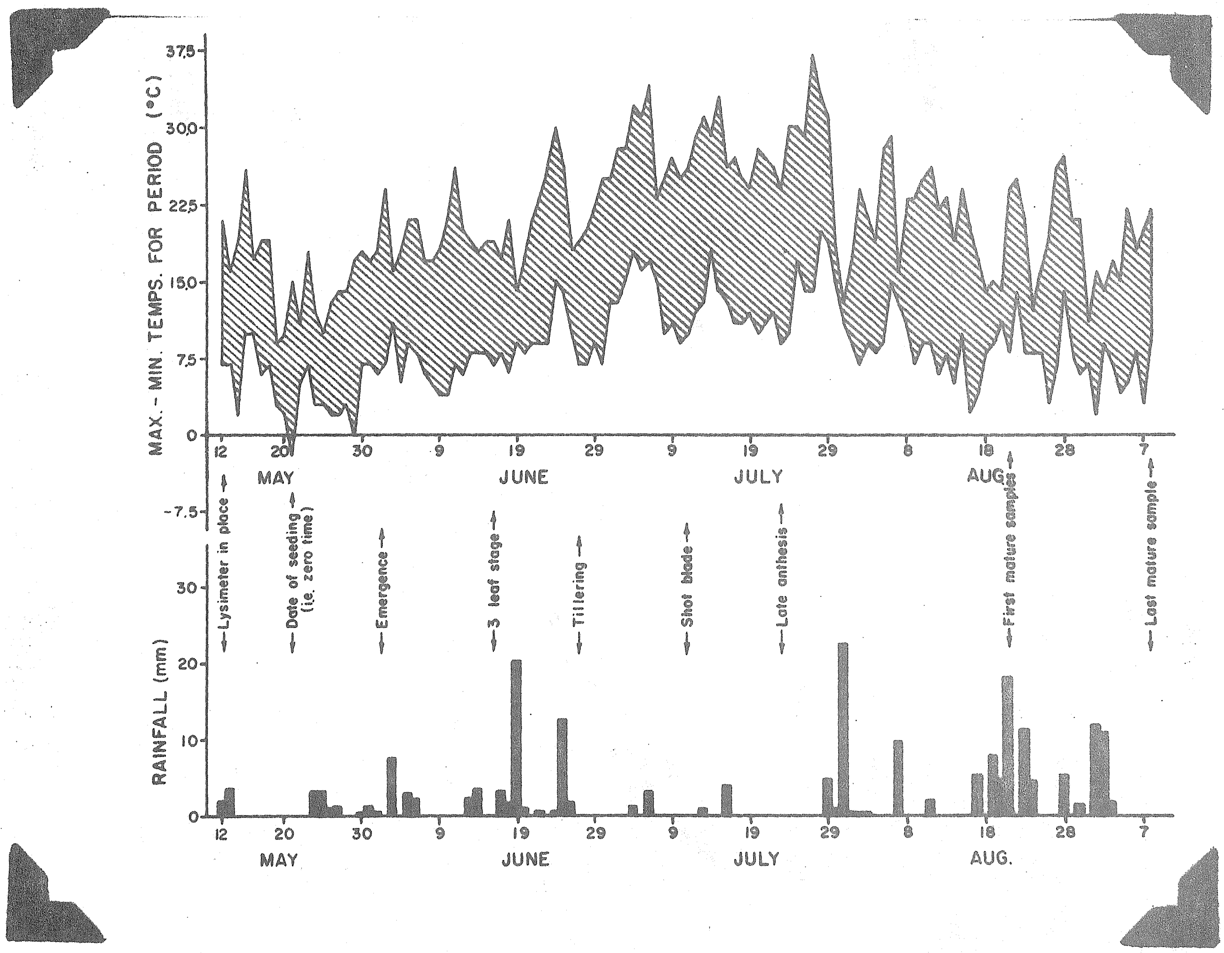


Fig. 1. Diurnal air temperature and precipitation during experimental period

## Effect of N Fertility and Water on Dry Matter Accumulation

As previously shown by Dr. Davidson (1976), dry matter of wheat increased sigmoidally with time under wet conditions, and also under dry conditions at rates of N $<$ 84 kg/ha [Fig. 2(a) and (b)]. Generally, dry matter also increased exponentially with applied N except under dry conditions at rates of N $>$ 84 kg/ha [Fig. 2(b)]. Under the latter conditions the dry matter remained relatively constant between shot blade and late anthesis. However, prior to shot blade, and also after late anthesis the dry, higher N treatments accumulated dry matter more rapidly than the dry, low N treatments. As will be shown later, these interactions were related to the rate of soil moisture use as influenced by fertility, as well as to the relative amount of available N still present in the soil just after late anthesis.

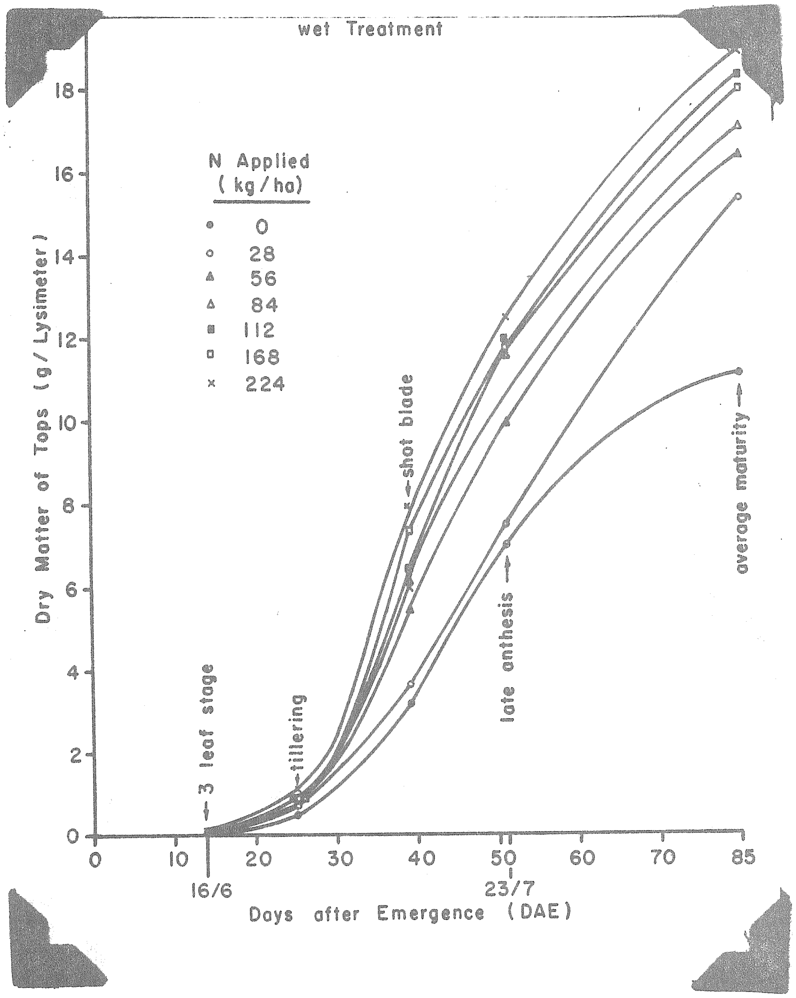


Fig. 2(a). Dry matter production of above-ground parts - wet treatment

Effect on N Concentration in Above-Ground Parts

Nitrogen concentration in the above-ground vegetative parts decreased with time (Fig. 3). This was at least partly due to the gradual decrease in available soil N with time (data not shown). The average % N in plant tissue for all N treatments was 5.3 at the 3-leaf stage, 4.6 at tillering, 2.2 at shot blade, 1.5 at late anthesis and 0.5 at maturity (only straw). Thus, the greatest decrease in N concentration occurred between the tillering and shot blade growth stages; this corresponds to the period of maximum dry matter accumulation (Fig. 2). Although the differences were small, % N tended to be greater in the drier treatments; this was especially true during the later stages of development. Nitrogen concentration tended to increase with N application

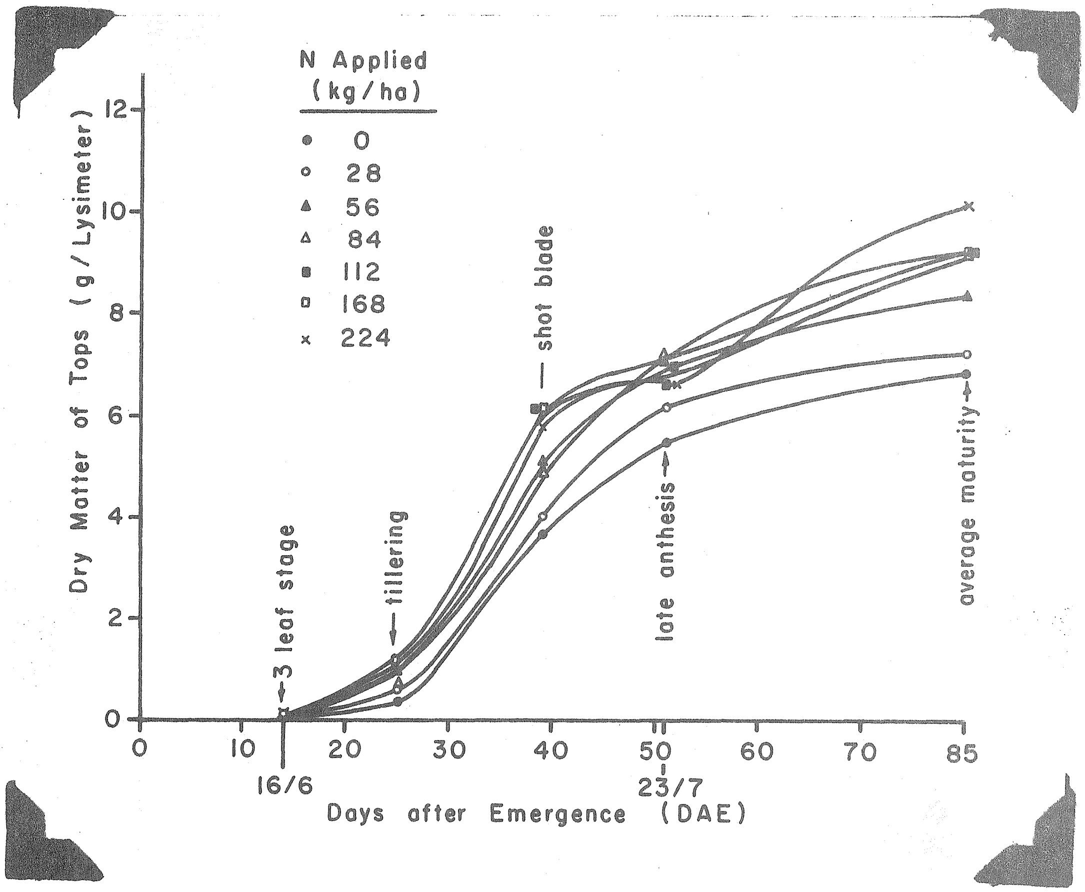


Fig. 2(b). Dry matter production of above-ground parts - dry treatment

up to 84 kg/ha but above this there was no further increase.

The relationship between N concentration and dry matter accumulation was inversely and curvilinearly (concave upwards) related (data not shown). Willcox (1954) has suggested that yield was inversely and linearly related to % N, while Steenbjerg (1954) reported that these parameters were related by U- or S-shaped curves. However, Viets (1965) reported that the latter types of curves were rarely obtained when semiarid soils were irrigated.

We attempted to quantify the relationship between N concentration and dry matter accumulation. First we checked Willcox's "increase yield-nitrogen law" (1954) by plotting the reciprocal of % N versus dry matter at various stages of development. The results (not shown) indicated that during vegetative growth the law held but not thereafter. Furthermore, the rate of change in N concentration with dry matter accumulation was a function of

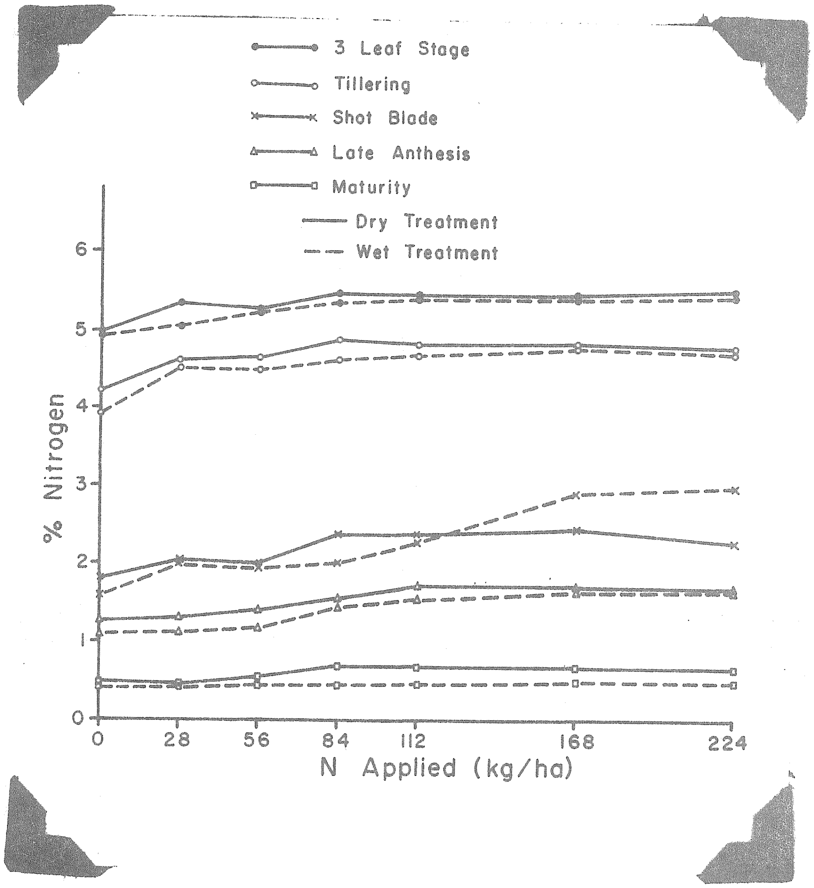


Fig. 3. Effect of N and water on vegetative N concentration

fertility level and soil moisture. In another attempt at quantification we tested the hypothesis that dry matter was related to N concentration by a negative power function of the type:

$$\text{Dry matter (DM)} = (\%N)^{-k}.$$

Except for the values at the 3-leaf stage of growth this relationship fitted the data much more precisely than did the "inverse yield-nitrogen law" (Fig. 4); k was calculated to be 0.63, 0.52, 0.37 and 0.43 under unfertilized-wet and -dry, and fertilized-wet and-dry conditions, respectively.

Effect on N Content in Above-Ground Parts

Under wet conditions N content was as great in the early stages of development and much greater in later growth stages than for the corresponding dry treatments (Fig. 5). The latter was primarily

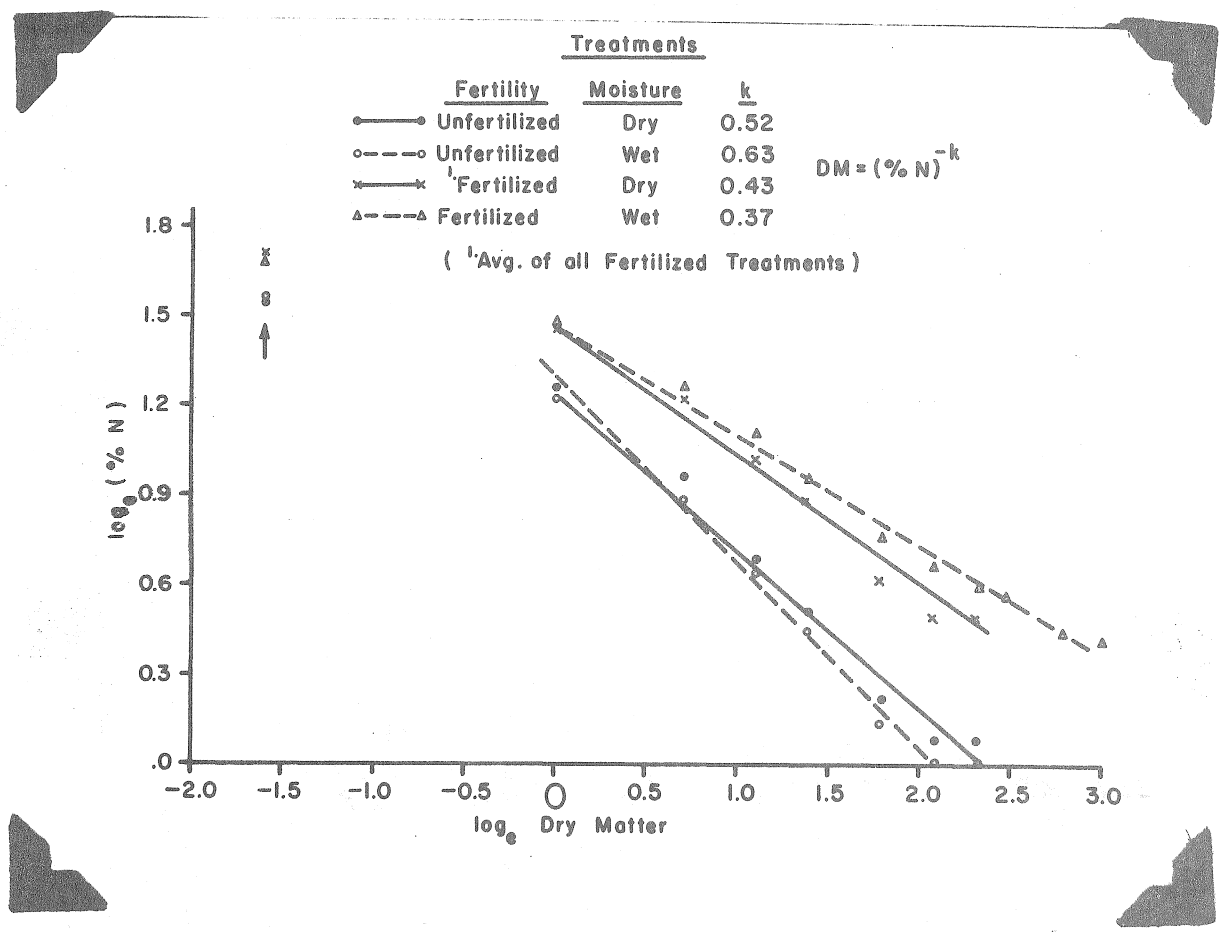


Fig. 4. Quantitative relationship between dry matter and N concentration

because of the substantially greater dry matter produced under the wetter conditions. N content increased more or less exponentially with time under wet conditions. Under dry conditions the same was true up to shot blade but between shot blade and late anthesis there was no increase in N content at rates of N $<$ 84 kg/ha, while at the three highest rates there was actually a loss of N from the tops of about 0.03 g N/ lysimeter (i.e., 20% of the N in the tops at shot blade). The roots of these dry, high N treatments also lost N during this period of drought (data not shown). This loss of N was due to a lower N concentration (Fig. 3) because dry matter had remained constant during the period in question /Fig 2(b)/. The total N of all treatments increased significantly between late anthesis and maturity, with the treatments which had received $>$ 84 kg/ha increasing more rapidly than those which had received smaller rates. These increases were, no doubt, facilitated by the timely rainfall received in late July to early August after late anthesis (Fig. 1). The relative increase was likely related to the amount of unused fertilizer N which was still present in the rooting depth at late anthesis. The latter was calculated to be 15, 25, 20, 28, 75, 138 and 231 mg N/90 cm depth in the treatments which received 0, 28, 56, 84, 112, 168 and 224 kg N/ha-15 cm, respectively.

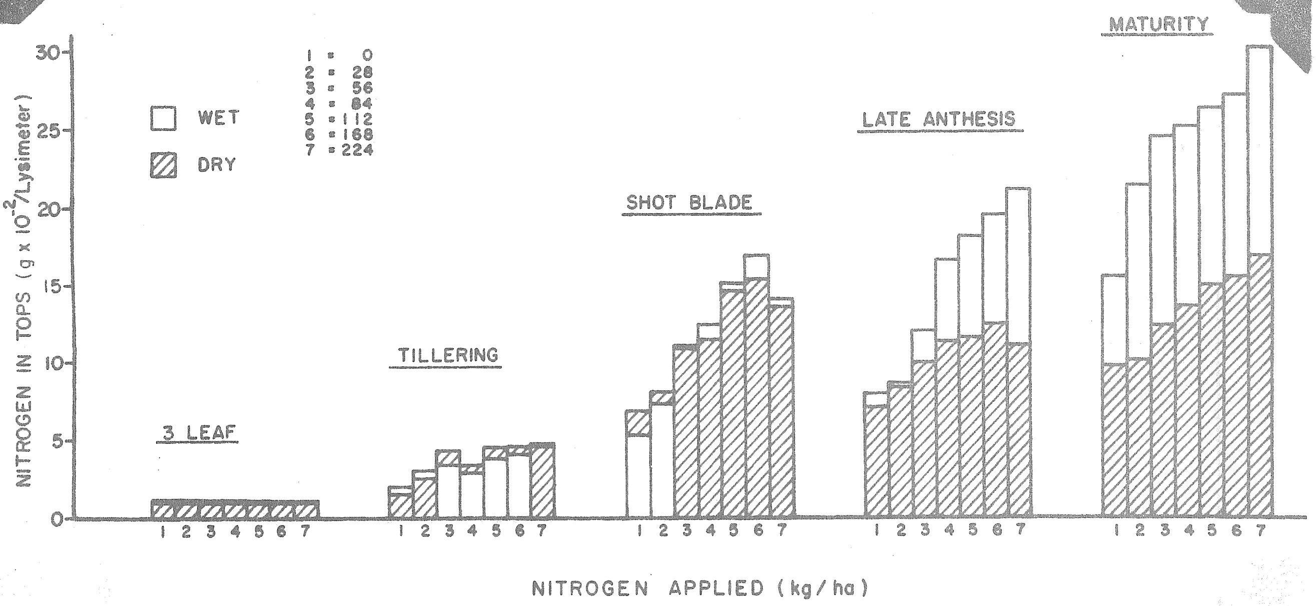


Fig. 5. Effect of N and water on N in wheat - above-ground parts

<u>Effect on Grain Yield, N Concentration and Total N at Maturity</u>

Grain yields increased exponentially with N application (Fig. 6). However, under dry conditions the response was adequately described by a curve of the type

$$Y = ae^{kN}$$

while under wet conditions it was fitted by a "Mitscherlich type curve" of the form

$$Y = A(1 - e^{-k'N})$$

In these equations Y = yield at any initial level of nitrogen (N) in the soil; A = the maximum yield expected; a = a constant; and k and k' are proportionality constants which are dependent on the conditions of growth. The response under dry conditions was different from that normally obtained. For example, the response to low increments of N was small, while response to increments > 84 kg N/ha was large (Fig. 7).

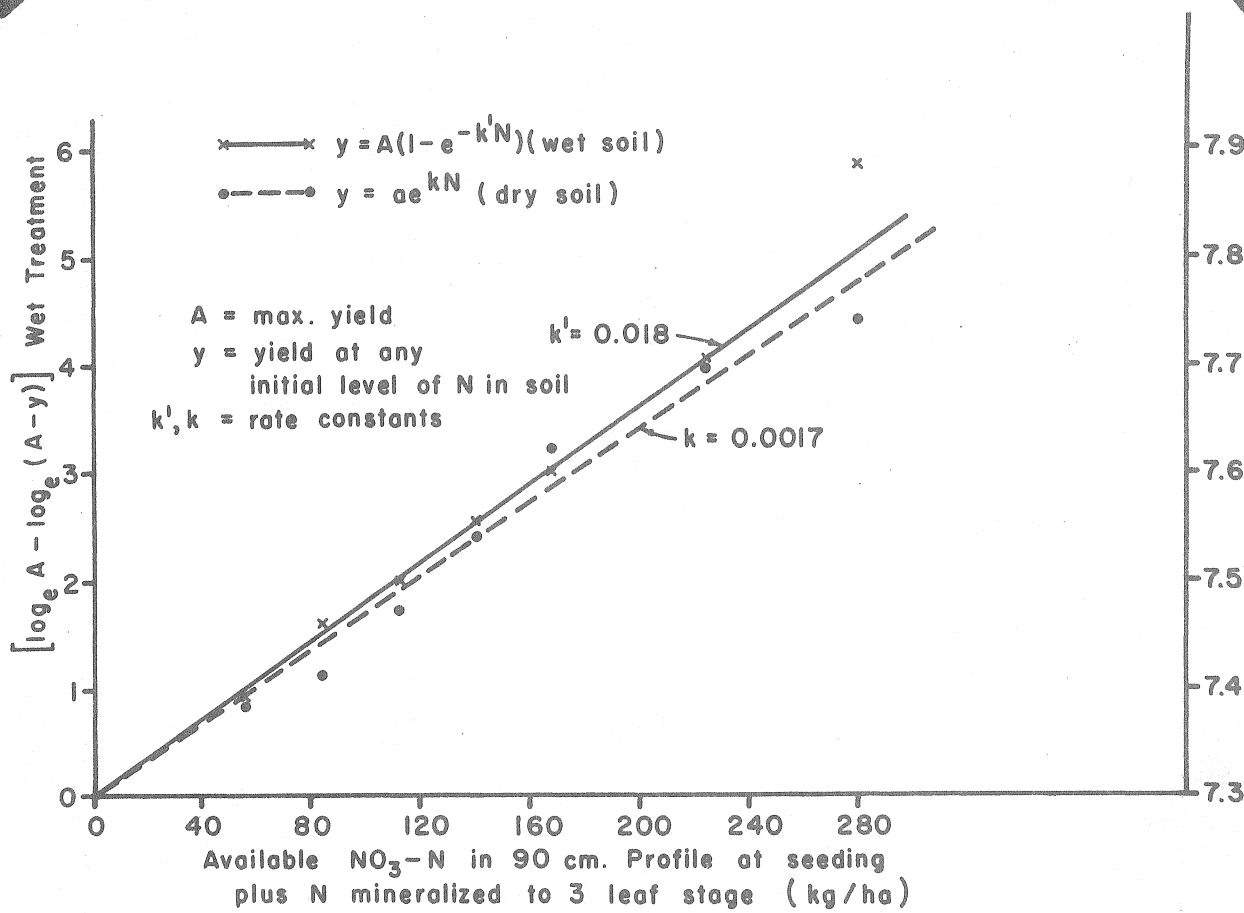


Fig. 6. Quantitative relationship between grain yields and N concentration in soil

Extrapolating the lysimeter yields to a kg/ha basis showed that without added water or N stubble-wheat yielded 1600 kg/ha. (Incidentally, this was exactly the same yield obtained when square meter samples of the inter-lysimeter guard crop was sampled). Irrigation alone increased yield by 72% (2740 kg/ha); addition of 224 kg N/ha increased yield by about 45% (2352 kg/ha) under dry conditions and by 75% (4795 kg/ha) under wet conditions.

Under dry conditions grain crude protein concentration increased from 15.4% in the zero-N treatment to 17% at rates of N application ≥ 84 kg/ha (Fig. 7). Under wet conditions protein increased from 14.1% to just over 15% with increasing N fertility. The protein yield was

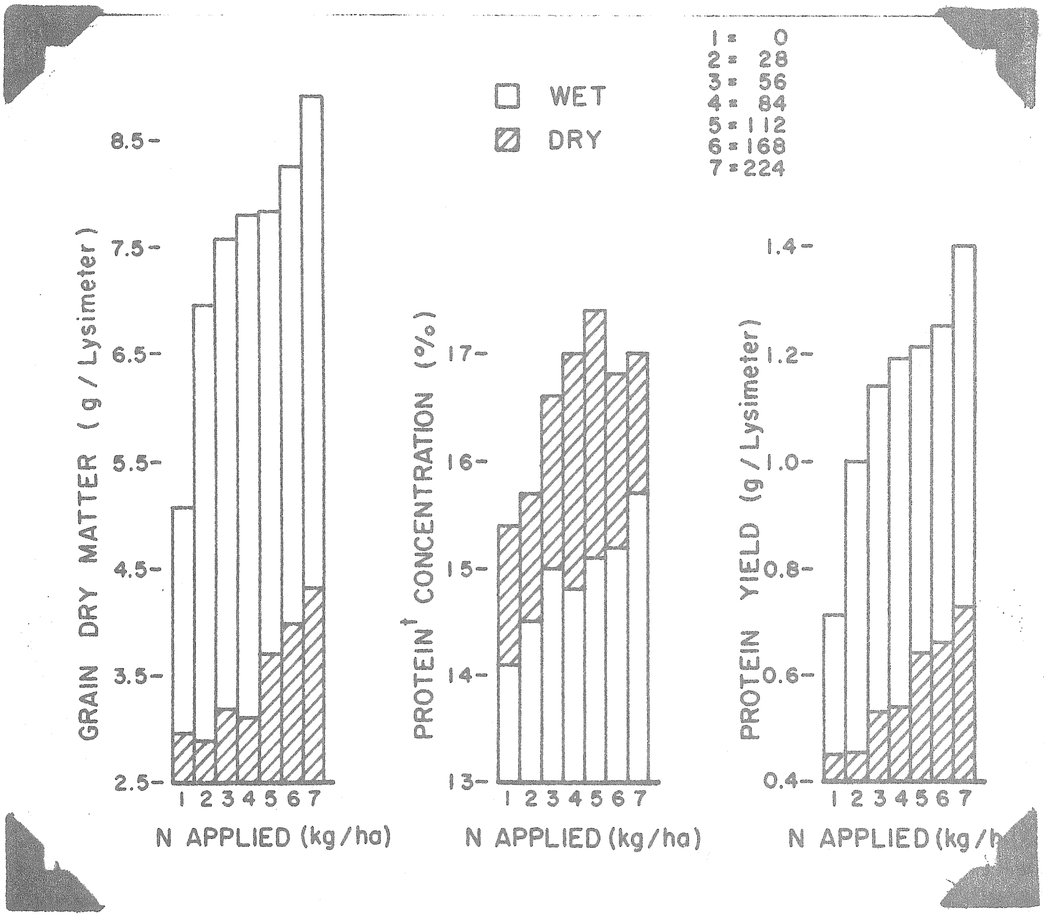


Fig. 7. Effect of N and water on grain yield and protein

approximately twice as much under wet as under dry conditions even though protein concentration was higher under the dry conditions.

## Available Water in the Profile as Influenced by N, Time and Irrigation

Up to the 3-leaf stage of growth, applied N had no obvious effect on the amount of available water in the soil profile (Fig. 8). By tillering there was a trend towards a decrease in available water with increasing rates of nitrogen under wet conditions. The inverse relationship between available water and nitrogen fertility was evident in both moisture treatments at the shot blade stage. By late anthesis the same trend was evident in the wet treatment, but in the dry treatment all available water had already been depleted at all levels of nitrogen and soil moisture was actually below the 15 atm level (zero line).

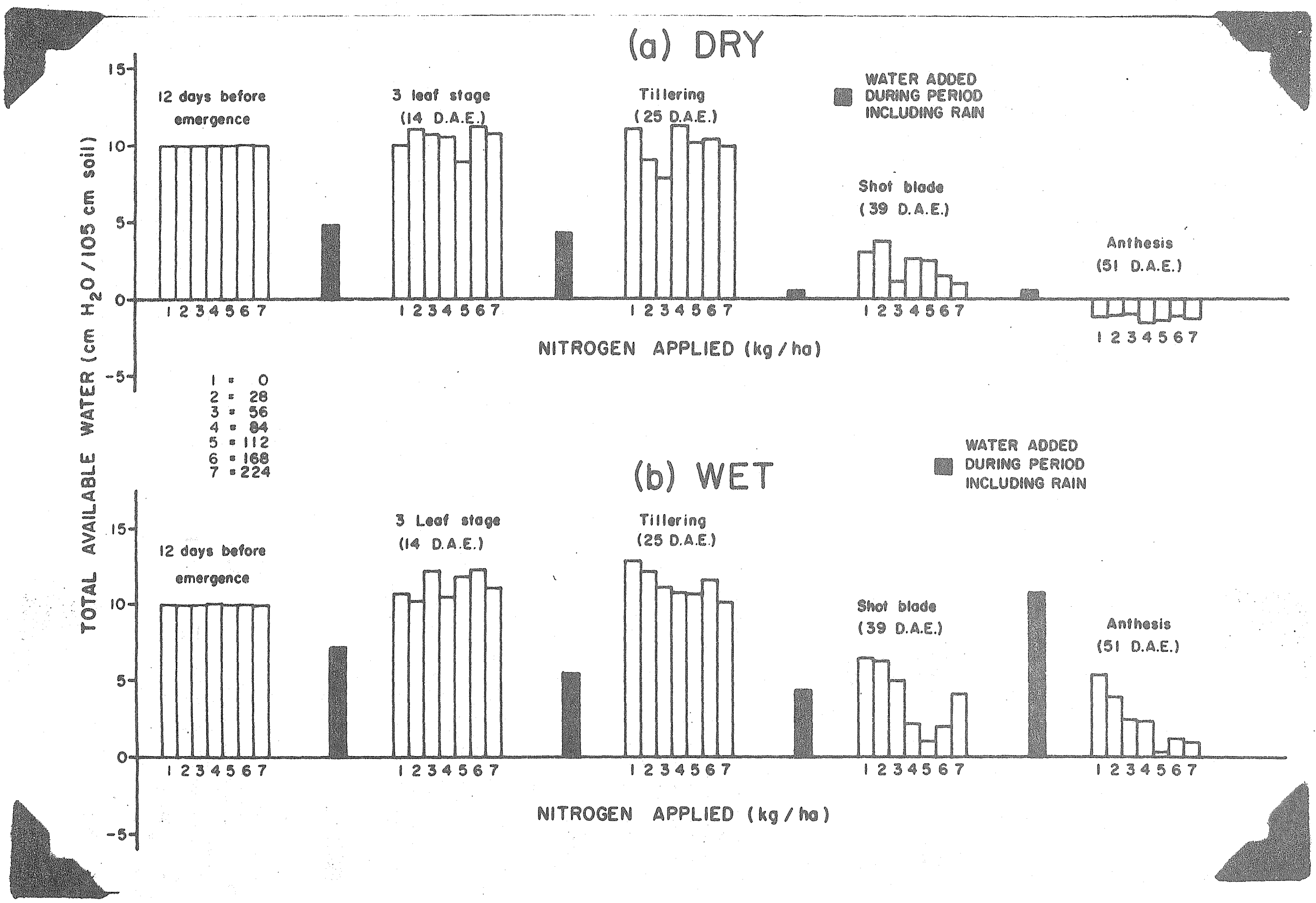


Fig. 8. Effect of fertilizer N on total available water in soil profile at 4 growth stages

## DISCUSSION

Under wet conditions growth and yield responded to N in the classical manner, conforming to Misterlich's law of diminishing returns principle (Russell 1973). Under dry conditions growth started out in a similar manner to that under wet conditions because soil moisture conditions were good up to near shot blade. However, because of the direct relationship between rate of water use and rate of N applied (where available water was not limiting), plants grown under the dry conditions at rates of N $>$ 84 kg/ha depleted their available water more rapidly than those grown at lower rates of N. Consequently, between shot blade and late anthesis when we received $<$ 1 cm of rain and very hot conditions the "dry" plants at low N continued to increase slowly in dry weight, but the plants grown at the highest rates of N levelled off abruptly in dry matter production. Shot blade to anthesis is the most critical stage of growth with respect to the effect of moisture stress on grain yield. For example, Bauer (1971) reports that serious moisture stress at the heading to anthesis stage of growth will reduce the grain yield by 30 to 40%. In our study, if the wet treatment is considered to have represented optimum moisture, then the reduction in grain yield was 42, 57, 59, 57, 55, 52 and 50% in the dry treatment grown at 0, 28, 56, 84, 112, 168 and 224 kg N/ha, respectively.

Immediately after late anthesis, and up to maturity, the soil moisture and temperature were again good for grain production. As can be seen from the yield curves (Fig. 7), in the dry treatment the good weather conditions benefited the plants grown at 112, 168 and 224 kg N/ha considerably more than it affected those grown at lower rates of N. Why? The reason for this interaction was apparently due to the following: By the late anthesis stage the treatments receiving up to 84 kg N/ha had absorbed almost all of the readily available N in the lysimeters, they had incorporated the N into plant tissue, some of which died off during the mini-drought period between shot blade and late anthesis. The plants grown at $\geq$112 kg N/ha had also absorbed a good portion but not all of the available N in the lysimeters (data not shown). Consequently, when the rains came just after late anthesis all plants recovered sufficiently to produce a better-than-average crop but the ones receiving the highest rates of N were still able to translocate more residual N from the soil to the tops to be combined with stored starch in the flag leaves and produce substantial grain yields and protein. On the other hand, the rate of mineralization was too slow to provide the plants grown at the lower nitrogen rates with sufficient available N to replace that which was lost in the tillers and leaves which died during the mini-drought. This then explains how weather-fertility interactions can result in apparent anomalies in plant response to fertilizer. It should be noted that if the recommended rate of fertilizer had been applied (28 kg/ha) there would have been little response under natural rainfall, and even 56 kg N/ha would have given little response.

The top growth (and roots) of dry, high N fertilized plants apparently lost N during the droughty shot blade to late anthesis period; however, the treatments which were experiencing less moisture stress during this period did not lose N. The soil tension in the dry treatment at late anthesis was well above 15 atm (Fig. 8). We postulate that the moisture tension in the plants was lower than that in the soil, and this created a gradient that induced liquid excretion from roots to soil during this period. This exudate might have carried with it soluble N compounds. Marshall (1972) has reported that plants fertilized heavily with N have been found to excrete materials from the roots.

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