INFLUENCE OF TEMPERATURE, NITROGEN FERTILIZER AND MOISTURE STRESS ON YIELD AND PROTEIN CONTENT OF MANITOU SPRING WHEAT

- A SIMULATED DRYLAND STUDY

C.A. Campbell and H.R. Davidson

INTRODUCTION

Nitrogen, temperature, and moisture are the three most important factors influencing grain yield and grain protein of spring wheat. However, the relative importance of these factors is not well understood because the relationships are usually dependent on interactions between site and year (weather). In recent years a series of studies has been carried out at Swift Current both in the field and growth room with the objective of elucidating these interactions.

An example of the need for this type of study can be demonstrated by examining the alleged reasons for the recent trends observed in Western Canada and U.S.A. which show that grain protein concentration is apparently decreasing to uneconomical levels (Jackel 1979). It has been suggested in several quarters that this trend is due to the present inability of our soils to supply plants with the required rates of nitrogen and that the latter has been precipitated by our past abuse of soil organic matter (Smith 1979). However, it is quite conceivable that this trend could also be a function of the weather factors throughout this period. For example, a series of years with below-normal temperatures and/or above-normal precipitation could have resulted in this same trend. A proper analysis and assessment of this type of situation requires that we obtain more realistic data than that now available.

One of the main factors to be considered in this type of study is temperature. But usually temperature studies dictate that experiments be carried out under controlled conditions. This usually leads to various attendant problems in experimental design; consequently, the results obtained, though useful, are often not very representative of field conditions. In the present study we have tried to be more realistic than usual in simulating the soil moisture factor in an attempt to obtain reliable qualitative results.

Our objective was to determine the effect and relative contribution of temperature, moisture stress at various growth stages, and nitrogen fertility on grain yield and protein content of spring wheat under simulated dryland conditions.

MATERIALS AND METHODS

The experiment was conducted in three similar growth rooms, one maintained at day/night temperatures of 27°C and 12°C (T27/12), and the second and third at T22/12 and T17/12, respectively. Daytime light intensity was about 600 μEinsteins, m^{-2} sec^{-1}, the photoperiod was 16 hr and the relative humidity was about 65%.

Spring wheat, cv. Manitou, was grown in ½ gallon cardboard milk cartons, each 10 x 10 cm^2 at the top, containing 2328 grams of air dry Wood Mountain loam, a Brown Chernozem. At 0.3, 15 and 40 atm tension, this soil retains 21.6, 10.3 and 9.0% water by weight, respectively. One plant was grown per pot. Three rates of KNO_3-N (58, 116 and 174 mg N/pot) were applied in solution. On an area basis these rates are equivalent to 58, 116 and 174 kg N/ha. Phosphorus as superphosphate was applied in suspension with the KNO_3 at a rate of 116 kg P_2O_5/ha.

There were three levels of moisture stress applied, viz., no stress (0.3 atm), medium stress (15 atm) and high stress (40 atm). The 15 and 40 atm stresses were applied during three stress periods (tillering to maturity, near boot stage to maturity, and from late flowering to maturity); there was also a no-stress (0.3 atm) treatment throughout (Fig. 1). Plant and soil samples were taken at eight sampling times, including maturity, and there were five replicates. The 1500 pots which made up this experiment were weighed each day and water added through a centre tube (Fig. 2) to bring the soil moisture content back to that equivalent to the appropriate stress treatment whenever the weights indicated that the soil had dried out beyond the limit. The idea was to attempt to keep the moisture contents as close as possible to the chosen limit by replacing the water used daily. For the drier treatments the amount of water added each time was therefore very small. The limits cited were upper limits of wetness for the average soil in the pot (near the tube would be wetter and farther away drier than average).

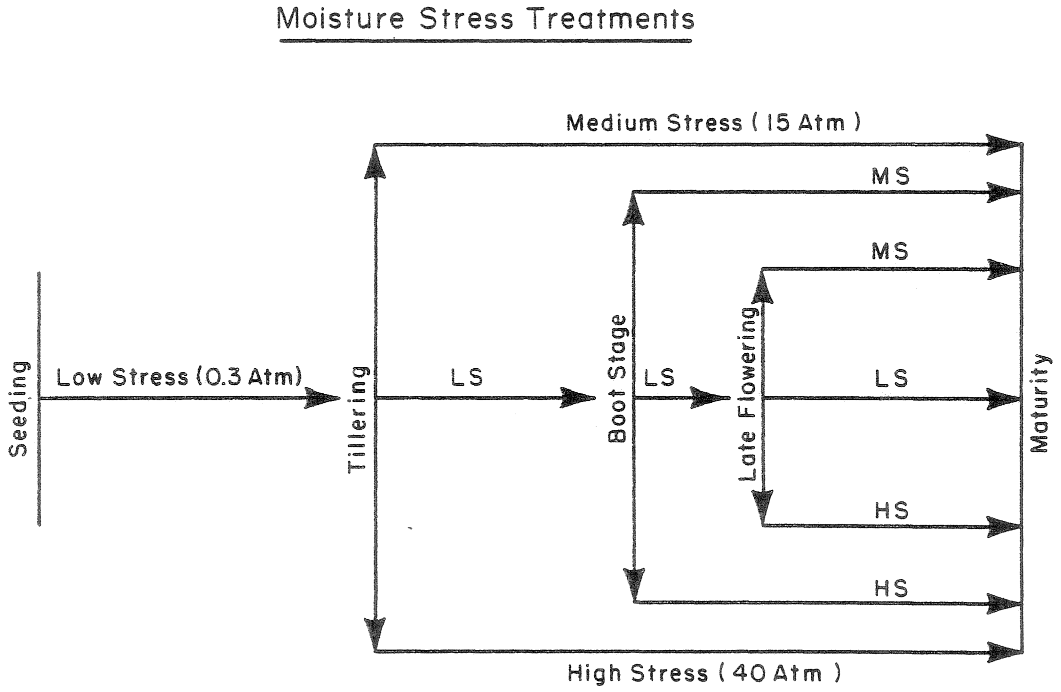


Figure 1

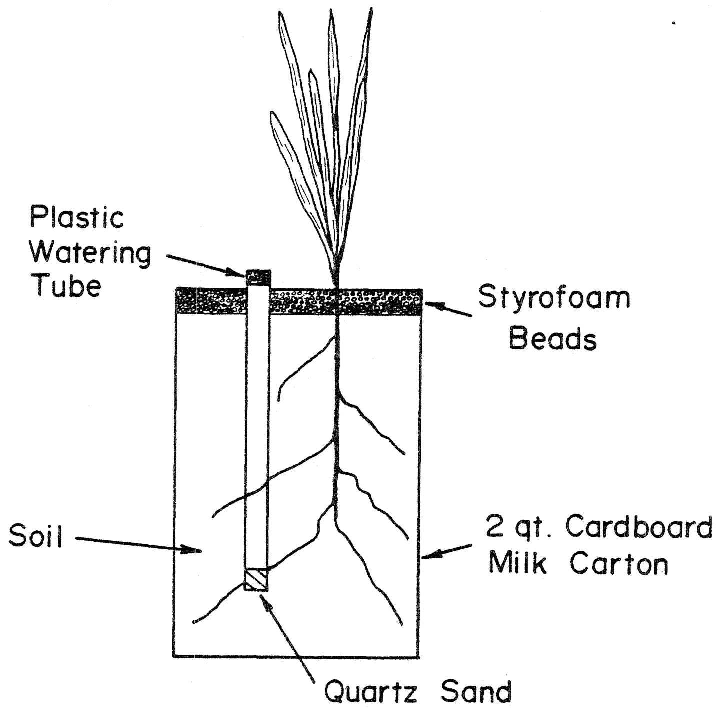


Figure 2

Numerous parameters were assessed in this study, but the ones of interest in this paper are grain yield (after drying overnight at 80°C) and percent protein in grain (% Kjeldahl N x 5.7).

Analysis of variance, covariance, and regression analysis were used to analyze the data. Tukey's W value was used to test for significant differences between treatment means (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Grain Yield

Highest grain yield was obtained under cool (T17/12), high fertility (N174), low moisture stress conditions, while the lowest yields were obtained under conditions that were hot (T27/12), low fertility (N58) and had high moisture stress from boot stage to maturity. These results confirmed our expectations.

Analysis of variance showed that all three factors significantly ($P < 0.01$) influenced yield. The effect of temperature was 22% > the effect of nitrogen which was 70% > the effect of moisture stress (data not shown). Temperature and nitrogen fertilizer and also moisture stress and nitrogen fertilizer interacted significantly ($P < 0.01$) in their influence on grain yield. Yields were similar at 17 and 22°C but >> at 27°C (Fig. 3). Under hot conditions increasing the nitrogen from 58 to 116 kg N/ha increased yields (Fig. 3), but a further 58 kg/ha increase

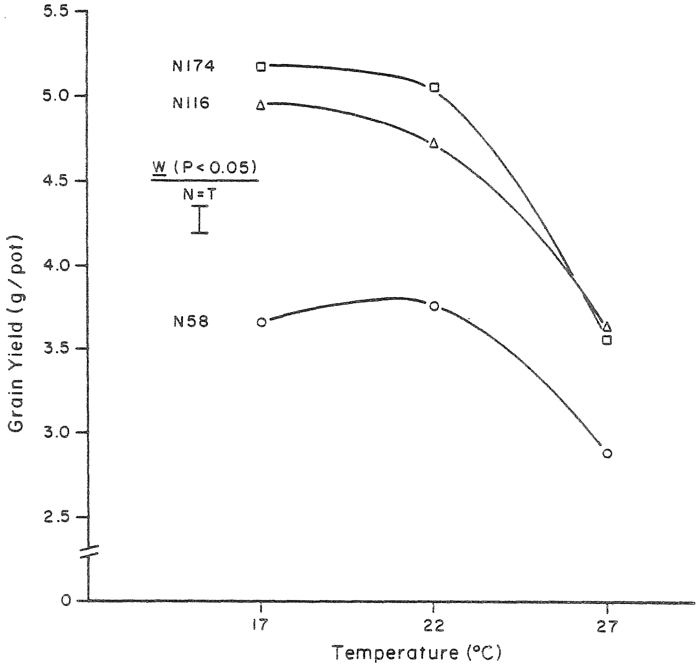


Figure 3

did not. Incidentally, the latter increment did not increase total dry matter either (data not shown) but, as will be shown later, it increased grain protein (concentration) of all treatments except those stressed from tillering. At 17 and 22°C (Fig. 3) and at all moisture stresses, except when stress was applied from near the critical boot stage to maturity (Fig. 4), yield generally increased with N fertilizer. If plants are stressed from the boot stage to maturity then high N rates can actually depress yields (Fig. 4). However, a detailed examination of the results showed that the latter effect might not occur where the plants were already stressed by growing them at high temperatures. Thus, under hot conditions temperature may limit yield more so than does N fertility, and when plants are moisture stressed, especially near the boot stage, moisture stress and temperature may limit yield more than nutrient does.

Generally, near the boot stage was the most critical to yield as far as moisture stress was concerned (Fig. 4). But moisture stress during the boot stage is less detrimental if the stress began from early in the development of the plant (Fig. 4). Thus, the plant seems to be able to adapt to adverse moisture conditions if given sufficient time. This also shows that yield is not necessarily directly related to total growing season precipitation (plants stressed from tillering would have received much less water than those stressed from boot stage).

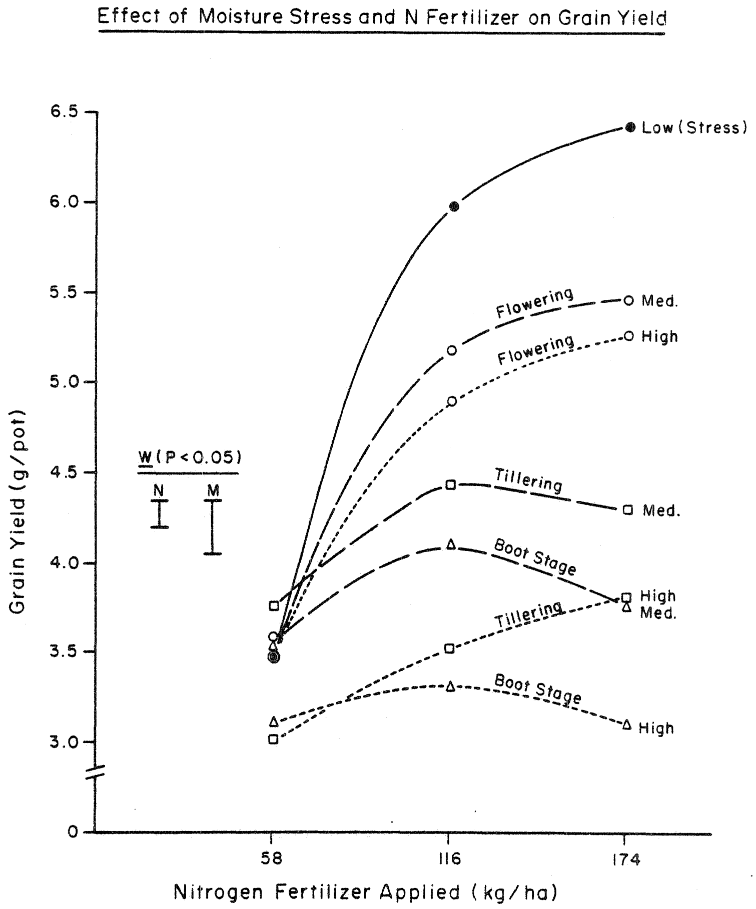


Figure 4

At the low N fertility rate only high moisture stress from tillering or from boot stage to maturity affected (reduced) yield, but at higher rates of N even medium stress and late stress (flowering to maturity) resulted in reduced yield (Fig. 4). It is worth noting that plants grown at high stress from tillering or boot stage on were still able to respond positively to N fertilizer up to 116 kg/ha. Rennie (1956) and Warder (1969) did not find this in the field, but Campbell et al. (1977) and Read et al. (personal communication) have found supporting evidence.

Grain Protein Concentration

The highest grain protein (20%) was obtained under hot, high fertility conditions when high moisture stress was applied from near boot stage to maturity; the lowest (7%) was obtained under cool, medium fertility conditions when stress was applied from late flowering to maturity. In an earlier simulated irrigation study the maximum protein we were able to obtain with a maximum rate of 132 kg N/ha was 12% (Campbell and Davidson 1979b). In the present study, the highest protein was obtained not only because of the higher N rate but because the plant/N fertilizer ratio was smaller and also more denitrification would have occurred in the simulated irrigation study.

The analysis of variance showed that all three variables significantly ($P < 0.01$) influenced grain protein (Table 1). The effect of temperature was 60% > the effect of N which was three times the effect of moisture stress. The effect of temperature was independent of nitrogen or moisture stress. Thus, temperature effect can be expected to be the same, irrespective of whether it is wet or dry, stubble or fallow. Protein was similar at 17° and 22°C and about 33% < at 27°C (Fig. 5). Note that the protein response to temperature is inversely related to yield response. Nitrogen and moisture interacted significantly ($P < 0.01$) in their effect on protein.

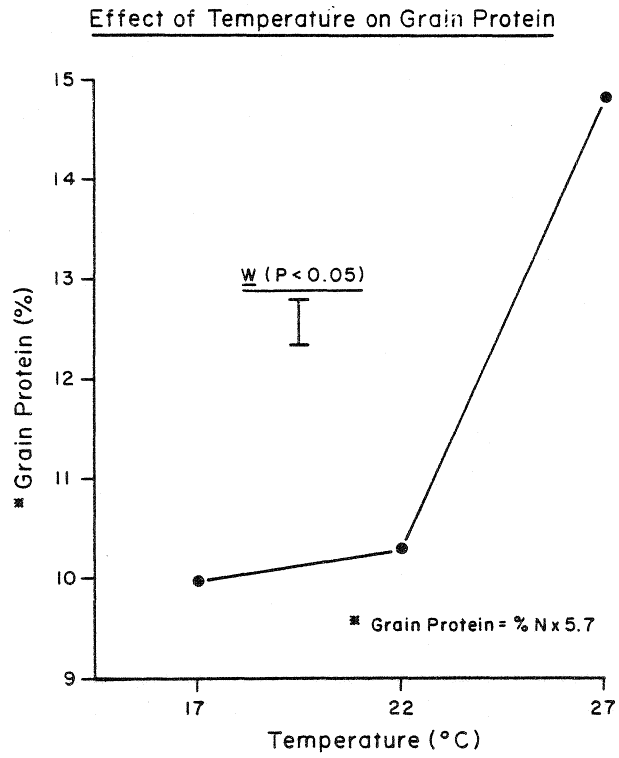
Table 1. Estimation of the direct effect of temperature, nitrogen and moisture stress on grain protein using covariance to remove the contribution of grain yield

	Anal. of var. (Unadjusted for yield)		Anal. of covar. (Adjusted for yield)		% of sum of squares due to variable
	df	MS	df	MS	
Temperature (T)	2	783.9**	2	162.0**	23.8
Nitrogen (N)	2	486.7**	2	372.0**	87.5
Moisture (M)	6	129.5**	6	25.3**	22.4
Reps (R)	4	14.7**	4	12.1**	-
T X N	4	1.0	4	2.0	-
T X M	12	3.5	12	2.4	-
M X N	12	14.3**	12	4.2**	-
T X M X N	24	3.3	24	2.5	-
Error	248	1.9	247	1.7	-

**Denotes significance at $P < 0.01$

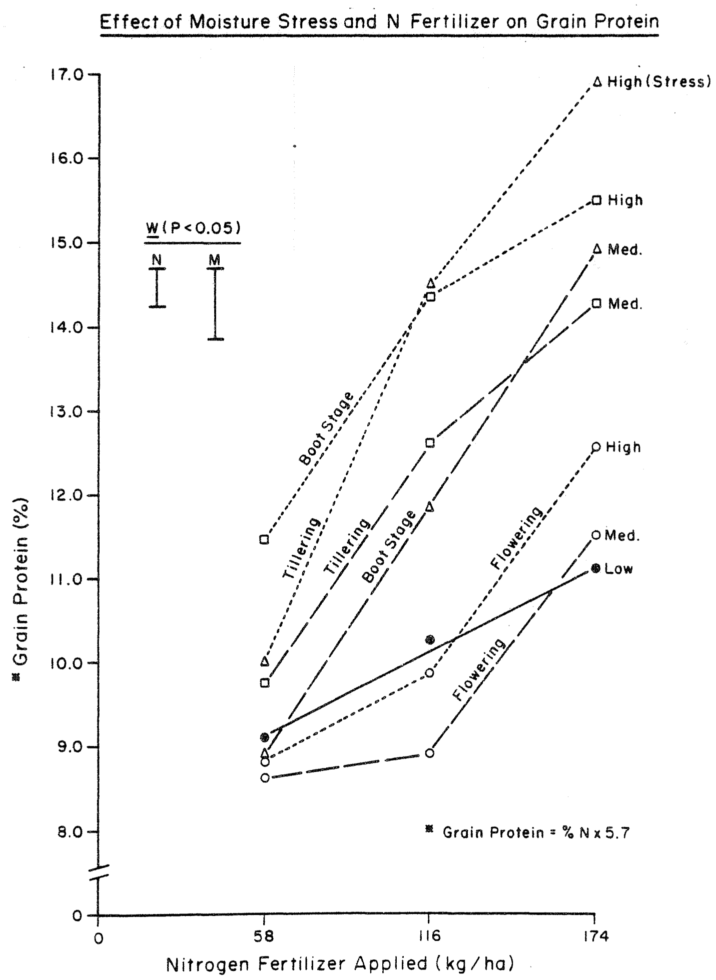
As expected, protein was directly proportional to fertilizer N (Fig. 6). The protein increase per unit of applied N was least for plants grown at optimum moisture and for plants stressed late (i.e., the treatments that gave the highest yields) (Fig. 6).

At low N fertility (such as that found in unfertilized stubble fields) only high stress, occurring from tillering or boot stage to maturity, increased protein (Fig. 6); medium stress or late stress did not influence protein. Nonetheless, it is worth noting that even under conditions of limited N fertility grain protein may be influenced by moisture stress. When plants were stressed late, only the high stress at the high fertility rate increased protein; medium stress at the N116 rate caused a decrease in protein (Fig. 6). This failure of late stress to cause large increases in protein like at the other stages could be a reflection of an inhibition of redistribution of N assimilates. Plants stressed earlier would have had an opportunity to adapt their physiology to the drought conditions, but the late stress takes place during the period of most active nitrogen redistribution (Campbell and



Effect of Temperature on Grain Protein

Figure 5



Effect of Moisture Stress and N Fertilizer on Grain Protein

Figure 6

Davidson 1979a). The effect of early stress compared with stress from boot stage was a function of N fertility. At low N fertility early high stress resulted in lower protein; at the medium N level there was no difference; at the high N level early high stress gave higher protein. No doubt, the relative effect of these treatments on grain yield and consequently on N dilution is at least partially responsible for these interactions.

Simple regression and correlation analysis relating grain protein to grain yield confirmed the usually obtained significant inverse relationship. Some workers in the U.S.A. (Smith 1979) and Partridge and Shaykewich (1972) in Manitoba have obtained evidence that indicates that at a high enough level of N fertility it should be possible to increase grain yield without decreasing protein (Fig. 7). Campbell and Davidson (1979b) in a simulated irrigation study did not find this (Fig.7), but assumed that this was because the rates of N used were too low. In our present study where the levels of N used were high enough to even leave residual N in soil in some treatments, we still did not obtain any indication that we could apply sufficient fertilizer N to increase both yield and protein (or even keep protein constant) at the same time (Fig. 7).

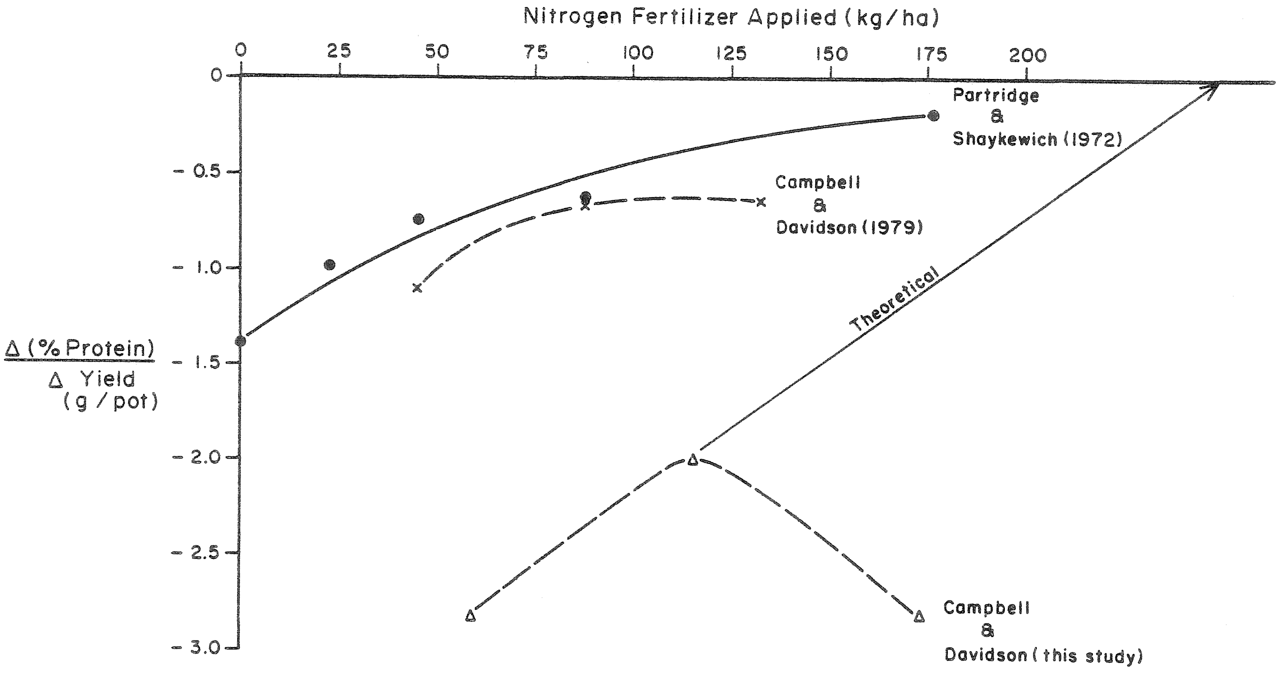

Changes in Grain Protein Relative to Changes in Yield at Different Levels of N Fertility

Figure 7

Since parts of the effect of the treatment variables on protein is via their influence on yield (dilution of protein) and some is direct, we used covariance analysis in an attempt to remove the effect of yield on protein and thus isolate the contribution of the variables per se (Table 1). This analysis showed that all three factors significantly ($P < 0.01$) influenced protein directly, but that the effect of N fertilizer was more than twice as great as that of temperature effect and 15 times as great as the moisture stress effect. It can also be seen that 76% of the nitrogen effect on protein was direct and not due to a dilution effect while the effect of temperature and moisture stress was mainly through its influence on grain yield (dilution effect).

SUMMARY

Manitou spring wheat was grown under controlled conditions at combinations of three temperatures (27/12°C, 22/12°C and 17/12°C), three levels of fertilizer N (58, 116 and 174 kg N/ha), and three moisture stresses (0.3, 15 and 40 atm). All plants were started at 0.3 atm, but while one set was carried through to maturity at this tension, some plants were stressed at 15 or 40 atm from either (i) tiller, (ii) boot stage, or (iii) late flowering, to maturity. Yield and protein concentration of grain were assessed.

Temperature was the most important factor affecting yield and protein and moisture stress the least important. Yields were equal at 17 and 22°C > 27°C. Conversely, protein was equal at 17 and 22° < 27°C. Yield was directly proportional to N fertility except at the highest temperature or where moisture stress was applied from the boot stage. Generally, if conditions were too hot, temperature limited yield more so than N fertility, while if plants underwent high moisture stress, especially from the boot stage, then moisture and temperature limited yield more so than nutrient did. Plants grown under high moisture stress from as early as tillering or boot stage were able to give yield increases when fertilized with up to 116 kg N/ha; but 174 kg N/ha depressed yield of plants stressed from the critical boot stage. The plant was able to adapt somewhat to moisture stress if given sufficient time; thus yield of plants stressed from tillering were generally > yields of plants stressed from boot stage.

Protein as high as 20% and as low as 7% was obtained. The effect of temperature on protein did not depend on the level of N fertility nor on the moisture stress. High moisture stress applied from tillering or boot stages increased protein even at the lowest N fertility level. Stress from late flowering rarely increased protein and decreased it in one instance; this could be due to inhibition of redistribution of N assimilates in the plant. Although high rates of N were used there was no indication that yield could be increased without decreasing protein. The usual inverse relationship between protein and yield (dilution) was obtained. The influence of treatment variables on protein was partly via yield and partly direct. When the influence via yield was removed by covariance, then the effect of N was twice as great as temperature effect and 15 times as great as the moisture stress effect. Furthermore,

most of the N effect on protein was a direct effect while the temperature and moisture acted mainly by influencing yield.

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