CANADIAN JOURNAL OF SOIL SCIENCE

Volume 46 JUNE 1966 No. 2

CONTROL OF THE PROTEIN CONTENT OF THATCHER WHEAT BY NITROGEN FERTILIZATION AND MOISTURE STRESS[1]

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Received November 8, 1965

ABSTRACT

Experiments are reported in which it was shown that the protein content of spring wheat, grown in the growth chamber, could be effectively controlled by nitrogen supply and soil moisture stress. Protein contents above 16% were obtained only where yields were below the maximum attainable. In the protein range from 11 to 16%, it was possible to increase both protein and yields concurrently; protein contents higher than 16% were realized only where a growth factor such as moisture was below optimum for maximum yields.

Moderate moisture stresses resulted in maximum efficiency of water use by the crop. High levels of nitrogen had more influence on the growth of straw than grain; the straw/grain ratio widened with increasing increments of nitrogen.

INTRODUCTION

Two of the more important factors influencing yield and protein content of wheat are soil moisture and nitrogen availability (1, 4, 6). Nitrogen has, in the past, not often been a limiting nutrient under Western Canadian field conditions where large amounts are stored in the soil during the summerfallow period (8) and where grains with a low yield potential, such as Thatcher, are commonly grown. The use of higher-yielding crops and the increased utilization of continuous cropping in recent years has placed greater demands on the soil nitrogen supply. The protein content of the currently utilized wheat varieties, too, is frequently lower than desirable in wet, cool years in which there is substantial plant growth coupled with a lower supply of available soil nitrogen.

In the field, much of the variation in protein values can be attributed to changes in the type of soil profile and the associated microclimate (5). These variations can, in part, be caused by temperature differences, since in the growth chamber, growth of grain at different temperatures (which affects water use and rate of plant growth) also affects the yield and the protein content (7). A single moisture stress applied during the growing period has been shown to alter both yield and protein content, with the greatest effect being shown by a stress applied at the soft dough stage (3).

Flour and wheat proteins obtained from plants grown at different levels of moisture stress, temperature, and nitrogen fertilization varied in their amino acid contents. The relative distribution of six amino acids was significantly correlated with protein content and quality (7). These changes could be explained on the basis of changes in the morphology of the wheat grain and the

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proportion of flour proteins. Efforts to establish higher-yielding varieties of spring wheat for growth in the Prairie Provinces have been hampered by reduced protein content and resulting reduced baking quality. The use of adequate fertilization practices may, however, overcome this problem. Therefore, it is necessary to investigate thoroughly the interaction of environmental conditions and fertilizer practices in relation to grain yield and protein content in an attempt to arrive at some combination of practices which will assure high grain proteins as well as high yields.

MATERIALS AND METHODS

Thatcher wheat was grown in the growth chamber in 1-gal glazed crocks, each containing 4,000 g of soil. The soil moisture content versus tension curves (Fig. 1) for the two Black Chernozemic soils were constructed using data obtained with the pressure membrane and a porous plate apparatus.

Phosphate as $NH_4H_2PO_4$ was added with the seed at the rate of 11 μg P/g soil. The different levels of nitrogen were applied as NH_4NO_3. A number

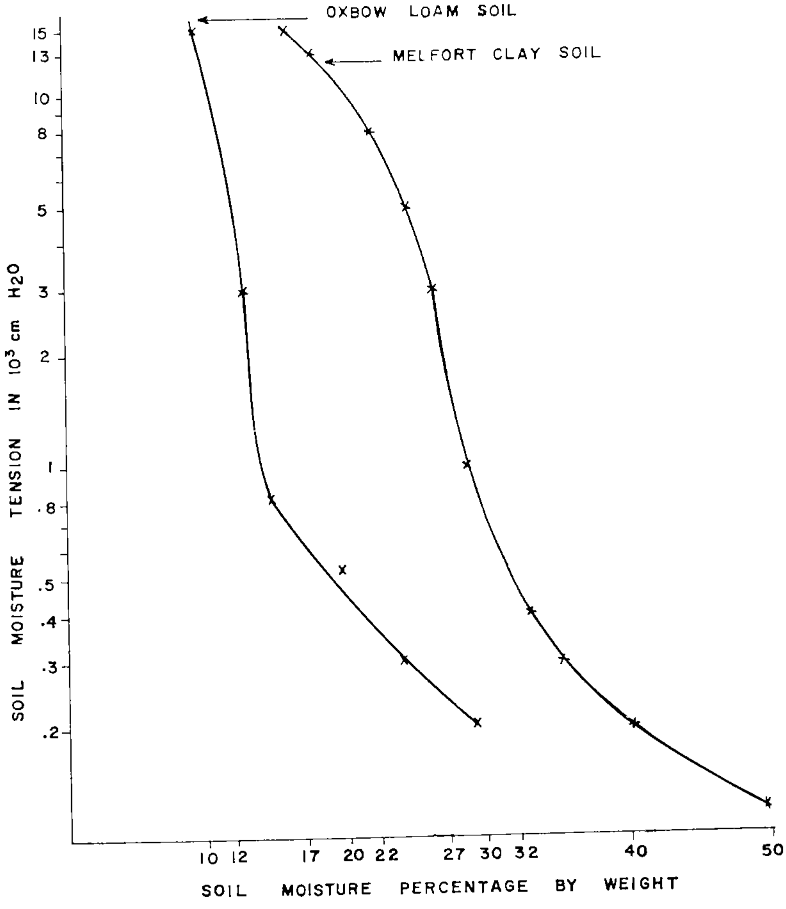

FIG. 1. Soil moisture–tension curve for Melfort clay and Oxbow loam.

of experiments (2) in which nitrogen was added during the growth period, either in the water or on top of the soil and then watered in, indicate that it is difficult to ascertain the nitrogen requirements of the crop at any specific date. It has thus been found most convenient to add the total specified nitrogen at planting time. This eliminates a number of problems and was the procedure employed in the study presented in this paper.

The soil moisture was maintained at a tension of less than 1 atm for 3 weeks to ensure uniform initial growth. After this time, the designated stresses were imposed. The stress treatments were carried out by watering each soil to field capacity, and then allowing the soil to dry to the moisture content approximating the minimum limit for a particular moisture regime. The soil moisture was then restored to field capacity, the amount of water added being recorded.

Two individual plants were grown in each pot. Mature plants were harvested approximately 100 days after seeding. The grain was dried, threshed by hand, weighed, and ground or milled. Nitrogen contents were determined using micro-Kjeldahl equipment. Further details concerning the growth conditions have been previously reported (3, 7).

RESULTS

Grain protein was increased but total yield, water use, and grain yield decreased markedly with increasing moisture stress (Fig. 2). These relationships were compared by plotting the data for a number of plant growth characteristics on an arithmetic scale, without specific units, against the logarithm of the maximum moisture tension, in cm of H_2O, to which the plants were subjected during their growing period. The values at the extreme left of each graph represent plants grown under low moisture tensions, very near the field capacity of the soil. The extreme right of each graph represents the plants that were subjected to a stress approximating the wilting point before rewatering. The effect of moisture tension on plant yield and consumptive use of water at the different fertilizer levels is logarithmic in the Oxbow soil; the plant yield and moisture-use figures, when plotted against the logarithm of the moisture tension, tended to produce straight lines.

High levels of nitrogen application had a greater influence on the growth of straw (total weight − grain weight) than on grain, thus, the straw to grain ratio widened with increasing increments of nitrogen. In every instance these ratios narrowed with increasing moisture stress. Under optimum moisture conditions (875 cm tension max.), the percentage protein increased with each additional increment of nitrogen (Fig. 3). In contrast, the grain protein of plants subjected to 18,000 cm tension were affected little by nitrogen fertilization. Treatment of the soil with 100 μg N/g soil (220 kg/ha) was not sufficient to produce maximum yields under the favorable moisture conditions of the 27–17% moisture treatment, whereas the crop growth and grain yield reached a maximum in the 27–14% moisture regime at 75 μg N/g soil. The total yield of 40.9 g/pot and the grain yield of 17.4 g/pot for the highest-yielding treatment are equivalent to 16,800 kg/ha (7½ tons/acre) and 7400 kg/ha (110 bu/acre) respectively.

At high moisture levels, increased nitrogen fertilization produced slight increases in the efficiency of the water used; 475 g of water were required to

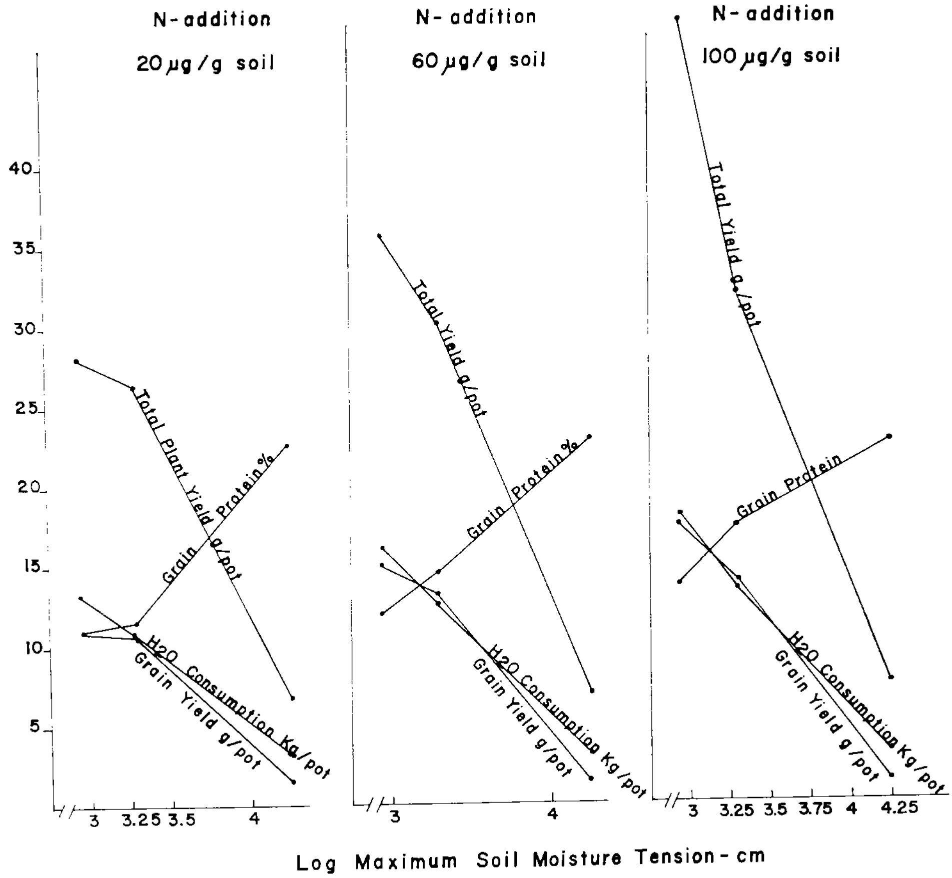

FIG. 2. The effect of moisture tension on the growth characteristics of Thatcher wheat (Oxbow soil).

produce 1 g of plant material (dry weight) at the low nitrogen level, whereas at higher rates of nitrogen, the moisture use was 443 g of water per gram of dry plant material. The moderate moisture stress resulted in the greatest efficiency with only 410 g of H_2O being utilized per gram of dry plant material. At the two higher moisture levels, a fairly consistent difference in yields equivalent to 600 kg/ha (9 bu/acre) can be attributed to the contribution of water to the growth process, with the total uptake of nitrogen by the above-ground parts of the plants tending to be equal for comparable nitrogen treatments within these two water regimes.

At optimum moisture and nitrogen levels the grain and plant yields in the Melfort clay soils were lower than the yields obtained with the Oxbow loam under similar conditions (Fig. 4). The Melfort soil was characterized by a very high nitrogen-supplying power in addition to a high content of inorganic nitrogen. Consequently, nitrogen additions did not produce significant changes in either yield or protein content. Nearly all of the grain protein per-

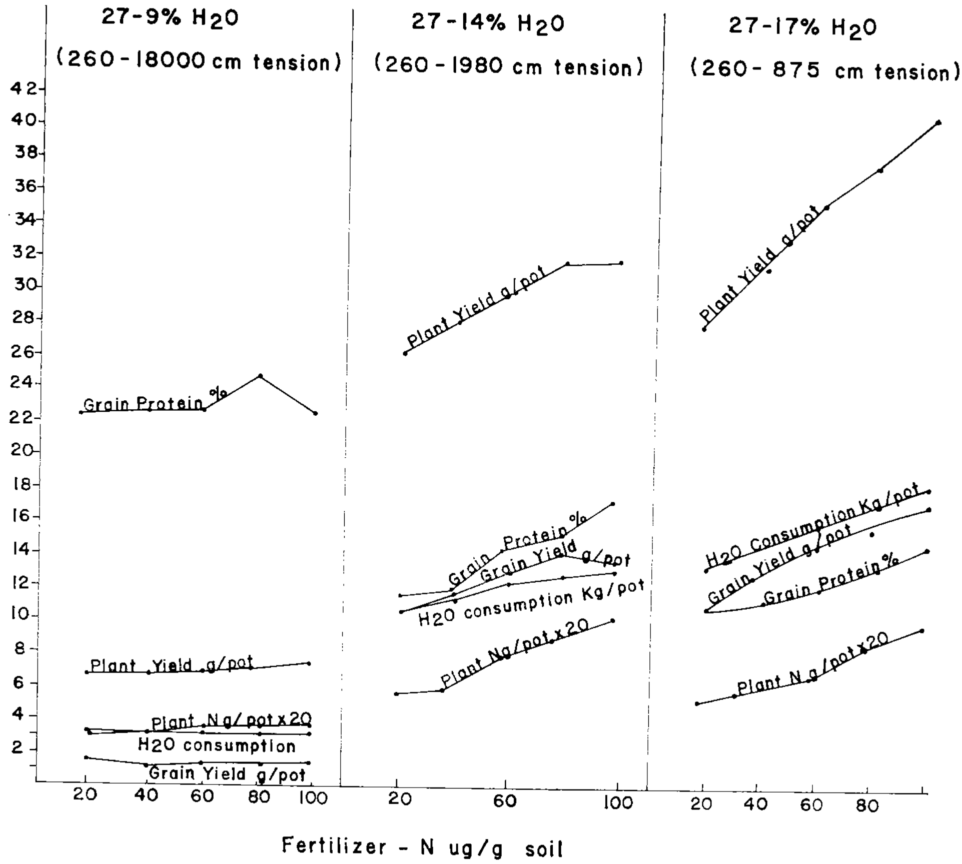

FIG. 3. The effect of nitrogen fertilization on grain and plant yield, water use, and grain protein contents (Oxbow soil).

centages were above 16, with the high nitrogen contents of the grain again being related to low yields of plant material resulting from high moisture stress.

The general relationship between grain yield and protein content is demonstrated in Fig. 5 which summarizes the yield–protein interactions obtained from a large number of experiments with Thatcher wheat over a 10-year period. These data show that it is possible to increase the grain protein percentage while maintaining or actually increasing the plant yield, up to a maximum of 16% protein. It does not appear possible to obtain higher concentrations of protein contents in this variety without limiting the yield in some manner. The decreased yield, which can be attributed to a lower dilution with carbohydrates, results in the increased concentrations of nitrogen in the grain.

A regression analysis was carried out on data obtained from these and six other related growth chamber experiments in which nitrogen and moisture stress were varied. Fifty-five different combinations of the treatments which affected the measured plant characteristics were used to calculate the correlation

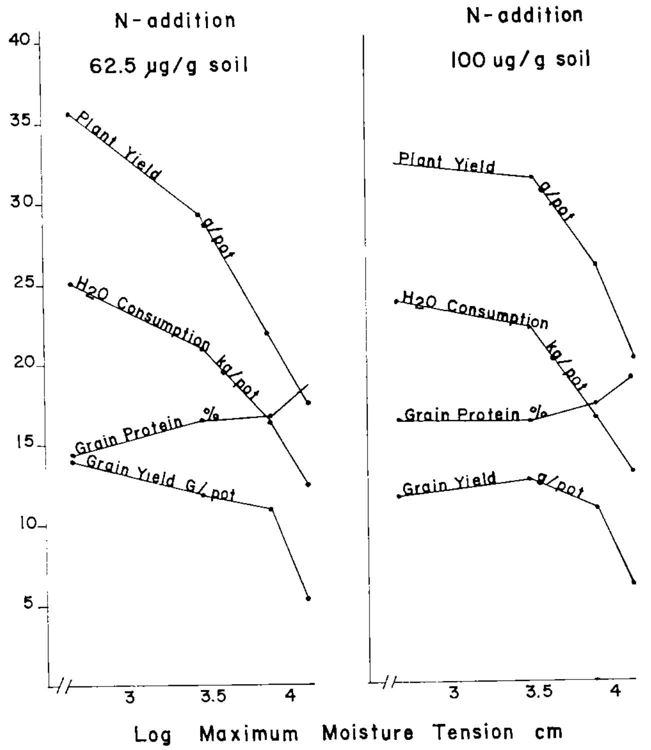

FIG. 4. The effect of moisture tension on the growth characteristics of Thatcher wheat (Melfort soil).

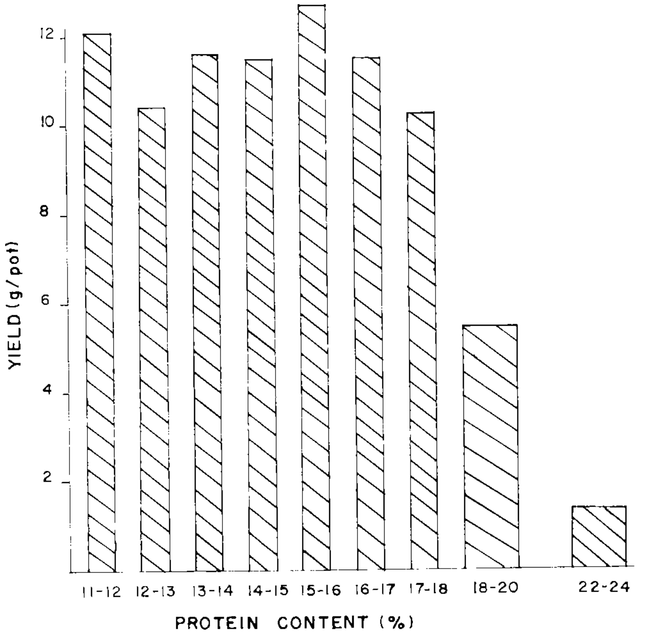

FIG. 5. The general relationship between grain yield and wheat protein content.

coefficients (Table 1). The effect of moisture stress and of nitrogen fertilization on straw yields in relation to that of grain yield has been previously discussed. The correlation between plant weight and grain weight was therefore understandably low.

Total plant weight and water consumption were closely related, with differences in plant weights accounting for 80% of the variation in total water consumption. The combined evaporation from the soil and transpired water varied from 5 to 17 kg/pot, depending on the plant growth. The evaporation from the soil surface totalled 1.3 kg/pot, which accounted for 7 to 25% of the total consumption. The correlation between transpired H_2O and plant yield would have been higher if the evaporated H_2O had been eliminated from the calculations.

Table 1. Correlation coefficients for a number of plant growth characteristics affected by moisture and nitrogen supply

Plant weight – grain weight	0.48**
Plant weight – protein content	−0.62**
Plant weight – water use	0.89**
Grain weight – water use	−0.60**
Grain weight – protein content	−0.63**
Grain weight – protein content (> 16% protein)	−0.89**

$^{**}P = < 0.01$.

DISCUSSION

Moisture stress altered grain protein content primarily through its action on yield of both grain and forage. At high moisture levels (low stress treatment), which appeared to favor production of carbohydrate materials both in the leaves and in the kernel, Thatcher wheat did not have protein contents higher than 16%. Under these conditions the various factors affecting yield and protein content interacted. It was possible (see Fig. 5) to increase both the protein content and the yield by nitrogen fertilization. Fairly high yields also could be obtained under conditions where the nitrogen supply was low, thus resulting in low protein levels. The correlation coefficient between yield and protein content over the whole growth range (Table 1) was, therefore, understandably low.

More than 16% protein was obtained with Thatcher wheat only if some external factor limited plant yield. The high correlation coefficient between wheat yields and protein contents above 16% substantiated this observation. This indicated that the production of materials such as carbohydrates in the grain is more sensitive to adverse growing conditions than is the production of proteins.

The plant nutrients nitrogen and phosphorus, the physical conditions such as moisture supply and aeration, and the environmental factors such as light and temperature interact under growth chamber conditions to control the growth characteristics and protein content of wheat. This study suggests that it is possible to grow wheat with a specified protein content, ranging from 11 to 22% with a variation of ±.5%, by varying the nitrogen supply and moisture stress of the soil. A preliminary growth study must, of course, usually be conducted to determine any physical or nutrient deficiencies affecting plant growth and to ascertain the nitrogen-supplying power of the soil.

Temperature has been shown in a previous study to have an independent effect on protein quality in addition to its general control of water use and grain yield (7). Under Western Canadian conditions, the nitrogen-supplying power of the soil also is affected by the soil moisture content and by the temperature during the growing season. The specific fertilization and yield figures obtained in growth chamber studies, therefore, cannot be applied directly to field conditions. Studies such as these, however, make it possible to interpret field results where the variations obtained make specific interpretations difficult.

ACKNOWLEDGMENTS

The financial assistance provided by the Canada Department of Agriculture is gratefully acknowledged.

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