THE EFFECT OF N FERTILITY ON THE RATE OF GROWTH OF SPRING WHEAT

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INTRODUCTION

Growth analysis techniques have long been used by botanists, crop scientists and agronomists to analyze quantitatively plant growth and development. Such concepts as Growth Rate (GR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR) and Leaf Area Index (LAI) have been adopted into the literature and have acquired specific meanings. Often these concepts have been used as the basis of mathematical models describing plant growth. Modeling biological systems, or to use a more general term, simulating them, has become a very popular analytical technique and has been encouraged in recent years by easy access to high speed electronic computers capable of storing and processing enormous amounts of data. Probably one of the best contributions modeling has provided, has come about indirectly. Simulating a complex organism is an instructive exercise inasmuch as it helps to organize knowledge, point out areas of weakness and demonstrate the interaction of the various components of the system under study.

This paper will describe in a very general way one approach to modeling wheat growth based on the Relative Growth Rate concept and will deal in more depth with that aspect of the model which describes the effect of nitrogen fertility on the accumulation of dry matter.

METHODS AND MATERIALS

The Model Investigated

By definition the Growth Rate (GR) of a plant is given by

$$GR = \frac{dW}{dt} \quad (1)$$

where W is the dry weight at any time t. The Relative Growth Rate (RGR) is defined as the "increase of plant material per unit of material present per unit of time".

$$\text{i.e.} \quad RGR = \frac{1}{W}\frac{dW}{dt} \quad (2)$$

An expression for the dry weight at any time t is obtained from equation (2) as follows:

$$\frac{dW}{W} = RGR\ dt$$

$$\ln W = \int RGR\ dt + C$$

$$W = e^{\int RGR\ dt + C}$$

$$W = W_o e^{\int RGR\ dt} \quad (3)$$

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where W_o is the initial weight at time zero. Clearly if equation (3) is to be used to predict W, a method must be found to evaluate $\int RGR\, dt$. This is not at all an easy proposition because such an evaluation must take into consideration the effects on RGR of such soil and environmental variables as: nitrogen fertility, soil moisture, soil and air temperature, radiation, humidity and wind velocity to mention only a few of the more important ones, all of which are strongly time dependent. A further complicating factor is the interaction which occurs between variables.

One approach to this problem which we are investigating is to consider RGR on a daily basis as the product of several functions each of which describes one of the environmental variables, i.e.:

$$RGR = m(i) \cdot f(T) \cdot g(I) \cdot h(S) \cdot q(N) \; . \; . \; . \; \text{etc.}$$

where m(i) is a function describing the maximum possible RGR for any day i and f(T), g(I), h(S) and q(N) are normalized functions for temperature, light intensity, soil moisture, and nitrogen fertility respectively. Hence

$$\int RGR\, dt = \sum_{i=1}^{n} m(i) \cdot f(T) \cdot g(I) \cdot h(S) \cdot q(N) \; . \; . \; . \; \text{etc.} \; . \; . \; . \; . \quad (4)$$

Of course, the more environmental paramaters which are taken into account in equation (4) the closer the simulation approximates reality. In practice the functions in equation (4) are usually determined by growth chamber or field studies and the number of functions used is limited by practical considerations. The remainder of this paper will concern itself with some preliminary determinations of only one of these functions, q(N), the contribution nitrogen fertility makes to dry matter accumulation.

Experimental Work

During the 1975 crop year we performed an experiment at the Swift Current C.D.A. Research Station which was intended, in part, to investigate the effect of nitrogen on dry matter accumulation. One hundred and forty cylindrical lysimeters were installed in a field plot as described in the previous paper (Dyck et al. 1976). The experiment consisted of a factorial combination consisting of two moisture levels (irrigated and dry), seven nitrogen levels and five sample times with two replicates. Three wheat plants, variety Manitou, were grown in each lysimeter. For further experimental details see Campbell et al. 1976 which follows.

OBSERVATIONS

Figures 1 and 2 illustrate the environmental conditions during the experiment. As can be seen in Figure 1 the maximum and minimum air temperatures increased to a maximum during July and then decreased. Associated with this was a period of drought during July. The available soil moisture (Figure 2) decreased accordingly and this had a pronounced effect on the development of the wheat plants. In the wet treatments the plants experienced only a slight stress and the cool weather and rains in August retarded their maturity. However, the "dry" plants were severely stressed and, as will be shown later, their development was quite different.

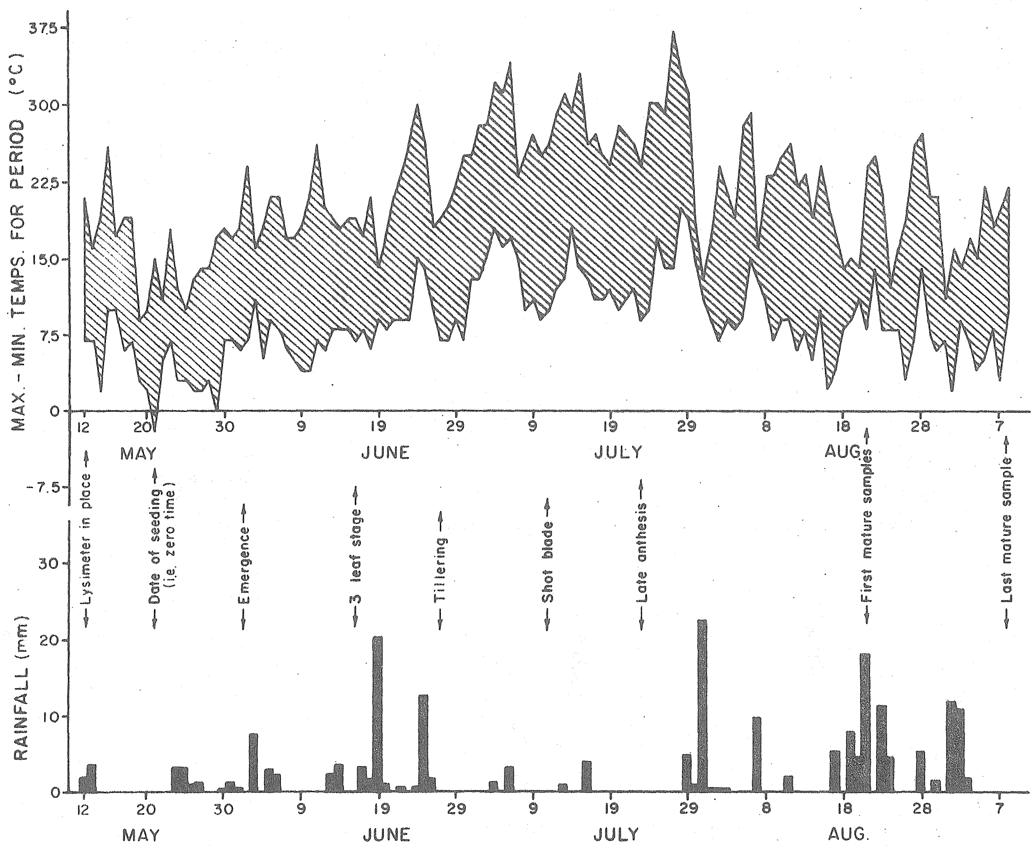

Fig. 1. Diurnal air temperature and precipitation during experimental period

In Figure 3 the dry weight for the plants grown in the irrigated lysimeters is plotted as a function of nitrogen applied for each of the five sample times: three leaf (14 days), tillering (25 days), shot blade (39 days), late anthesis (51 days) and maturity (70 days). For the earlier times, that is, less than 25 days, the effect of the nitrogen treatment is not as pronounced as for the later stages. By maturity, the first 112 kg/ha of nitrogen applied produced an increase of 7.8 gm of dry matter per three plants whereas the next 112 kg/ha only produced about one gm. By extrapolating the graph, further application would seem to result in only a very slight increase in dry weight if any at all. This suggests that the increase in dry matter obtained from the application of nitrogen might be governed by the law of diminishing returns. It is reasonable therefore to assume that q (N) follows the law of diminishing returns, i.e.

$$q(N) = 1 - e^{-\alpha N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where $0 \leq \alpha \leq 1$ is a constant typical for Manitou wheat and N is the amount of available nitrogen present in the soil in kg/ha. It should be pointed out here that the applied nitrogen in Figure 3 is only part of that available to the wheat plants. Some was present in the soil initially and more is made available by mineralization. For this reason the curves do not all go through the origin for zero applied nitrogen.

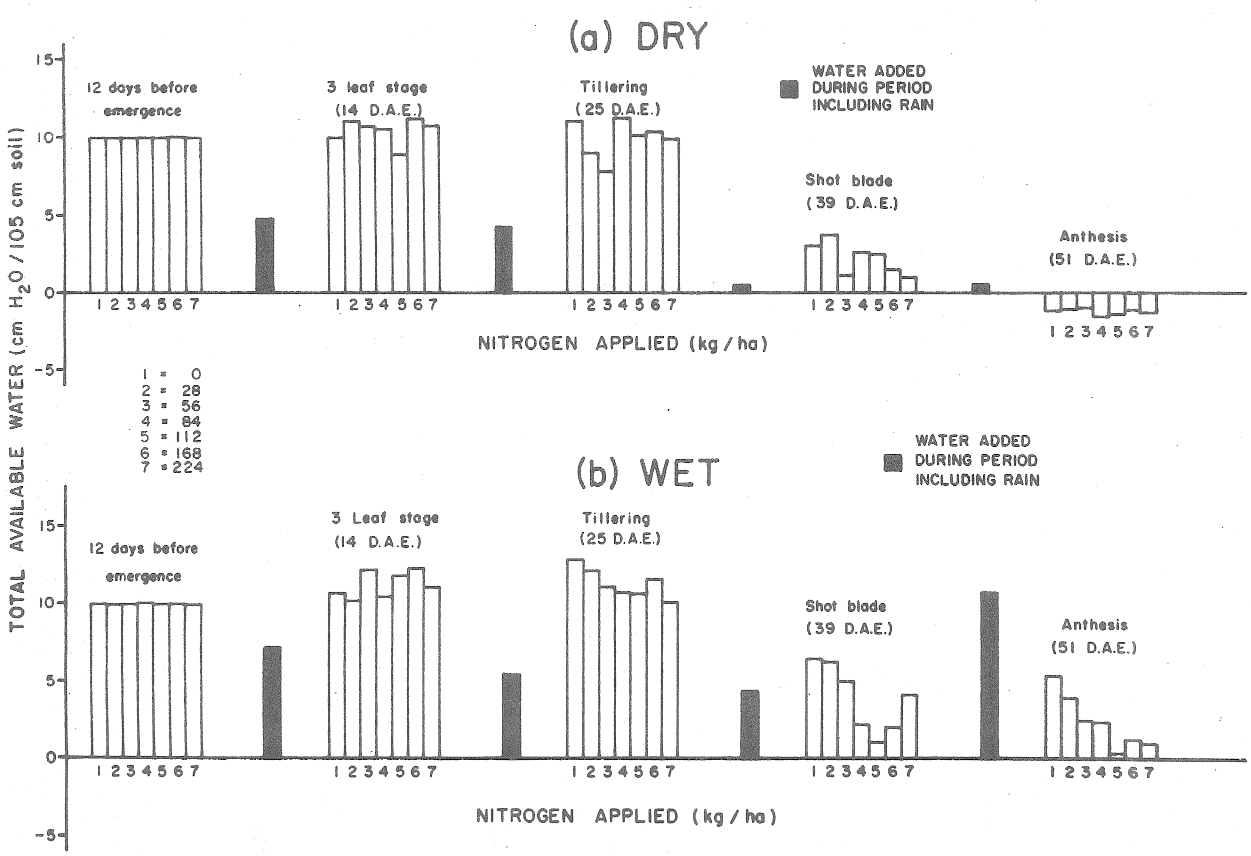

Fig. 2. Effect of fertilizer N on total available water in soil profile at four growth stages

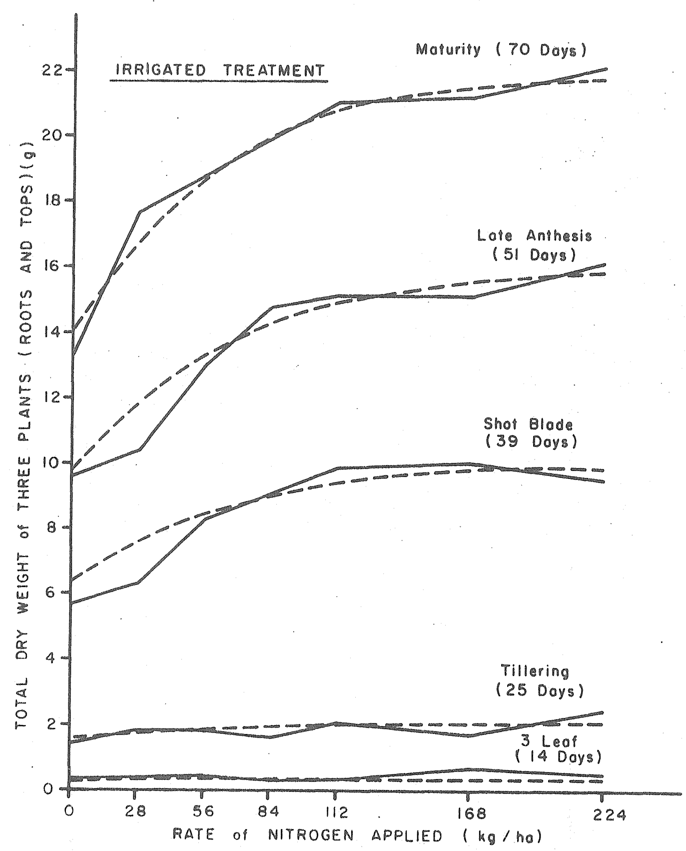

Fig. 3. Total weight of dry matter produced (tops and roots) by three plants under irrigated conditions for different rates of applied nitrogen

The problem of how to determine the value of α in equation 5 now presents itself. This is done by making the following observation. From equation (3) it follows that

$$\ln W - \ln W_o = \int RGR\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Figure 4 is a plot of the accumulated dry weight for three plants with time for the irrigated treatment at 224 kg/ha of applied N. At this level nitrogen fertilizer is no longer a limiting factor and RGR can be considered to be independent of q (N). Equation (6) was used to evaluate $\int RGR\ dt$ using the graph in Figure 4. For convenience let us designate $\int RGR\ dt$ at 224 kg/ha of applied N as F (t). Hence for all other levels of applied N

$$\int RGR\ dt = F(t).q(N) \quad \ldots\ldots (7)$$

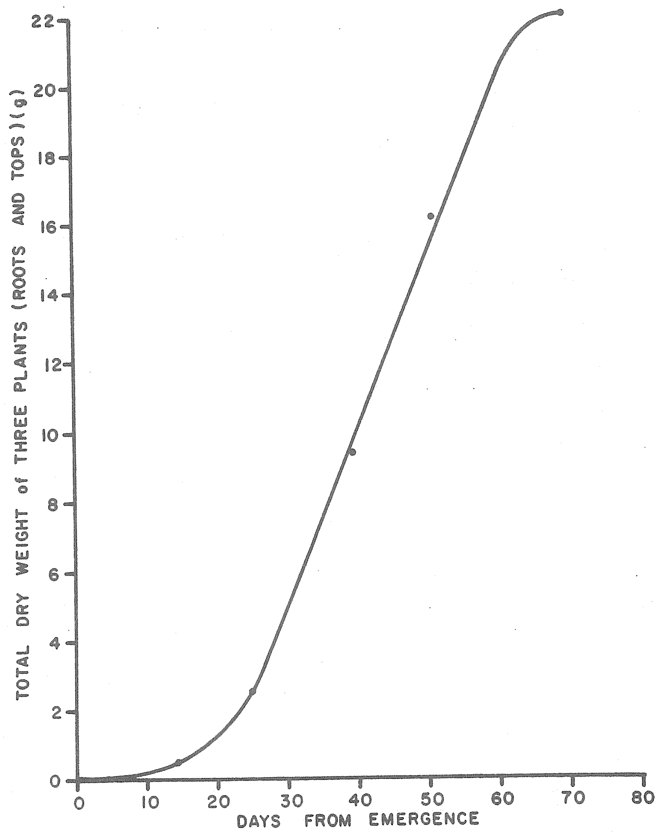

Fig. 4. Total weight of dry matter produced (tops and roots) by three plants with time at 224 kg/ha of nitrogen applied

The general equation for growth of Manitou wheat thus becomes

$$W = W_o e^{F(t).q(N)} \quad \ldots\ldots (8a)$$

OR $$W = W_o e^{F(t)\cdot(1-e^{-\alpha N})} \quad \ldots\ldots (8b)$$

where all the coefficients and functions are known except α .

By performing some simple manipulations equation (8b) can be linearized to the following form:

$$\ln \left[1 - \frac{\ln {}^{W}/W_o}{F(t)} \right] = -\alpha N \quad . . . . (9)$$

Hence a plot of $-\alpha N$ against N should produce a straight line having a slope of α . The left hand side of equation (9) has been evaluated for each nitrogen level and corresponding values of F(t). These are plotted in figure 5 and the least squares regression line determined. The value of α obtained was 0.02. The dashed lines in Figure 3 are obtained from equation (8b) using α = 0.02 and illustrate how well the model fits the data.

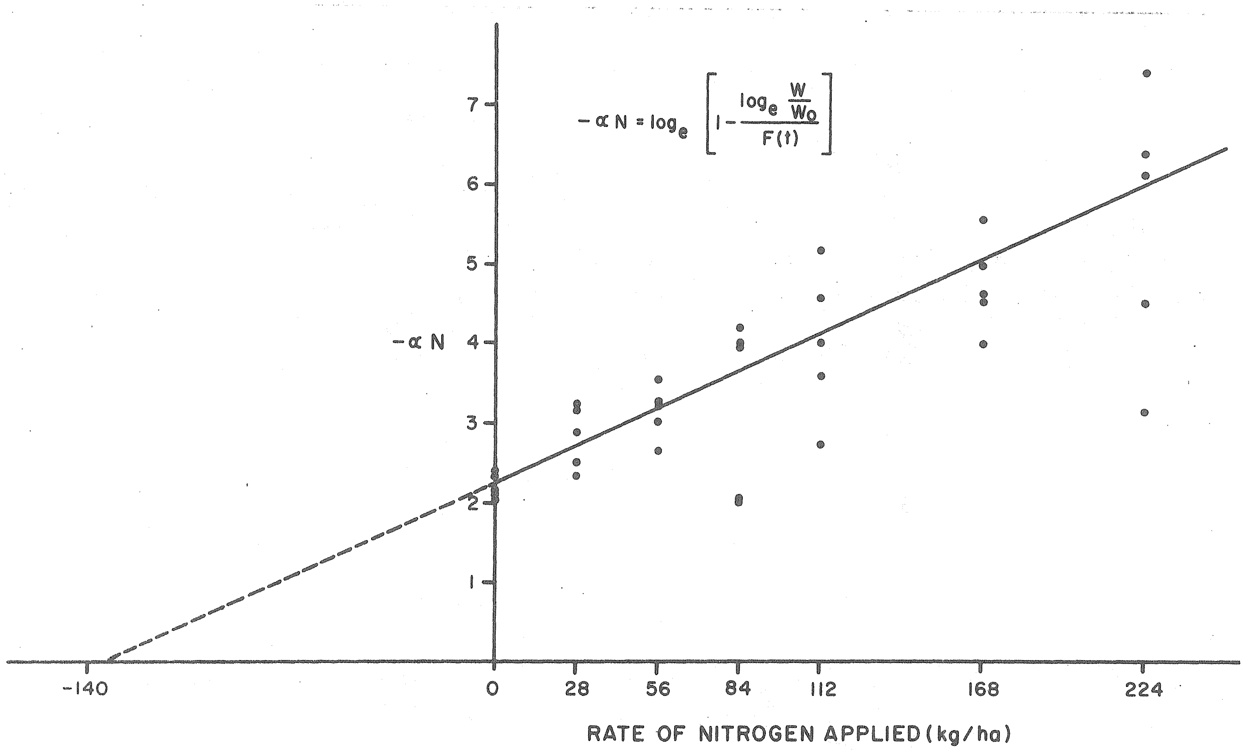

Fig. 5. Graphical evaluation of α .
For explanation see text.

A second interesting feature of this graph is the point of intersection of the regression line with the horizontal axis. This point, -140 kg/ha, is an independent estimate of the amount of nitrogen available to the wheat plants which was initially present at the start of the experiment or mineralized during the growing season. This figure agrees reasonably well with that obtained at the end of the experiment of 110 kg/ha by chemical analysis of the plant soil system. However, not too much emphasis can be placed on this feature of the technique as it is doubtful if equation (8b) holds for very low nitrogen levels.

Figure 6 is a plot of the results obtained from the dry treatment. These are presented to demonstrate the difficulties encountered in the modeling approach. As is illustrated in the graph, for applied nitrogen levels greater than 56 kg/ha, accumulation of dry weight is depressed during the shot blade and anthesis stages. A slight recovery is experienced before maturity. In general, the dry treatment produces less dry matter than the wet treatment but it is the variation within the treatment which causes trouble. This internal variation is probably due to interactions between enironmental variables. Such internal feed-back mechanism must be taken into account before a general simulation model can be developed which is reliable under all combinations of environmental conditions.

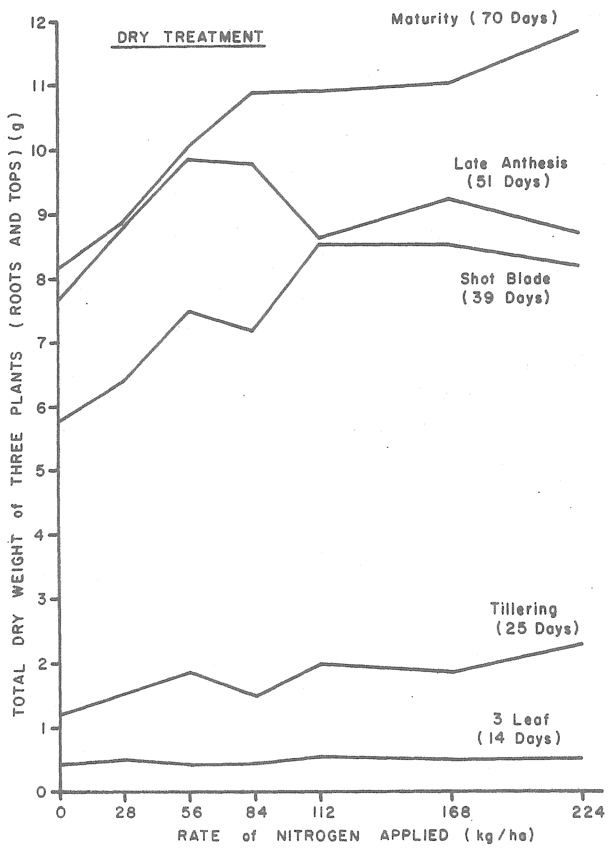

Fig. 6. Total weight of dry matter produced (tops and roots) by three plants under dry conditions for different rates of applied nitrogen

CONCLUSIONS

Under conditions of adequate soil moisture equation (5) is a reasonable predictor of the effect of nitrogen fertility on the RGR. However, under dry conditions the relation is no longer adequate. The model must be developed further to account for interactions between environmental parameters.