Simple Simulation Models for Agronomic Research

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Abstract

An increasing number of countries in the tropical belt have reacted to increased wheat consumption by establishing local wheat research and production programs. By means of simple simulation models based on climatic variables, potential wheat yields (root, shoot and grain yields) can be calculated for tropical environments. These models may be helpful for extrapolation of results to other geographical areas, where less detailed or no experimention has been carried out, or for generalization over longer time periods. Such models can help identify suitable areas for wheat research, and determine optimum sowing dates, days to reach specific developmental stages and dates for supplementary irrigation. They may also help assess whether long or short-maturation cultivars should be used in a specific area.

Wheat has one of its centers of origin in the tropical belt in Ethiopia. Here, it is fully integrated into the diet and into the farming systems, and long-term data on wheat performance are available (4). In several other countries in the tropical belt, wheat was introduced by European and Arab traders and settlers after the year 1500. Before the 1970s, wheat was mainly grown in the tropics as a cash crop for export or to feed expatriates (1,3,6,7, 13,15,23). In the 1970s, local wheat consumption increased (5), world wheat prices were subject to large price fluctuations (14) and wheat production for local consumption became more and more important, e.g., in Zambia and Thailand (6,8). In tropical countries, wheat production still needs to be integrated into the farming systems, and long-term data are scarce or not readily available. Possibilities and constraints need to be investigated before large-scale wheat production is undertaken (6,9); if not, costly errors may be made, giving negative stimuli to local wheat production. Following are examples of simple simulation models that may be of assistance in local agricultural research.

Simulation Models and Calculation Methods

At present, modeling can be used for three sets of conditions or production levels (12):

- Production Level 1—Growth is limited by genotype and interaction with weather (temperature, radiation, etc.)
- Production Level 2—Growth is limited by water shortage and by weather conditions part of the time
- Production Level 3—Growth is limited by nitrogen shortage, water shortage and weather part of the time

Simulation of conditions whereby growth may also be limited by nitrogen, phosphorus, other minerals, water and weather conditions is not yet sufficiently advanced for practical use.

Models have been made that use day-to-day input or mean daily data averaged over a five (17) or ten-day period (18, 19,20,21). While in many areas day-to-day weather data are not available, monthly data are available. In models for both short-cycle spring or summer wheat (21) and long-cycle winter wheat (17), monthly data and long-term data can be used. The computer is a useful tool to reduce the time needed for calculations, but simulations can also be performed with a desk calculator (18,20).

At Production Level 1, irradiation and temperature are two factors of importance for dry-matter production of a wheat crop during development from emergence to maturity. Biotic and abiotic factors other than global radiation and temperatures are assumed to be nonlimiting. Simple simulation models and calculation methods can define the phenological state of the crop, making use of heat sums expressed in degree days. This not only applies to Production Level 1, but can also be applied to levels 2 and 3 (17,18,19,20,21). Rate of plant development is governed by genetic properties and environmental conditions. Genetype accounts for the distinction in short, medium and long-maturation types (Table 1), while environmental factors cause variations in growth duration for one genotype between locations and seasons.

Presently, the effects of day length are difficult to describe quantitatively. The heat sum for the period from anthesis to maturity appears to be constant for wheat genotypes (22).

Potential yields (root, shoot and grain) can be calculated for crops sown at different dates, in different years and at different locations, as was demonstrated with a model developed for Zambia (21). Thus, simple simulation models can help, among other things, to eliminate areas unsuitable for production, to identify potentially suitable areas for research and production and to plan for sowing-date experiments at one or more locations. The influence of the duration of the vegetative period (to anthesis of the plant) on calculated yields for wheat sown at a given location at different dates can be evaluated (21). This may help in deciding whether to use short, medium or long-maturation cultivars. Using the heat sum, the maturation of various phenological development stages of wheat, as well of rice, maize and

Table 1. Heat sum in degree days (°Cd) above a base temperature of 0°C for wheat and rice

	Degree days (°Cd)		
Genotype	**Emergence to anthesis**	**Anthesis to maturity**	**Total**
Wheat			
Short maturation[a]			
Emergence January 1	820	900	1720
Emergence July 1	950	900	1850
Medium maturation[b]	1100	900	2000
Long maturation[a]	1175-1350	900	2075-2250
Rice[c]			
Short maturation			2850
Medium maturation			3400

Sources: [a] Van Keulen and De Milliano (21)
[b] Van Keulen and Seligman (22)
[c] VanKeulen (18)

sorghum, can be calculated. This may be useful for agronomists and breeders when planning visits to experiments at various locations.

Van Keulen (12,19,20) developed a calculation method for estimating crop yields at Production Level 2 where, at times during the growing season, water may be a limiting factor. The degree of water shortage for the crop, during different periods, can be calculated. This gives an indication of what amount of irrigation water is necessary to achieve potential production and when to apply supplemental irrigation. Existing simulation models for Production Level 3 are still in a preliminary stage, for use only by specialized scientists (12,22).

Discussion

One of the problems in interpreting the results of long-term yield trials is the assessment of the relative influence of genotype characteristics, environmental factors and management practices on the final results in a particular situation. This difficulty limits the possibilities for extrapolation of results to other areas, where less-detailed experiments have been carried out or for generalization over longer time periods. The use of models, in which the influence of such factors is described quantitatively, may be helpful in analyzing experimental results and applying them for the purpose of prediction. At present, simple models at Production Levels 1 and 2 may be useful to agronomists, breeders and planners.

Table 1 shows that the total heat sum for the development of wheat from emergence to maturity is considerably lower than for rice. One interesting challenge to breeders could be to increase this total heat sum; this might facilitate the introduction of wheat into warmer areas. Preventive breeding may also be an important element of overall crop improvement, in order to prevent the increase of minor pests and pathogens already present in the ecosystem and to preclude future problems (2).

In the model by Van Keulen and de Milliano (21), actual grain numbers are not simulated; rather, a function is introduced in the model representing this sink-effect. When the maximum temperature is above 25°C in the ten-day anthesis period, only a fraction of available carbohydrates is translocated to the grain. This fraction declines with increasing temperatures, reaching 0 at 35°C. This model worked well for Zambia, but not for Niger. In Niamey, Niger, maximum air temperature during anthesis is between 35 and 40°C. In reality, a grain yield of 2.4 t/ha can be achieved, which is more than twice the amount calculated by the model (1.1 t/ha), even if the influence of maximum air temperature on seed set is removed. Evidently, the model needs further improvement for wider application, especially for areas where maximum air temperatures during the growing season exceed 30°C.

How existing cultivars behave under high temperatures is still a subject of study (10,11,24). Vernalization and photoperiod sensitivity can delay the rate of plant development until anthesis, but the delay may not be matched with an increase in number of grains per spikelet or per spike (10). Genotypes which are relatively insensitive to vernalization and photoperiod and, hence, early, appear to be best at many locations, especially at hotter, lower elevations (11). Most of the models mentioned here apply to genotypes (bread and durum wheats) which are relatively insensitive to vernalization and photoperiod and follow the universal heat sum well. Care should be taken with the application of data and experience collected in western high-input systems to other agricultural systems (6,17). Therefore, local research should precede production.

The computer has become a valuable assistant to the agronomist (16), and is a useful tool for performing simulations. The thinking, data interpretation and synthesis, however, still need to be done by man. Where money is a limiting factor, time is usually not as limiting. In these areas, the calculation methods mentioned can be performed with a desk calculator.

The use of simulation models for agrometeorological purposes in developing countries was recognized by the World Meteorological Organization. In 1983, they organized a workshop in Wageningen, Netherlands, to train students from various tropical countries (20). The Centre for World Food Studies also developed simulation models for different countries, such as Bangladesh, Thailand and Indonesia. Some of the models are available in a simple form for use by individuals and research centers.

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