Review on Yield Gap Analysis: Modeling of Achievable Yields at Farm Level

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ABSTRACT: *In the present context, 'model' is expressed as a computer program that can be repeatedly run several times for computing several designed mathematical or statistical expressions (equations) governing crop growth-environment relations, given appropriate input data. The experiment station yields obtained under a rainfed situation without any nutrient deficiency mostly considered as the potential yields of rainfed crops. Actual yields are obtained by recording crop yields of farmers in the region under investigation and achievable yield is between actual and potential yield. Actual yields are compared with the potential yields to estimate yield gaps of crops for that area and others which have the same agro-ecology. Achievable yield is determined by factors like availability of moisture and nutrients, Precipitation and irrigation as input, Soil profile water holding characteristics, Plant water balance (transpiration, water uptake), Soil water balance (evaporation, infiltration, runoff, flow, drainage) and Nitrogen fertilizer applications as input, Soil nitrogen conditions, Plant nitrogen balance (uptake, fixation, mobilization), Soil nitrogen balance (mineralization, immobilization, nitrification, denitrification). Generally, modeling Achievable yield of farm depend on water and nutrient data of the area and Actual yield is determined by factors like weeds, insect pests, diseases and pollutants.*

KEYWORDS: Modeling, Gap analysis, Achievable yield and Farm level

INTRODUCTION

In the present context, model is expressed as a computer program that can be repeatedly run several times for computing several designed mathematical or statistical expressions (equations) governing crop growth-environment relations, given appropriate input data. A model is a mathematical representation of a real world system (CRIDA, 2011). As agriculture becomes more intensive, the demand for a higher level of control of the environment in which the plants grow increases. This control ranges from better strategies of soil management to "closed" environments, where most, if not all, the atmospheric and soil variables can be adjusted. Based on this premise, plant growth and development models should be elaborated to supply a basis for planning and managing crop production.

Crop modeling can also be useful as a means to help the scientist define research priorities. Using a model to estimate the importance and the effect of certain parameters, a researcher can observe which factors should be more studied in future research, thus increasing the understanding of the system. The model has also the potential of helping to understand the basic interactions in the soil-plant-atmosphere system (D. Dourado Neto, D. A. et al., 1998). Crop simulation models in general calculate or predict crop growth and achievable yield as a function of genetics, weather conditions, soil conditions and crop management. The

Agricultural Production Systems Simulator (APSIM) has been used in a broad rangeof applications, including support for on-farm decision making, farming systems design forproduction or resource management objectives, assessment of the value of seasonal climateforecasting, analysis of supply chain issues in agribusiness activities, development of wastemanagement guidelines, risk assessment for government policy making and as a guide to

research and education activity. The semi-arid regions of Asia and Africa are primarily dependent on rainfed agriculture, where the agricultural productivity of rainfed systems is low. Sub-Saharan Africa and South Asia will remain hot spots of child malnutrition, food insecurity and poverty, where underdevelopment, rapid population increase, land degradation, climate uncertainty and water scarcity, and unfavourable government policies are the major bottlenecks to achieving higher agricultural production and improved rural livelihoods frequent climate change is problem which decreases reliability of modeling achievable yield of the area (P. Singh et al., 2009).Objective of this paper is reviewing on yield gap analysis: modeling of achievable yields at farm level.

MODELING AND YIELD GAP ANALYSIS

Modeling techniques applied to agriculture can be useful to define research priorities and understanding the basic interactions of the soil-plant-atmosphere system. Using a model to estimate the importance and the effect of certain parameters, a researcher can notice which factors can be most useful. The modeler should define his objectives before beginning his work and construct a model that fulfills the proposed objectives. The experiment station yields obtained under a rainfed situation without any nutrient deficiency mostly considered as the potential yields of rainfed crops. Actual yields are obtained by recording crop yields of farmers in the region under investigation. Actual yields are compared with the potential yields to estimate yield gaps of crops for that area and others which have the same agro-ecology (Piara Singh et al., 2001).

For example, yield gap analysis of maize in vietnam was done as follows, Maize is normally sown in spring and summer in the rainfed area of northern Vietnam. During the spring season, simulated potential yields of maize ranged from 4800 to 5430 kg/ha across six provinces, with an overall mean of 5030 kg/ha. The province yields of maize ranged from 2660 to 4180 kg/ha with an overall mean of 3380 kg/ha. The yield gap between the simulated and province yield was 1650 kg/ha. During the summer season, simulated potential yields were higher than those obtained during the spring season. Simulated potential yields during the summer season ranged from 5250 to 5570 kg/ha across six provinces, with an overall mean of 5370 kg/ha. The yield gap between the simulated and province yield was 1990 kg/ha (P. Singh et al., 2009).

Methods of Yield Gap Analysis

Crop environment interactions are unlimited in number. They can be studied from several points of view (physical, physiological, chemical, biochemical, bio-technological, agronomical, entomological or pathological, economic benefit angles etc.). We have the roots growing with passage of time and interacting with soil, taking up water and nutrients for transport to the aboveground parts of a plant. The stem, branches, leaves as they grow interact with environment (both individually and together), under the influence of solar radiation to produce flowers and pods / oils, grains ultimately yield (CRIDA, 2011).

Evapotranspiration, leaf-air interactions, photosynthesis, respiration, carbon dioxide assimilation, are the other processes involved in crop growth. Crop is also affected by pest/disease incidence. Thus crop growth is usually viewed as a complex system which comprises of sub-systems in which several processes take place. One process leads to the other and so, individual processes (water or nutrient uptake by roots, biomass accumulation, grain growth etc.) are considered as sub-systems. All the processes which interact among themselves (since the start of growth of plant from seeding to final yield) and put together are considered as a "system". Thus one can have "sub-models" as part of a model, sub-systems and a System. One can simulate water uptake, branching pattern and growth, leaf development, pod growth, etc. and their interaction with soil and aerial environment, as individual models. The point to note is that there is no limit to the items that can be taken up to develop a simulation model (CRIDA, 2011).

The potential yields were estimated using a crop simulation approach and review of research station experimental data.

Simulated potential yields
This is the potential yield of an improved variety simulated by the crop growth model under optimal management conditions, except that water availability is the main limiting factor for crop growth. All the crop models in these software need similar kind of weather (daily solar radiation, maximum and minimum temperatures and rainfall) data, soil profile data and cultivar specific parameters (genetic-coefficients) to simulate crop growth, yield and resource use by the crops. Multi-year simulation of the rainfed potential yield of a crop was carried out for several locations in a state and averaged over time and space to estimate the rainfed potential yields (Bhatia et al., 2006).

Experimental station yields
This is the maximum possible rainfed yield of an improved cultivar usually obtained at the experimental stations in research plots under good care and supervision when factors other than water availability have minimal effect on limiting crop growth (P. Singh et al., 2009).

Mean yields
State mean yields were determined from the area and production data of a crop for each district in a state. Total production was divided by the total area under the crop to calculate mean yield. Mean yields were then further averaged over the years (number of years depending upon the data availability) and compared with the potential yields to estimate yield gaps. Finally, yield gaps quantified using simulated potential yields, experimental potential yields and the mean yields. Simulated yield gap is the difference between the simulated mean potential yield and the mean yield. The experiment station yield gap calculated as the difference between the experiment station mean yield and the mean yield. (Singh et al., 2000).

Potential Yield, Achievable Yield and Actual Yield

Going from type one to type four productions generally decreases and the variables thatdetermine system behavior increase. At all levels, growth-reducing factors such as insects, pathogens, and weeds can be introduced. Models for all production levels can be developed.Models at the first level are further developed than models at the others. Data and methods adopted to quantify potential yields and yield gap of crops varied across countries, depending upon the nature of data availability to perform such analyses. Broadly, the potential yields and yield gaps of the crops were estimated based upon the data generated through crop simulation methods, research station yield maximization trials, on-farm technology demonstrations with improved management, and farmers' actual yields reported at state, district or province level by each country (P. Singh et al., 2009). Potential production, where production is determined by solar radiation, temperature, and crop and varietal characteristics (CRIDA, 2011).

Achievable yield is determined by factors like availability of moisture and nutrients, Precipitation and irrigation as input, Soil profile water holding characteristics, Plant water balance (transpiration, water uptake), Soil water balance (evaporation, infiltration, runoff, flow, drainage) and Nitrogen fertilizer applications as input, Soil nitrogen conditions, Plant nitrogen balance (uptake, fixation, mobilization), Soil nitrogen balance (mineralization, immobilization, nitrification, denitrification). Generally, modeling Achievable yield of farm depend on water and nutrient data of the area and Actual yield is determined by factors like weeds, insect pests, diseases and pollutants (WFP, 1992).

Modeling Methods Used to Simulate Achievable Yield at Farm Level

Models can be classified in different types: conceptual, physical or mathematical (Acock and Acock, 1991). All of us have our own concepts of how the world works and why certain things happen, every hypothesis that is tested has a conceptual model supporting it. Physical down-scaled representations (physical models) of the system have been used by engineers for a long time, but they are rarely used to represent biological systems, although it can be said that a plant in an experimental plot or container is a physical model of the crop in the field.When the behavior of a system is described mathematically, through equations, that representation of the system is a mathematical model. The mathematical model represents quantitatively assumed hypotheses about the real system, allowing one to deduce its consequences. They have gradually become more popular, yet more sophisticated, becausepersonal computers have become more accessible. They can be classified in a number of classes, but the two main ones are the empirical, and the mechanistic models (Acock & Acock, 1991).

The empirical models, sometimes called correlative or statistical models, describe relationships among variables without referring to the correlated processes. The mechanistic models (models at the level of processes or simulators), also called explanatory models, try to represent cause-effect relationships among the variables. While a mechanistic model of vegetative growth describes the plant performance based on the knowledge of the processes that are taking place in its growth and development, an empirical model describes the plant behavior based directly on observations at the plant level. It should be clear that, at certain organization level, all models are empiric (P. Singh et al., 2009).

A model that simulates crop yield can be mechanistic at one level, if it represents the relations between all plant processes, but it will sure be empirical at some lower level, such as the variation in gross photosynthetic rate according to the temperature and combination of two models used to predict achievable yield of certain crop with specific agro ecology. An empirical model at the prediction level can be found in Waggoner (1984), in which wheat yield in a given year and place is calculated in function of meteorological variables, such as temperature, precipitation and number of days warmer than 32°C, in a simple equation, without representing the plant processes, by just varying the constants of the equation (weights of each variable) according to the location.

One problem with these models, already empirical at the forecast level, is that they cannot be extrapolated. They must only be used in conditions similar to those in which they were generated. In contrast, mechanistic models try to represent processes in the system up to two organization levels below the forecast level. A mechanistic model to forecast crop yield will represent the processes at organ level, like photosynthesis, respiration, and foliar expansion and abscission, only being empirical down to this level. One is still learning how to develop and create mechanistic models and, nowadays, the empirical models at the forecast level are still the most popular. However, the mechanistic models have a much larger potential to allow extrapolation in the forecasts outside the boundaries in which they were generated (Chanter, 1981).

Constraints for Increasing Crop Yields

Extensive land degradation and unfavourable climate are the major abiotic constraints limiting crop production in most areas and biotic constraints are also the major yield reducers of crops. Major constraints that limit the yields of crops are frequent droughts and floods, low soil fertility, soil erosion and land degradation, poor soil water conservation practices, low-yielding crop varieties, shortage of labour, poor agricultural extension for technology transfer, uncertainty of prices and marketing problems, uncertainty of tenure as a disincentive to invest in land development and poor credit facilities and high interest rates by private moneylenders. Bridging the yield gap would require adoption of improved soil and water conservation practices, integrated soil fertility management including the greater use of legumes, improved cultivars, a stable land tenure system, affordable credit facilities and assured prices and marketing of agricultural produce (Wangkahart et al., 2005).

For example, Unfavourable soil physical conditions preventing advanced sowing and low water-holding capacity of shallow black soils, leading to terminal drought to the crop, are the main reasons preventing the significant increase in productivity of rabi sorghum in a sustainable manner. Therefore, the input components, including supplemental irrigation, rather than the high-yielding varieties of rabi sorghum, were responsible for the increase in productivity.

An integrated genetic and natural resource management (IGNRM) approach in the watershed framework is needed to enhance the productivity of rainfed crops in the rainfed areas. Integrated watershed management, comprising improved land and water management, integrated nutrient management including application of micronutrients, improved varieties and integrated pest and disease management, has been evaluated by ICRISAT in several states of India. Substantial productivity gains and economic returns have been obtained by farmers (Wani et al., 2003a, b).

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