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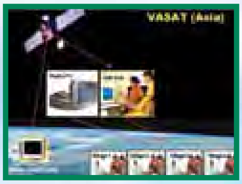

Use of High Science Tools in Integrated Watershed Management

Proceedings of the National Symposium

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Use of Agroclimatic Datasets for Improved Planning of Watersheds

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Abstract

Maximizing agricultural production from rain-fed areas in a sustainable manner is the need of the day to feed the ever-increasing population. Integrated watershed management with focus on productivity enhancement and livelihood improvement is one of the high priority areas identified and promoted for producing both tangible and non-tangible benefits to the individuals as well as for communities as a whole. Reliable and long-term data on agroclimate, soils, crop varieties and crop production at taluk/block/district-level for several years are needed for undertaking climatic analyses and to understand variations in agricultural productivity and changes in the cropping patterns. Data on crop phenology, growth and yield characters are needed to quantify crop-weather relationships and for validating crop-growth simulation models. Agroclimatic datasets need to be developed at individual watershed level and climatic analyses help in assessing rainwater harvesting potential, efficient land use planning, determining suitability of crops, risk analysis of climatic hazards, adoption of farming methods and choice of farm machinery. In this paper, results of climatic analysis of selected watersheds in India with respect to water balance and length of rain-fed crop-growing period, yield gap analysis of some important crops are presented and discussed. Use of agroclimatic datasets goes much beyond agroclimatic analysis of watersheds. Current issues like end-of-the-season crop yield forecasting, climatic change impact assessment, crop insurance to farming community, maintaining quality of produce to compete with international market, sustainability of the yield and environment are also to be addressed. Enhancing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

Introduction

The importance of weather assumes greater importance in rain-fed regions where moisture regime during the cropping season is highly variable and is strongly dependent on the quantum and distribution of rainfall *vis-à-vis* the soil water holding capacity and water release characteristics. In spite of cultivation of high yielding varieties, improved cultural practices and plant protection measures, favourable weather is a must for good harvests (Rao et al. 1999). Even in irrigated agriculture, the thermal and radiation regimes influence the choice of crops, cropping patterns, and the optimum dates of sowing for achieving better crop yields.

It is imperative that the vast potential of rain-fed agriculture needs to be realized, as irrigated agriculture alone cannot meet the total foodgrains requirements of the country. High rainfall variability, severe land degradation, poor soils, frequent droughts, high population density and low investments lead to poverty and fragile livelihoods. These factors characterize the rain-fed areas. Growing scarcity for water and fodder has become a sad reality in these areas. In rain-fed areas, rainwater management at watershed/catchment scale is used as an entry point for increasing agricultural productivity (Wani et al. 2003b). Agroclimatic analyses helps in devising suitable management practices for watersheds to conserve, harvest and efficiently use rainwater for increasing agricultural production.

Agroclimatic Datasets and Database Management

Reliable and long-term agroclimatic data are needed for undertaking any climatic analyses along with data on soils, crop varieties and production at *taluk*/block/district-level for several years to understand the variations in agricultural productivity and changes in the cropping patterns. Data on crop phenology, growth and yield characters are needed to quantify crop -weather relationships and validating the crop-growth simulation models.

Several organizations like India Meteorological Department IMD), Indian Council of Agricultural Research, state agricultural universities maintain meteorological and agrometeorological observatories in the country have long-period of data. Data need to be collected from those stations which are nearby to the watersheds. The conventional method of handling data is to store it in a “file”. Application programs are needed to quality check and analyze the data stored in files. Database management following the conventional method requires application programs or software to: (i) add new stations and related data, (ii) calculate means, sums etc., on weekly and monthly basis, (iii) compute derived parameters and indices, and (iv) generate various reports

A database management system or DBMS is a set of application programs that act as layers between the physical database and its users. All the requests from users for access to the database are handled by the DBMS. Though there are several models, the Relational Database Management System (RDBMS) is most suitable for agroclimatic data. RDBMS eliminates explicit parent-child relationships and there are no pointers maintained and records are logically connected by key values. Hierarchical and network models deal with one record at a time while relational model reads and writes data in units of a set of records. In RDBMS, data is organized in the form of tables comprising rows and columns. Any row is identified by a column or set of columns that form a primary key. Development of agroclimatic database is thus a pre-requisite for climate analysis and the DBMS includes:

- computer hardware and software
- data acquisition, entry, storage, quality control and archiving
- designing an appropriate agroclimate DBMS with scope for scalability,
- data access and application software development, and
- data administration, monitoring and policy on data sharing.

In addition to collecting the historic agroclimatic data, weather needs to be monitored at the watersheds to assess the impacts of interventions made during the development phase by establishing a manual agromet station or by installing an automatic weather station (AWS). Manual agromet station is to be established by following the standard procedures prescribed by the IMD and the observer or the volunteer has to be trained thoroughly in recording the data and maintaining the instruments. AWS is a system to record the changes in the weather continuously without any human intervention. The AWS consists of a datalogger, set of sensors, power supply, solar panel, mounting stand and other accessories. The AWS should be located in such a place that it represents the general agroclimatic conditions of the watershed area. Datalogger program should be optimised for power and memory usage and checked thoroughly for any bugs. Proper protection against theft and damage is to be ensured for the instruments. Weather data monitored at the watersheds need to be quality checked and datasets developed.

Agroclimatic datasets once developed would lead to various agroclimatic analyses based on the concepts of rainfall probability, water balance, length of growing period, dry and wet spells, droughts, crop-weather modelling, climate variability and change at the watersheds. Development of software for quality check of weather data and various agroclimatic analyses including water balance was taken up by ICRISAT. Results of the analyses help in assessing rainwater harvesting potential, efficient landuse planning, determining suitability of crops, risk analysis of climatic hazards, production or harvest forecasts and in adoption of farming methods and choice of farm machinery.

Water Balance

In selected watersheds in the semi-arid Andhra Pradesh, water balance analysis indicated that between the wet and dry years, variation in the water surplus was much higher compared to the water deficit (Kesava Rao et al., 2007). Climatic water surplus accrued contributes to runoff, which could be harvested and stored for use during the intra-seasonal dry periods as well as for partially meeting the crop water requirements of the second crop season. Analysis indicated that runoff water that could be harvested and stored for a watershed area of 500 ha is 0.3 to 0.6 million m^3 water during normal years. In the wet years, this potential may go up to about 1.72 million m^3.

Length of growing period (LGP) is defined as the length of the rainy season, plus the period for which the soil moisture storage at the end of rainy season and the post-rainy season and winter rainfall can meet the crop water needs. Soil depth in a toposequence can alter the LGP across the watershed, being highest in the low-lying regions and lowest in the upper reaches of the watersheds. Weekly water balance indices are mostly used to delineate the LGP and such analyses done over several years help to determine the assured begin and end of the rainfed growing period based on probability of occurrence. It was observed that at selected watersheds in Andhra Pradesh (Kesava Rao et al.

2008) start and end of the crop-growing season varied across years; however, begin was more variable compared to the end. There was no definite relationship between the start and length of growing period.

Climate Change Impacts on LGP

Solapur in southwestern Maharashtra is under hot dry semi-arid ecological sub-region with shallow and medium deep loamy black soils. Available water capacity is about 100-200 mm. Normal length of growing period (LGP) is about 150 days. Sorghum, groundnut, pigeonpea, chickpea, wheat and sugarcane are major crops. Daily agroclimatic dataset of Solapur for the period 1975-2004 was used in the study. Reference crop evapotranspiration was estimated following the FAO-Penman-Monteith method (Allen et al. 1998) and water balances were computed based on modified water balance (Thornthwaite and Mather 1955). LGP was delineated for all the years based on the Index of Moisture Adequacy (ratio of actual evapotranspiration to reference crop evapotranspiration) for the present and imposed conditions. Considerable variation exists in both start and end of growing period, however, no definite relation between beginning and end could be established. Growing period starts by 25 June and ends by 25 November with a growing period of about 150 days. At 75% probability, season starts by 10 July and ends by 15 November with a duration of 130 days. In certain years, growing season started as early as 01 June or as late as 30 July. End of the season could be as early as 30 September or can extend up to 31 December. The longest (220 days) season occurred in 1978 and shortest (85 days) occurred in the year 2003. In general, dry spells occur more at vegetative stage. LGP might shorten by 10-20 days (delayed begin and early end) due to climate change projections of temperature increase by 2°C and rainfall decrease by 20% (Fig. 1). End-season dry-spells are likely to increase.

Time series analysis indicated that the average annual maximum and minimum temperatures increased by 0.5°C in the past 30-years from 33.5°C to 34.0°C and from 19.5°C to 20.0°C, respectively. No trend could be seen for rainfall. Highly erratic rainfall distribution in the growing season is seen and crop yields are highly variable. Climate change is likely to increase variability in rainfall. Monsoon cropping

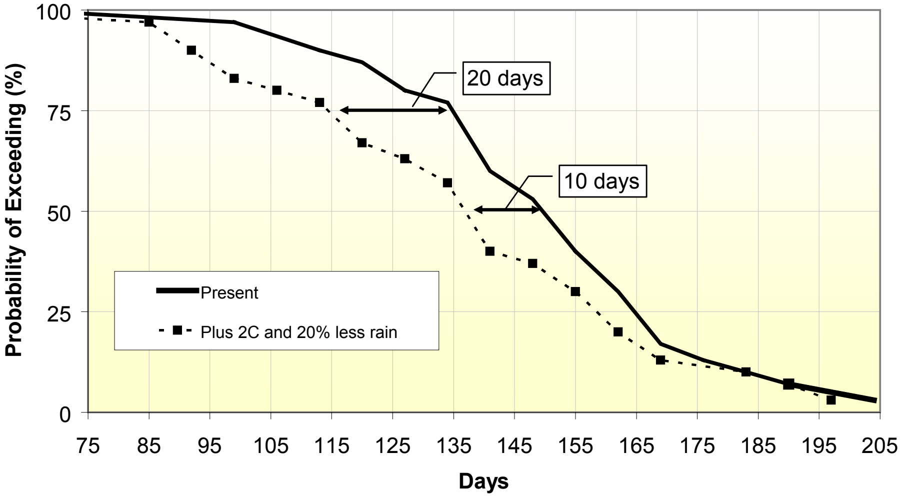


Figure 1. Projected climate change impact on LGP at Solapur.

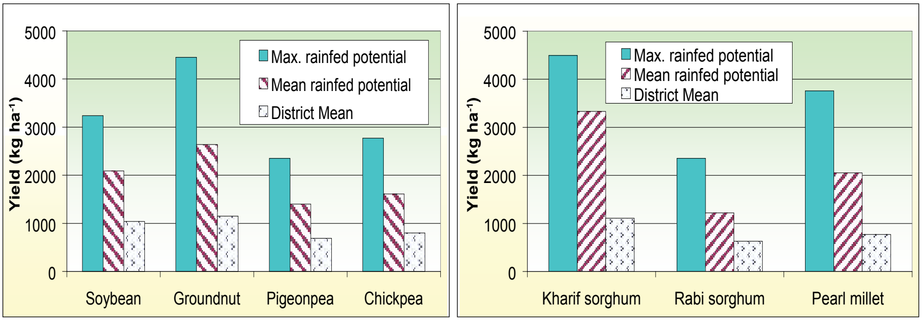
is fairly undependable, particularly with long-duration crops. Crops that are sensitive to rain aberrations at vegetative and at maturity have greater risk. Drought-hardy crops are more suitable for rain-fed cultivation. Short-duration crop of pearl millet or grain legume followed by a sorghum grown on conserved moisture could be successful. Agroclimatic analysis coupled with crop-simulation models, and better seasonal and medium duration weather forecasts, help build resilience to climate variability/change at watersheds.

Yield Gap Analysis

Based on the agroclimatic datasets, yield gap analysis of selected major rain-fed crops was carried out, which showed that substantial yield gaps exist between current (farmers') and experimental or simulated potential yields. Simulated rain-fed potential yield in different production zones of India ranged from 3,210 to 3,410 kg ha^{-1} for *kharif* sorghum, 1,000 to 1,360 kg ha^{-1} for *rabi* sorghum and 1,430 to 2,090 kg ha^{-1} for pearl millet. Total yield gap (simulated rain-fed potential yield – farmers' yield) in production zones ranged from 2,130 to 2,560 kg ha^{-1} for *kharif* sorghum, 280 to 830 kg ha^{-1} for *rabi* sorghum and 680 to 1040 kg ha^{-1} for pearl millet. These gaps indicate that productivity of *kharif* sorghum can be increased 3.0 to 4.0 times, of *rabi* sorghum 1.4 to 2.7 times and of pearl millet 1.8 to 2.3 times from their current levels of productivity (Murty et al. 2007).

Large spatial and temporal variation in yield gap was observed for the four legumes. The yield gaps for the production zones ranged from 850 to 1,320 kg ha^{-1} for soybean, 1,180 to 2,010 kg ha^{-1} for groundnut, 550 to 770 kg ha^{-1} for pigeonpea and 610 to 1,150 kg ha^{-1} for chickpea. The results showed that on average the productivity of legumes and oilseeds can be increased 2.3 to 2.5 times their current levels of productivity under rain-fed situations. Supplemental irrigation would further increase these yields (Bhatia et al. 2006). Yield gaps of selected legumes, sorghum and pearl millet are presented in the Figure 2.

Extensive land degradation and unfavourable climate are the major abiotic constraints limiting crop production in the rain-fed areas of India. Erratic rainfall results in frequent droughts and water-logging in the rainy-season crops. Both low and high temperatures and drought limit the productivity of post-rainy-season crops, especially legumes. Most of the soils in the rain-fed regions of India have low soil fertility caused by soil erosion, continuous mining of nutrients by crops with inadequate nutrient inputs by the farmers. Biotic constraints are also the major yield reducers of rain-fed crops. High-yielding improved cultivars resistant to some of these biotic constraints have been developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the national institutes in India and are being promoted for adoption by farmers.



a. Legumes b. Sorghum and pearl millet

Figure 2. Rain-fed potential yields and yield gaps of selected crops in India.

An integrated genetic and natural resource management (IGNRM) approach in the watershed framework is needed to enhance the productivity of rain-fed crops in the rain-fed 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). Widespread deficiency (80-100% of fields) of micro- and secondary nutrients (zinc, boron and sulfur) has been observed in the farmers' fields in Andhra Pradesh, Gujarat, Rajasthan and Karnataka. Application of micronutrients resulted in a 20-80% increase in yield of several crops, which further increased by 70-120% when micronutrients were applied with adequate amounts of nitrogen and phosphorus (Rego et al. 2007). Thus, improved varieties along with improved management of natural resources have the potential to increase crop production in rain-fed areas of India, which need to be promoted and scaled up by the promotion and adoption of the existing 'on-the-shelf' technologies presently available.

Several studies indicate that global warming is likely to reduce 'days to maturity' resulting in crop yield reduction. ICRISAT's Integrated Genetic and Natural Resource Management (IGNRM) philosophy is to help farmers mitigate the challenges and exploit the opportunities that are posed by climate change through (i) the application of existing knowledge on crop, soil and water management innovations, and (ii) through the re-deployment and re-targeting of the already available germplasm of ICRISAT's mandate crops viz., sorghum, pearl millet, pigeonpea, chickpea and groundnut.

Simulations on sorghum at Aurangabad, Maharashtra using DSSAT software considering treatments of low input farming, improved practices, enhanced temperature and better variety have indicated encouraging results (Cooper et al. 2009) as shown in Figure 3.

A temperature increases of +3^{O}C had very little impact (145 kg ha^{-1} reduction) on the sorghum yield under low input fertilizer use as nutrient limitation remained a strongly limiting factor. Even under climate change, the adoption of improved fertilizer use (column 3) resulted in

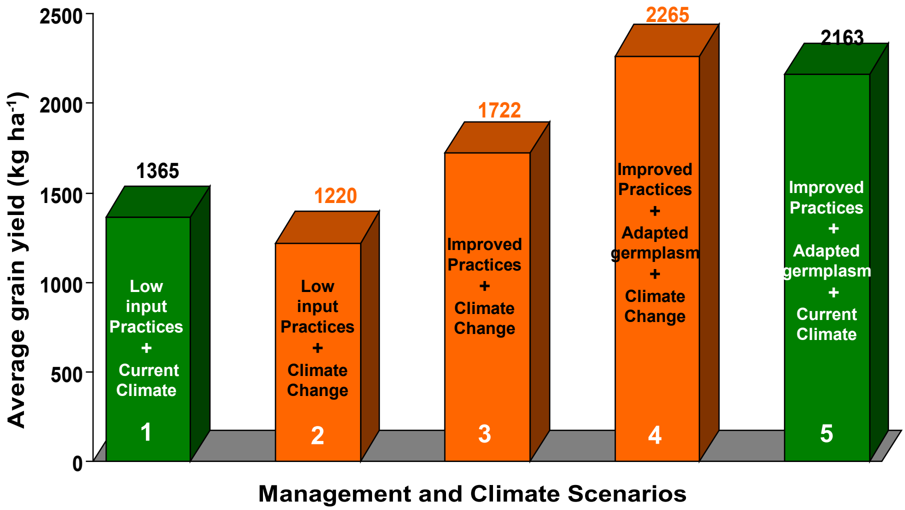


Figure 3. Sorghum yield simulations at Aurangabad, Maharashtra.

yield gains of 357 kg ha^{-1} over what farmers are currently getting under low input practices and today's climatic conditions (column 1). Perhaps the most notable result in this case is that growing the longer duration variety (Brandes), better suited to grow in a warmer world (column 4) resulted in farmers being able to achieve yields 5% higher than they could under "improved practices" with today's climate (column 5). The simulations show that the impact of climate change on the yields of low input agriculture is likely to be minimal as other factors will continue to provide the overriding constraints to crop growth and yield. The adoption of currently recommended improved practices, even under climate change, will result in substantially higher yields than farmers are currently getting. The adaptation of better 'temperature adapted' varieties could result in the almost complete mitigation of climate change effects.

Weather Forecasting and Advisories

Many a times, a great proportion of crop and livestock losses are due to direct weather effects such as droughts, flash floods, untimely rains, hail, strong winds and storms. Crop losses due to pests/diseases and in harvest and storage are highly influenced by the weather.

Agrometeorological methods have great potential in providing practical solutions when specifically tailored weather support is readily available to the needs of agriculture. They contribute towards making short-term and long-term adjustments in agricultural operations to minimize losses in agricultural production. Based on the NOAA satellite imageries received at ICRISAT in near real-time and forecasts issued by the India Meteorological Department, experimental weather advisories during southwest and northeast monsoon seasons of 2007-2009 were prepared for selected watersheds in India and shared among the watershed team at ICRISAT and watershed field personnel. It was observed that majority of these were successful in prediction and were useable.

Current issues like end-of-the-season crop yield forecasting, global warming and climatic change impact assessment, crop insurance to farming community, maintaining quality of produce to compete with international market, sustainability of the yield and environment are to be addressed. Bringing climate awareness among the rural stakeholders using new IT tools is the need of the hour.

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