Enhancing Productivity of Water Under Variable Climate

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Abstract

Water is the most limiting factor for crop production in the semi-arid tropics (SAT), and its efficient use deserves special attention in our efforts to increase the productivity and profitably of agriculture in these areas. The availability of skillful forecasts due to the growing understanding and advances in modelling the global climate system has opened up new opportunities for farmers to consider a number of adjustments to management practices based on seasonal conditions predicted for the forthcoming season. The Machakos district in Kenya is characterized as hot and dry with bimodal distribution of rainfall. Annual rainfall at Katumani ranges between 330 and 1260 mm, with a coefficient of variation of 28%. Average seasonal rainfall is less than 300 mm, with more than 40% of seasons receiving less than 250 mm. Maize is the main food crop in the district with an average productivity of 0.8 t ha^{-1}*. However, average maize yields have declined by nearly 50% to 0.4 t/ha during the decade 1993-2002, mainly due to the adoption of low-input management techniques. Further analysis of yield trends confirms that the farmers' strategy is well suited for below normal seasons, but fails to capitalize on good seasonal conditions during normal and above normal seasons.*

The reliability of hindcasts generated by the International Research Institute for Climate Prediction for 43 short rain seasons starting from 1961 was evaluated, and their potential value in reducing risk and improving productivity and profitability was assessed for the situation in Katumani using the crop simulation model APSIM. Though the available skill in forecasts is not sufficient to accurately predict the amount of rainfall or its distribution, it is possible to predict with some certainty whether the coming season is going to be below normal or not. Model simulations indicated significant gains in productivity and profitability with simple adjustments identified by the farmer such as application of the recommended dose of fertilizer and high plant population in seasons forecasted as normal to above, and low risk farmer strategies during the years forecasted as dry years.

Introduction

Water is the most limiting factor for crop production in the semi-arid tropics (SAT), and its efficient use deserves special attention in our efforts to increase the productivity and profitably of agriculture in these areas. Rainfall, the only source of water, shows high temporal and spatial variability, and the risk associated with such variable weather acts as a major deterrent for the farmers to invest in expensive inputs such as the fertilizers and improved seeds required to achieve higher productivity. Farmers, particularly smallholders in developing countries, show risk-averse behaviour (Binswanger, 1980) and adopt conservative management strategies that reduce negative impacts in poor years, but with resulting reduced average productivity and profitability (Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003). According to IPCC (2001), global changes in climate are expected to further exacerbate this variability. This means that farmers will have to deal with more uncertain weather and with extreme events occurring more frequently. If deliberate attention is not directed to managing the impacts of climate variability, the majority of poor farmers, especially in semi-arid areas, will face higher insecurity in food and incomes.

Much of the past research on managing climate variability has been devoted to the analysis and understanding of the complexities associated with the variability and distribution of rainfall (Sivakumar, *et al.* 1983; Janowiak, 1988, and Hulme, 1992). However, many critical agricultural decisions must be made several months before impacts of climate are realized, making it difficult to tailor management to the season's potential. The Response Farming technique tried in Kenya in the late 80's was an attempt to predict rainy season potential and adjust farming practices to the prevailing environmental conditions (Stewart and Faught, 1984), but was met with limited success due to difficulties in assessing the season's potential. Other risk management strategies developed include maintaining storage reserves, diversifying production, insurance, forward selling, future trading, government subsidies and taxation incentives (Kurukulasuriya and Rosenthal, 2003). However, adoption of these interventions requires good institutional and policy support, which is limiting in many developing countries in general and in Africa in particular.

Recent developments in the understanding of interactions between the atmosphere, sea and land surfaces, and in modelling the global climate system have made it possible to predict climatic conditions months in advance in many parts of the world (Goddard *et al.,* 2001; Mutai *et al*., 1998; Indeje *et al.,* 2000; Hansen and Indeje, 2004). Some efforts were also made in the use of seasonal climate forecasts in disaster preparedness by agencies such as FEWSNET, but use of seasonal climate forecasts in farm level decision-making is minimal in the region.

In this paper we present the results of a case study conducted to assess the potential value of seasonal climate forecasts in reducing risk and improving the productivity and profitability of smallholder farms in Machakos district, Kenya. The case study is based on Machakos district crop production data, results of a farmer survey conducted in Mwala division of Machakos district, data from a long-term trial conducted at Katumani research station and results of system simulation analysis using the crop simulation model APSIM (McCown *et al.,* 1996).

Climate variability and crop production in Machakos

Machakos District is generally characterized as hot and dry with bimodal distribution of rainfall. Throughout the district, rainfall is subject to pronounced variability from year to year and breaks in rain occur often and at any time during the rainy season. Long-term rainfall data for the period 1957-2003 recorded at Katumani research station was analyzed to get a good understanding of the variability in frequency and distribution of seasonal rainfall. Annual rainfall at Katumani ranged between 330 and 1260 mm with a coefficient of variation of 28%. Nearly 85% of the average annual rainfall is received during the two cropping seasons, long rains (LR) between March and May and short rains (SR) between October and December. Though both SR and LR seasons receive similar amounts of rainfall, SR seasons are more reliable than the LR seasons and therefore more important for crop production. With an average seasonal rainfall of less than 300 mm and a coefficient of variation of more than 40% the district is considered a marginal area for maize production (Dowker, 1961). About 40% of all seasons receive less than 250 mm rainfall, while 27% of recorded rainfall is in excess of 350 mm (Table 1). The average seasonal rainfall of below normal SR and LR seasons is about one third that received during above normal seasons. The big difference in the seasonal rainfall presents different opportunities and challenges for management to tailor crop mix and/or management practices such that the seasonal potentials are realized and risks are minimized.

Since agriculture in the district is predominantly rain fed, maize yield trends are closely related to trends in rainfall (Figure 1). Long-term average yield of maize in the district is 0.8 t/ha. However, since 1990, a strong declining trend has been observed in maize productivity, resulting in a steep fall in maize yields. Average maize yields declined by nearly 50% to 0.4 t/ha during the decade 1993-2002. A similar declining trend in maize yields during the same period was also observed at national level. Further analysis of district level information indicated that much of this decline comes from the districts having a high percentage of medium and low potential areas primarily located in semi-arid and arid environments. The two major factors contributing to the observed decline in yields could be declining soil fertility as a result of non-application of fertilizers and extension of agriculture into more marginal areas. Because fertilizers are expensive and the risk of losing on investment is very high, farmers in these environments tend not to apply fertilizers. At the same time increasing population and limited availability of good agricultural land is pushing agriculture into more marginal lands and environments where the need for external inputs and the risks of crop failure are high.

District level production data for maize were also analyzed for trends in crop productivity during various seasons classified as below normal (< 250 mm), normal (250 – 350 mm) and above normal (> 350 mm) results, which are presented in Figure 2. It is interesting to note that maize yields during the years in which both LR and SR seasons received above normal rainfall are lower than the yields recorded during the years in which both seasons received below normal rainfall. Productivity of maize per mm of rainfall followed a similar trend, except that the productivity when both seasons were below normal is higher than that during any other year (Figure 3). The average productivity achieved was 2.9 kg maize grain mm^{-1} of rain. The productivity during the wettest years was about 1.2 kg maize grain mm^{-1}, while during normal years it was about 3 kg maize grain mm^{-1}. Since loss of rain water through runoff and erosion is high during wet years, we tried to estimate productivity using effective rainfall (rainfall-runoff-drainage). We have estimated the effective rainfall using system simulation model APSIM, which was earlier calibrated and validated for the Katumani location by (Okwach and Simiyu, 1999; Okwach, 2002). Productivity of rainwater when based on effective rainfall increased to 4.2 kg maize grain mm^{-1}, which is nearly 45% higher than that observed with total seasonal rainfall. However, there is no change in the observed trend.

The observed productivity of rain water is very similar to that recorded under a low input system with 22,000 plants ha^{-1} and no fertilizer application in a long-term trial conducted at Katumani research station between 1990 and 1999. This treatment is very similar to what farmers normally do on their farms. In the same trial, average productivity of effective rainfall more than doubled when plant population was increased to 53,000 maize plants ha^{-1} and urea fertilizer equivalent to 70 kg N ha^{-1} was applied. Data from a long-term trial was also analyzed to identify trends in maize yields in different seasons. Of the total 20 seasons over which the trial was conducted, eight seasons were below normal, five were normal and the remaining six seasons were above normal rainfall. The productivity during above normal years, with or without moisture conservation through application of mulch, was less than that during normal years, but higher than that in below normal seasons when no fertilizer was applied. Fertilizer application increased yields significantly in all seasons, but the increase was greater in the normal and above normal seasons (Figure 4). During the normal and above normal seasons, application of fertilizer resulted in a gain of 1 t maize grain ha^{-1}. However, application of fertilizer was profitable in only three of the eight below normal seasons. The crop completely failed during the LR season of 1993, and no increase in yield due to fertilizer application was observed during the 1998 LR season and the 1996 SR season. This risk of losing crops under unfavorable seasonal conditions is the major constraint in using fertilizers.

Seasonal climate forecasts and their reliability

Farmers would be able to consider a number of adjustments in the management practices used if they had prior knowledge of what the rainfall conditions are going to be during the forth-coming season. One way of having advance information about the forth-coming season is through the use of long-term/seasonal climate forecasts made by institutions such as the International Research Institute for Climate Prediction (IRI) and ICPAC (IIgad Climate Prediction and Application Centre; formerly Drought Monitoring Centre). Since 1998, ICPAC in collaboration with several international climate centres is providing seasonal climate outlooks through its regional climate outlook forums and IRI has the capability to develop hindcasts using GCM SST data.

The reliability of hindcasts generated by IRI for 43 SR seasons starting from 1961 was evaluated by comparing the predicted with the observed seasonal conditions (Table 2). The predicted and observed rainfall amounts correlated poorly with a coefficient of determination (R^2) of 0.336 which shows that existing skill in predicting the amount of rainfall is not very high. We then looked into the type of season by classifying the season using the criteria described earlier and the amount of rainfall hindcasted. While a total of thirteen seasons were predicted to receive below normal rainfall, the prediction turned out to be true in ten seasons, or in 77% of instances. The predictability of normal seasons is better with an accuracy of 84%. The predictability of above normal seasons is least amongst the three groups, with prediction coming true in 55% years. However, none of the seasons predicted to receive normal or above normal rainfall turned out to receive below normal rainfall.

During a one-day workshop with farmers at Mwala, farmers were asked to assess the reliability of these hindcasts by comparing them with actual rainfall recorded at Katumani research station and their own experiences. According to the farmer assessment, 32 of the 43 predictions (about 74 %) were extremely good, and use of these forecasts in farm management can result in substantial productivity gains during wet years and in minimizing losses during dry years. Farmers ranked eight predictions as good during which the gap between predicted and observed rainfall amounts was high but both observed and predicted rainfall amounts were more than that required for harvesting a good crop.

Management decisions that can be influenced by forecasts and potential benefits

During the workshop, farmers were also asked to identify how this information would benefit them and what adjustments they would like to make using the existing skill in forecasting. Farmers felt that the forecasts are extremely good in identifying whether the forthcoming season is going to be below normal or normal to above normal. It is only in three out of the 43 seasons that the predictions went wrong and all three of them were under-predictions. According to the farmers, the possibility of making a loss from underestimations is less than that from over overestimations. Hence, they did not consider this as a constraint.

Farmers then identified a number of management decisions that can be made using the existing skill in the forecasts (Table 3). Farmer response to forecast-based decision-making indicates that they clearly understood the variability in seasonal rainfall and the potential role forecasts can play in improving management of their farms. The management practices identified, for example, the need to plant drought-tolerant or drought-escaping crop varieties if the forecast indicates a dry season, and to increase manure and fertilizer inputs when the forecast is for a wet season, as a clear demonstration that small-holder farmers can make tactical decisions if the required information is made available.

Potential benefits from the changed decisions

Using the system simulation model APSIM, a scenario analysis was conducted to space estimate the potential benefit from the adjustments identified by the farmers based on the hindcasted seasonal conditions. The management options simulated include application of 30, 40, and 60 kg nitrogen ha^{-1} with a density of 35,000 maize plants ha^{-1} during normal to above normal seasons; and no fertilizer and 22,000 maize plants ha^{-1} during below normal seasons. Though the adjustments were made only to the SR seasons that were predicted to be normal or above normal, significant gains were also observed during the below normal years when low input farmer practice is used. This is the spill-over benefit coming from the residual effect of the adjustments made during the other seasons. The simulation analysis has clearly indicated that forecast-based farming can result in an overall average gain ranging from 139-251% when adjustments are made only to those years predicted to be either normal or above normal (Table 4).

Summary and conclusions

Given the high variation in seasonal rainfall and the need to plan farm operations without knowing the seasonal conditions, farmers in semi-arid regions generally favour using low risk conservative management strategies which do not capitalize on the opportunities created by the better seasonal conditions during the normal and above normal seasons. Farmers would be able to consider a number of adjustments to the management practices used if they had prior knowledge of what the rainfall conditions are going to be during the forthcoming season. This study has highlighted the benefits that can be derived by these adjustments.

For use in farm-level decision making, the forecasts should preferably give information about the expected amount and distribution of rainfall. However, with the current understanding of climatic anomalies and the factors contributing to them, it is still not possible to predict accurately the amount of rainfall or its distribution in advance. However the existing skill is good enough to predict with some certainty whether the coming season is going to be below normal or not. This in itself is an important piece of information from which significant benefits can be derived. As indicated by the simulation analysis, there is a potential to increase the yields by 2 to 3 times through adoption of simple adjustments to the management involving very low levels of risk under variable climatic conditions.

Uses are of climate information and seasonal climate forecasts are not systematically explored. While the ability to forecast weather events has increased and is expected to improve further, our ability to transmit this information to the end user in a form that can be utilized by them is not yet developed. The approach presented in this paper not only helps in coping with current climate variability, but has the potential to serve as an adaptation strategy to long term climate change.

Table 1. Average seasonal rainfall (mm) recorded at Katumani (1957-2003) during short and long rain seasons

	Short Rains (Oct-Dec)			Long Rains (Mar-May)		
	Average rain (mm)	No of years	CV (%)	Average rain (mm)	No of years	CV (%)
<250 mm	190	22	20.5	151	17	32.8
250-350 mm	300	15	10.9	293	14	10.9
>350 mm	507	10	29.3	415	16	12.9
All years	292	47	48.8	283	47	42.6

Table 2. Observed and predicted short rain season types at Katumani

Rainfall class	Predicted	Observed Below Normal	Observed Normal	Observed Above Normal	Avg. RF Predicted	Avg. RF Observed
Below normal (BN) <250 mm	13	10	2	1	207	221
Normal (N) 250-300 mm	19	0	16	3	299	287
Above normal (AN) >350 mm	11	0	5	6	437	437

Table 3. Some farmer-identified management options for below normal and normal to above normal seasons.

Management decisions	
Dry season	Normal to wet season
1. Use low plant density (2.2 plants/m^2)	1. Use higher plant density (3.5 to 4.5 plants/m^2)
2. Reduce labour and other input use	2. Apply fertilizer
3. Increased use of drought tolerant crops such sorghum, millet, green grams and cassava	3. Plant hybrid maize varieties such as pioneer
4. Plough and plant early before the start of the rain	4. Adopt intercropping
5. Adopt water conservation measures	5. Strengthen terraces
6. Reduce area under cultivation	6. Increase area under cultivation

Table 4. Expected gain in maize yield (kg/ha) with forecast based adjustments to SR seasons predicted to receive normal to above normal rainfall

		Forecast-based farming with 35,000 plants ha^{-1} and		
		30 kg N ha^{-1}	40 kg N ha^{-1}	60 kg N ha^{-1}
Dry	555	951 (71)	1052 (90)	1206 (117)
Normal to wet	666	1879 (182)	2286 (243)	2822 (323)
All	613	1467 (139)	1747 (185)	2151 (251)

(Figures in parenthesis indicate percent gain)

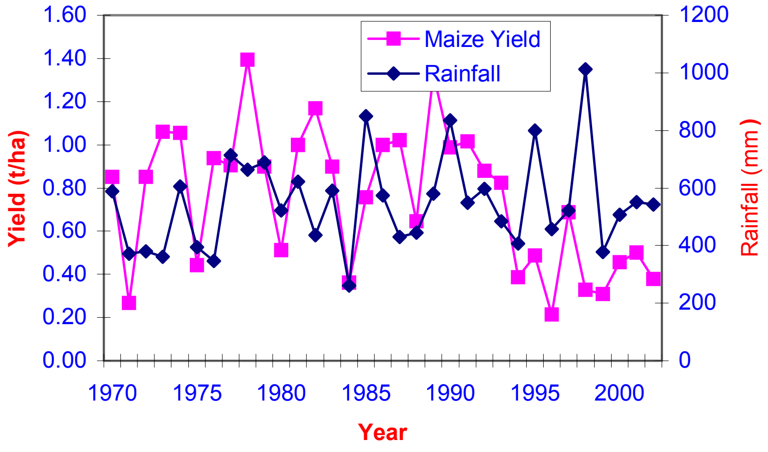

Figure 1. Rainfall and maize yields in Machakos district

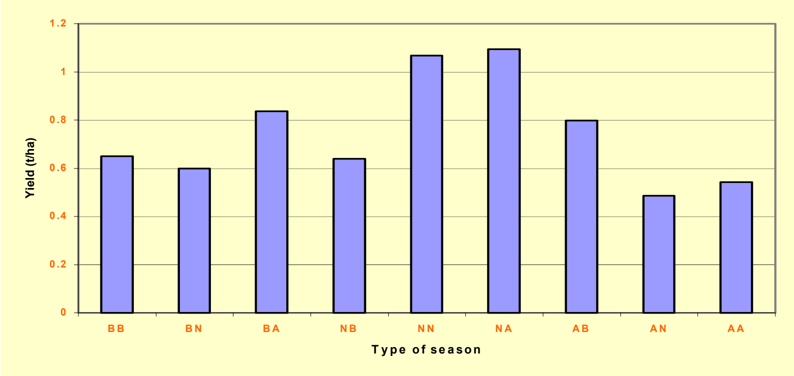

Figure 2. Productivity of maize (t ha-1) during the below normal (<250 mm), normal (250-350 mm) and above normal (>350 mm) short and long rainy seasons for the period 1970-2002

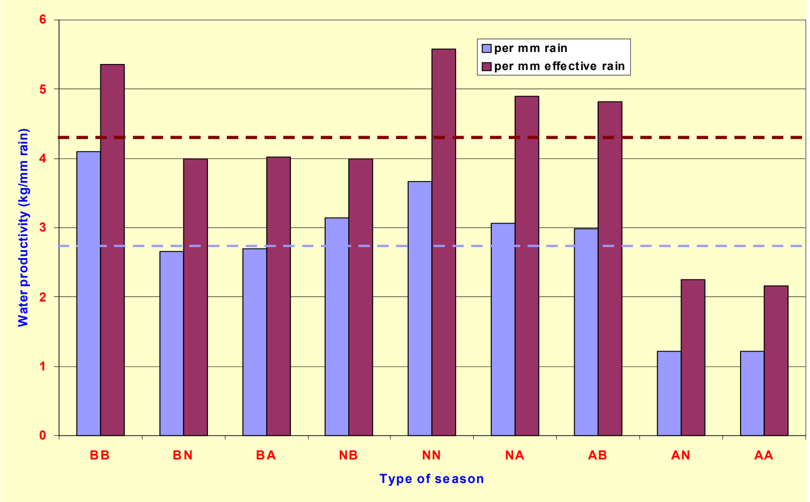

Figure 3. Productivity of total and effective rainfall (kg maize grain/ mm rain) during below normal (<250 mm), normal (250-350 mm) and above normal (>350 mm) short and long rainy seasons for the period 1970-2002

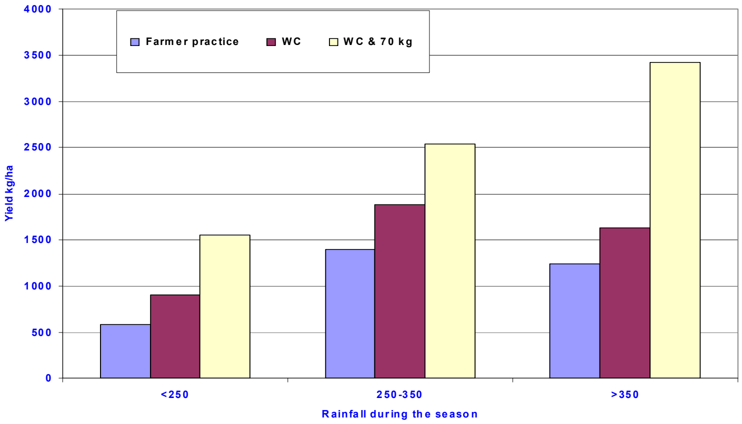

Figure 4. Average maize yields (kg/ha) recorded under farmer practice, water conservation by mulching (WC) and with WC and application of 70 kg N/ha treatments during the below normal (<250 mm), normal (250-350 mm) and above normal (>350 mm) crop seasons between 1990 and 1999

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