Long-term evaluation of dryland cropping systems intensification for sustainable production in the semi-arid tropics of India

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Introduction

We report some of the results from a 15-year long rotational trial conducted at ICRISAT in the Southern Peninsular India that will eventually form the basis for a detailed model evaluation of Agricultural Production Systems Simulator (APSIM). This model will then be used to design crop rotations that have higher productivity and lower risks than conventional rotations like rainy fallow and post rainy sorghum or chickpea. The experimental results reported here show that this is entirely feasible. Our specific objectives were to: 1) quantify the benefits of grain legumes to non-legumes in the cropping system rotations; and 2) identify improved and sustainable cropping system options for crop productivity and intensification.

Variability in the onset and distribution of monsoonal rains in June-July constitute a key risk of crop production on Vertisols. As such, fields are usually left as fallow during the rainy season (*kharif*) and cropped with sorghum or chickpea during only the post-rainy season (*rabi*) on stored soil moisture. However, due to the high water holding capacity of Vertisols, there is an opportunity to make better use of both seasons, and as such, a crop intensification approach with sequential double cropping was explored. Besides the extra crop yield gained from double -cropping, this practice may help to reduce erosion in the rainy season.

Vertisols in this part of the world are generally deficient in nitrogen (N) and phosphorus. Response to N fertilization is much higher than with any other nutrient, and the response in the rainy season is greater than in the post-rainy season (Katyal, 1988). Legume-based systems have been particularly successful in providing N inputs where fertilizer is of marginal economic benefit as well as providing grain as part of the crop production system. In India, farmers remove stalks from the field for fodder, however relatively little N is removed in this process because stalks have very low N content. Legume root material and nodules remaining in the soil have shown positive residual effects on the subsequent cereal crop equivalent to 30-40 kg N ha^{-1}(Kumar Rao et al., 1983). While this is not large enough to approach potential crop yields of rainy season crops, even a moderate N input could double the yield because the soils may supply as little as 30 kg N ha^{-1} to cereal crops. Such results led to the establishment of a long-term experiment at ICRISAT to examine the productivity of cropping systems with improved technologies including broad bed furrow land management, high yielding varieties, fertilizers and the inclusion of short duration legume crops in rotations.

Materials and Methods

An experiment was established with 10 different cropping system rotations on a Vertisol (Table 1) at the ICRISAT Centre (lat. 17.5°N, long. 78.2°E), Patancheru, India. The experiment was established in 1983 and continued until 1997, a total of 15 years. In this paper, we analyse the effects of four cropping systems described in Table 2. The experimental design was split-plot with cropping systems as main plots and four levels of N fertilizer application as subplots. Two of the four cropping systems were double crop sequential systems; mung bean (*Vigna radiata* (L.) Wilczek) sown in rainy fallows followed by post-rainy sorghum (*sorghum bicolour* (L.) Moench), constituted the mung bean and sorghum sequential system (MS-MS); and rainy season sorghum followed by chickpea (*Cicer arietinum* L.) rotated annually constituted the sorghum and chickpea sequential system (SCP-SCP). The other two systems were traditional rainy-season fallow systems sown to a post-rainy season crop; either annual repetition of sorghum after a fallow (FS-FS), or a two-year rotation of chickpea after a fallow and sorghum after a fallow (FS-FCP). This sequential rotation had a mirror image (FCP-FS) treatment, so that in any given year both sorghum and chickpea were grown in order to account for the effect of climate variability. Rainy season mung bean in the MS-MS rotation and sorghum in the SCP-SCP rotation were dry-sown ideally in the first fortnight of June before the onset of the south-west monsoon. The post-rainy season crops were sown soon after the harvest of the rainy season crop using the available soil moisture. Main plot size was 12 x 12 m with 8 sets of broad bed and furrows. Each plot was divided into four subplots receiving either 0, 40, 80, or 120 kg N ha^{-1} applied as urea to each non-legume crop. Details of primary tillage, fertilizer nutrient application and crop management information were provided in Rego and Nageswara Rao (2000). The same crop varieties were used throughout the experiment with the exception of a sorghum variety (CSH-8R swapped with SPV-421) during the post-rainy season.

Table 1. Soil properties at a depth of 0-15 cm in a Vertisol at the experimental site at ICRISAT in 1983.

Soil series	pH (H_2O)	EC (dS m $^{-1}$)	CEC (meq 100 g $^{-1}$)	C-org (%)	N (mg kg $^{-1}$)
Kasireddipalli	8.1	0.25	56.6	0.61	550

Table 2. Main plots (three replicates): cropping system rotations.

1st Year		2nd Year	Rotation Abbreviation
Rainy	Post-rainy	Rainy Post-rainy	
Fallow (F) +	Sorghum (S)	Fallow + sorghum	FS-FS
Mung bean (M) +	sorghum	Mung bean + sorghum	MS-MS
Fallow +	sorghum	Fallow + chickpea	FS-FCP
Sorghum +	chickpea	Sorghum + chickpea	SCP-SCP

In subplots N application was made at 0-N, 40-N, 80-N and 120-N kg ha^{-1} to non-legume crops.

To compare rotations of different lengths, we present grain yields per two year rotation and we use the minimum support price announced by the Government of India for 2010-11 for a simple gross return analysis. Marketable grain prices per quintal (100 kg) were mung bean, Rs. 2760; chickpea grain, Rs.1760; and hybrid sorghum grain, Rs.880. We estimate sorghum fodder value at Rs.1400 per ton.

Results and Discussion

Overall the productivity of the sequential double cropped systems (MS-MS or SCP-SCP) was greater than any of the fallow plus post-rainy crop systems. Mean grain yield of post-rainy sorghum in the MS-MS system without N application (2520 kg ha^{-1} two-year rotation^{-1}) was significantly greater than the mean grain yield in the continuous fallow-sorghum system (1940 kg ha^{-1} two-year rotation^{-1}), and with the added benefit of the mung bean grain yield (1000 kg ha^{-1} two-year rotation^{-1}) with the MS-MS system. However, mean grain yield of FS-FCP sorghum at 0-N (2260 kg ha^{-1} two-year rotation^{-1}) was not significantly different from the mean grain yield of MS-MS sorghum (2520 kg ha^{-1} two-year rotation^{-1}). Total grain productivity of the MS-MS system was significantly higher than that of the FS-FS or FS-FCP systems (Figure 1) at the same level of applied N. The residual effect of mung bean on sorghum is the difference in grain yield between the MS-MS and FS-FS systems at each N level, which was on an average lower with increased N application.

In the SCP-SCP system the additional grain yield of rainy sorghum (3400 kg ha^{-1} $cycle^{-1}$) ensured that the total productivity of this system was greater without N application and a small additional investment on seed and harvesting. However, farmers are generally more concerned about year-to-year yield variability and are prepared to trade-off some long-term yield benefits for short-term guarantees of minimum yields. Essentially, they use stored soil moisture from the fallow as insurance for a minimum yield and as a buffer against rainfall variability. Hence, we also investigated the yield variability of the different systems. Grain yield of sorghum in FS-FS was less than 50% of mean grain yield during 5 years and mean grain yield of chickpea in FS-FCP system rotation was less than 50% of mean grain yield during 4 years out of 15 years in these traditional systems. Sorghum grain yields with the MS-MS system were less than 50% of its mean yield in only two out of 15 years. During these two years mung bean grain yields were higher than its mean yield of 500 kg ha^{-1} annually, thus minimising the risk of productivity with this double crop system in all 15 years of experimentation. Rainy season sorghum grain yields in the SCP-SCP system were well above 50% of the mean grain yield in all 15 years, complementing the chickpea grain yields in this system and avoiding any productivity risks.

Double cropping MS-MS and SCP-SCP sequential systems without N application had greater mean gross returns (42408 and 55598 Rs. ha^{-1} two-year rotation $^{-1}$ respectively), than those achieved in the FS-FS or FCP-FS systems (19739 and 30710 Rs. ha^{-1} two-year rotation $^{-1}$, Figure 2). Similar ranking of cropping systems gross returns was evident with increasing nitrogen levels. Thus, crop yield, total productivity and economic returns were greater with double cropped sequential systems compared to post-rainy season single cropped traditional rotations. Furthermore, these systems can easily be adopted by dryland small holder farmers. However, there were significant year-to-year yield variations due to seasonal weather conditions, suggesting the need for further study of the data to identify suitable systems options for different ENSO analogue years to minimise the risks of climate variability. This dataset now forms the foundation for model validation and for model supported identification of better cropping systems options those will aid the design of future farming systems that are best adapted to the regional climate variability by minimizing risks.

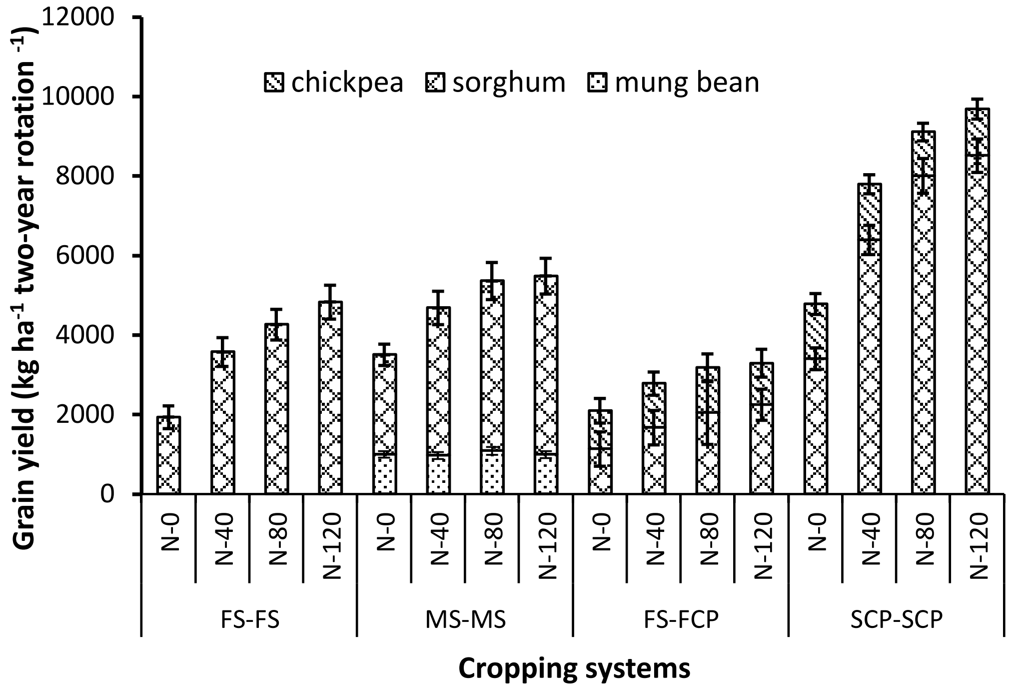

Figure 1. Grain yield of rainfed cropping systems (Table 2) with increasing levels of nitrogen application, averaged over 15 years. Bars represent ±1 SE for each crop type.

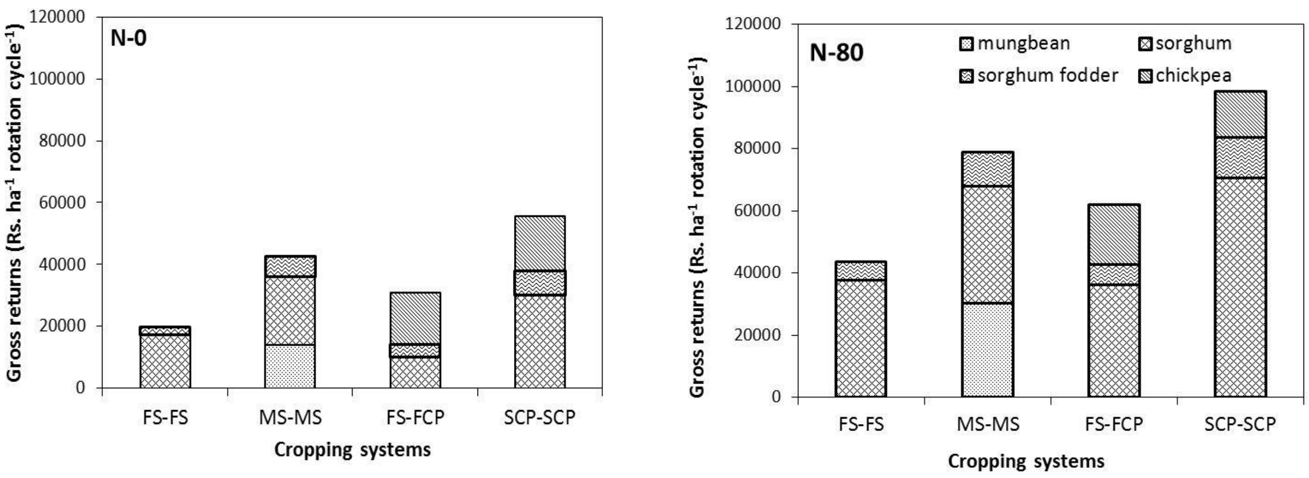

Figure 2. Gross returns from rainfed cropping systems (Table 2) with no added nitrogen, averaged over 15 years.

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