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Agronomic and economic performances of different cropping systems in a hot, arid environment: A case study from North-western Rajasthan, India

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ABSTRACT

A four-year field experiment was conducted in order to assess the productivity and economic potential of five cropping systems, with two tillage (conventional and deep) and four nutrient management [no application, farm yard manure (FYM) at 5 t ha^{-1}, chemical fertilizer (CF), FYM at 5 t ha^{-1} + CF] treatments in a hot, arid environment at Bikaner, India. Pearl millet [*Pennisetum glaucum* (L.) R. Br], cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] and moth bean [*Vigna aconitifolia* (Jacq.) Marechal] were grown in five rotations. The five rotations were: moth bean–pearl millet, cluster bean–pearl millet, moth bean–cluster bean, pearl millet–pearl millet and pearl millet + cluster bean–pearl millet + cluster bean. The moth bean–cluster bean cropping system recorded 21–148%, 36–246% and 33–178% higher equivalent yields, return and water use efficiency, respectively than other cropping systems. Deep tillage increased equivalent yields by 20% higher than conventional tillage. The combined application of CF and FYM recorded 15 and 32% higher equivalent yields than their respective sole application. In this hot, arid ecosystem, a legume–legume system was more productive and profitable than other systems, and higher crop yields could be achieved by combining deep tillage with the integrated use of CF and FYM.

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1. Introduction

A key question facing agricultural scientists in the 21st century is how to produce sufficient amounts of food, feed and farm income while protecting and improving environmental quality (Robertson and Swinton, 2005). Approximately 854 million people are food-insecure globally (Borlaug, 2007). There are warnings of even bigger challenges to food security by 2050 when the present population of 6.7 billion reaches 9.5 billion, before stabilizing at about 10 billion by the end of the 21st century (Lal, 2009). Food insecurity is also related to a worldwide decrease in per capita arable land (Horrigan et al., 2002), the decline in production capacity of soils (Lal, 2009), a decrease in renewable freshwater supply (Barnett et al., 2005) and projected changes in the climate (Parry et al., 2004).

Land and water, the two basic inputs of agricultural production, are becoming scarce. Worldwide per capita arable land decreased from 0.40 to 0.25 ha between 1961 and 1999 (Horrigan et al., 2002). The agricultural production of biomass for food and fiber uses about 86% of the world's available freshwater (Hoekstra and Chapagain, 2007). In many parts of the world, the use of water for agriculture competes with other uses, such as urban supply and industrial activities (Falkenmark and RockstrÖm, 2004). In the future, higher agricultural production must come from the natural resource base that is currently available. This requires a process of sustainable intensification by increasing land use and water use efficiency (FAO, 2005). The problem of ensuring an adequate supply of agricultural products and protecting natural resources is particularly acute in arid regions, which cover around 32% of world's land area and is home to about 21.2% of the human population (Safriel and Adeel, 2005). These regions are characterized by low precipitation, highly variable rainfall patterns, high evapotranspiration rates, poor soils, severe land degradation processes, a short crop growing season and low crop yields (Groombridge, 1998; Heathcote, 1983).

Identification of suitable cropping systems that make the best use of available resources and provide higher yields is important if the diverse needs of farming communities and environmental sustainability in arid regions are to be catered for (Joshi et al., 2009). Water use efficiency (WUE) and nutrient uptake, along with

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profitability and productivity, are important criteria when comprehensively assessing cropping systems. Management inputs interact with cropping systems and dictate their efficiencies (Riedell et al., 1998). Water is the most critical input for crop production in rainfed arid regions and the proper conservation and use of rainwater is very important if sustainable crop production is to be realized (Faroda et al., 2007). Crop management practices that efficiently utilize rainwater are essential if higher crop productivity in rainfed hot, arid regions is to be achieved.

The Indian hot, arid region covers 31.7 million ha (Fig. 1) and is characterized by low (100–400 mm y^{-1}) and erratic (coefficient of variation > 50%) rainfall, high evapotranspiration (1600–2000 mm y^{-1}) and strong winds (Rao and Singh, 1998). Soils are coarse textured, deficient in organic matter and nitrogen (N) and have poor moisture retention capacities (Gupta et al., 2000). Water resources and vegetation cover are therefore low and the average productivity of crops in this region is very low (<0.5 t ha^{-1}). High biotic pressure (human and livestock numbers have increased from 5.87 million and 13.80 million in 1950 to 22.50 million and 27.50 million in 2001, respectively) has resulted in the overexploitation of resources and poses a serious threat to the sustainability of the region (Gupta and Narain, 2003).

To date, very little information is available regarding the agronomic and economic performance of contrasting cropping systems in the hot, arid region of India. There is a lack of information pertaining to the comprehensive assessment of cropping systems in the region. Earlier research conducted in the region dealt with the component crops of cropping systems and mostly focused on a narrow range of criteria, e.g. yields, returns and the effect on soil properties of different cropping systems (Rao et al., 1995; Saxena et al., 1997). The present experiment was conducted with the objective of assessing yields, returns, water use efficiency and nutrient uptake of five cropping systems. This paper reports the results of a four year long field experiment that tested the hypothesis that a legume–legume rotation could provide yields, WUE and net returns that matched or exceeded those from millet–millet and legume–millet rotations. Crop yields are reduced by water and nutrient deficiencies in hot, arid environments, so this study also tested the hypothesis that tillage and nutrient management could also improve crop yields. An appropriate tillage system can increase water availability for crops by increasing infiltration, water storage in the soil profile (Gupta et al., 2000) and root growth of the crops (Gajri et al., 1994). Alleviating nutrient deficiencies is an important way of enhancing the productivity and water use efficiency of crops in arid regions (Faroda et al., 2007; Joshi et al., 2009). The results from this study facilitate the selection of efficient cropping systems, tillage and nutrient management options in iso-agroclimatic regions of the world.

2. Materials and methods

2.1. Location

The experiment was conducted between 2004 and 2007 at the Central Arid Zone Research Institute, Regional Research Station, Bikaner, India (28°4′ N; 74°3′ E; 238.3 m above mean sea level) located in the northwestern part of the Indian Thar Desert (Fig. 1). The climate of the experimental site is hot and arid and mean annual rainfall is 286 mm. The weather data for the crop growing seasons during the four year experiment are presented in Fig. 2. The soil at the site is loamy sand (Typic Torripssamentes). Soil samples taken at the beginning of the experiment at 20 cm depth on 10 July 2004 indicated a mean pH of 8.5, a mean organic carbon content (Walkley and Black procedure) of 0.1%, a mean available phosphorus (P) content (Olsen's procedure) of 8.4 kg ha^{-1}, and a mean available potassium (K) content (1 N ammonium acetate method) of 234.1 kg ha^{-1}.

2.2. Treatments and experimental designs

There were two tillage treatments: conventional (CT: 15 cm deep), and deep (DT: > 25 cm deep) tillage. The five cropping systems tested used three crops: pearl millet [*Pennisetum glaucum* (L.) R. Br], moth bean [*Vigna aconitifolia* (Jacq.) Marechal] and cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.]. The rotations followed were: moth bean–pearl millet (hereafter, MB–PM), cluster bean–pearl millet (CB–PM), moth bean–cluster bean (MB–CB), pearl millet–pearl millet (PM–PM), and pearl millet + cluster bean–pearl millet + cluster bean (PM + CB–PM + CB). There were four nutrient management treatments: no application (0 or control); farm yard manure (FYM) applied at 5 t ha^{-1}; a chemical fertilizer application of N and P at 10 and 20 kg ha^{-1} for legumes (i.e. moth bean and cluster bean) and 20 and 10 kg ha^{-1} for pearl millet and pearl millet + cluster bean intercrop (CF) and combined use of FYM and chemical fertilizer (FYM + CF).

The present study was conducted with a factorial experiment in a split–plot design along with three replications. Tillage treatments were taken in main plots. Factorial experiments (5 × 4) with five cropping systems and four nutrient management treatments were

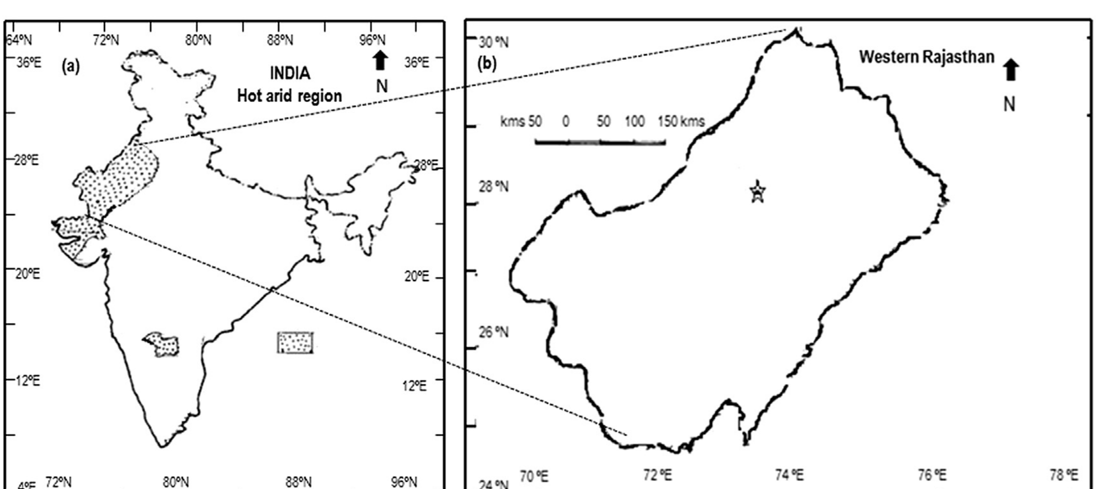

Fig. 1. (a) Extent of hot arid region in India (shaded part of map); (b) the northwestern Rajasthan and the black star indicate the location of the experimental site.

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