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Empirical evaluation of sustainability of divergent farms in the dryland farming systems of India

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ABSTRACT

The present study argues that there are heterogeneous farm systems within the drylands and each farm system is unique in terms of its livelihood asset and agricultural practice, and therefore in sustainability. Our method is based on household survey data collected from 500 farmers in Anantapur and Kurnool Districts, in Andhra Pradesh State of India, in 2013. We carried out principal component analysis (PCA) with subsequent hierarchical clustering methods to build farm typologies. To evaluate sustainability across these farm typologies, we adopted a framework consisting of economic, social and environmental sustainability pillars and associated indicators. We normalized values of target indicators and employed normative approach to assign different weights to these indicators. Composite sustainability indices (CSI) were then estimated by means of weighted sum of indicators, aggregated and integrated into farm typologies. The results suggested that there were five distinct farm typologies representing farming systems in the study area. The majority of farms (>70%) in the study area are small and extensive (typology 1); marginal and off farm based (typology 2). About 20% of the farms are irrigation based and intensive (typology 3); small and medium and off farm based (typology 4) and irrigation based semi-intensive (typology 5). There was apparent variability among farm typologies in terms of farm structure and functions and composite sustainability indices. Farm typologies 3 and 5 showed significantly higher performances for the social and economic indices, while typologies 2 and 4 had relatively stronger values for environment. These discrepancies support the relevance of integrated farm typology- and CSI approaches in assessing system sustainability and targeting technologies. Universally, for all farm typologies, composite sustainability indices for economic pillar was significantly lower than the social and environment pillars. More than 90% of farmers were in economically less-sustainable class. The correlations between sustainability indices for economic and environment were typology specific. It was strong and positive when aggregated for the whole study systems [all samples ($r = 0.183$; $P < 0.001$)] and for agriculture dependent farm typologies (e.g. typologies 1 and 3). This suggests the need to elevate farms economic performance and capacitate them to invest in the environment. These results provide information for policy makers to plan farm typology–context technological interventions and also create baseline information to evaluate sustainability performance in terms of progress made over time.

1. Introduction

Globally dryland (arid and semi-arid) ecosystems occupy more than 3 billion ha and are home to 2.5 billion people: equivalent to 41% of the earth's land area and more than one-third of its population (ICARDA, 2010, 2012). In view of their area and current intensive uses, drylands and their allied agricultural production systems are of great significance. For example in India, where this study focuses on, dryland ecosystems contribute about 40% of the total food grain production and support two thirds of the livestock population (CRIDA, 2011).

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Natural resource scarcity, sustained overexploitation – and as result land degradation, are pervasive in many parts of dryland ecosystems (Van Ginkel et al., 2013). In South Asia alone about 46.5 million ha of land is defined as degraded and thus production systems' sustainability has become a major area of concern (ICARDA, 2012). Evaluations of sustainability of agricultural production systems are most often generalized, at large scale (e.g. IFMR, 2011) and often described by a single indicator. There have been few attempts to develop composite sustainability indices using multiple indicators at farming[1] and farm system scales. Existing studies invariably take only economic or environmental performance into account or use single indicators such as nutrient balance or water productivity (e.g. Haileslassie et al., 2011; Rego et al., 2003). Farm typologies in the study area are also commonly based on the size of the holdings (e.g. Haileslassie et al., 2013a,b); for example marginal (<1 ha), small (1–2 ha), semi-medium (2–4 ha), medium (4–10 ha) and large (>10 ha) holdings. The present study explores two sets of hypotheses. First, there are diverse farm systems within dryland farming systems, and each farm system is unique in terms of its livelihood asset and agricultural practice. In contrast to typologies built on the basis of land holding size, these built based on key livelihood assets should help to explicitly understand the potential and limitations of farms to adopt technologies (Giller, 2013; Riveiro et al., 2013; Jain et al., 2009). Second, agricultural sustainability varies among farm typologies and this establishes relative reference values for sustainability assessment across spatial, temporal and social scales. Put differently sustainable development is now rather seen as a dynamic process. So, in absence of clear cut targets, it is rather common to conduct a relative sustainability assessment of a range of development scenarios. This also allows capturing future development trends rather than only analyzing the current situation. In this respect Van Cauwenbergh et al. (2007) show that reference values are an important component of sustainability evaluation and suggest that reference values provide guidance to users in the process of continuous improvement towards sustainability. They proposed that sustainability should be assessed based either on the comparison of an indicator value with previously defined absolute reference, or on the comparison of indicator values from different systems among each other. Absolute reference values include scientific and legal reference values, while relative reference values involve comparison among sectors, farm typologies, farming systems and commodities. According to Floridi et al. (2011) it is also possible to use scientific knowledge to choose indicator(s) and set sustainability ranges for them. In many other cases, however, we lack reliable objective reference points: benchmarking to actual performance becomes then the only available route. In this case relative composite indices allow for comparison across countries, regions and time: that is they map relative sustainability.

This study therefore explored the following objectives: (1) to generate more comprehensive farm typologies in dryland production systems; (2) to generate composite sustainability indices, integrate into farm typologies and evaluate sustainability in relative terms (comparing between sustainability pillars and values for farm typologies); and (3) to better understand the determinants of sustainability in dryland production systems.

2. Materials and methods

2.1. *The study region*

2.1.1. *Location and bio-physical settings*

Anantapur and Kurnool Districts in the State of Andhra Pradesh, India, are among 'action sites' in the South Asian target region for the Dryland Systems Consortium Research Program [CRP (ICARDA, 2010)]. These sites were selected to represent typical farming systems in the respective regions based on vulnerability maps (CRIDA, 2011), available geospatial information [rainfall, population, soil, etc. (ICARDA, 2012)], and expert opinion. Two villages in each of two Districts, *Mallapurum* and *Kurlapally* in Anantapur and *Yerraguntla* and V. *Bonthiralla* in Kurnool, were identified in consultation with stakeholders. These sites were designated as action and learning sites for the dryland CRP (Fig. 1). District scale climatic data shows that mean annual rainfall for Kurnool and Anantapur (Semi-arid ecoregion) is 670 and 560 mm (CV 28%), respectively (Craufurd and Haileslassie, 2012). Rainfall variability is one of the major factors limiting agricultural productivity in both Districts. Annual mean maximum and minimum temperature in Anantapur is 34.2 and 21.6 °C respectively with comparable values recorded for Kurnool. At District scale more than 33% of Kurnool and 78% of Anantapur land surface is dominated by red soils (or Alfisols). More than 59% of the Alfisols in Anantapur are described as shallow soils (<0.3 m depth). Rego et al. (2003) illustrated that in addition to variability in rainfall soil nutrient depletion is one of the major production limiting factors in these areas.

2.1.2. *Characterization of agricultural production systems in the study regions*

It is generally believed that livelihoods in Kurnool and Anantapur Districts and the study villages is dependent on agriculture. In spite of the prevailing moisture stress and subsequent low crop productivity, mixed crop-livestock agricultural systems constitute an important source of income. Depending on farm structure and objectives, off-farm activities and livestock enterprises supplement farm households' revenue. The contribution of these livelihood activities to farm income shows disparities across seasons and among farmers.

In response to biophysical factors (e.g. soil and climate) and socio-economic drivers (e.g. market), farmers in Anantapur and Kurnool practice pulses based crop livestock system. Groundnut (*Arachis hypogaea* (L.)] is priority pulse in Anantapur, while pulses such as pigeon-pea (*Cajanus cajan*) and chickpea (*Cicer arietinum* (L.)), in addition to groundnut, are priority in Kurnool District (Haileslassie et al., 2013a,b). Foxtail millet (*Setaria italica*) is also commonly included in cropping systems in Kurnool. The cropping season in groundnut based crop-livestock systems is mainly in the Kharif or monsoon (June to October rainfall) season. Groundnut is usually intercropped with pigeon pea or sunflower (*Helianthus annuus* (L.). In addition to Kharif pigeon pea and groundnut on its Alfisol areas, in Kurnool District where Vertisols (black soils) are present chickpea is also grown on residual soil moisture and/or irrigated in the Rabi season [November to April (Haileslassie et al., 2013a,b)]. District scale data shows that yields of rainfed crops are low, around 1 Mg ha^{-1} for groundnut in Kharif season and double that in the Rabi season which is commonly irrigated (Haileslassie et al., 2013a,b; Craufurd and Haileslassie, 2012).

It is important to note that District administrative units used above to characterize farming system are just a zoning based on natural capital (land use type, climate, soil, etc.). While these differences in resources endowment lead to differences in farms of one zone compared to another as illustrated above, there are still significant differences within zones because of other factors such as human and social capital. Depending on the way zones are defined,

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[1] According to Giller (2013) a 'farm system': referring to the conceptualisation of an individual farm as a system, a set of inter-related, interacting components or sub-systems and a 'farming system': referring to a single category within a broader typology, where the category groups together farms that are 'similarly structured'.