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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.

[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'.

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,

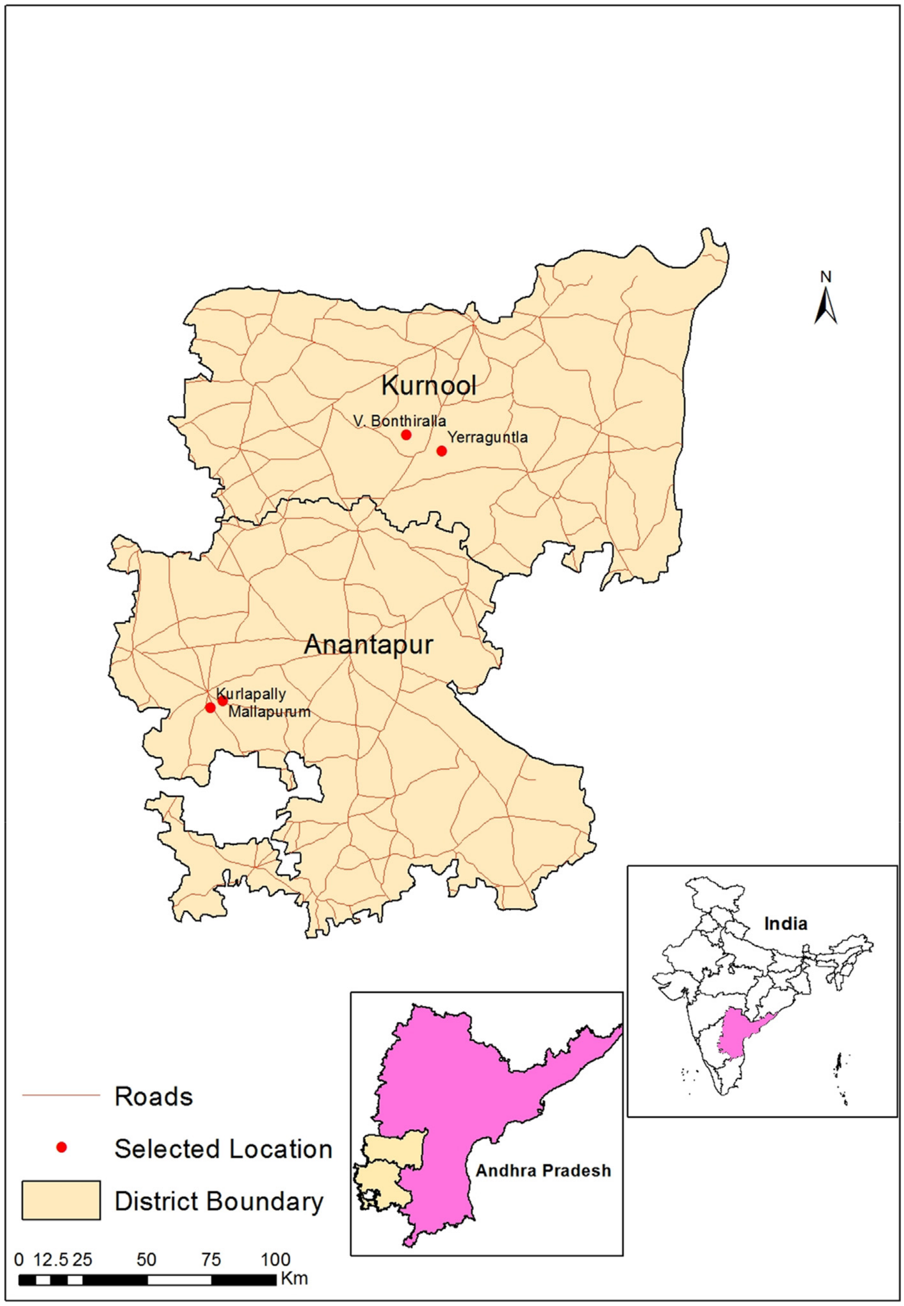

Fig. 1. Location of the study villages in Anantapur and Kurnool Districts, Andhra Pradesh, India.

it is possible to find farms of the different types within a zone or farms of the same type in different zone (e.g. http://www.icra-edu.org).

2.2. Data sources and framework for analysis

2.2.1. Data sources

Fig. 2 depicts the overall flow of data sources and framework for the analysis (Dantsis et al., 2010). This study was based on two sets of data: (i) primary data from sample farm household surveys in *Mallapurum* and *Kurlapally* villages in Anantapur and *Yerraguntla* and V. *Bonthiralla* villages in Kurnool; (ii) computed data based on combination of information from the household surveys and literature values. Five livelihood assets (social; financial; natural; physical and human) and associated indicators were identified (see also Bebbington, 1999) and shared with stakeholders for a review before implementing the household survey. The number of households in *Mallapurum*, *Kurlapally*, *Yerraguntla* and V. *Bonthiralla* villages were 380, 245, 335 and 131, respectively, and these were used as a sampling frame. Before sample selection we held village level appraisals to understand the level of heterogeneity in terms of major livelihood indicators, including access to land and irrigation water. Then we followed a systematic random sampling technique to select 500 sample farm households (~50% of the population). The questionnaire was administered to the sample farm households between April and May 2013. In addition to farm agricultural production data for 2011/2012 production year, information on the trend of income from major income sources was collected. In this respect sample farm households were asked whether income from major farm activities (i.e. crop production, livestock and off farm) over the last 5 years has increased, decreased or stagnated.

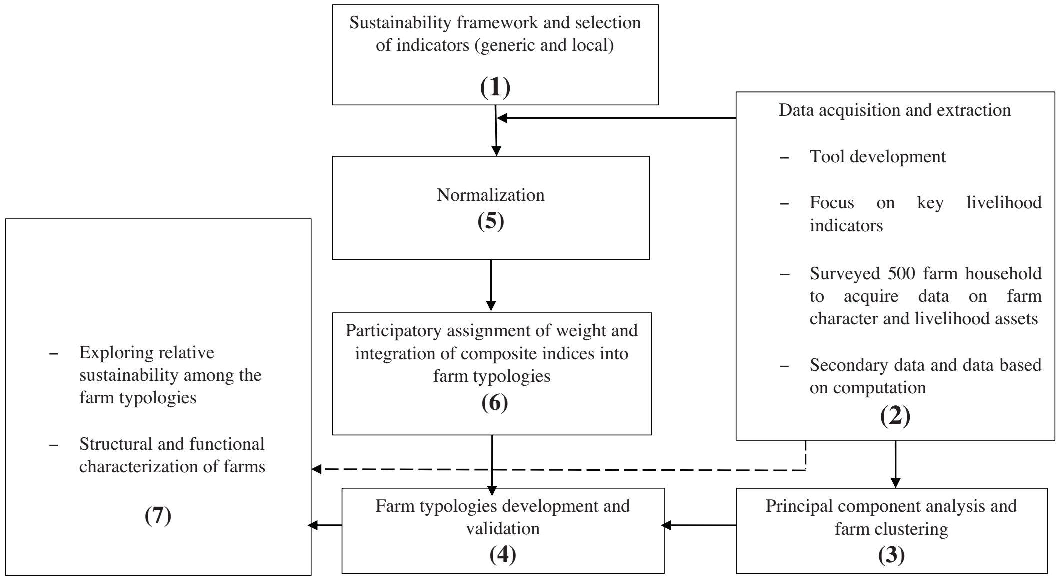

Fig. 2. Analytical framework used to build composite sustainability indices.

Income from the livestock was estimated using livestock off-take rates (i.e. sold, slaughtered or given away); milk production; traction services and dung production. Dung production was estimated by converting livestock population numbers into standard livestock units (SLU equivalent to 350 kg or 1.4 tropical livestock unit) using the conversion coefficients of Ramachandra et al. (2007) and assuming 50% feed digestibility and 3% of live weight (LW) dry matter intake. Financial estimates for dung and livestock services were collected during in the household surveys. Estimation of income from crop production valued production costs (labour, fertilizer, seed, and machinery, oxen) and benefits from and grain and crop residue harvests.

A partial nutrient balance for N was applied to elucidate the differences between composite sustainability indices and single indicator based sustainability assessment using Eq. (1).

$$\mathrm{Mpb} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}((\mathrm{I}+\mathrm{O})-((\mathrm{Y}_h * \mathrm{NC}_h)+\mathrm{R}_h * \mathrm{NC}_h))_i}{m} \quad (1)$$

whereby Mpb stands for mean partial nitrogen balance of a farm typology; j is for sample household; m is for total number of sample farm households in each typology; i stands for individual farm plot under specific crop; and n is for number of plots under individual farm household; I stands for nitrogen input from inorganic fertilizer sources (DAP and UREA); O for nitrogen input from organic nutrient sources (farmyard manure); Y_h is for yield of crop h; NC_h nitrogen concentration in grain and residues of crop h (Haileslassie et al., 2013a,b); R_h is for residue yield for crop h.

For crop-livestock integration we used percent of households who have both crop and livestock on farm as a proxy indicator (Haileslassie et al., 2006).

2.2.2. Principal component analysis, farm clustering and exploring diversity

As illustrated by the theoretical framework (Fig. 2, box 2), data collected and computed fed into a principal component analysis (PCA). Firstly, livelihood assets (human, social, financial, physical and natural) indicator variables (compare also Alvarez et al., 2014) collected through the household survey and tested for intercorrelation. Multivariate techniques of PCA and cluster analysis (CA) were then sequentially used to identify key explanatory variables to cluster farms into homogeneous farm systems respectively (Usai et al., 2006; Rufino et al., 2013; Köbrich et al., 2003). From a total of 34 variables used, 13 PCs, which explained 73% of the variability, were identified. Then loadings of the 13 PCs, having more than one eigenvalue, were subjected to CA to generate typologies. To check whether the model-generated typologies resemble the reality, in terms variability within and among typologies, validation was done with local experts and study farmers (Fig. 2, box 4). In this regard key informants were selected from each farm typology and commonly known indicators (e.g. farm income; landholding size, etc.) were identified by experts. Using these indicators a qualitative comparison (low, high) between the different typologies and for individual farms in every typology was facilitated by local experts.

To explore diversity in structural and functional characteristics of the study farm, twenty three variables were selected among the data-sets used to develop the typologies including data on cultivated land holding, availability of labour, access to tube well, livestock holding, access to credit, different fertilizer inputs (Fig. 2, box 7). Additional data sets such as productivity of major crops, agricultural income per capita, cropping pattern of major crops, access to machinery, land to labour ratio, crop livestock integration, percent share of crop and livestock inputs were also used from the household survey and computed data sets (Milán et al., 2006; Usai et al., 2006).

2.2.3. Building composite sustainability indices

Fig. 2, boxes 5 and 6, illustrates key activities to develop composite sustainability indices. Sustainability indicators are increasingly seen as an important tool for assessment and implementation of sustainable farming systems (Singh et al., 2012). Indicators can be used individually or in the form of a composite index, whereby individual indicators scores are combined into a single number (Dantsis et al., 2010). Zhen and Routray (2003) proposed operational indicators for measuring agricultural system sustainability in developing countries. They reflect environmental, economic and social pillars of sustainability (Gomez-Limon and Sanchez-Fernandez, 2010; Dantsis et al., 2010). In this study we adopted this framework and targeted only key variables among the bulk of variables used for typology building (Table 1). Similar to the data sources for typology building and farm characterization explained earlier, sustainability indices building activity also shared some data sets with typology building and farm characterization, but also had exclusive data sets such as total farm water use, depth of ground water, irrigation methods, calculated net farm incomes. Here it is important to

Table 1
Framework (sustainability pillars, indicators and their definitions) used to analyze sustainability.

Sustainability-pillars	Indicators	Definition, and nature of the indicators used
Economy	Crop productivity	Major crops and their productivity (kg ha^{-1}). Indicate land use efficiencies (additive)
	Net farm income-crop	Income (USD farm^{-1}) from crop (additive)
	Net farm income-livestock	Income from livestock (USD farm^{-1}). Proxy for the degree of integration between farm enterprises (additive)
	Agricultural income	Estimated as USD head^{-1}. A proxy for the capacity of farmer to invest in sustainable intensification (additive)
	Income from off-farm (%)	It indicates alternative sources of livelihood to support investment on farm (additive)
Social	Access to inputs for crop production	Farmers access to inputs for crop production is recorded as binary (0, 1) from farmers interview and it indicates financial and physical capital necessary to achieve more productive use of land (additive)
	Access to bank credit	Binary (0, 1) data collected quantitatively from farmers' interview and access indicates opportunities to invest in sustainable intensification (additive)
	Access to veterinary services	This was recorded as binary (0, 1) from farmers' interview. Access shows less level of risk a farm is facing (additive)
	Access to training	This was recorded as a binary (0, 1) from farmers' interview. It indicates farmers exposure to theoretical and practical aspects of improved farm technologies (additive)
	Farm experience	Number of years the farm household head is farming. It represents farmers knowledge (additive)
	Education of household head	Level of education: illiterate (0), primary (1), secondary (2), higher education (3), etc. It shows level of farmers' awareness (additive).
	Livelihood strategies	Number of livelihood strategies farms are practicing were recorded from farm interview. Proxy for diversity of income sources and farm capacity to invest in agriculture (additive)
Environmental	UREA applied (kg ha^{-1})	This is quantity of UREA applied (kg ha^{-1}) to crop land. Shows degree of N mining or over accumulation in farm (additive)
	DAP applied (kg ha^{-1})	This is quantity of DAP applied (kg ha^{-1}) to crop land. Shows degree of N and P mining or over accumulation in farm (additive)
	Water use	This is quantified as the absolute volume of water used per cultivated hectare (m^3 ha^{-1}). This represents the amount of water drawn from hydrological systems (subtractive)
	Application of FYM	Quantity of manure applied (kg ha^{-1} on dry matter basis) recorded from farm interview. It shows degree of nutrient recycling and soil nutrient replenishing, and also crop livestock interaction (additive)
	Depth of ground water	Estimate of average depth of farm tube well (m). Proxy for ground water depletion (subtractive)
	Irrigation method	Methods a farm is practicing: flood (1), furrow (2), sprinkler (3), drip (4). Proxy for water use efficiency (additive)
	Crop diversity	Ratio of number of crops to total farm cultivated areas. Shows on farm genetic resources conservation (additive)

note that the nature of an indicator matters in the final value of composite indices. For example, for binary data (0, 1) these which meet the criteria will get 1 multiplied by their assigned weight, while these which do not meet the criteria will get 0. For categorical variable such as education (illiterate, primary school, secondary school, higher education) and also types of irrigation methods (furrow, sprinkler, drip) we built a dummy variable (0, 1, 2 and 4). Thus we defined the nature of the indicators either as additive or subtractive in consultation with local experts (Table 1).

A composite sustainability index is encouraged for its comprehensiveness and for covering the three pillars of sustainability, i.e. social, environmental and economic, unlike a traditional single indicator (Gomez-Limon and Sanchez-Fernandez, 2010). As part of developing composite sustainability indices, normalization of the data is an important component before the indicators were aggregated since these are calculated using different units of measurement [Gomez-Limon and Sanchez-Fernandez, 2010 (in Fig. 2, box 5)]. They therefore need to be expressed in homogeneous units in order to allow them to be compared and to perform arithmetical operations on them. The present study employed a normalization approach (Eq. (2)) whereby X' is for normalized value of observation X and min(X) and max (X') stand for maximum and minimum observation in the whole sample (Freudenberg, 2003). The output is a normalized indicator within a dimensionless range (0, 1), where 0 corresponds to the worst possible value of the indicator (i.e. the least sustainable) and 1 is the best (i.e. most sustainable).

$$X' = \frac{X - \min(X)}{\max(X) - \min(X)} \tag{2}$$

The next step after normalization is assignments of weight and aggregation [Gomez-Limon and Sanchez-Fernandez, 2010 (Fig. 2, box 6)]. Several methods for assigning weights are proposed. In this study we used participatory approaches whereby we consulted the community in the study villages to assign values to each indicator on a consensus basis (compare also Ripoll-Bosch et al., 2012). Primarily we selected key informants among the sample farm households used in the survey and explained the different indicators categorized under the three sustainability pillars. Then we asked farmers to compare these indicators in terms of their role for their livelihood and assigned a value between 0 and 10. The sum of the values they proposed for all indicators under each sustainability pillar must equal 10. Separate consultations with local experts were also held to understand the differences in the relative importance of an indicator between farmers and experts. Eq. (3) illustrates details how indicators were aggregated into sustainability composite indices

$$\mathrm{CI} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}((w*\mathrm{ad})+(w*\mathrm{ad})+(\cdots))-((w*\mathrm{sub})+(w*\mathrm{sub})+(\cdots))_i}{m} \tag{3}$$

whereby CI is for mean composite indices for a sustainability pillar (economic or social or environmental) of a farm typology; j is for sample household; m is for total number of sample farm households in a typology; i is for an indicator in a target sustainability pillar; and n is for number of indicators under the target sustainability pillar; w stands for weight value of respective indicator; ad is for additive indicator under the target sustainability pillar; sub is for subtractive indicator. Note that when the subtractive value is higher than the additive the CI value will be negative. In this case we considered CI as equals to 0.

The final aggregated composite indices were integrated into the farm typologies. For a meaningful characterization of the different classes of sustainability a suitable fractile classification, from assumed probability distribution, is beta distribution which is generally skewed and takes value interval 0–1. The distribution is assumed to have the same probability weights of 10%: i.e., <20, 20–30, 30–40, 40–50, >50 representing less sustainable, moderately sustainable, sustainable, highly sustainable and very highly sustainable classes respectively (Lyengars and Sudarshan, 1982).

3. Results

3.1. Characterization of the farm typologies

3.1.1. Variations in structural characteristics of farm typologies

Following the methods explained in the earlier sections, our study identified the following five distinct farm typologies, and named them after their key livelihood assets and activities (Table 2). 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); irrigation based semi-intensive (typology 5). Variation between the two study Districts existed in the proportions of farmers in each typology. Thus typology 1 comprised of 16% the farms from study villages in Anantapur and 84% from farms in Kurnool District. Typology 2 was composed of 93% farms from villages in Anantapur and 7% from villages in Kurnool. For typology 3, farms from villages in Anantapur and Kurnool were 64%, and 36% respectively (Table 2).

Table 3 depicts the basic descriptive statistics of farm structures for the above defined farm typologies as well as the average farm in the study farming systems. In smallholder agricultural production systems land holding is an important production enabling resource and key attribute in defining farm structure and function. An average farm in the study farming system has 2.7 ha (Table 3) but there were marked differences among farm typologies. Farm typology 3 showed higher value of land holding ($P = 0.05$) than farm typology 2. Farm typology 3 is also unique in that 63% of farms have access to farm machinery. Farm typologies 2 and 4 had land holdings below average in the study systems and thus mainly dependent on off farm income. Value for farm typology 1, where 48% of the study farms belong to, had land size closer to the value for an average farm in the study systems.

Table 3 also shows percent area of major crops in the study systems. For an average farm in the study farming system, groundnut (50%), millet (20%), pigeon pea (10%) were important crops. There were apparent differences across farm typologies both in terms of crop diversity and areas under different crops. For example for farm typology 2 groundnut covers more than 85% of the farm land, whilst for farm typology 1 groundnut covers only 29% of the crop land areas.

The major source of water input to these farming systems is rainfall. In the study systems, on average, about 25% of the study farms had access to tube wells for irrigation. The number of farmers having access to tank and open well sources of water were negligible. Generally there were distinct differences across the study farm typologies for access to water for irrigation. In farm typologies 3 and 5, about 49 and 54% of the farms had access to irrigation water, respectively. These farms were only about 19% of the total study farms.

Commonly the study systems are referred as a mixed crop-livestock systems indicating the role of livestock in crop production and vice versa. Livestock breeds, both large and small ruminants, in the study systems were mainly indigenous (i.e. local breed). An average farm in the study system had 1.64 SLU. Overall correlations between land, livestock holding and person-equivalent labour force per household were positive and significant at $P < 0.01$. About 47% farms reported having livestock on their farms. The highest number of farmers who integrated livestock and crops were in farm typology 2.

To understand investment trends, Table 3 depicts farmers' choice of investment in major farm structural components, i.e. livestock and crops. Farmers in the study area invest 45% of their income in crops and 5% in livestock. No significant differences were observed among the study farm typologies in this respect. More generally farm typologies 1 and 2 tended to invest more on livestock than the other typologies.

In the study areas subsidies and credit are two major forms of public sector support to farmers, with credit being more important to farmers. On average farm credit at system level was equivalent to 60% of farm household's income. Although the differences across farm typologies were not remarkable, we recorded higher values of credit and subsidies for farm typologies 3 and 5 (Table 3).

3.1.2. Diversity in productive performance of farm typologies

Farm productivity, income and nutrient stock management are some of the productive aspects of systems we focused on as depicted in Table 4. Groundnut, pigeon pea and foxtail millet constitute the major crops grown. Average productivity values (for 2012 production year) for major crops in the study system were 621, 831 and 508 kg ha^{-1} for groundnut, foxtail millet and pigeon pea respectively. There were distinct differences across the farm typologies. For example groundnut productivity recorded for farm typologies 2 and 5 was 11 and 7% less than the average farming system value while the other three typologies showed generally higher productivity values.

The results of this study also illustrated that the livelihood strategies of the study farms are generally dependent on three major income sources: income from crop production, livestock and off-farm. For the study farming system a mean value of income from crop was estimated at USD 508 farm^{-1} year^{-1} (Table 4). There were noticeable differences among the study farm typologies, and these were not directly related to crop productivity. For example farm typology 5, which showed below average crop productivity, had the highest income from crop production.

Based on calculations from data on manure, livestock off-take, milk production and traction services the income from livestock was estimated at USD 248 farm^{-1} year^{-1} for the study system. Differences among farm typologies were not remarkable, though farm typology 5 showed about 40% higher value than the farming system average.

For the study system income from off-farm constitutes about 35% of farm income. Variation among farm typologies was evident. The highest share of income from off-farm (50%) was recorded for farm typology 2 and followed by typology 4 (42%).

Fertilizer input and maintaining nutrient stock on farm are important indicators of farm performance. These activities include inorganic fertilizer (external inputs) and also recycling of on-farm organic sources fertilizer (FYM). For the study system inorganic fertilizer input was estimated at 49 and 83 kg ha^{-1} year^{-1} for UREA and DAP (fertilizer types) respectively. Variation among farm typologies was also apparent; farm typology 2 showed a lower value of inorganic fertilizer input and this was consistent with the trend of crop productivity and income from crop production. There were also differences among farm typologies in quantity of FYM input which tended to have a similar trend to inorganic fertilizer input (Table 4).

To see the overall balance of nutrient inputs and outputs, a partial N balance was used as indicator. Here we focused on N balances and the result showed overall negative value for N balance. Mean values of N balances for typologies 2–4 were positive, while

Table 2
Significances of the study farm typologies and their distribution across the study Districts.

Name of farm typologies based on their key livelihood assets and activities	Assigned code	Share in the sample (%)	Distribution of typologies across the study Districts (%)
Small and extensive	1	48.8	Anantapur (16), Kurnool (84)
Marginal and off farm based	2	28.8	Anantapur (94), Kurnool (6)
Irrigation based and intensive	3	16.0	Anantapur (66), Kurnool (34)
Small and medium and off farm based	4	4.1	Anantapur (86), Kurnool (14)
Irrigation based semi-intensive	5	2.3	Anantapur (75), Kurnool (25)

Table 3
Features of farm structure by farm typologies (mean ± SD for continuous variables; frequencies for category variables).

Variables	Farm typologies					
	Small and extensive (N = 250)	Marginal and off farm based (N = 147)	Irrigation based and intensive (N = 85)	Small and medium and off farm based (N = 20)	Irrigation based semi-intensive (N = 11)	All (N = 513)
Cultivated land holdings (ha farm^{-1})	2.78 ±2.35	2.33 ± 3.85	3.28± 2.22	2.28± 1.48	2.87 ± 1.58	2.72 ± 2.82
Cropping pattern (major crops %)[a]	GN (29), PP (14), ML (34)	GN (85)	GN (55), PP (10), ML (15), RC (5)	GN (80), COS (4)	GN (66), PP (18)	GN (50), PP (10), ML (20)
Access to machinery (% of farms)	5.20	9.50	63.50	5.00	18.20	16.30
Access to tube well (% of farms)	14.0	25.90	49.40	30.00	54.5	24.70
Availability of labour PELF[a]	3.26 ± 1.33	4.17 ± 2.10	3.62 ± 1.28	3.23 ± 1.43	3.84 ± 1.60	3.59 ± 1.63
Land to labour ratio	0.93 ± 0.89	0.63 ± 0.93	1.03 ± 0.91	0.72 ± 0.43	0.87 ± 0.60	0.93 ± 0.89
Livestock holdings in SLU[b]	1.64 ± 2.23	2.08 ± 4.88	1.64 ± 2.22	1.05 ± 2.26	2.74 ± 2.89	1.64 ± 2.23
Crop-livestock integration (%)	45	50	47	33	45	47
Credit (USD farm^{-1})	573.29 ± 548.40	482.49 ± 416.61	918.03 ± 678.27	670.90 ± 439.69	804.77 ± 524.61	613.16 ± 553.00
Investment in livestock (% of total investment)	4.94 ± 7.71	4.93 ± 10.90	4.00 ± 5.44	1.35 ± 2.74	2.73 ± 3.44	4.59 ± 8.30
Investment in crop (% of total investment)	43.996 ± 18.39	41.46259 ± 22.05	42.09412 ± 17.42	46.5 ± 20.90	43.63636364 ± 24.29	43.04483431 ± 19.55
Total amount of subsidies (USD farm^{-1} year^{-1})	41.88 ± 60.27	30.26 ± 41.10	48.92 ± 57.63	48.48 ± 85.99	36.66 ± 46.88	39.86 ± 56.18

N is for number of observation; GN is for groundnut; PP is for pigeon pea; ML is for millet; RC is for rice; COS is for caster bean.
[a] PELF is Person Equivalent Labour Force.
[b] SLU is for Standard Livestock Units in which one SLU is equivalent to 350 kg of live weight of animal.

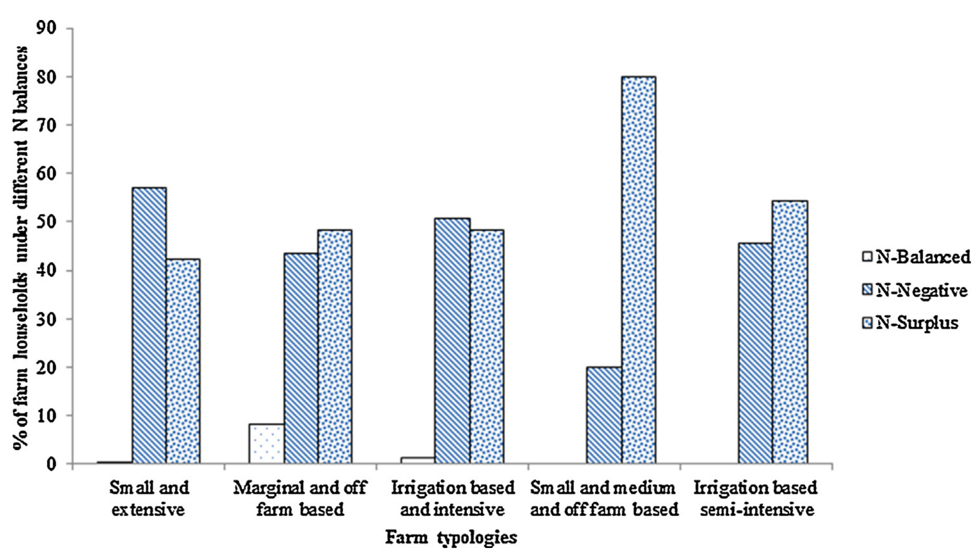

Fig. 3. Percent of farm typologies under different levels of partial N balances.

Table 4
Selected feature of farm function by farm typologies (mean ± SD for continuous variables).

Variables	Farm typologies					
	Small and extensive	Marginal and off farm based	Irrigation based and intensive	Small and medium and off farm based	Irrigation based semi-intensive	All
Ground nut productivity (kg ha^{-1})	669 ± 168.6 (84)	551 ± 206.6 (119)	695 ± 256.8 (56)	663 ± 248.3 (17)	575 ± 174.4 (10)	621 ± 216.9 (286)
Millet productivity (kg ha^{-1})	835 ± 193.6 (118)	750 ± 217.9 (3)	820 ± 173.0 (18)	875 ± 176.7 (17)		832 ± 189.9 (156)
Pigeon pea productivity (kg ha^{-1})	508 ± 90.2 (92)	483 ± 28.9 (3)	515 ± 67.9 (17)		500 ± 0.0 (2)	508 ± 85.1 (114)
Income (crop production, USD farm^{-1} year^{-1})	328 ± 1038.0 (247)	376 ± 1203.0 (131)	1018 ± 2136.9 (84)	700 ± 22.1 (20)	1885 ± 355.7 (11)	508 ± 1503.0 (493)
Income (livestock production, USD farm^{-1} year^{-1})	255 ± 346.1 (248)	252 ± 396.9 (135)	241 ± 372.1 (85)	115 ± 219.0 (20)	347 ± 442.7 (11)	249 ± 363.2 (535)
Agricultural income (USD farm^{-1} year^{-1})	137 ± 316.1 (249)	112 ± 246.7 (135)	297 ± 541.3 (85)	212 ± 68.5 (20)	457 ± 68.8 (11)	168 ± 385.4 (500)
Income from off-farm (%)	27.5 ± 18.1 (250)	50.1 ± 25.1 (147)	34.3 ± 21.9 (85)	42.0 ± 23.2 (20)	29.5 ± 16.8 (11)	35.7 ± 23.2 (513)
Fertilizer input UREA (kg ha^{-1})	46.6 ± 32.4 (250)	29.7 ± 54.1 (147)	84.4 ± 147.4 (85)	67.1 ± 88.4 (20)	77.2 ± 139.0 (11)	49.5 ± 77.0 (513)
Fertilizer input DAP (kg ha^{-1})	56.2 ± 43.3 (250)	99.44 ± 99.7 (147)	119.15 ± 126.9 (85)	117.20 ± 82.5 (20)	148.45 ± 141.7 (11)	83.4 ± 88.4 (513)
Fertilizer inputs others (kg ha^{-1})	13.3 ± 27.2 (250)	40.9 ± 122.3 (147)	48.2 ± 78.9 (85)	31 ± 64.3 (20)	8.1 ± 27.0 (11)	27.6 ± 77.7 (513)
Farmyard manure input (kg ha^{-1})	1391 ± 798.8 (250)	1245 ± 1160.7 (147)	1951 ± 1245.6 (85)	1311 ± 1030.1 (20)	1410 ± 1282.0 (11)	1439 ± 1037.5 (513)

Figures in parentheses are sample size.

Table 5
Mean value of partial Nitrogen balance across farm typologies (kg ha^{-1} year^{-1}).

Farm typologies	N	Mean	SD	Min	Max
Small and extensive (N = 247)	250	−60.7	112.3	−428	107
Marginal and off farm based (N = 131)	147	5.1	48.4	−250	139
Irrigation based and intensive (N = 84)	85	0.3	114.2	−248	665
Small and medium and off farm based (N = 20)	20	27.2	41.7	−27	152
Irrigation based semi-intensive (N = 11)	11	−23.8	161.8	−348	257

N is for number of observation.

values for typologies 1 and 5 were negative (Table 5). Fig. 3 depicts the percent distribution of farm households in N balanced, positive (surplus) and negative (depleted) categories. The majority of farms in farm typology 1 were N-depleted, while these for typologies 4, 2 and 5 N-surplus.

3.2. Variability of composite sustainability indices across farm typologies and economic, social and environmental pillars

Table 6 depicts composite sustainability indices (SI) by farm typologies, economic, social and environmental sustainability pillars. Differences in magnitude of the SI among the sustainability pillars were apparent. The value of SI for the economic pillar was the lowest, whilst index for the social pillar was more than two fold higher than the economic pillar. Divergence across farm typologies was also evident. For example farm typologies with irrigation facilities and better fertilizer input (i.e. typologies 3 and 5) showed significantly stronger composite SI for the economic pillar (P = 0.05). Interestingly the value for environmental SI was higher for farm typology 2, i.e. farms which are less agriculture dependent. Table 6 also illustrates diversity of values of composite indices for the three sustainability pillars when examined from farmers and experts perspectives. Under farmers weighing methods composite SI for the economy tended to be stronger than the expert weighing methods. Conversely under experts weighing methods composite SI for the environment tended to be stronger than the farmers weighing methods.

Overall correlation among the three pillars was positive and significant at [P < 0.01 (Table 7)]. When disaggregated at the scale of farm typologies a slightly different picture emerged. For farm typology 1 the correlations between the three pillars were positive and strong (P < 0.01). Typology 2 had a negative relation between the economic and environmental pillars, while for farm typologies 3 and 5 relations between social and environmental, and economic and social, respectively, were positive.

3.3. Relative sustainability of farm typologies

Five relative SI, from less sustainable (<20) to very highly sustainable (>50) was developed using beta distribution. Accordingly the distribution of study farmers across sustainability classes for economy, environmental and social sustainability pillars and across all data (global) is given in Table 8. For the economic SI, the majority of farmers (93%) were in less sustainable zone. This contrasts with the social sustainability pillar where farmers under the less sustainable category are virtually absent. For social SI the majority of the study farmers were clustered in the moderately sustainable and sustainable classes. For the environment SI, most farmers (74%) were in the moderately or less sustainable classes. In all three SI's virtually no farmers were in the very highly sustainable class.

Table 6
Variability of composite sustainability indices (mean ± SD) across farm typologies based on farmer or expert weighting (by sustainability pillar).

Weighing	Sustainability pillars	Farm typologies				
		Small and extensive (N = 247)	Marginal and off farm based (N = 131)	Irrigation based and intensive (N = 84)	Small and medium and off farm based (N = 20)	Irrigation based semi-intensive (N = 11)
Farmers	Economy	0.12 ± 0.06*a*	0.14 ± 0.07*b*	0.17 ± 0.09*c*	0.15 ± 0.09*ab*	0.21 ± 0.17*c*
	Environmental	0.21 ± 0.05*a*	0.28 ± 0.05*b*	0.27 ± 0.08*b*	0.28 ± 0.04*b*	0.25 ± 0.06*b*
	Social	0.42 ± 0.09*a*	0.39 ± 0.10*b*	0.47 ± 0.11*c*	0.42 ± 0.11*ab*	0.44 ± 0.11*abc*
Experts	Economy	0.10 ± 0.06*a*	0.12 ± 0.07*b*	0.14 ± 0.09*c*	0.12 ± 0.09*ab*	0.19 ± 0.16*c*
	Environmental	0.21 ± 0.07*a*	0.34 ± 0.05*b*	0.29 ± 0.09*c*	0.33 ± 0.06*bd*	0.28 ± 0.09 *cd*
	Social	0.38 ± 0.10*a*	0.38 ± 0.12*a*	0.47 ± 0.14*b*	0.41 ± 0.12*a*	0.44 ± 0.12*b*

N is for number of observation; *abcd* mean is for with different letter across column differ significantly at $P = 0.05$.

Table 7
Correlation between sustainability pillars (by the study farm typologies).

Farm typology	Economy vs. social	Economy vs. environmental	Social vs. environmental
Small and extensive (N = 247)	0.35**	0.24**	0.44**
Marginal and off farm based (N = 131)	0.14	−0.25**	0.06
Irrigation based and intensive (N = 84)	0.43**	0.07	0.40**
Small and medium and off farm based (N = 20)	0.49*	0.38*	0.05
Irrigation based semi-intensive (N = 11)	0.20	−0.03	0.01
Overall (global, N = 513)	0.34**	0.15**	0.28**

Number of observation = 157.
* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
Figures in parenthesis are sample size.

Table 8
Relative sustainability of the study farms (using beta distribution percentile).

Relative sustainability classes		Distribution of farmers across sustainability classes (%)			
		Global	Economy	Environmental	Social
Less sustainable	<20	18.86	93.10	33.27	0.97
Moderately sustainable	20–30	59.83	3.65	41.18	20.47
Sustainable	30–40	19.26	1.42	24.34	44.83
Highly sustainable	40–50	1.82	1.22	1.22	15.20
Very highly sustainable	>50	0.20	0.61	0	18.50

Table 9 presents sustainability gaps for the different typologies as indicated by CV of the composite SI. With the exception of farm typology 3, all farm typologies showed a high CV for the economic SI. Differences in CV across the farm typologies were relatively uniform for environment and social SI.

3.4. Determinants of sustainability indices

In order to understand farm characteristics and practices that explain the variability of economic SI, we ran a General Liner Model using variables related to farm characteristics. Table 10 depicts the results. Generally the independent variables explained about 52% of the variability of SI between farms ($F(23, 48) = 16.877$, $P < 0.0005$).

Access to irrigation water, irrigation method, livestock diversity, extent of production of FYM and numbers of crops grown showed a positive and significant relation with economic SI, whilst livelihood diversity showed a significant but negative relation. At the scale of farm typologies, for example for farm typology 1, many of the explanatory variables such as irrigation methods, fertilizer application, and livestock diversity remained similar to system scale. For some others, for example for farm typology 3, access to farm machinery and farm implement showed a strong and positive relation with the economic SI: while relation with explanatory variables such as fertilizer and irrigation methods were not significant.

4. Discussion

4.1. Farming systems in transition: how farm typology approaches help in understanding their diversity

Land is one of the most critical inputs to agricultural activities, be it crop production or livestock. The present study estimates the overall average agricultural land holding at 2.7 ha $farm^{-1}$, a value

Table 9
Sustainability variation within farm typologies as indicated by coefficient of variation (CV) of composite sustainability indices.

Sustainability pillars	Farm typologies				
	Small and extensive (N = 247)	Marginal and off farm based (N = 131)	Irrigation based and intensive (N = 84)	Small and medium and off farm based (N = 20)	Irrigation based semi-intensive (N = 11)
Economy	54.7	55.6	7.9	70.3	82.4
Environmental	23.8	28.4	26.9	28.1	26.0
Social	28.9	17.2	30.0	17.0	26.7

N is for number of observation.

Table 10
Determinants of Economic composite sustainability indices for the study farms (dryland ecoregion; values in bold are significant at $P < 0.05$).

Explanatory variables	Unstandardized coefficient		*t*	*P* value
	B	SE		
Intercept	0.053	0.022	2.436	**0.015**
Access to irrigation water	0.040	0.009	4.693	**0.000**
Access to veterinary services	0.002	0.012	0.123	0.902
Number of training on NRM	−0.010	0.008	−1.142	0.254
Years of experience	7.482E−5	0.000	0.311	0.756
Level of education	0.004	0.003	1.446	0.149
Livelihood diversity	−0.018	0.007	−2.548	**0.011**
Fertilizer – UREA applied	2.327E−5	0.000	0.553	0.580
Fertilizer – DAP applied	−4.414E−5	0.000	−1.159	0.247
Fertilizer – other applied	−3.088E−7	0.000	−0.009	0.993
Total water used for irrigation	6.510E−6	0.000	1.209	0.227
Depth of bore-well	0.000	0.000	−0.969	0.333
Irrigation method	0.035	0.007	4.772	**0.000**
Land to labour ratio	0.003	0.002	1.407	0.160
Number of visits by extension	0.001	0.002	0.242	0.809
Number of small ruminants	0.000	0.000	−0.996	0.320
Holding of large ruminants	0.002	0.001	2.068	**0.039**
Livestock diversity	0.014	0.004	3.922	**0000**
Access to farm machinery	0.015	0.010	1.477	0.140
Access to farm implements	0.020	0.012	1.706	0.089
Membership in social group	−0.001	0.004	−0.293	0.770
Farm feed metabolizable energy (ME) production	−1.485E−6	0.000	−1.984	0.048
Farm manure production	0.003	0.001	2.036	**0.042**
Number of crops grown	0.047	0.006	8.246	**0.000**

Fig. 4. Distribution of the study farm households under different land holding size across the study typologies: classes for landholding are marginal (<1 ha), small (1–2 ha), semi-medium (2–4 ha), medium (4–10 ha) and large (>10 ha).

close to the district average (e.g. Haque, 1996; 2.0 ha for Anantapur). According to local classification, which groups farms into marginal (<1 ha), small (1–2 ha), semi-medium (2–4 ha), medium (4–10 ha) and large (>10 ha), the study farms are dominated by small farms (36%) followed by semi-medium (27%) and marginal farms (21%). Large farmers were only about 2% of the sample. The average values of land holding for marginal, small, semi-medium, medium and large farmers in the study areas were 0.60, 1.62, 3.10, 6.00 and 15.3 ha respectively. Fig. 4 illustrates the distribution of these farm sizes across the study farm typologies. The presence of farms with different land holding size in a single typology indicates comprehensiveness of livelihood based farm clustering approaches and implicitly its relevance to target technologies.

Haque (1996), from a sample study in Anantapur District, argues that with the current level of productivity and land holding size farm households may not be sustainable, particularly in view of meeting the annual income required to be above the poverty line (i.e. USD 1.25). What is equally relevant here is also the trend in decreasing land holding size and increasing number of holdings as observed from district scale data (Haileslassie et al., 2013a,b) – and presumably a similar trend exists for the sample farms. This puts pressure on the household economy and explains why farmers are opting more for off-farm income.

When asked if the trend in off farm income over the last 5 years has increased, decreased or stagnated, the majority of farmers in all farm typologies replied increased. This substantiates our argument related to farming and farm systems in transition. Variation across farm typologies regarding their perception of the trend can be better explained by the strong negative correlation (−0.25, $P < 0.01$) between land–labour ratio and off-farm. With lower values of land to labour ratio and less opportunities for irrigation activities (which demands extra labour), farmer's income from off-farm activities was higher (e.g. farm typology 2). In their work in agricultural production systems in East Africa, Tittonell et al. (2010) also suggested that farmers with land–labour ratio >1 produced more food to cover their diet compared to these with a ratio <1. According to these authors the latter category also generate more than 50% of their income from off-farm activities.

The major driver for the study farms to opt for alternative livelihood (off-farm income) was shrinking land holding size and its failure to absorb household labour. As indicated in Haileslassie et al. (2013a,b), from longer term data in response to change in weather pattern and probably degrading land, major crop yield (e.g. groundnut for example in Anantapur) is generally declining. Farmers were asked if their income from crop production over the last 5 years has increased, decreased or stagnated. For the overall study sample 46% replied that productivity has stagnated. But across farm typologies there were differences: for farm typologies 2 and 4 (>44%) farmers responded a decreasing trend in productivity. With increasing family size, shrinking landholding and declining yield, depending only on crop production can be a challenge.

Generally livestock is an important source of livelihood; it directly generates income and indirectly supports crop production through provision of draft power (traction) and also recycling nutrients (Haileslassie et al., 2013a,b). For the whole study livestock brings about USD 249 farm^{-1} year^{-1}. Although there were differences among farm typologies, these values were not statistically significant. Our estimate of 24% was higher than what farmers claimed as the contribution of livestock (i.e. 17% of agricultural income). The difference between our estimate and that of farmers can be explained by the fact that we included manure production in financial terms and also the income from draft power which farmers do not most likely consider as an income.

When asked about the trends in income from sale of the livestock and livestock products during the last 5 years, the majority of the study farmers replied that there had been no change. Disaggregation at farm typology level also yielded a similar result, but exceptionally in farm typology 4 the majority of farmers replied increasing trend. This can be also observed from the total SLU they hold currently. For this typology the increased trend was not as the result of increased livestock productivity but rather from the sale of livestock. Similar to income from crops, the income from livestock has stagnated and this can be related to the declining crop yield and less availability of feed. From discussions with farmers it was also clear that labour is one of the major constraints. There was a positive and significant correlation (Table 10) between income from crop and land to labour ratio that substantiates this argument. With its current level of productivity and consistently increasing labour shortage, livestock and crop production will be incompetent with off-farm income.

To explain the relation between shrinking land size, increasing uncertainty of agricultural production and increasing off-farm income, and how this shapes farm structure, it is important to have a closer look at theories of change that recognize agriculture as family entrepreneurship. In this theory Gasson and Errington (1993) have drawn heavily on a model of family entrepreneurship, arguing that agricultural trajectories can only be understood in the context of the strong commitment of most farmers to continue farming and pass on land to their children. Few farmers are growth oriented but seek to expand or contract according to their stage in the lifecycle or to create a role for a son or daughter. Taking off-farm employment or reducing costs during an economic downturn is seen as a survival strategy that allows a farm household to retain its involvement in agriculture. Although not verified using longer term data, the trends of shrinking land size and farmers tendency to focus on off-farm income, illustrated in this study, is consistent with this argument. In explaining this theory, Gasson and Errington (1993) showed that the ability of a farm household to follow such strategies will depend on the human and social capital at its disposal, so that survival and change in farming has as much to do with demographic and family dynamics as with strategic economic behaviour. In this relation empirical evidence from this study demonstrated that such approaches of off-farm income is very much related with the availability of labour, farm productivity and whether exiting land can absorb existing family labour or not. A strong correlation exists between land to labour ratio and off farm income irrespective of farm access to other agricultural resources.

The question then is how to promote trends of sustainable intensification or build system resilience with the prevailing farm system diversity. Literature argues that off-farm income can complement farm activities and thus accelerate adoption of improved technologies (Haileslassie et al., 2013a,b). At system scale, the relation between off-farm income and income from crop production and livestock showed a strong and negative correlation (−0.81 and −0.22, $P < 0.01$, respectively). A similar relation was observed between income from livestock and crop (−0.23, $P < 0.01$). In fact this is obvious from the meagre investment in the livestock indicated in Table 3. For different farm typologies the relation between income from crop and livestock showed discrepancy. For example, for farm typologies 1 and 2, the majority of farm households, the relation was negative; while for typologies 3–5 there was no correlation between income from livestock and crop. Implicitly there is a weak complementarity between system components and thus can negatively affect sustainable intensification. The bottom line is to make agriculture a remunerative venture by encouraging farmers to invest in crop and livestock from part of their off-farm income. These need context specific matching, mixing and demonstration of technologies in relation to variation in farm typologies as illustrated here (compare also Tittonell et al., 2010). For example typologies 2 and 4 are less dependent on agriculture and thus less likely to benefit from agriculture focused interventions.

4.2. *Assessment of relative sustainability across farm typologies and its implications*

Sustainable development and definition of indicators to assess progress towards sustainability have become a high priority in scientific research and policy agendas (Alvarez et al., 2013). Careful selection of indicators targeting a certain reference value is one of the important steps for a successful sustainability assessment across scale (Van Cauwenbergh et al., 2007). These authors suggested that reference values describe the desired level of sustainability for each indicator. They give users guidance in the process of continuous improvement towards sustainability. A number of frameworks, for example Sustainability Assessment of Farming and the Environment (SAFE), allow an assessment based on either on the comparison of an indicator value with a previously defined absolute reference value or on the comparison of indicator value from different systems among each other, i.e. relative sustainability. Relative sustainability assessment, which this study focuses on, can take the form of comparing sustainability indices across temporal (years) or spatial (regions, farms, and social scale). This approach allows the establishment of a baseline value for newly launched interventions and, more importantly, helps to draw lessons from indigenous best performing farm typologies. It helps also to compare alternatives and evaluate performance progress over time. By comparing value and establishing relation between sustainability pillars, it is possible also to conceptualize a macro-scale sustainable intensification trajectory (Dantsis et al., 2010).

The present study clearly demonstrated differences in magnitude of the SI among the investigated farm typologies. The global composite indices value (mean value of the environment, social and economy SI) tended to show that farm typologies 3 and 5 had higher value, while typology 1 (i.e. extensive farmers) had the lowest values. This was partly a reflection of their farm structure (e.g. land holding size, livestock holding) and functions (productivity and income level). Studies elsewhere similarly show that farm structure and function are highly associated with their sustainability – for example soil nutrient depletion and also water productivity (Tittonell et al., 2010; Haileslassie et al., 2011). As indicated in Table 5, the value of partial nutrient balance, which is often used as sustainability indicator, does not necessarily match with composite SI. Only farm typology 3 had a balanced nutrient status – other typologies had either over supply (2 and 4) or depletion (1 and 5) meaning less sustainable.

Divergence across the three sustainability pillars was also apparent. Value of SI for economy was the lowest while indices for social pillar was twofold higher than the economy. Dantsis et al. (2010), who investigated sustainability level of agricultural plant production in Greece, reported higher value for economy pillar, followed by social and environment. The differences between the two studies can be accounted for by the differences in the level of intensification and resultant productivity and production which were considered as an important indicator in estimating the economic composite indicator. For our study region the productivity of the lead crop (groundnut) was only 621 kg ha^{-1}: a value which is 16% and 34% lower than the study Districts' and the states' averages respectively. Estimation of net income from the crop production suggested that about 25% of the survey farmers had negative return for the production year considered in the study. These having negative returns were considered as a subtractive effect which in fact contrasts with the social indices where the majority of indicators had an additive effect.

The contention put forward in this paper is that economic development and environmental protection are not necessarily mutually exclusive. It is supported by logic that seeks to establish a link between the economy and environment, particularly in terms of lifting farmers from poverty. First, in addition to the empirical evidence on low agricultural productivity provided earlier, there were strong coefficients of variation of economic composite indices. Furthermore, >90% of the farmers are in less sustainable category for economic composite indicator (Table 8). Under the prevailing economic sustainability gap, a decision to invest in eco-friendly agricultural practices is unlikely to happen (Clement et al., 2011). Secondly lessons can be also drawn from the differences in correlation between the economic, social and environment sustainability pillars (Table 7). For the overall study system the relation was positive and significant ($P < 0.01$). This is substantiated by the work of Institute for Financial Management and Research (IFMR) (2011), which suggests strong correlation between economy and investment in environment for different states of India.

When disaggregated at farm typology level different picture emerged. Unlike for the social composite SI, which had positive relation with the economy, the relation between economy and environment SI was negative for those farm typologies that earn substantial amount of their income from off-farm (e.g. typology 2).

4.3. Factors influencing farm sustainability in dryland systems

From regression analysis number of explanatory variables emerged as common to all farm typologies and the discussion here focuses on these. Explanatory variables that had a significant and positive relation with economic SI were improved access and methods of application of irrigation water, diversification of crop and livestock, and access/level of production of organic fertilizer. Contrastingly livelihood diversity had a significant but negative relation with economic SI. As those typologies that showed higher value of SI had good access to water and water is one of the key factor of productivity and sustainability in dryland systems, we will focus our discussion as to how these explanatory variables influences system sustainability from perspectives of water management and subsequent economic rewards.

Rockström and Barron (2007) suggest two main avenues to unlock the potentials of rainfed mixed crop-livestock systems: (1) increase plant water uptake capacity, and (2) increase plant water availability. A closer look at the explanatory variables having positive and significant relation with dependent variables suggests that they fall within these two main avenues suggested by Rockström and Barron (2007). Even though these strategies focus on water, the approaches and practices to achieve them are not necessarily solely associated to water management according to these authors.

Access to irrigation water and improved irrigation methods are directly related to increasing plant water availability and also increasing plant water uptake. They both enable farms to produce more under full or supplementary irrigation: implicitly this has positive impact on farm economic performance and its SI. Explanatory variables such as use of FYM influences the structure of the soil, and thereby root development. Application of FYM is also one means to conserve soil and water (e.g. in situ water conservation) through maximization of rainfall infiltration. Together with crop diversification it positively contributes to plant water availability and these in turn influence crop productivity and subsequently farm economic SI. Despite the positive economic gain of some farm typologies (3 and 5) due to their better access to irrigation water, the environmental trade off in terms of ground water withdrawal from the natural cycle needs attention. Probably lesser magnitude of environmental SI for these farms, indicated in Table 6, explains these trade off better.

Livelihood diversity in dryland system does not necessarily lead to sustainability. Although there is a general notion that farm livelihood diversification has advantage in risk spreading, consumption smoothing, labour allocation smoothing, credit market failures, and coping with shocks some types, diversification may result in stagnation on the home farm (Ellis, 1999). This typically occurs when there are buoyant distant labour markets for male labour, resulting in depletion of the labour force required to undertake peak farm production demands such as land preparation and harvesting. Furthermore, under rainfed conditions households aim to minimize risk. The strategies to avoid risks are diversifying economic activities, by engaging in low-external input, low-capital-investment technologies and by investing in social relations to maintain a social safety network. Low-risk livelihood strategies necessarily yield low returns. In the study area migration to urban centres for labour work is a typical kind of income diversification strategies which substantiates the arguments of Ellis (1999) and probably explains the negative and significant relation between economic sustainability pillar and livelihood diversification.

5. Conclusion

A variety of methods, including principal components and cluster analysis, were combined to detect five farm systems/typologies in the drylands of southern India. These farm types are: small and extensive (typology 1); marginal and off farm based (typology 2); irrigation based intensive (typology 3); small and medium and off farm based (typology 4) and irrigation based semi-intensive (typology 5). The farm typology approach is an important tool to understand farm diversity and may help in targeting technological innovation. It can also help in prioritizing which type of farm households to work with. For example, the majority of farmers in this study are under typologies 1 (small and extensive) and 2 (marginal and off farm based) and in view of pressing need for sustainable intensification and resilience building, these farms should be the priority groups to work with.

By integrating composite SI into farm typologies, this paper demonstrated relative differences in SI between farm typologies. Despite the low values of composite SI for majority of the farms, farm households having access to irrigation showed significantly higher values. Access to water and its improved management also emerged as one of the key variables determining farm sustainability in these drylands. The question was also how to improve overall farm sustainability as all typologies had low values, irrespective of the sustainability pillar (i.e. social, economic and environmental). For example, >90% of the study farms were in less sustainable classes for economic composite SI. Given the importance of short term economic gain for smallholders this is a key issue to address first. In the paper it is also clearly shown that economic development and environmental protection are not necessarily mutually exclusive. It can be concluded that policy measures that elevate the economic performance of farms and capacitate them to invest in the environment, while enhancing a short term productivity goal, could be highly beneficial for the majority of the farmers in these dryland systems.

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