Sustainable Intensification of Agricultural Productivity in Semi-Arid-Tropics (SAT) of India – Case studies

Synthesis Report

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1. Introduction

Sustainable intensification is a term now much used in discussions around the future of agriculture and food security. The term actually dates back to the 1990s and was coined in the context of African agriculture, where yields are often very low, and environmental degradation a major concern. This pro-poor, smallholder oriented origin of the phrase is worth noting in the context of the current controversy around sustainable intensification.

Sustainable intensification (SI) has been defined as a form of production wherein *"yields are increased without adverse environmental impact and without the cultivation of more land".* In this sense, the term denotes an aspiration of what needs to be achieved, rather than a description of existing production systems, whether this be conventional high input-farming, or smallholder agriculture, or approaches based on organic methods. While the intensification of agriculture has long been the subject of analysis, sustainable intensification is a more recent concern (Garnett T and Godfray C, 2012).

1.1 Definitions of intensification and sustainability

Intensification generally refers to the increased use of inputs. Growing of more crops on the same land in a unit time period is referred as increasing cropping intensity. Increasing the use of manures, fertilizers, other chemicals like pesticides, fungicides and weedicides, human or bullock or machine labour, water etc., per unit area and time is characterized as the intensification of agriculture. The 'Green revolution' strategy banked up on the more and more intensive use of inputs to achieve higher yields. As the newly improved varieties and hybrids responded to the intensive-use of inputs by giving higher yields and economic returns, the process of agricultural intensification gained momentum in the irrigated regions of the country. In some areas, agricultural intensification caused environmental damage through increased salinity, alkalinity and water logging problems and limited the response to applied inputs. The policies of subsidization of fertilizers, water and electricity by the governments have greatly aided the agricultural intensification process. Concerns about declining organic matter content, deficiencies of macro and micro nutrients and loss of balance between organic and inorganic manures and fertilizers and unbalanced use of nutrients have raised the issues of sustainability to the fore.

Scientists and environmentalists have emphasized up on the un-sustainability of the intensification process. The concern for sustainability of resources and long-term productivity of soil and water has resulted in new strategies of integrated nutrient management and integrated pest management practices. While these packages are developed by the research stations all over the country, they are not adopted by the farmers widely. Farmers are apprehensive of losing yield if they moderate the intensive-use of inputs. The non-governmental organizations have taken up the issues of pollution and environmental degradation caused by the intensive-use of inputs. They are promoting organic farming and, even natural farming as an alternative to the intensive agriculture. But their reach is limited and the intensive-use of inputs is going on unabated, although with some degree of moderation. The need of the hour is to strike a balance between high yields and sustainability. This urge has given rise to the concept of 'sustainable intensification'.

Finally, it is always important to be clear on how it is defined. This concept aims to meet the multiple aspirations of society in terms of securing and increasing yields, as well as the benefits it values, such as protecting landscapes and wildlife. However, a common definition can be found below (Pretty et al. 2011):

> *Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Royal Society, 2009; Godfray et al. 2010).*

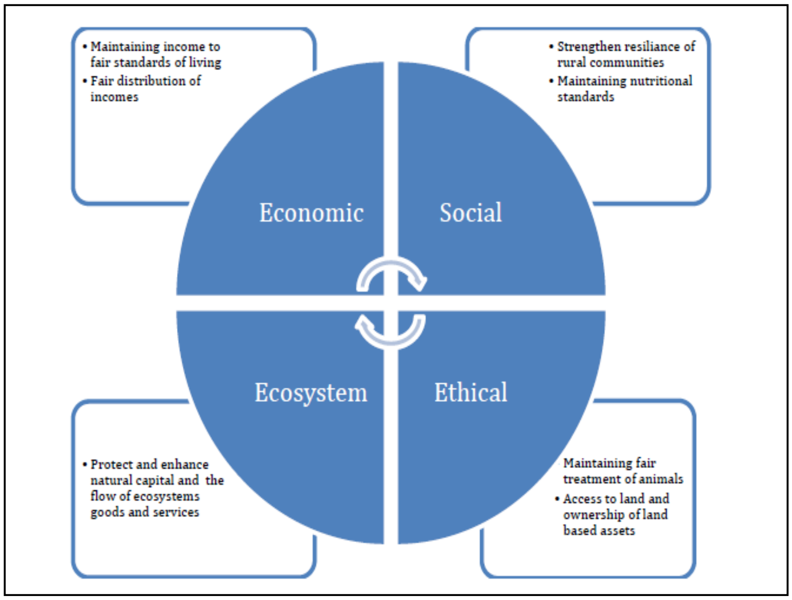
Russell (2005) identified differences in definitions predominantly related to an economist's and an ecologist's view both of intensification and sustainability. This seems to boil down to a short term view and a long term view of how to achieve sustainable intensification. Within the economic literature, agricultural intensification involves increasing the use of inputs per hectare, but also encapsulates brining in previously uncultivated land into cultivation or increasing the use of fixed costs, such as labor, and machinery on cultivated land. In the view of Russell, this implies 'a short-run search for ways to increase variable inputs and output per hectare without comprising the integrity of the ecosystem within which production is embedded'. He goes on to highlight a longer term view, adopted by natural science disciplines, that defines intensification as any increase in inputs per hectare plus any increase in output per hectare whether or not it is accompanied by an increase in inputs. Broadly speaking, therefore, we will define intensification as:

'….an increase in output per ha through technology and best practice adoption, as well as an increase in material inputs to increase output per ha' (Barnes A. 2012).

Overall sustainable intensification (SI) is a new, evolving concept, its meaning and objectives subject to debate and contest. But SI is only part of what is needed to improve food system sustainability and is by no means synonymous with food security. Both sustainability and food security have multiple social and ethical, as well as environmental, dimensions. Achieving a sustainable, health-enhancing food system for all will require more than just changes in agricultural production, essential though these are. Equally radical agendas will need to be pursued to reduce resource-intensive consumption and waste and to improve governance, efficiency, and resilience.

1.2 Dimensions of sustainable intensification

Some thought is needed towards how sustainability could be defined. Sustainable intensification emerged from the ecological arena and, as such, policy and research documents seem to have a bias towards this area of sustainability. However, sustainability can cover a number of dimensions. With the current context of the study, sustainable intensification can be divided in to four major dimensions which could be used a basis for understanding sustainability within agricultural intensification.



Source: Barnes A. 2012

In general, economic sustainability encompasses the income aspects of farming, covering both farmer and employer incomes, in terms of maintaining a sustainable level of income. This implies that the maintenance of a fair standard of living is indicated by economic factors. Net farm income will also have effects on the long-term sustainability of the system, through reducing debt ratios and maintaining capital to ensure efficiency of operation.

Social sustainability embeds the impact of farming within the rural communities under which they operate. Most studies are now finding a decoupling of farm income from rural communities (in terms of the input output impacts), i.e. evidence of leakage of monetary payments.

Ecosystem sustainability and intensification is intrinsically linked with the biophysical capacity of primary inputs (MEA, 2005). The most comprehensively studied aspects of intensification have been the relationship with other ecosystem services (Firbank et al. 2011; Storkey et al. 2011). This literature has generated a wealth of sustainable management recommendations, including initial explorations of sustainable intensification itself (Pretty 1995; Matson et al.

1997). Ethical dimensions of SI are also important and indeed may not include this within a definition of sustainable.

2. Measuring agricultural intensification and sustainability in SAT

Semi-arid tropics (SAT) have largely remained outside the process of excessive intensification, due to the paucity of water. Rather agricultural intensification was restricted to the smaller fractions of irrigated areas in the vast areas of semi-arid tropics. In the rainfed areas, the response to applied inputs like fertilizer, plant protection chemicals was not profitable enough to motivate wider use of these inputs. The investments made in ground water exploration have often become counter-productive and impoverished the farmers. Perhaps, the risk of failure has resulted in under-investment by the farmers to some extent. With the development of watershed management technologies and integrated nutrient and pest management strategies, the scope for sustainable intensification might exist to some extent. But, it may not be feasible as a general rule. The right crop combinations and rotations are required to explore the scope of sustainable intensification further in the semi-arid tropics. Detailed assessments of those systems are required to deeply understand the issue of where the scope still exists and where it has already reached.

A workable definition is required to explore the range of complementarities between intensification and sustainability. Further intensive-use of inputs should only be attempted if it does not compromise the long-term fertility and productivity of land and water resources in the SAT areas. Wherever, intensive-use of inputs is already proving detrimental to the objective of long-term sustainability, either excessive input use has to be cut or the crop combinations/systems and rotations have to be modified. Of course, the requirements of human beings, livestock and other living beings should also be met in the short-run, while striving for long-term sustainability issue. Technological change provides opportunities to push-up the production frontiers and for increasing the range of complementarities between intensification and sustainability. It is the only hope to support the ever-growing populations of human beings and livestock. Wherever, it fails to support them, people tend to migrate to more resource rich areas or urban conglomerations. In some areas of SAT, sustainable intensification is taking place while, in some other areas, people are migrating away as the repeated droughts and famines are emphasizing that the limits of sustainable intensification have already been reached.

Measuring sustainable intensification presents both conceptual and measurement difficulties. It is no inconsiderable task to ensure that progress is being made towards increased sustainability, while also reconfiguring a farming system towards more intensive production. Measuring SI firstly requires appropriate monitoring. Whilst the farm account surveys (FAS) provides indicators of input usage, it does not provide any spatial focus, nor activity at field or system level. Other data sets, such as national and census data could be merged with the FAS to provide a clearer picture on sustainable intensification. However, the intricacies of sustainable intensification could only be captured through detailed on-farm assessments over time which, naturally, has cost associations for policy makers. Secondly, strong multi-disciplinary working is needed to set measurement goals. All the dimensions of sustainability should be fully captured within the measurement process. Furthermore, it requires greater understanding of how to reconcile the (sometimes conflicting) indexes of sustainability and intensification which requires methodologies to extract weightings for individual indexes over different farming landscapes and, also, over time (Barnes A. 2012).

2.1 Approaches for measuring agricultural intensification

The aim of this research is to examine and document sustainable intensification process. This implies a temporal change, as oppose to simply examining intensity within one time period. Hence, datasets are needed to explore how this may have changed over time. A number of datasets are available that meet this criteria. In the present study context, both household primary survey data and secondary sources of information (area and production) reported by Directorate of Economics and Statistics at state-level was used for assessing agricultural intensification over time in particular geographical area unit. To complement these sources of information, geospatial data also used which is available periodically for specific target location. However, the details of major approaches used in this study are summarized below:

2.1.1 Geospatial analysis for measuring intensity

Geospatial analysis is a modern innovative science tool for measuring agricultural intensification in the targeted location over a period of time. Both spatial and temporal changes in per unit cropped area will be captured with more precision and accuracy. This particular approach has been attempted initially in case of chickpea crop in Andhra Pradesh and the process and results are highlighted below.

The Moderate-resolution imaging spectro-radiometer (MODIS) Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V005 (MOD13Q1 product) imagery was downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/lpdaac/get_data/data_pool). MOD13Q116-day composite, four-band data for all 23 composite dates for 2012 were used in this analysis. The spatial resolution of the data is approximately 250 m. Although the data have already undergone atmospheric correction (Vermote and Vermeulen, 1999) and cloud screening, each MODIS 16-day composite was further processed and cloud contamination was removed as explained in previous studies (Thenkabail et al., 2005; Gumma et al., 2011d).

The MODIS data were used to map spatial extent of land use / land cover during 2000-01, 2005-06 and 2012-13. The 16 day NDVI images were taken from MOD 13Q1 product: 23 cloud free images for year 2000-01, 2005-06 and 2012-13 (each datasets start from June to May). The process begins with rescaling 16 day interval NDVI images and stacked in to a single data composite for each cropping year (Thenkabail et al., 2005; Dheeravath et al., 2010; Gumma et al., 2011d; Gumma et al., 2014a).

MODIS 16-day composites were converted to NDVI monthly maximum value composites (NDVI MVC) with the equation 1, where MVCiis the monthly maximum value composite of the ith month and i_1 and i_2 are every 16 days' data in a month:

$$NDVIMVC_i = Max(NDVI_{i1}, NDVI_{i2}) \qquad \text{.................................} \quad (1)$$

In our study, monthly NDVI MVC were used for classification and an NDVI 16-day data set was used for identifying and labeling land use/land cover classes with chickpea areas.

Mapping land use /land cover and chickpea areas

Each cropped year dataset was then classified using unsupervised ISOCLASS cluster K-means classification, for generating class NDVI time series signatures. Unsupervised classification was performed with a convergence threshold of 0.99 and 100 iterations, yielding 100 classes followed by successive generalization. Unsupervised classification was used instead of supervised classification in order to capture the range of variability in phenology over the image, particularly in the large (state level) analysis of this kind, the NDVI signatures of all potential class were not known. Class identification and label each class, we compared each class spectra with ideal spectra (Fig 2.1). The ideal spectra are generated using time series imagery for each ground truth point of same type of land use at spatially distributed location. The ideal spectra are the combination of the spectra of above locations representing a crop type class or crop dominance class. Similar class spectra are grouped to reduce the 100 classes using spectral similarity values. Lower the spectral similar value higher the similarity between the two classes and they are merged to a single class (Thenkabail et al., 2007; Biradar et al., 2009; Thenkabail et al., 2009; Gumma et al., 2011b; Gumma et al., 2011d). Land use/land cover class identification and labeling were based on MODIS NDVI time-series plots, ideal spectra, ground-truth data, and very high resolution images (Google Earth). The class spectra are matched with the ideal spectra and labeled with that class of land use. In rigorous classification process, most of the classes were identified and named. When a study area contains many distinct land cover classes over a large spatial extent, there is a risk that some of the classes from the unsupervised classification may contain several mixed classes. These mixed classes were resolved by extracting them from the stack, reclassifying them, and applying the methodology above on these new classes in order to separate them.

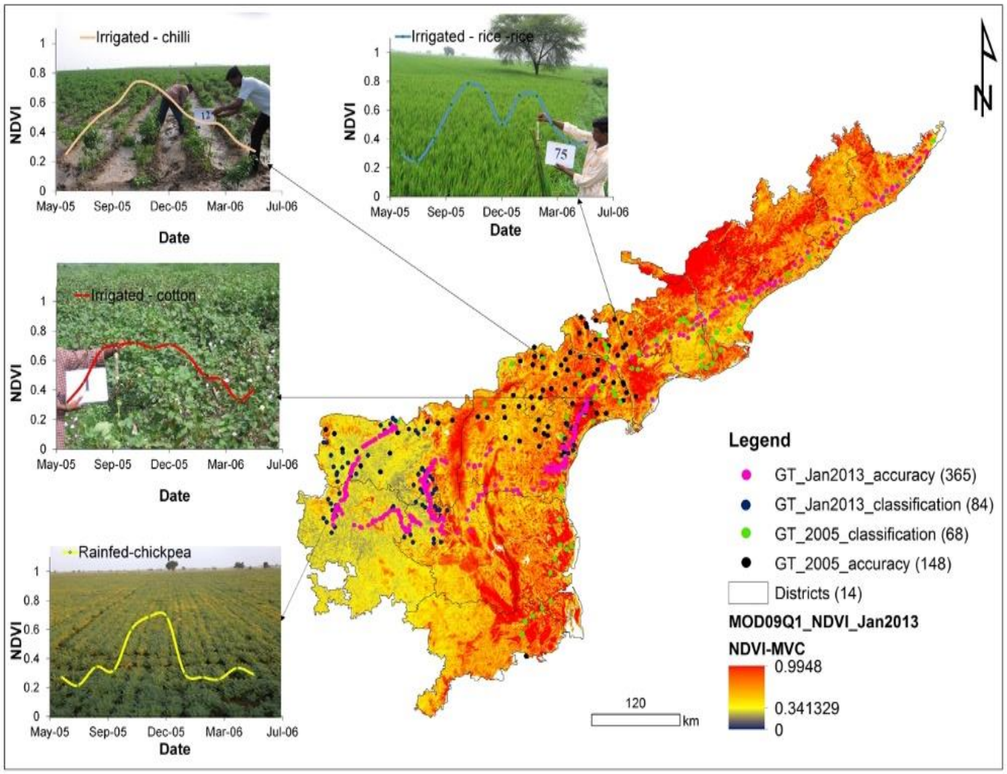


Fig. 2.1 Ground data point locations in Andhra Pradesh. There are 605 field-plot locations where data on crop type, cropping intensity, water source (irrigated vs. rainfed), and a number of other parameters.

Ground data points collected from 449 locations during January 14-22, 2013 and 216 locations during October 13-26, 2005 were used to assess the accuracy of the classification results, based on a theoretical description given by (Jensen, 1996; Congalton and Green, 1999; Congalton and Green, 2008), to generate an error matrix and accuracy measures for each land use / land cover map.

Land use changes, chickpea expansion using NDVI signatures

Land use changes were identified using spectral signatures. NDVI is a combination of red and near infrared bands (Rouse et al., 1973; Tucker, 1979) and is extensively used to differentiate vegetation conditions, including vigour and density (Teillet et al., 1997). NDVI values vary from -1 to +1 and high NDVI values indicate high vegetation vigour and vice-versa. Changes in irrigated area were mapped using NDVI time-series plots, which also indicate cropping intensity, health, and vigour (Thenkabail et al., 2005; Gumma et al., 2011b).

A comparison was made between the land use changes areas and ideal spectra signatures (Fig. 2.1) by using spectral matching techniques and ground data (Thenkabail et al., 2007; Gumma et al., 2011a; Gumma et al., 2011b; Gumma et al., 2011d). In 2012 Chickpea areas were identified by taking into consideration the duration, magnitude, and peak of NDVI curve with ground data. A higher value of NDVI has been noticed during the rabi season (with the peak of NDVI observed during December/January) when compared with the kharif season. In Andhra Pradesh, the highest value of maximum mean NDVI was 0.65 during the kharif season in 2000-01 (which mean rainfed-sunflower), but the value of NDVI was never above 0.3 in any of the kharif months during years with land use change in 2012-13.

2.1.2 Primary and secondary sources of data

Both the primary and secondary sources of data need to be collected and analyzed to assess the levels of agricultural intensification and the possibilities for enhancing it. The tripod of resources, outputs and requirements of human and livestock have to be periodically reviewed in the light of existing and potential technologies feasible in a given area. The quantity and quality of resources have to be assessed constantly and the investments required to maintain and improve them to serve the posterity have to be appraised. The distinction between primary and secondary is only largely temporal in nature. What is collected recently by a researcher becomes the primary source and what was collected in the past by institutions and has been systematized becomes the secondary source and both of them need to be weighed in balance to judge about the sustainability of resources and possibilities of their further intensive-use.

In the present study, both primary and secondary sources of information were complemented to understand the intensification process over a period of time in the targeted states. Specifically designed, nationally representative household surveys were conducted for each of the target site and crop. Further, the detail of each survey was explained in detail in the respective case studies. Secondary information on both crop area and production were also obtained from respective 'State Directorate of Economics and Statistics' over last three decades period to deeply understand the intensification process. The results of those data are presented and discussed in section 3.

2.2 Approaches for measuring agricultural sustainability

Sustainable agriculture implies long-term maintenance of natural systems, optimal production with minimum input, adequate income per farming unit, fulfillment of basic food needs, and provision for the demands and necessities of rural families and communities (Brown et al. 1987; Liverman et al. 1988; Lynam & Herdt 1989). All definitions of sustainable agriculture promote environmental, economic and social harmony in an effort to attain the meaning of sustainability. Sustainability being a concept, it cannot be measured directly. Appropriate indicators must be selected to determine level and duration of sustainability (Zinck & Farshad, 1995). An indicator of sustainability is a variable that allows us to describe and monitor processes, states and tendencies of the agricultural production systems at various hierarchical scales, including the cropping, farm, regional, national and worldwide levels.

The present study basically dealt with two approaches for addressing the issue of sustainability at farming system level rather than firm unit level. Since sustainability is a long-term phenomenon, it cannot be judged either at single point of time or at single firm unit. Due to limitations in the data sources, an integrated approach was followed using both long-term crop simulation models as well as primary household survey data for assessing various indicators of sustainability. The details of those approaches are summarized and discussed below:

2.2.1: Crop simulation models

Crop simulation models can be used as valuable tools in assessing sustainability of cropping systems. Some of the methodological challenges in assessing sustainability in both temporarily and spatially can be addressed using crop simulation models. Hence we used a model-based sustainability assessment in fallow-chickpea based cropping system in semi-arid regions of Andhra Pradesh, India using the CROPGRO-Chickpea, CERES-maize and sorghum models available in Decision Support System for Agro technology Transfer (DSSAT). The chickpea model is part of the suite of crop models available in DSSAT v4.5 software (Hoogenboom et al., 2010). The major components of the model are vegetative and reproductive development, carbon balance, water balance and nitrogen balance. It simulates chickpea growth and development using a daily time step from sowing to maturity and ultimately predicts yield. Genotypic differences in growth, development and yield of crop cultivars are affected through genetic coefficients (cultivar-specific parameters) that are inputs to the model. The physiological processes that are simulated describe the crop response to major weather factors, including temperature, precipitation and solar radiation and include the effect of soil characteristics on water availability for crop growth.

Model inputs

The minimum data sets required to simulate a crop for a site include site location and soil characteristics, daily weather and agronomic management data. The model also needs input of cultivar-specific parameters (genetic coefficients) that distinguish one cultivar from another in terms of crop phenology, growth and partitioning to vegetative and reproductive organs and seed quality. The soil-profile data for the study sites were obtained from the profile characteristics data published by ANGR Agricultural University, Hyderabad and NBSSLUP, Nagpur.

Weather data

Thirty-years (1980-2010) of observed daily weather series was obtained from ANGR Agricultural University Agromet observatory located at Anantapur, Nandyal, IMD observatories in Ongole and from NASA AgMERRA data sets. Similar datasets were also obtained from Agromet Divisions of MAU, Parbhani for sorghum crop simulations as representative location for Marathwada region. Simulation studies were not attempted in other regions of Maharashtra due to non-availability of soil and long-term weather datasets. Crop simulations studies were not attempted in case of pearl millet because of lack of well calibrated pearl millet model. The baseline weather datasets were quality controlled and inspected for outliers or anomalous values and if found, such values were adjusted and corrected using bias corrected AgMERRA data. AgMERRA consists of historical climate datasets prepared based upon a combination of daily outputs from retrospective analyses ("reanalyses"), gridded temperature and precipitation station observations, and satellite information for solar radiation and rainfall (Ruane et al., 2014).

Model-based sustainability assessment

To develop a model-based sustainability assessment, the present study selected four chickpea growing districts having different soil and weather conditions that is representative of each major four districts. We initially reviewed key issues for agricultural sustainability and key cropping system followed in these districts prior to chickpea adoption. Also we surveyed the current chickpea management practices followed in each districts by the farmers and then reviewed the improved management strategies and decided to include farm yard manure application, supplemental irrigation and advancing sowing dates in simulated fallow-chickpea rotations. In the present study we evaluated eight sustainability indicators, crop yield, water-use efficiency (WUE), the amounts of soil organic carbon (OC) across cycles of the rotation, nitrogen fixing, 'N' leaching, Nitrogen-use-efficiency, inorganic 'N' in soil at maturity, total 'N' uptake at maturity. We later explored the simulation scenarios of the various crop rotations, management options and used sustainability polygons to illustrate the sustainability state of a chickpea rotations compared to traditional fallow-sorghum/maize rotations. Similarly, dominant sorghum and soybean systems existing in Maharashtra locations were also tested and evaluated for the sustainability issues.

2.2.2 Econometric analysis

There are number of frameworks available for sustainability assessment that evaluate the performance at macro to micro level and there is now rapidly developing literature on the use of sustainable indicators. Approaches commonly known by researchers in evaluating sustainability include either studying individual components or integration of all four major components of sustainability i.e., ecological, economic, social and ethical. In the present study, to measure sustainability, household survey data collected from designated studies was used to derive indicators of economic sustainability. A range of sustainability indicators were generated from the survey relating to ecological, economic and social dimensions. The main purpose of this study was to elicit changes across the farming systems and agro-ecological regions and derive conclusions about sustainability across study locations.

Sustainability was measured by integrating all the major components except the policy as this is beyond the scope of data collected or present study. To analyze the sustainability among different systems, initially simple statistical means were used followed by econometric methods (such as Cobb-Douglas and Stochastic Frontier production functions) applied. For assessing the efficiency of different resource-uses in diverse production systems, most robust techniques (such as PCA) and variables were used for integrating economic, social and ecological dimensions of sustainability at household level.

The following indicators were identified and analyzed across study regions to compare the sustainability indicators for alternative management system relative to values obtained with a reference system using sustainable polygons (ten Brink et al. 1991). The present study used the long-term average values for all the indicators studied such as yield per ha, water-use efficiency (WUE), nitrogen-use efficiency (NUE), total organic carbon at maturity (OCTAM), nitrogen by phosphorus (N/P) ratio, returns over variable costs (ROVC), fodder availability per acre (FAA), share of ROVC in total expenditure and share of cereal consumption to total food production etc.

Parameter	References
1. Parameters estimated through crop simulation models	
1.1 Yield/ha	Hayati et.al (2010); Moeller et. al (2014)
1.2 Water use efficiency (WUE)	Moeller et. al (2014)
1.3 Nitrogen use efficiency (NUE)	Hayati et.al (2010); Moeller et. al (2014); Murray-Prior et al. 2005
1.4 Total organic carbon at maturity (OCTAM)	Moeller et. al (2014); Arshad and Martin 2002;
2. Parameters estimated through primary household data	
2.1 Return over variable cost (ROVC)	Rasul and Thapa (2003); Moeller et. al (2014)
2.2 Fodder availability per acre (Qtl)	-
2.3 Share of ROVC in total household food expenditure (%)	-
2.4 N/P ratio	Rasul and Thapa (2003)
2.5 Share of household cereal consumption to total food production (%)	Hayati et.al (2010)

The parameter yield per ha was used mainly because it integrates all factors of crop production and measures the efficiency with which all the resources and inputs converted in to single physical output. Water-use efficiency (WUE) with which the highly scarce and variable rainfall is converted in to yield. Nitrogen-use efficiency (NUE) is a measure of efficiency with which the highly dynamic nitrogen input is converted in to yield. The organic carbon is a key indicator for soil health and it integrates important soil properties such as aggregate soil stability, nutrient availability and water retention (Moeller et. al 2014).

Return over variable costs (ROVC) measure the degree with which a system is economically viable in short-run. Livestock is an integral component of SAT agriculture. It contributes significant share of farmer annual household income (Rao et al. 2007). Hence, production of fodder per unit area per household is a key sustainable determinant. The share of ROVC in the total household food expenditure shows the economic sustenance of an average household. NPK ratio of 4:2:1 ($N:P_2O_5:K_2O$) is generally considered ideal and accepted as best agricultural nutrient management practice. However, in the present study we have used N/P ratio as a measure for assessing the sustainable usage of fertilizer application across different cropping systems in a specified targeted location. The average household food production as a proportion of cereal consumption indicates the extent of food security of household members.

Cobb-Douglas production function

The present study applied the Cobb-Douglas production function to assess the production efficiency of various crop inputs across major cropping systems in the study region. Nine explanatory variables were identified to explain efficiency of various inputs used in the system. As the units differ from one explanatory variable to other, we harmonized them by multiplying with costs obtained while conducting the field survey. The following form of The Cobb-Douglas production function was fitted for the analysis:

$$\text{Log } Y_i = \log a + b_1 \log X_1 i + b_2 \log X_2 i + b_3 \log X_3 i + b_4 \log X_4 i + b_5 \log X_5 i + \log \mu_i$$

Where,

Y_i : Gross revenue per ha

'a' Constant parameter in the equation, and 'X_{1-n}' are defined as below and varies according to the cropping system.

Cropped area (in ha), labor cost per ha, bullock cost per ha, manure cost per ha, machinery cost per ha, irrigation cost per ha, seed cost per ha, fertilizer cost per ha and plant protection cost per ha were used as explanatory variable in assessing resource-efficiency.

Returns to scale:

Returns to scale is the measure defined as how much additional output will be obtained when all factors changed proportionally.

Returns to Scale = Σb_i

If returns to scale =1, the production function has constant returns to scale.
If returns to scale > 1, the production function has increasing returns to scale.
If returns to scale < 1, the production function has decreasing returns to scale.

Stochastic frontier production function

Any cropping system is sustainable if the productivity is not stagnating or declining. The stagnating/declining yields are indicative of this serious concern (Pingali and Heisey 1999). Consequently, future gains in productivity also depend on improving the utilization efficiency of the agricultural resource base particularly land, which requires greater access to information and improvement in management potential of the farmers (Rejesus and Heisey 1999).

Following Aigner et al. (1977) and Kumbhakar and Lovell (2000), relative efficiency of farmers was analyzed to have basic understanding of sustainability using the stochastic frontier production function which was given as below:

$$TE_i = \frac{y_i}{f(\chi_i\,;\beta).\exp\{V_i\}}$$

Where,

TE refers to the technical efficiency of the ith farm, yi is the observed output, f (xi ; β) indicates the deterministic part that is common to all producers, exp {vi} is a producer specific part, which captures the effect of random noise on each producer.

According to Battese and Coelli (1995), technical inefficiency effects are defined by;

$U_i = Z_i\delta + w_i$

Zi is a vector of explanatory variables associated with the technical inefficiency effects, δ is a vector of unknown parameters to be estimated, and wi represents unobservable random variables, which are assumed to be identically distributed. They are obtained by truncation of the normal distribution with mean zero and unknown variance σ2, such that ui is non-negative.

All crop outputs and inputs were converted into monetary values using the price information collected during the survey (Bamlaku et al. 2009). The model specified was given here under:

LnY = β0 + β1*ln* Area + β2*ln* Land cost + β3*ln* Bullock cost + β4*ln* Machinery cost + β5*ln* Seed cost + β6*ln* Manure cost + β7*ln* Fertilizer cost + β8*ln* Pesticide cost + δ1Age + δ2 District1+ δ3 District2 + δ4 Distric3 + δ5 Education +δ6 Crop diversification index+ δ7 Network index + ε

Principal Components Analysis (PCA)

Principal components analysis (PCA) is a technique for determining the key variables in a multi-dimensional data set that explain the differences in the observations. This is a method of data reduction and provides a way of weighting of all variables related to the underlying structure of the data. The PCA approach provides a relatively simple means of exploring issues of weighting different dimensions of sustainability and intensification. The coefficients derived from this analysis were mapped to look into way forward and to assess the impact of the integrated components on sustainability.

The main problem of aggregation of parameters value is that they may be expressed in different units (Gomez, 2008). So normalization of parameters is important. In this study normalization technique by Freudenberg, 2003, re-scaling in a range [0, 1] was adopted. In this sense, after normalization, the scores of indicators range between 0 (the worst value, meaning the least sustainable option) and 1(the best value, corresponding with the most sustainable option). Equation 1 & 2 were used for normalization among various inputs.

$$I_{ki} = \frac{x_{ik} - Min\ x_{ik}}{Max\ x_{ik} - Min\ x_{ik}} \dots\dots\dots (1)$$

$$I_{ki} = \frac{Min\ x_{ki} - x_{ki}}{Max\ x_{ki} - Min\ x_{ki}} \dots\dots\dots (2)$$

Nine indicators were chosen for the present study and they are: return over variable cost (ROVC), n/p ratio (NP), fodder availability per acre, share of ROVC to household total food expenditure, crop diversification index, network index, age and education etc. Indices like network, age of household and level of education represents social components of sustainability.

The present study did not attempt to develop any composite indicator for assessing the sustainability across systems due to limitation in the household data. However, the study made systematic effort in analyzing the available cross-sectional household data for addressing the issue of agricultural intensification and sustainability. An indicative evidences on agricultural intensification and sustainability were documented in SAT, India. However, more robust and concrete evidences could be generated through long-term panel studies and datasets.

3. Evidences for agricultural intensification and sustainability

To document possible evidences from semi-arid tropics of India, the present study has taken three specific cases purposefully to assess the agricultural intensification and sustainability of existing cropping systems in the three targeted states. Correspondingly, three comprehensive and representative household surveys were taken with structured survey instruments. The data was validated, analyzed and presented below as three case studies. The results were also complemented with both geospatial analysis and long-term crop simulation models.

Case 1: Chickpea cultivation in Andhra Pradesh

Chickpea crop was selected as a first case to deeply understand the agricultural intensification and sustainability aspects from Andhra Pradesh. In the recent times, chickpea crop in the state has expanded significantly (ten folds) and showed a remarkable increase in crop productivity (doubled) during the last two decades period due to development and introduction of short-duration chickpea cultivars which are resistant to Fusarium wilt disease. The extent of adoption of those cultivars reached its peak with in span of eight years period because of strong institutional support (Department of Agriculture), seed supply (APSSDC) and conducive policy (hike in minimum support price) environment[1]. Due to high market demand and suitability of chickpea for mechanical cultivation, the unit rental values of land have gone-up significantly in major study districts. Because of these peculiarities, it would be a classical first case for understanding the intensification and sustainability issues in SAT.

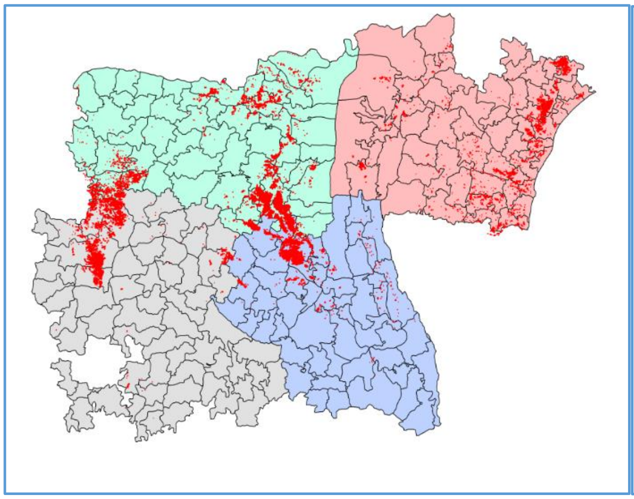
3.1.1 Geospatial analysis of chickpea

This study produced crop extent maps for Andhra Pradesh including other land use / land cover areas at 250m spatial resolution using MODIS imagery and ground data. These maps were tested for accuracy using ground data collected by this research team and national statistical data obtained from government agencies. Temporal variation on chickpea areas in Andhra Pradesh from 2000-01 to 2005-06 and 2012-13 at the district level as showed in table below, spatial maps shown in Figure 3.1.

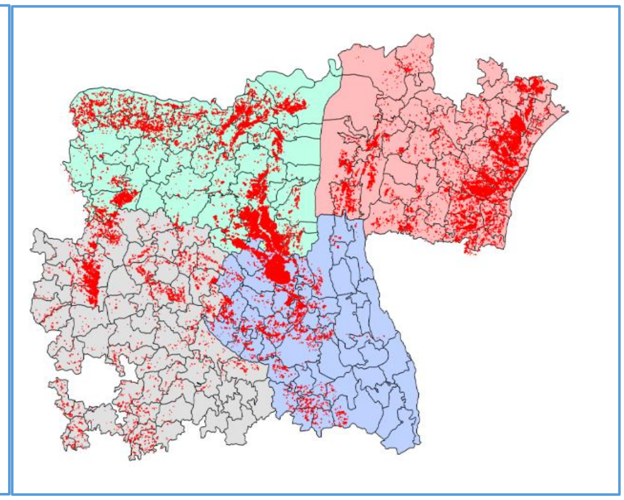
Fig. 3.1. is also providing spatial information of chickpea and expansion of chickpea in major growing districts. In Fig. 3.1a, total chickpea area was mapped 168,362 ha in these four districts and this was located in rainfed-black cotton soils. In Fig. 3.1b, total chickpea area was mapped 389,361 ha in these four districts and this was located in rainfed-black cotton soils and Fig. 3.1c was mapped 558,713 ha. Anantapur and Prakasam districts were largely increased chickpea areas when compare from 2005-06 to 2012-13: there was an estimated more than 65%

[1] *For more details refer Bantilan et al. 2014*

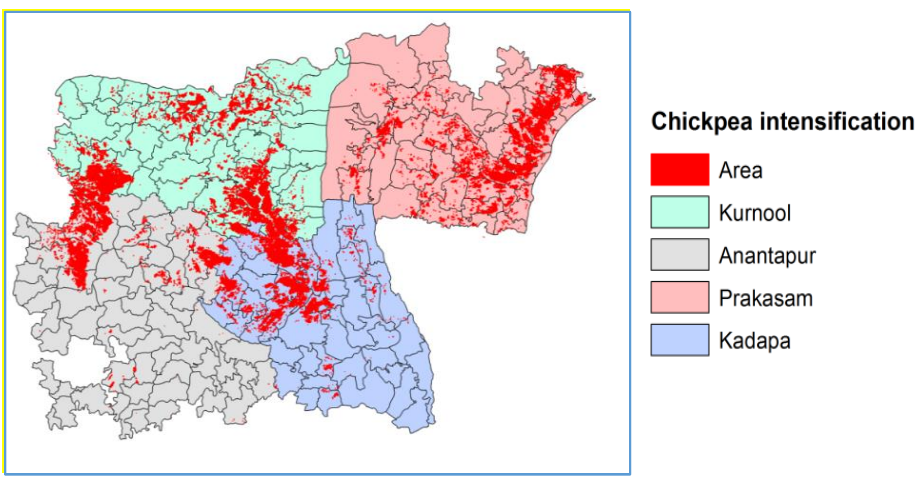
increase in chickpea planted. Overall, four districts together chickpea area of 2012-13 was increased by 232% compared from 2000-01.



a) **2001- 02: 0.18 m ha**



b) 2005-06: 4.18 m ha



c) 2012-13: 5.99 m ha

Fig 3.1 Geospatial analysis chickpea expansion in Andhra Pradesh

Major expansion chickpea areas across Andhra Pradesh derived from MODIS 250m

Districts	Area (ha)		
	MODIS-2000	MODIS-2005	Modis-2012
Anantapur	34777	51304	84493
Cuddapah	30343	69258	117903
Kurnool	68113	140511	196793
Prakasam	35129	128288	159524

3.1.2: Primary and secondary data analysis

As discussed earlier, both primary and secondary data was used for assessing the intensification of agriculture in Andhra Pradesh. The details of primary household survey, sampling framework and its coverage are described below:

Time series data on area, production and yield were obtained from FAOSTAT and relevant Government of India and State of Andhra Pradesh offices. State (sub-national) and district data were collected for examining the spatial distribution of crop production across all of India. More detailed sub-district (mandal) distribution available for the whole state of Andhra Pradesh was used as basis for constructing the primary level sampling frame for the study. The systematic collection of available census village/household data followed to construct the secondary and tertiary sampling frame for the study. For example, it was most useful to be guided by the spatial GIS map (see Fig 3.2) drawn using the mandal level data available.

Out of the 281 chickpea growing mandals in seven districts, mandals with chickpea area more than 3000 ha was initially considered for the study (i.e. nearly 61 mandals). The details on the sampling scheme (specifying the number of sample mandals, sample villages and sample households) are presented in Table 3.1. A sample of nine chickpea growers were randomly selected and interviewed with a structured questionnaire. The study collected information that pertained to the 2011-12 cropping season. Overall, a total of 810 households were covered from 90 villages and 30 mandals in seven districts of Andhra Pradesh representing more than 71% of the chickpea area in the state. The details of final sample mandals selected for study are summarized in Table 3.2.

Fig 3.2 Spatial distribution of area grown to chickpea by mandal in A.P, 2010-12

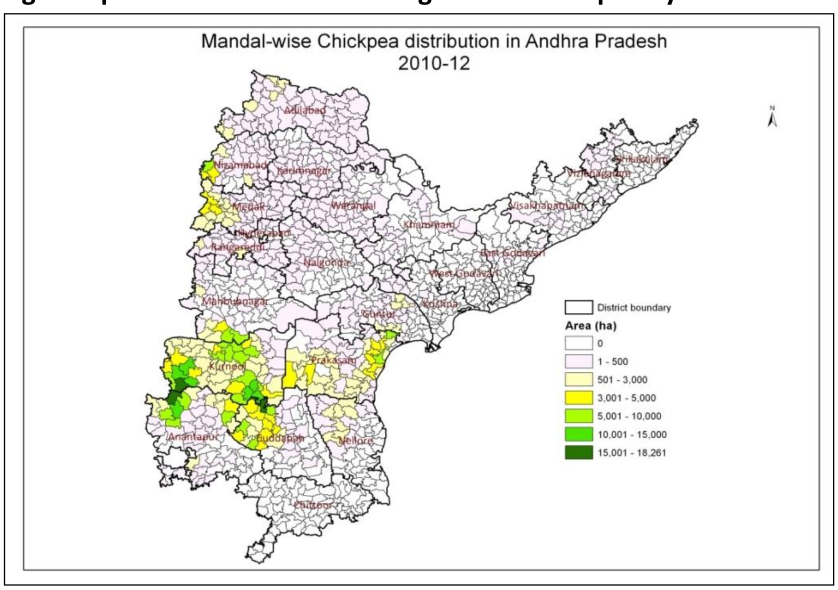


Table 3.1 Primary, secondary and tertiary samples based on the sampling frame constructed

District	No. of mandal growing chickpea	Mandals with chickpea area > 3000 ha	No. of mandals selected for the study	No. of villages covered in the study
Kurnool	53	23	13	39
Prakasam	50	10	4	12
Anantapur	42	7	5	15
Kadapa	30	12	5	15
Medak	45	3	1	3
Nizamabad	30	3	1	3
Mahabubnagar	31	3	1	3
Andhra Pradesh	281	61	30	90

Table 3.2 Final sample of mandals for the chickpea survey

Sl.no	District	Mandal	Sl.no	District	Mandal
1	Anantapur	Kanekal	16	Kurnool	Dornipadu
2	Anantapur	Vidapanakal	17	Kurnool	Sanjamala
3	Anantapur	Tadpatri	18	Kurnool	Uyyalawada
4	Anantapur	Uravakonda	19	Kadapa	Mylavaram
5	Anantapur	Beluguppa	20	Kadapa	Peddamudium
6	Kurnool	Gudur	21	Kadapa	Rajupalem
7	Kurnool	Kurnool	22	Kadapa	Simhadripuram
8	Kurnool	Midthur	23	Kadapa	Veerapunayunipalle
9	Kurnool	Adoni	24	Prakasam	Parchur
10	Kurnool	Alur	25	Prakasam	Janakavarampanguluru
11	Kurnool	Aspari	26	Prakasam	Naguluppalapadu
12	Kurnool	Banaganapalle	27	Prakasam	Ongole
13	Kurnool	Chippagiri	28	Mahabubnagar	Manopad
14	Kurnool	Maddikera (East)	29	Medak	Manoor
15	Kurnool	Koilkuntla	30	Nizamabad	Madnoor

Trends in growth of area and production of chickpea in Andhra Pradesh

During the past two decades, chickpea made rapid strides in both area and production in Andhra Pradesh. Area under chickpea increased at a compound growth rate of 12.40 per cent during the last decade of the twentieth century and by 8.90 per cent during the first decade of the twenty first century (Table 3.3). Production of chickpea increased even faster than area due to an increase in productivity. Production of chickpea increased at the rate of 15.63 per cent per annum during 1991-2000 and by 11.40 per cent during 2001-2010. Among the districts, Prakasam registered a phenomenal growth of 24.75 per cent in area during 1991-2000. It was followed by Kadapa, Anantapur and Kurnool in terms of double digit area growth during 1991-2000. Among the Telangana districts, Adilabad, Mahabubnagar, Medak and Rangareddy registered area growth in single digit. But Karimnagar, Nizamabad, Nalgonda and Guntur districts reported negative growth rates in area in this decade. However, all the five districts in Andhra and two districts in Telangana for which data were available recorded positive growth rates in production.

Table 3.3: District-wise historical trends of chickpea in Andhra Pradesh

District	Area growth rate (%)		Production growth rate (%)	
	1991-2000	2001-2010	1991-2000	2001-2010
Adilabad	8.36	17.06	-	20.44
Nizamabad	-4.46	30.17	-	38.81
Karimnagar	-6.03	0.55	-	-2.06
Medak	5.98	4.99	2.08	4.99
Rangareddy	4.30	3.26	11.59	4.16
Mahabubnagar	7.58	14.50	-	20.30
Nalgonda	-4.39	-	-	-
Warangal	-	2.26	-	-1.64
Guntur	-3.74	8.65	6.45	8.90
Prakasam	24.75	5.76	31.63	5.90
Nellore	-	31.13	-	25.16
Kadapa	21.65	7.47	20.57	6.03
Kurnool	12.17	9.53	5.74	13.61
Anantapur	18.47	8.79	17.46	18.87
Total AP	12.40	8.90	15.63	11.40

But, in the next decade, all the seven districts in Telangana and six districts in Andhra reported positive growth rates in chickpea area. Highest growth rates (double digit and positive) in area were reported by Nellore, Nizamabad, Adilabad and Mahabubnagar districts. The remaining districts reported relatively lower growth rates (positive but single digit) in chickpea area. The maximum growth rate of 38 per cent in production was reported by Nizamabad district and it was followed by Nellore, Adilabad, Mahabubnagar, Anantapur and Kurnool districts. The remaining districts of Guntur, Kadapa, Prakasam, Medak and Rangareddy recorded positive but single digit growth rates.

Such high growth rates in both area and production both at the state level as well as at the district level illustrate the fact that chickpea crop has gained considerable importance in the state because of its relative profitability *vis*-a-*vis* the other competing crops during the post rainy season.

Table 3.4 presented the *quinquennial* average area data from 1966 to 2010 in different districts of Andhra Pradesh state. In 1966-70, Medak, Guntur and Hyderabad (Rangareddy) were the important districts for chickpea cultivation in the state. The area under chickpea in the state declined between 1966-70 and 1981-85. But the lost area was regained between 1981-85 and

1991-95. There was a rapid increase in the area under chickpea in the state between 1991-95 and 2006-10, registering a more than six fold growth in a matter of two decades. Kurnool, Prakasam, Anantapur and Kadapa districts emerged as the important chickpea growing districts in the state. Medak, Nizamabad and Mahabubnagar occupied fifth, sixth and seventh positions in area under chickpea.

Fig 3.3 illustrates the share of chickpea area in the total net sown area of the state between 1996 and 2010. Until early 1990s, the share of chickpea in the state was confined to below 0.010 only. After that it showed a remarkable increase and reached its peak by 2009 (0.060). It was declined slightly after and reached to 0.050. This clearly reveals the intensification of chickpea in the state during the last two decades of period.

Table 3.5: Share of chickpea in net sown area of selected districts in Andhra Pradesh

Triennium	PRM-SI	KUR-SI	KAD-SI	ANT-SI	MED-SI	NIZ-SI	MAH-SI
1990-92	0.005	0.024	0.012	0.007	0.029	0.010	0.002
1999-01	0.056	0.092	0.082	0.035	0.043	0.009	0.006
2007-09	0.156	0.264	0.115	0.082	0.090	0.101	0.030

Fig 3.3 Share of chickpea in net sown area in Andhra Pradesh

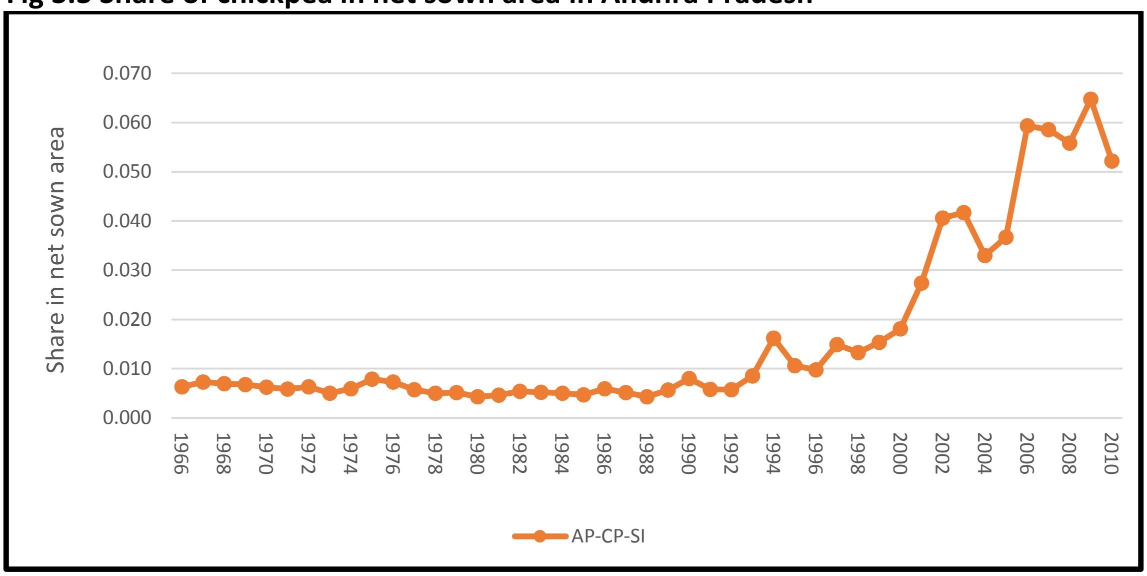
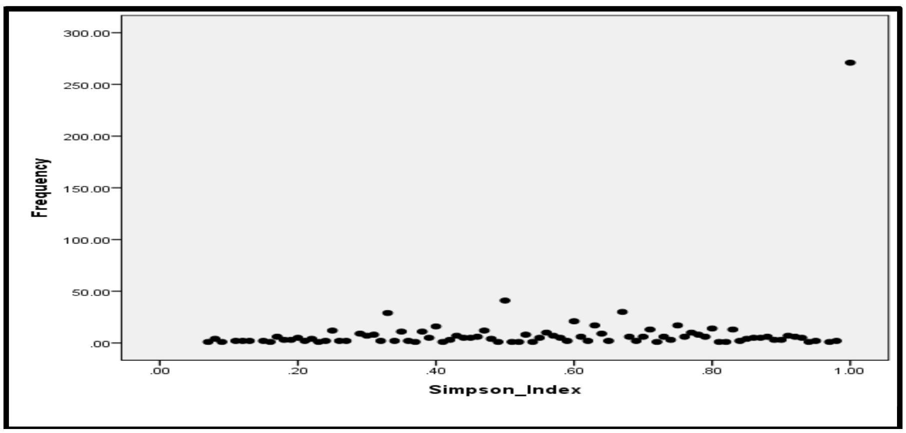


Table 3.4: Area grown to chickpea from 1966 to 2011in districts of Andhra Pradesh ('000 ha)

District	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95	1996-2000	2001-05	2006-10	2009-11
Kurnool	6	5	6	6	15	35	54	128	227	228
Prakasam	1	1	1	1	3	8	18	70	94	84
Anantapur	2	2	2	3	7	16	26	49	84	94
Cuddapah	1	1	1	1	3	7	18	42	71	73
Medak	18	16	15	13	12	15	19	31	38	40
Nizamabad	13	12	9	6	4	4	3	6	24	25
Mahabubnagar	5	4	3	3	2	3	3	11	23	28
Adilabad	5	5	4	3	2	2	3	6	17	11
Guntur	8	5	5	5	3	2	1	8	12	9
Nellore	0	0	0	0	1	0	0	2	11	10
Karimnagar	5	5	3	2	1	1	1	4	3	3
Warangal	2	2	2	1	1	1	1	2	2	2
Krishna	1	1	1	0	0	0	0	0	1	1
Nalgonda	2	2	2	1	0	1	1	0	1	1
East Godavari	1	1	0	0	0	0	0	0	0	0
Visakhapatnam	0	0	0	0	0	0	0	0	0	0
Khammam	1	1	1	1	0	0	0	0	0	0
Srikakulam	0	0	0	0	0	0	0	0	0	0
Chittoor	0	0	0	0	0	0	0	0	0	0
Hyderabad	8	8	7	5	3	0	0	0	0	0
West Godavari	0	0	0	0	0	0	0	0	0	0
Total	80	71	62	52	59	95	147	361	607	609

In order to understand the relative importance of chickpea in the cropping pattern of the selected chickpea growing districts, triennial averages of chickpea area to the total net sown area are worked out and are presented for three different time periods, 1990-92, 1999-2001 and 2007-09 in Table 3.5. It can be seen that the share of chickpea in total sown area has gone up 31 times in Prakasam district during the 17 years period, 1990-92 and 2007-09. The same increased by 11 times in case of Kurnool district, nearly by 10 times in Kadapa district and by nearly 12 times in case of Anantapur district. In the same way, the share of chickpea in total sown area went up 15 times in Mahabubnagar district, by 10 times in Nizamabad district and by three times in Medak district. Thus, in all the seven major chickpea growing districts of Andhra Pradesh, the share of chickpea increased several fold, although the degree of increase differed in each case. Prakasam district recorded a phenomenal growth of 31 times, while it was modest at three times in case of Medak district at the other extreme.

Fig. 3.4: Intensification of chickpea among sample farmers (n=810)



In case of primary sample household survey farmers also, the area allocated to chickpea by them showed an increase. The Simpson index computed clearly indicated an increased allocation of land by the farmers to chickpea (Fig. 3.4). The scatter diagram showed that the intensification ranged between 0.80 and 1.00 for different sample farmers.

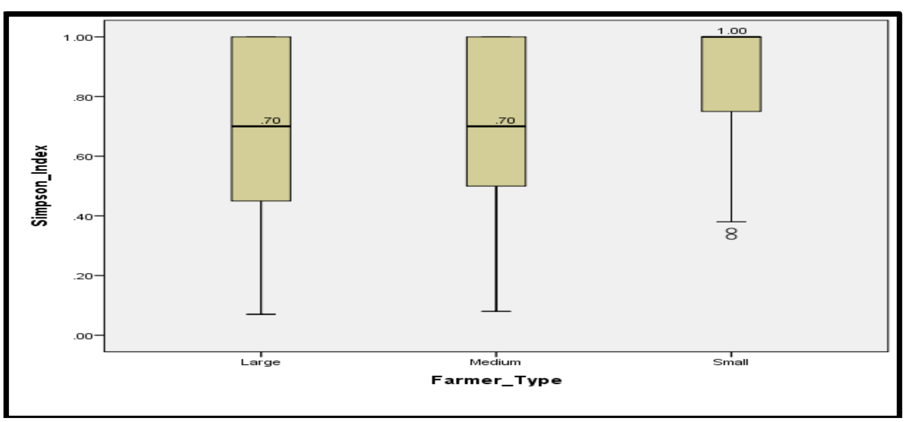


Fig. 3.5: Intensification of chickpea by category of farmers

The measure of intensification indicated that it was highest in case of small farmers. For the large and medium categories of farmers, the measure of intensification averaged 0.70, while it touched 1.00 in case of the small farmers, indicating complete specialization in chickpea (Fig 3.5).

3.1.3: Assessing chickpea sustainability using crop simulation models

The geospatial and secondary data together revealed that the cropped area under chickpea has increased nearly ten folds and intensified in the state during last two decades period (1990-2010). At this stage, it is worthwhile to assess the sustainability of chickpea cultivation in the state. The present study used well calibrated and evaluated CROPGRO-chickpea model using JG 11 cultivar (Singh et al. 2014a) to document long-term indicators for sustainability in Fallow-chickpea vs Fallow-maize/sorghum systems in study locations.

Using crop-simulation model, different efficiency parameters were computed for the three major cropping systems (fallow-chickpea, fallow-fallow and fallow-maize/sorghum) using improved management practices (*under ideal situations*)and they are reported in Tables 3.6(a), 3.6(b), 3.6(c) and 3.6(d) respectively for the districts of Prakasam, Kurnool, Kadapa and Anantapur. The improved package of practices include early sowing, improved fertilizer application + FYM, providing supplemental irrigation at 60 DAS and maintaining of optimum plant population.

We used the long-term average values of the sustainability indicators for an alternative management system such as fallow-sorghum/maize relative to the values obtained with reference system (fallow-chickpea) using sustainability polygons. In case of all the four districts, fallow-chickpea gave the best yields (in terms of chickpea equivalent yield) when compared with the fallow-maize/sorghum system. It also scored better in terms of water-use-efficiency and nitrogen-use-efficiency. It outperformed the other two systems in terms of other parameters like nitrogen fixed during the crop season, nitrogen leached during the crop season, inorganic nitrogen at maturity and crop nitrogen. Thus, fallow-chickpea system stood out as the best system in the four study districts. No wonder, chickpea was able to perform best both in terms of productivity as well as sustainability indicators. These positive factors might have contributed to the crop intensification in the state. It is, indeed, a case of sustainable intensification.

The fallow-chickpea system reported nearly 92 per cent of higher yield than the chickpea equivalent yield given by the fallow-maize system in Prakasam district. Besides reporting higher yield, it also scored better in case of other indicators of sustainability (Table 3.6a). The water-use-efficiency was more than twice that in case of fallow-maize system. Being a leguminous crop, chickpea reported nitrogen-use-efficiency which was higher than that of the competing system by hundreds of times. Same was the case with the nitrogen availability at crop maturity.

Table 3.6a: Sustainability of different cropping systems in Prakasam district

Parameter	Fallow-Chickpea	Fallow-Fallow	Fallow-Maize (Equivalent yield to CP)
Yield	3662	0.0	1912
WUE	7.4	0.0	3.5
NUE	183.1	0.0	0.2
NFXM	136.4	0.0	0.0
NLCM	46.9	1.2	3.8
NIAM	85.5	3.1	1.2
CNAM	168.5	0.0	1.4
OCTAM	133	1.2	1.3

Yield: Kg/ha; WUE: water use efficiency (Kg/ha mm); NUE: nitrogen use efficiency (Kg/Kg); NFXM: Nitrogen fixed during crop season (kg/ha); NLCM: nitrogen leached during crop season (kg/ha); NIAM: inorganic nitrogen at maturity (Kg/ha); CNAM: crop nitrogen uptake (Kg/ha) and OCTAM: Total organic carbon at maturity stage (tons/ha)

Table 3.6b: Sustainability of different cropping systems in Kurnool district

Parameter	Fallow-Chickpea	Fallow-Fallow	Fallow-Sorghum (Equivalent yield to CP)
Yield	2610	0.0	712
WUE	5.9	0.0	5.9
NUE	130.5	0.0	8.9
NFXM	91.7	0.0	0.0
NLCM	7.7	5.1	1.1
NIAM	111.1	33.7	20.3
CNAM	127.9	0.0	6.8
OCTAM	134	11.6	12.3

The yield advantage with fallow-chickpea is much higher when compared with the chickpea equivalent yield of fallow-sorghum system in Kurnool district (Table 3.6b). The fallow-chickpea system gave 267 percent higher yield than the fallow-sorghum system. The water-use-efficiency of both these systems were at par. But, fallow-chickpea system scored far better with respect to nitrogen-use-efficiency, total nitrogen level at crop maturity and nitrogen-phosphorous ratio.

Table 3.6c: Sustainability of different cropping systems in Kadapa district

Parameter	Fallow-Chickpea	Fallow-Fallow	Fallow-Sorghum (Equivalent yield to CP)
Yield	2961	0.0	774
WUE	6.3	0.0	4.9
NUE	148.1	0.0	9.7
NFXM	79.3	0.0	0.0
NLCM	10.1	1.1	2.5
NIAM	113.8	6.75	30.7

CNAM	144.3	0.0	7.3
OCTAM	134.1	11.6	12.3

Just as in case of Kurnool district, fallow-chickpea system in Kadapa district out yielded fallow-sorghum system (equivalent yield to chickpea) by 283 per cent (Table 3.6c). The water-use-efficiency was also higher in fallow-chickpea system, unlike the case in Kurnool district. Being a leguminous crop, chickpea recorded far higher levels of nitrogen-use-efficiency and total nitrogen availability at the harvest. Similarly, the nitrogen fixation during the crop season and organic carbon accumulation in the soil was far better in case of fallow-chickpea system than fallow-sorghum system.

Table 3.6d: Sustainability of different cropping systems in Anantapur district

Parameter	Fallow-Chickpea	Fallow-Fallow	Fallow-Sorghum (Equivalent yield to CP)
Yield	1928	0.0	806
WUE	4.3	0.0	3.9
NUE	96.4	0.0	10.1
NFXM	66.2	0.0	0.0
NLCM	8.6	1.0	0.8
NIAM	62.3	6.3	11.4
CNAM	111.4	0.0	8.9
OCTAM	118.3	10.2	10.9

The results of analysis of productivity and sustainability indicators for Anantapur sample were also on the same lines of Kadapa district (Table 3.6d). The productivity of fallow-chickpea system was 139 per cent higher than that of fallow-sorghum system when its equivalent yield to chickpea was considered. The water-use-efficiency was also higher with the fallow-chickpea system. Naturally, the leguminous crop of chickpea recorded far higher nitrogen-use-efficiency as well as nitrogen level at the crop maturity.

In Figure 3.6, chickpea yields (average of 30 years) were compared with the historical sorghum/maize yields. In Prakasam district, chickpea yields were about twice those of maize. In the other three districts, chickpea yields were more than twice that of sorghum yield in the post-rainy season.

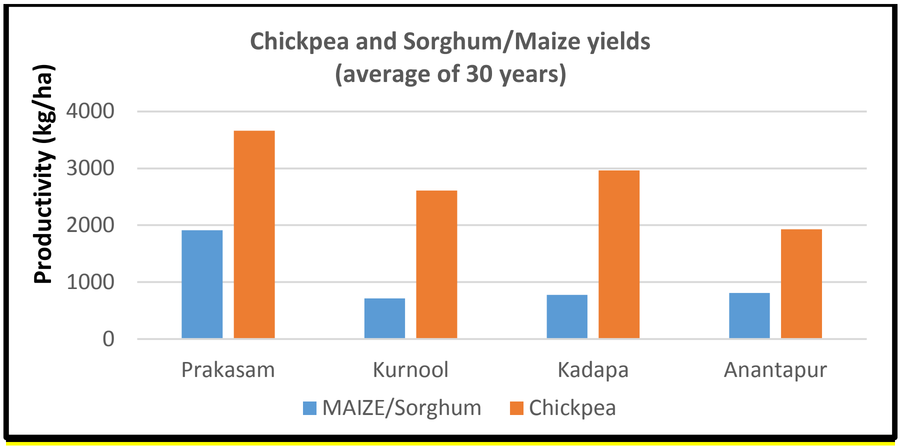


Fig. 3.6: Mean equivalent yields of chickpea and competing crops

The model results indicate that the chickpea yields are much higher with the improved practices than with the farmers practice in all the four major chickpea growing districts of Prakasam, Kurnool, Kadapa and Anantapur (Table 3.7). The other efficiency parameters like Water-Use-Efficiency (WUE), Nitrogen-Use-Efficiency (NUE), Nitrogen Fixed during the Crop Season (NFXM) and Organic Carbon at Maturity (OCTAM) were also higher when improved practices are followed. The Nitrogen leached during Crop Season (NLCM) and Inorganic Nitrogen at Maturity (NIAM) was lower with the improved practices when compared with those under farmers' practice. The Total Crop Nitrogen (CNAM) was higher with the improved practices than with farmers' practice in all the districts except Kurnool.

Table 3.7: Sustainability of chickpea cultivation in study districts

Parameters	Prakasam		Kurnool		Kadapa		Anantapur	
	FP	IMP	FP	IMP	FP	IMP	FP	IMP
Yield	2666	3662	2582	2609	2045	2961	1133	1927
WUE	5.94	7.42	5.86	5.92	5.01	6.28	2.95	4.28
NUE	27.21	183.12	40.36	130.50	52.44	148.05	28.33	96.38
NFXM	47.17	136.37	60.50	91.70	40.80	79.30	31.33	66.17
NLCM	51.07	46.87	9.07	7.73	13.70	10.13	11.77	8.67
NIAM	180.70	85.47	144.20	111.13	185.13	113.80	130.97	62.27
CNAM	133.93	168.50	129.93	127.93	111.23	144.30	82.07	111.43
OCTAM	127.14	132.70	128.15	134.25	127.99	134.11	112.04	118.27

FP: Farmers practice; IMP: Improved management practice

Farmers were found to be using more nitrogen per hectare (39 to 98 kg per ha) and higher seed rates (103 to 123 kg per ha). They were also maintaining more plant population per sq. meter (40 to 45). They were sowing chickpea between September and November (Table 3.8).

Table 3.8: Farmers' practices in chickpea cultivation across study districts

Parameter	Anantapur	Kadapa	Kurnool	Prakasam
FYM (ton/ha)	-	-	-	-
Total 'N' per ha	40	39	64	98
Seed rate per ha	106	103	105	123
Plant Population per sq m	40	40	40	45
Sowing window	9/15 to 10/15	10/5 to 11/5	9/15 to 10/15	11/5 to 11/25
Irrigation	-	-	-	-

Source: Field survey

Table 3.9: Improved chickpea management practices across study districts

Parameter	Anantapur	Kadapa	Kurnool	Prakasam
FYM (ton/ha)	5	5	5	5
Total 'N' per ha	20	20	20	20
Seed rate per ha	75-80	75-80	75-80	75-80
Plant Population per Sq m	30-35	30-35	30-35	30-35
Sowing window	9/16 to 9/30	10/1 to 10/15	9/16 to 9/30	10/15 to 11/1
Irrigation (mm)	50	50	50	50

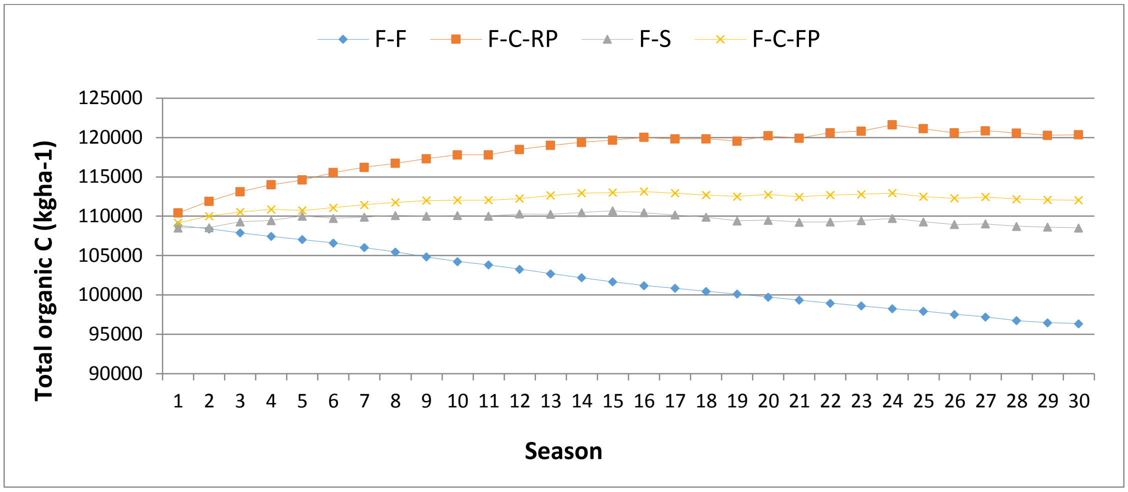
Source: Improved practices, ANGRAU

Improved practices were found to be best as they emphasized balanced fertilizer application along with organic fertilizers which are environmentally sustainable practices (Table 3.9). The seed rates were lower than in case of farmers' practices by about 30 to 40 per cent. It involves considerable saving in seed cost and wider spacing. Consequently, the plant population per square meter was lower by 25 to 30 per cent in case of the improved practices.

3.1.4 Simulated soil carbon dynamics of chickpea system over last thirty seasons

The carbon sequestration was better with improved practices of fallow-chickpea (F-C-RP) when compared with the farmers' practice of fallow-chickpea (F-C-FP) (Fig. 3.7). Even fallow-sorghum (F-S) system resulted in better carbon sequestration than fallow-fallow (F-F) system. The results from Anantapur model revealed that the improved practices of fallow-chickpea system yielded the highest carbon sequestration than fallow-sorghum and fallow-chickpea under farmers' practices. All these three systems gave better results than fallow-fallow system (Fig 3.7).

Fig. 3.7: Carbon sequestration across cropping systems in Anantapur



F-F: Fallow –Fallow; F-C-RP: Fallow-Chickpea (Improved practice); F-S: Fallow-Sorghum; F-C-FP: Fallow-Chickpea (farmer practice)

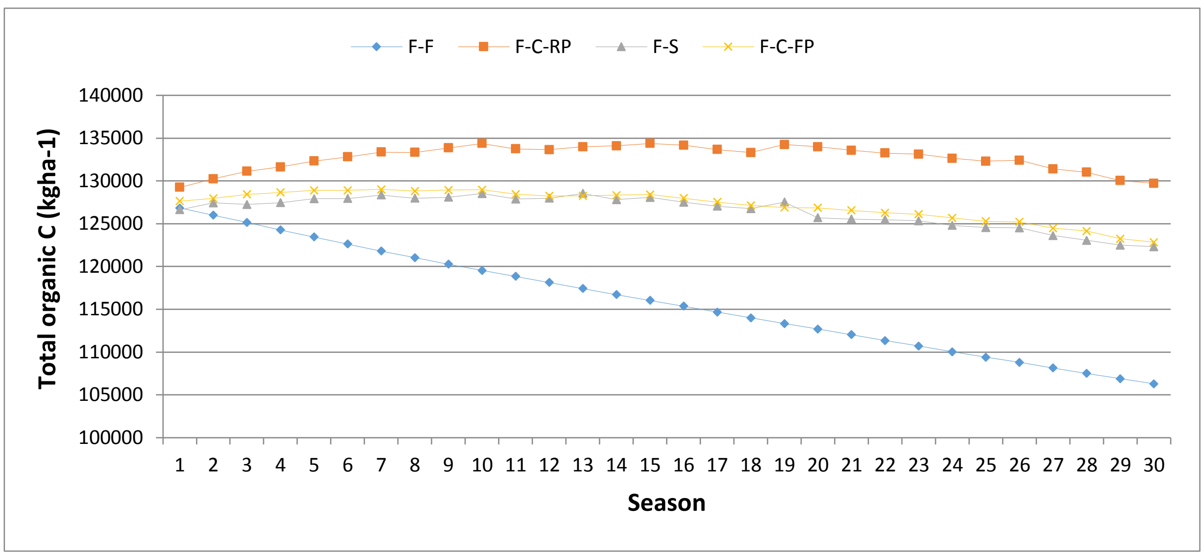
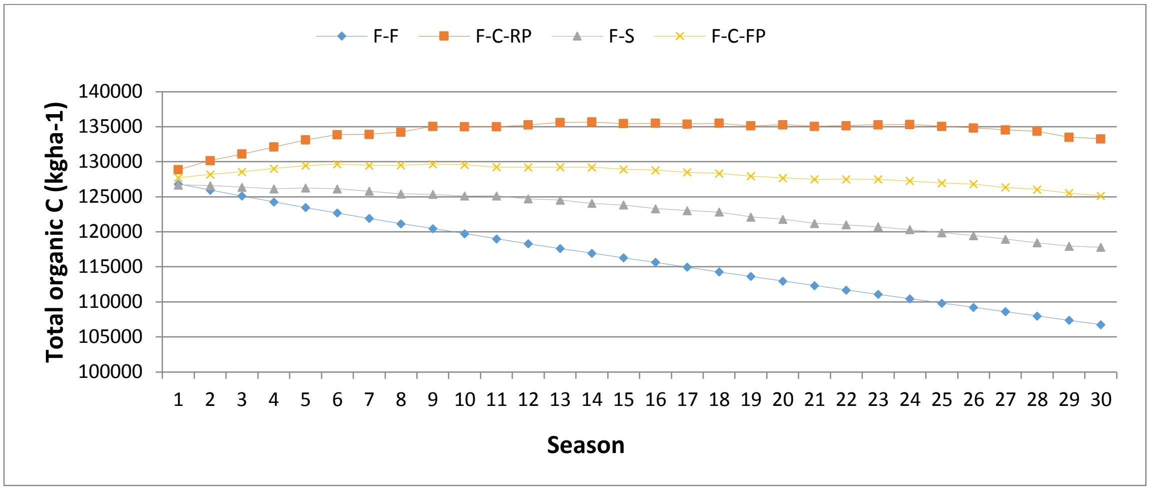


Fig. 3.8: Carbon sequestration across cropping systems in Prakasam

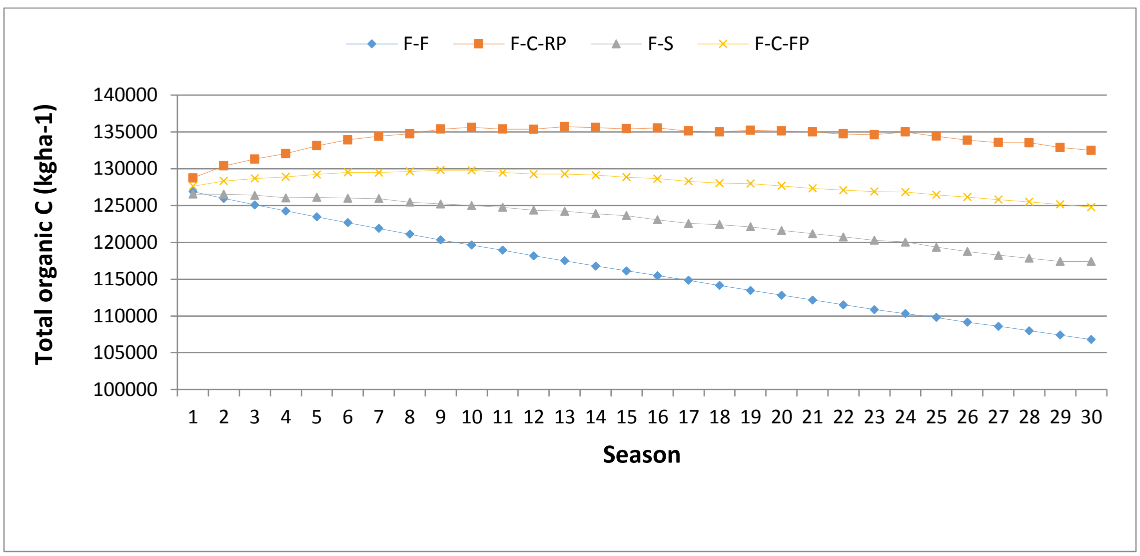
The model for Prakasam district also gave similar results as in case of Anantapur district (Fig. 3.8). The fallow-chickpea system with improved practices gave the best carbon sequestration among the four systems under comparison. The fallow-sorghum system and fallow-chickpea system with farmers' practices gave almost similar pattern of carbon sequestration. The fallow-fallow system was the least efficient of all in carbon sequestration.

Fig. 3.9: Carbon sequestration across cropping systems in Kurnool



The model results for Kurnool district followed the same ranking as in Anantapur district (Fig. 3.9). The fallow-chickpea was the best one, followed by fallow-sorghum and fallow-chickpea with farmers' practices. Fallow-fallow system was the least efficient of all the four in carbon sequestration.

Fig. 3.10: Carbon sequestration across cropping systems in Kadapa district



The results of the model for Kadapa district were also similar to those of Anantapur and Kurnool district (Fig. 3.10). As in case of other districts, fallow-chickpea with improved practices was proved to be the best and it was followed by fallow-sorghum and fallow-chickpea with farmers' practices. The fallow-fallow system was least effective in carbon sequestration.

3.1.5: Assessment of chickpea economic sustainability

The economic sustainability was assessed based on primary data collected during the household surveys. The returns over the variable cost per ha for fallow-chickpea estimated were higher by 21 per cent than the fallow-maize system (Table 3.10). But, fallow-maize supplied approximately 6 times higher chickpea equivalent fodder per acre than the fallow-chickpea system. Both the systems had similar shares of returns over variable costs in the total household expenditures, indicating comparable income security of crops. While fallow-maize system used 2.7 times higher nitrogen relative to phosphorous, but chickpea used less than one half of the nitrogen than that of phosphorous. Both the systems were at par with respect to cereal consumption as a share of food production.

Table 3.10: Economic indicators of sustainability in Prakasam district

Parameter	Fallow-Chickpea	Fallow-Maize (Equivalent yield to CP)
ROVC ($ per ha)	908.8	749.1
Chickpea equivalent fodder availability per acre (Qtl)	3.0	16.9
Share of ROVC in total expenditure (%)	0.32	0.32
N/P ratio	0.46	2.7
Share of cereal consumption in total food production (%)	90.6	89.0

Table 3.11: Economic indicators of sustainability in Kurnool district

Parameter	Fallow-Chickpea	Fallow-Sorghum (Equivalent yield to CP)
ROVC ($ per ha)	693.2	693.6
Chickpea equivalent fodder availability per acre (Qtl)	3.0	49.8
Share of ROVC in total expenditure (%)	0.27	0.30
N/P ratio	0.55	1.1
Share of cereal consumption in total food production (%)	90.7	91.3

The returns over variable costs were also comparable for both these systems in Kurnool district (Table 3.11). Chickpea equivalent fodder availability per acre was significantly higher for fallow-sorghum system than fallow-chickpea. Similarly, fallow-sorghum system did record a marginally higher share of returns over variable costs as a proportion of total household expenditure. But, the N/P ratio was estimated much higher in case of fallow-sorghum system than fallow-chickpea. Both the systems indicated similar with respect to share of cereal consumption in total food production. Thus, fallow-chickpea system stood out both with respect to productivity as well as efficient utilization of resources.

Table 3.12: Economic indicators of sustainability in Kadapa district

Parameter	Fallow-Chickpea	Fallow-Sorghum (Equivalent yield to CP)
ROVC ($ per ha)	533.3	214.8
Chickpea equivalent fodder availability per acre (Qtl)	4.0	44.6
Share of ROVC in total expenditure (%)	0.22	0.08
N/P ratio	0.55	1.27
Share of cereal consumption in total food production (%)	91.0	94.1

Fallow-chickpea system gave much higher returns over variable cost than fallow-sorghum system in Kadapa district (Table 3.12). The share of returns over variable cost in total household expenditure was also much higher in case of fallow-chickpea system than the competing fallow-sorghum system. This clearly visualizes the high income security from chickpea than sorghum crop in the district. The fallow-sorghum system was marginally better with respect to two indicators, chickpea equivalent fodder availability per acre and share of cereal consumption in total food production. Thus, overall, fallow-chickpea fared much better with respect to both productivity and other indicators of sustainability.

Table 3.13: Economic indicators of sustainability in Anantapur district

Parameter	Fallow-Chickpea	Fallow-Sorghum (Equivalent yield to CP)
ROVC ($ per ha)	462.3	180.7
Chickpea equivalent fodder availability per acre (Qtl)	4.0	59.0
Share of ROVC in total expenditure (%)	0.19	0.08
N/P ratio	0.46	0.76
Share of cereal consumption in total food production (%)	89.2	88.0

Even the returns over variable cost per hectare were higher for fallow-chickpea system by 156 per cent than competing fallow-sorghum system in Anantapur district (Table 3.13). But the chickpea equivalent fodder availability per acre was decisively in favor of fallow-sorghum system. Fallow-chickpea system also reported a higher ratio of returns over variable cost in total expenditure than the competing fallow-sorghum system. The nitrogen-phosphorous ratio was more balanced in its case. It even reported a slightly higher share of cereal consumption in total food production than fallow-sorghum system. The results clearly indicates the household income chickpea security of chickpea farmers than sorghum in the study district.

3.1.6: Resource-use-efficiency and returns to scale

To know about the resource-use-efficiency, production function was fitted to the farmers who raised JG-11. The Cobb-Douglas production function fitted which explained about 84 per cent of the variation in gross income from the farm (Table 3.14). Labour cost and machinery cost influenced gross income positively and significantly. A one per cent increase in labour cost increases the gross income by 0.51 per cent. Similarly, a one per cent increase in machinery cost leads to an increase of 0.31 per cent in gross income. Area of the farm also influenced the gross income positively and significantly. Fertilizer cost also influenced gross income positively, but it missed significance at 5 per cent level of probability. Bullock cost, seed cost, manure cost and pesticide cost did not have any significant influence on gross income, although they have weak negative effects. Input intensification may be feasible with labour, machinery, area and fertilizer, provided the marginal value products exceed their acquisition costs. The returns to scale add up to 1.22, indicating increasing returns to scale in case of chickpea cultivation with JG-11 variety.

Table 3.14: Resource-use efficiency in chickpea (JG 11) cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.148	1.676		2.474	.014
Area	.532*	.207	.415	2.572	.011
Labour cost	.514*	.131	.354	3.913	.000
Bullock cost	-.015	.011	-.048	-1.360	.175
Machinery cost	.310*	.092	.265	3.375	.001
Seed cost	-.250	.157	-.198	-1.594	.113
Manure cost	-.008	.007	-.038	-1.187	.237
Fertilizer cost	.169***	.092	.141	1.832	.069
Pesticide cost	-.036	.058	-.031	-.617	.538
n = 201, R^2 = 0.84, F static = 124.93*			*: sig at 1%; **: sig at 5%; ***: sig at 10%		

The Cobb-Douglas production function estimated for the Kabuli varieties, Vihar and KAK-2 also gave a good fit with highly significant regression equation and explaining 97 per cent variation in gross income (Table 3.15). Area of the farm, machinery cost and seed cost had positive and significant influence on gross income. It may be possible to increase the gross income by increasing the area, machinery cost and seed cost. Manure cost and fertilizer cost did have negative and significant effect on the gross income, suggesting that the gross income can be increased by reducing their use. Labour cost and pesticide cost did not have any significant effect on the gross income. The returns to scale added up to 1.01, indicating constant returns to scale in case of the Kabuli varieties.

Table 3.15: Resource-use efficiency in chickpea (Vihar/KAK2) cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	6.00	1.28		4.70	0.00
Area	0.49*	0.14	0.47	3.36	0.00
Labour cost	0.00	0.13	0.00	0.03	0.98
Bullock cost	0.01***	0.01	0.07	1.73	0.09
Machinery cost	0.28*	0.09	0.26	3.04	0.00

Seed cost	0.37*	0.12	0.35	2.98	0.00
Manure cost	-0.02**	0.01	-0.05	-2.05	0.04
Fertilizer cost	-0.10**	0.05	-0.11	-2.00	0.05
Pesticide cost	-0.02	0.04	-0.02	-0.45	0.66
n = 65, R^2 = 0.97, F static = 202.2*		*: sig at 1%; **: sig at 5%; *** sig at 10%			

Table 3.16: Resource-use efficiency in sorghum cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	5.94	1.91		3.11	0.00
Area	0.58**	0.23	0.44	2.50	0.02
Labour cost	0.28	0.20	0.19	1.44	0.16
Bullock cost	-0.02	0.03	-0.04	-0.47	0.64
Machinery cost	0.08	0.12	0.08	0.68	0.50
Seed cost	0.05	0.11	0.05	0.45	0.65
Manure cost	-0.01	0.02	-0.04	-0.44	0.66
Fertilizer cost	0.06	0.06	0.11	1.00	0.32
Pesticide cost	0.00	0.02	-0.01	-0.16	0.87
Irrigation	0.07*	0.02	0.32	3.37	0.00
n = 52, R^2 = 0.81, F static = 19.85*			*: sig at 1%; **: sig at 5%; *** sig at 10%		

The Cobb-Douglas production function fitted for sorghum gave a weak regression equation, explaining only 81 per cent of the variation in gross income (Table 3.16). Area of the farm and irrigation cost had positive and significant effect on gross income. None of the other variables did have any significant influence on gross income. The returns to scale were estimated at 1.1.

Table 3.17: Returns to scale of chickpea and competing crop sorghum

Crop	Returns to scale
Chickpea (JG-11)	1.22
Chickpea (Vihar/KAK2)	1.02
Sorghum	1.10

In general, the returns to scale ranged between constant to increasing returns (Table 3.17). It was constant returns from Kabuli varieties, while there were increasing returns to scale in case of JG-11 variety. The returns to scale for sorghum ranged in between them.

Estimating inefficiencies in chickpea cultivation

The results of stochastic production function suggest that the area under the chickpea crop, expenditures on labour, machine labour and fertilizers impacted the production of the farm positively and significantly (Table 3.18). However, the expenditure on manures influenced the production negatively. The intercept values for Prakasam, Kurnool and Kadapa were negative and significant, suggesting that the production at zero levels of factors are lower for these districts when compared with the intercept value for Anantapur. It may be perhaps due to the higher response levels to the applied factors in these three districts. In the same way, the intercept value of production was lower in case of uneducated farmers when compared with that for educated group. Household head age, crop diversification index (CDI) and household network index (NWI) did not show any influence on chickpea production.

Table 3.18: Stochastic Frontier Production function for estimating inefficiencies

Variable	Coefficient	Standard-error	t-ratio
beta 0	5.23	1.44	3.63
Area	0.54*	0.17	3.17
Labour cost	0.34*	0.15	2.29
Bullock cost	0.01	0.01	1.51
Machinery Cost	0.22*	0.09	2.49
Seed cost	-0.07	0.12	-0.55
Manure cost	-0.02*	0.01	-3.34
Fertilizer cost	0.15**	0.09	1.71
Pesticide cost	-0.01	0.06	-0.10
delta 0	1.18	0.32	3.68
Age	0.00	0.00	0.96
Prakasam	-1.53*	0.39	-3.95
Kurnool	-0.41*	0.13	-3.12
Kadapa	-0.35*	0.15	-2.38
Un-educated	-0.27*	0.13	-2.15
CDI	0.11	0.27	0.40
NWI	-0.56	0.53	-1.05
Sigma-square	0.16	0.03	5.34
gamma	0.97	0.03	28.99
Log likelihood ratio 0.67	*: Sign at 1% level; **: Sign at 5% level		

Table 3.19: Average technical efficiency by farmer category

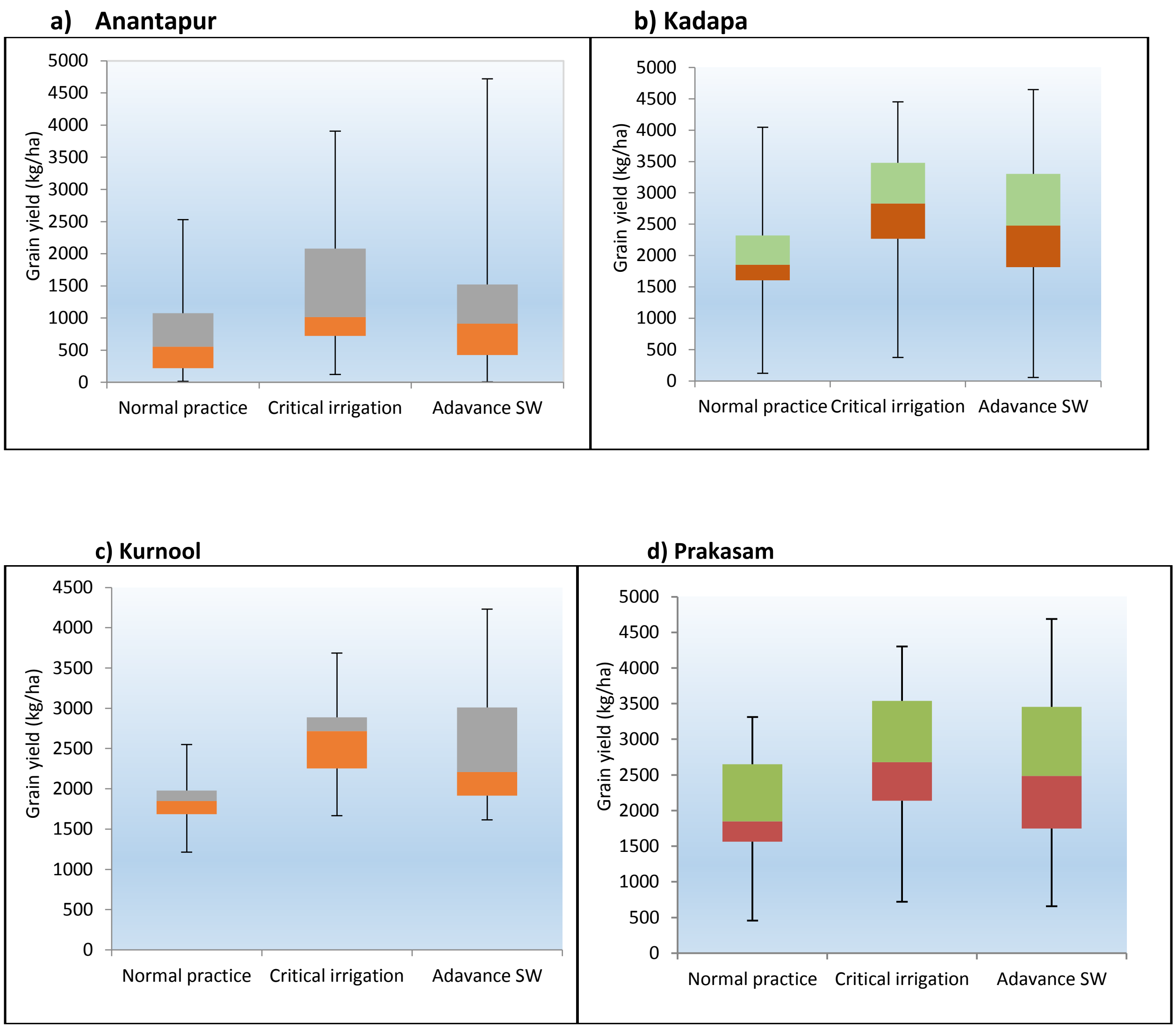
Farmer type	Anantapur	Kadapa	Kurnool	Prakasam	Average
Large	0.45	0.61	0.57	0.78	0.58
Medium	0.35	0.43	0.53	0.86	0.55
Small	0.45	0.45	0.64	0.93	0.59
Average	0.42	0.53	0.57	0.83	0.57

The average technical efficiencies of different categories of chickpea growers using stochastic frontier production function are summarized in Table 3.19 for different districts and for the sample as a whole. The average technical efficiencies were lowest in case of Anantapur district, while they were the highest in case of Prakasam district. The average technical efficiencies of farmers in Kurnool and Kadapa districts lied in between them. Large farmers attained the highest levels of technical efficiency in Anantapur and Kadapa districts relative to small and medium groups. But, in Kurnool and Prakasam districts, small farmers attained better levels of technical efficiency than the large and medium groups of farmers. The technical efficiency levels attained by the combined sample was only 0.57. Relative to the medium size group farmers, both the small and large groups of farmers attained higher levels of technical efficiency in the combined sample.

3.1.7: Possible agronomical interventions for enhancing chickpea yields

In all the four districts, chickpea responded well to critical irrigation by registering higher yield levels (Figs. 3.11a to 3.11d). In the same way, advancing the sowing date also resulted in higher yield levels. Farmers would get higher yields wherever they can advance the sowing date and wherever they can provide critical irrigation. These two are potential agronomical interventions for enhancing chickpea yields across study districts.

Fig. 3.11: Response of chickpea yields to better agronomic practices



Case 2: Rainy season sorghum in Maharashtra

Rainy sorghum crop was considered as a second case in the present study. Sorghum was one of the dominant kharif (rainy season) crop in the Maharashtra state until early 1990s. But the crop has last lost significant cropped area under sorghum between 1990 and 2011. However, the extent of adoption improved cultivars was in its peak up to > 95 per cent (mostly hybrids). Due to lack of market demand for the crop and changes in food consumption pattern in the state, the importance for rainy sorghum has declined. It was replaced by other remunerative crops like soybean, cotton and maize etc. It would be one of an interesting case to study agricultural intensification and sustainability in Maharashtra state.

3.2.1 Primary and secondary data sources analysis

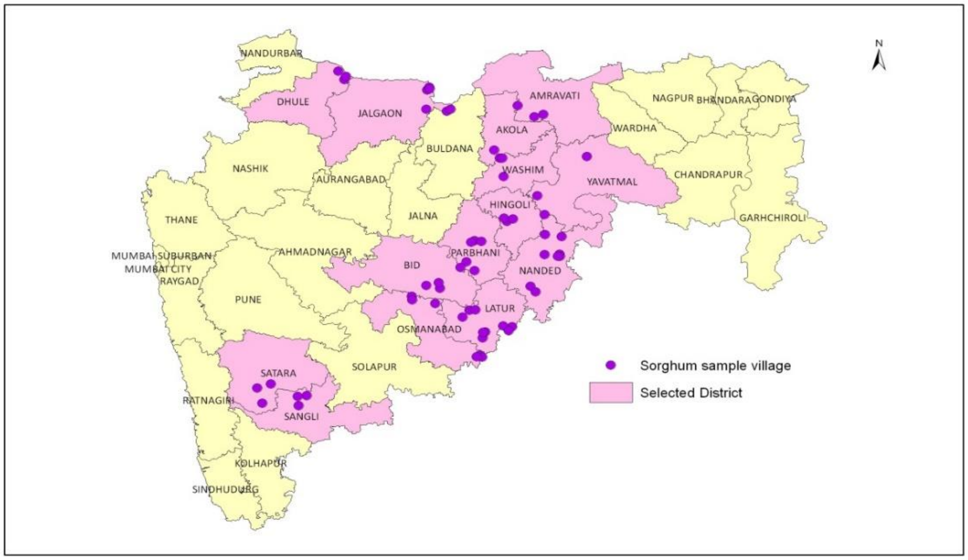
As explained earlier, both primary and secondary data was used for assessing the agricultural intensification and sustainability in the study. The details of primary household survey, sampling framework and its coverage were furnished below:

The twenty tehsils selected for the study are listed in Table 3.20. Three tehsils each were selected from Nanded and Latur districts which have the highest area under rainy season sorghum. Jalgaon, Parbhani and Osmanabad, with medium concentration of rainy season sorghum area are represented by two tehsils each. The remaining eight districts with relatively less area under rainy season sorghum are represented in the sample by one tehsils each. The sample districts, tehsils and villages selected for the survey are shown in Fig. 3.12.

Table 3.20: Tehsils selected for the sample from different districts

S.no	District	Tehsils	S.no	District	Tehsils
1	Akola	Patur	11	Nanded	Bhokar
2	Amravati	Daryapur	12	Nanded	Hadgaon
3	Beed	Kaij	13	Nanded	Mukhed
4	Dhule	Shirpur	14	Parbhani	Sonpeth
5	Hingoli	Aundha	15	Parbhani	Parbhani
6	Jalgaon	Muktainagar	16	Sangali	Khanapur
7	Jalgaon	Rawer	17	Satara	Karad
8	Latur	Devani	18	Osmanabad	Umerga
9	Latur	Latur	19	Osmanabad	Kalamb
10	Latur	Nilanga	20	Yavatmal	Pusad

Fig 3.12: Selection of districts and villages for primary survey in Maharashtra



Three villages from each selected tehsil and thus a total of sixty villages were chosen for the primary survey. Six rainy season sorghum growers were identified randomly from each selected village. So, a total of 360 farmers were interviewed from 60 villages and 20 tehsils in the state[2].

The declining share of rainy season sorghum in the net sown area is clearly illustrated in Fig. 3.13 and Table 3.21. In Maharashtra, the share of rainy season sorghum was around 14 per cent in 1966, which increased to 18 per cent by 1977 (Fig. 3.13). But after that, there was a gradual decline in its share of 5 per cent in 2008, which slightly recovered to 6 per cent in 2010. In all the important rainy season growing districts, the same tend was seen (Table 3.21). Rainy season sorghum in Latur district had 39 per cent share during the triennium 1990-92 which dropped to 24 per cent in the triennium 2007-09. In the corresponding period, the share of rainy season sorghum dropped from 34 per cent to 13 per cent in Akola district; from 33 per cent to 19 per cent in Nanded district; from 25 to 7 per cent in Amravati district; from 26 to 9 per cent in Yavatmal; from 26 per cent to 14 per cent in Parbhani district and from 26 per cent to 10 per cent in Jalgaon. In the same way, rainy season sorghum lost its share in the net sown area of other districts like Sangli, Osmanabad, Satara, Dhule and Beed.

[2] *For more details refer Kumara Charyulu D. et al. 2015a*

Fig. 3.13: Share of rainy season sorghum in net sown area of Maharashtra

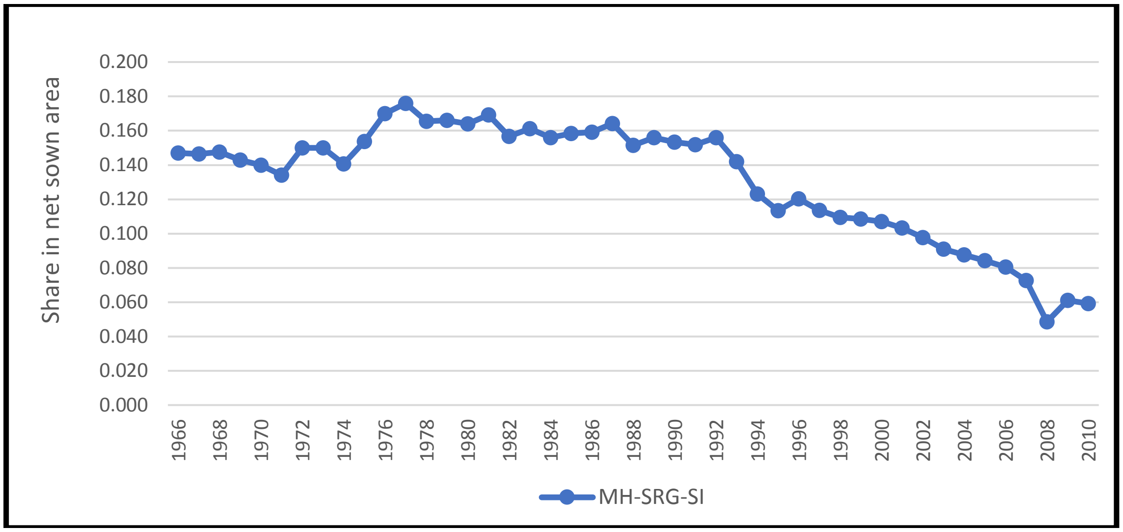


Table 3.21: Shares of rainy season sorghum in net sown areaof selected districts

Triennnium	Akola	Amravati	Beed	Dhule	Hingoli	Jalgaon	Latur
1990-92	0.336	0.254	0.131	0.138	-	0.257	0.392
1999-01	0.194	0.152	0.113	0.095	0.233	0.175	0.315
2007-09	0.131	0.074	0.048	0.057	0.133	0.096	0.242

Table 3.21 ***Contd.,***

Triennnium	Nanded	Parbhani	Sangli	Satara	Osmanabad	Yavatmal
1990-92	0.328	0.255	0.229	0.153	0.200	0.261
1999-01	0.266	0.226	0.206	0.119	0.145	0.182
2007-09	0.191	0.137	0.130	0.087	0.141	0.090

Fig. 3.14: Intensification of sorghum among sample farmers (n=360)

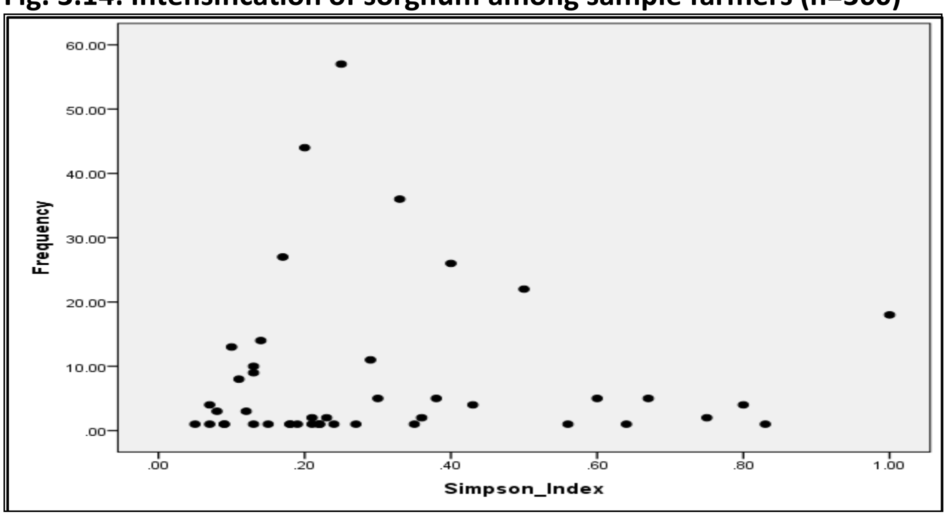
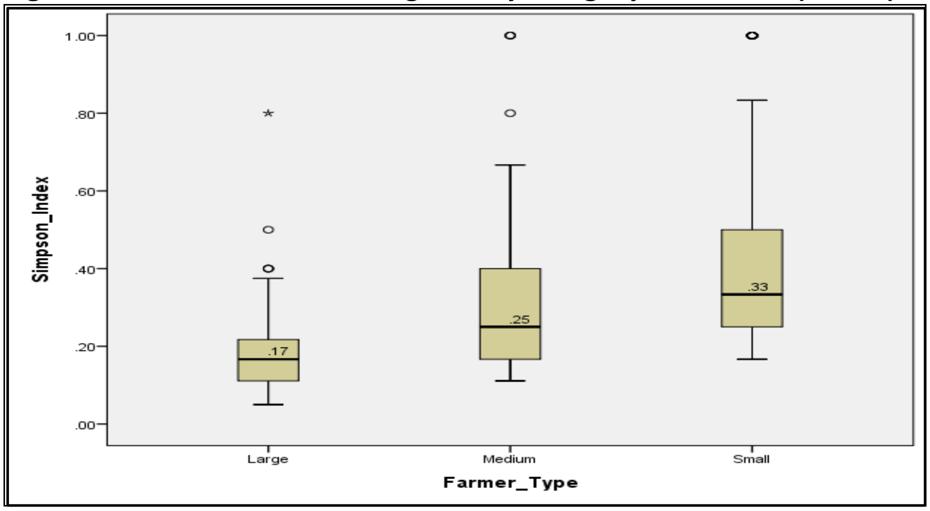


Fig. 3.15: Intensification of sorghum by category of farmers (n=360)



The macro-trends illustrated in Fig. 3.13 and Table 3.21 was evidently reflected in case of the sample farmers in Figs. 3.14 and 3.15. The area share of rainy season sorghum was less than 20 per cent in case of most of the farmers. It was higher than 20 per cent in case of some farmers only. The area share of large farmers averaged around 17 per cent, while that of medium category farmers was 25 per cent. But, in case of the small farmers, this share is still higher at 33 per cent, owing to their subsistence requirement.

3.2.2 Assessing sustainability using crop simulation models

The DSSAT CSM-CERES sorghum, CROPGRO-Chickpea and CROPGRO-Soybean models were used for the simulation studies. The cultivar used in the study was calibrated using All India Coordinated Research Project (AICRP) on sorghum trials data conducted across India (Singh et al. 2014b). Similarly, both chickpea (Singh et al. 2014a) and soybean cultivars were also well calibrated using AICRP multi-location trial data. The simulation results revealed that among the three alternate cropping systems available to the farmers, soybean-chickpea system was the most profitable one. Soybean-chickpea system was the most productive system with about 13 tons of sorghum equivalent yield in terms of value. Sorghum-chickpea system gave 59 per cent of the yield possible with the soybean-chickpea system (Table 3.22). Sorghum-fallow system was the least yielding system. The ranking of the systems remained the same with respect to both water-use-efficiency as well as the nitrogen-use-efficiency. In terms of water-use efficiency, sorghum-fallow system could give 48 per cent of the efficiency attained by soybean-chickpea system. Sorghum-chickpea could reach up to 68 per cent of efficiency given by the best system. Soybean-chickpea system was 3.6 times more efficient than sorghum-fallow system and 1.7 times more efficient than sorghum-chickpea system in terms of nitrogen use efficiency. In the fallow-sorghum system, nitrogen leached during crop season was the highest, followed by soybean-chickpea and sorghum-chickpea systems.

Nitrogen fixed during the cropping season was the highest in the legume-legume combination of soybean-chickpea system. As one can expect, sorghum-chickpea system fixed some nitrogen, while sorghum-fallow failed to fix any nitrogen. The same trend was noted with respect to inorganic nitrogen at maturity and crop nitrogen. Legume-legume system was better than cereal-legume system, which, in turn, was better than cereal-fallow system. However, sorghum-chickpea system scored marginally better than soybean-chickpea system, while sorghum-fallow system was far inferior to both these systems in terms of carbon dynamics. But organic carbon at maturity was slightly higher in case of sorghum-chickpea system than in case of soybean-chickpea system. Thus, sorghum-chickpea system turned-out to be the least profitable as well as least sustainable system. Sorghum-chickpea system occupied the intermediate position with respect to both profitability as well as sustainability. The best results in case of both profitability as well as sustainability were obtained with the soybean-chickpea system.

Table 3.22: Sustainability of different cropping systems in Maharashtra

Variables	Sorghum-Chickpea*	Soybean- Chickpea*	Sorghum-Fallow
Yield	7773	13180	3646
WUE	13.9	20.2	9.7
NUE	194.3	329.5	91.1
NLCM	3.0	3.6	5.5
NFXM	63.1	172.8	0.0
NIAM	18.7	45.0	6.6
CNAM	138.7	240.5	79.7
OCTAM	183522	175801	88182

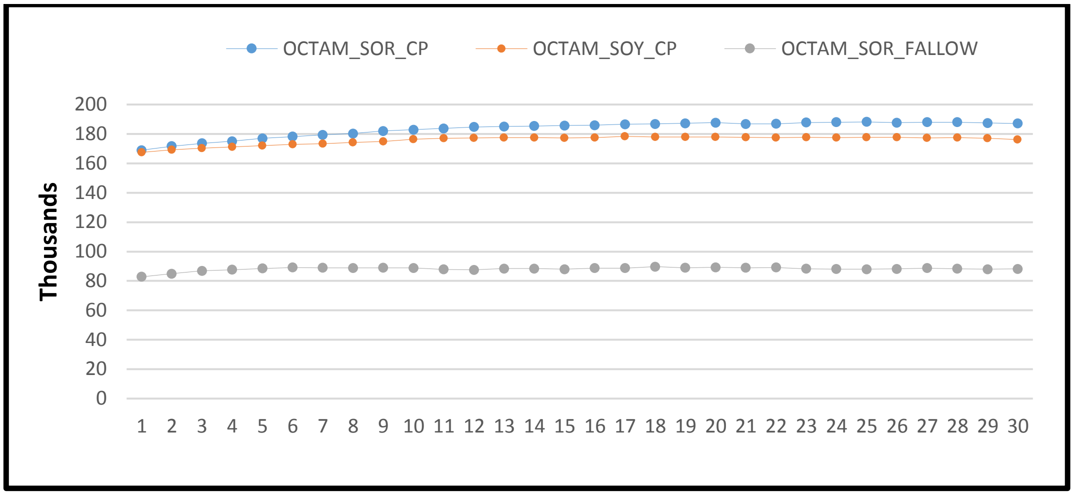
Yield: Kg/ha; WUE: water use efficiency (Kg/ha mm); NUE: nitrogen use efficiency (Kg/Kg); NFXM: Nitrogen fixed during crop season (kg/ha); NLCM: nitrogen leached during crop season (kg/ha); NIAM: inorganic nitrogen at maturity (Kg/ha); CNAM: crop nitrogen uptake (Kg/ha) and OCTAM: Total organic carbon at maturity stage (tons/ha)

*Soybean-chickpea/sorghum-chickpea yields represent sorghum equivalent yields

3.2.3 Soil carbon simulations

The results of the model at Parbhani location are presented in Fig. 3.16. Sorghum-fallow system was least efficient with respect to carbon dynamics. Sorghum-chickpea system turned out to be marginally superior to the soybean-chickpea with respect to carbon dynamics. Perhaps a cereal-legume rotation is better than legume-legume rotation with respect to carbon dynamics.

Fig. 3.16: Simulated soil carbon dynamics over last thirty seasons at Parbhani



3.2.4 Assessment of economic sustainability of different systems

The returns over variable costs were quite insignificant in case of sorghum-fallow system, forming only two per cent of the expenditure (Table 3.23). Sorghum-chickpea system was able to yield a respectable return over variable cost and it formed 36 per cent of the expenditure. Soybean-chickpea system could give a bountiful return over variable cost, measuring up to 87 per cent of the total household expenditure. Sorghum-fallow system yielded the highest fodder per acre, followed by sorghum-chickpea system. Soybean-chickpea system fared the poorest only in case of this indicator. The legume-legume system gave the best nitrogen-phosphorous ratio, while sorghum-fallow system used most nitrogen relative to phosphorous. All the three systems gave more or less the same share of cereal consumption in total food production.

Table 3.23: Economic sustainability indicators in Marathwada region

Parameter	Sorghum-chickpea	Soybean-chickpea	Sorghum - fallow
ROVC ($ per ha)	515	1239	35
Sorghum equivalent fodder availability per acre (Qtl)	42.1	9.3	42.8
Share of ROVC in total expenditure (%)	0.36	0.87	0.02
N/P ratio	1.2	0.88	1.46
Share of cereal consumption in total food production (%)	86.0	88.0	86.0

Table 3.24: Economic sustainability indicators in Western Maharashtra region

Parameter	Sorghum-chickpea	Sorghum-fallow
ROVC ($ per ha)	543	63
Sorghum equivalent fodder availability per acre (Qtl)	52.6	33.8
Share of ROVC in total expenditure (%)	0.40	0.04

N/P ratio	1.64	1.53
Share of cereal consumption in total food production (%)	90.0	90.0

In case of Western Maharashtra, soybean-chickpea system was not much in vogue and hence the comparison was restricted to sorghum-chickpea system and sorghum-fallow system (Table 3.24). On all the counts, sorghum-chickpea system gave a better performance with the exception of nitrogen-phosphorous ratio. Otherwise, sorghum-chickpea system yielded higher; gave significant returns and had higher water and nitrogen use efficiencies. Both were at par with respect to share of cereal consumption in total food production.

Table 3.25: Economic sustainability indicators in Vidarbha region

Parameter	Sorghum-chickpea	Soybean-chickpea	Sorghum - fallow
ROVC ($ per ha)	534	1231	54
Sorghum equivalent fodder availability per acre (Qtl)	47.4	11.8	39.6
Share of ROVC in total expenditure (%)	0.47	0.62	0.04
N/P ratio	1.42	1.03	1.46
Share of cereal consumption in total food production (%)	86.0	88.0	86.0

In Vidarbha region, all the three systems discussed in case of Marathwada were in vogue. The results were also similar to those obtained in Marathwada (Table 3.25). Both the efficiency indicators, yield, returns over variable costs and share of ROVC in total expenditure as well as sustainability indicators, water use efficiency, nitrogen use efficiency and nitrogen-phosphorous ratios were the most desirable in case of soybean-chickpea system. Sorghum-chickpea system scored better with respect fodder availability per acre. All the three systems were at par with respect to share of cereal consumption in total food production.

3.2.5 Resource-use efficiency and returns to scale

The explanatory power of the Cobb-Douglas production function was quite high in case of soybean, while it was moderate in case of chickpea and sorghum (Tables 3.26 (a) to (c)). But the all the three equations were statistically significant. In case of sorghum function, area under the crop, expenditures on human labour, bullock labour, machinery, pesticides and manures had significant impacts on the gross returns. Expenditures on seed and fertilizer did not influence returns significantly. In case of the production function for soybean, the area under the crop and the expenditures on seed and pesticides influenced the gross returns significantly. It is important to note that the traditional inputs like human labour, machine labour, bullock labour and manures were important in case of sorghum production. In case of chickpea, both cropped area and extent of labour cost per acre were significantly at one and five per cent level respectively. Seed cost also showed significant at 10 per cent level only. In case of both sorghum and soybean, use of hybrid seed was near universal and there was not much variability in case of seed costs. But it is significant that seed and pesticide investments had significant impacts on gross returns in case of soybean.

Table 3.26a: Resource-use efficiency of sorghum cultivation in Maharashtra

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.454	1.366		.333	.740
Area	.105**	.052	.156	2.007	.048
Labour cost	.447*	.096	.413	4.663	.000
Bullock cost	.243*	.051	.406	4.721	.000
Manure cost	.021***	.011	.133	1.828	.071
Machinery cost	.213*	.056	.342	3.777	.000
Seed cost	.323	.196	.117	1.648	.103
Fertilizer cost	-.001	.014	-.008	-.104	.917
Pesticide cost	.023**	.010	.157	2.199	.030
n =106 , R2 = 0.53, F static = 13.3* *: sig at 1%; **: sig at 5%; ***: sig at 10%					

Table 3.26b: Resource-use efficiency of soybean cultivation in Maharashtra

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	6.869	1.603		4.285	.000
Area	.643*	.211	.557	3.049	.003
Labour cost	.089	.112	.071	.795	.430
Bullock cost	-.072	.053	-.072	-1.338	.186
Manure cost	.006	.008	.038	.851	.398
Seed cost	.450*	.210	.398	2.137	.037
Fertilizer cost	-.060	.071	-.056	-.849	.399
Pesticide cost	.022***	.013	.071	1.647	.105
n = 69, R^2 = 0.89, F static = 78.01* *: sig at 1%; **: sig at 5%; ***: sig at 10%					

Table 3.26c: Resource-use efficiency of chickpea cultivation in Maharashtra

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.21	1.42*	2.96	2.97	0.00
Area	0.73	0.24*	3.04	3.09	0.00
Labour cost	0.44	0.23**	1.91	1.94	0.05
Bullock cost	-0.07	0.13	-0.54	-0.54	0.58
Seed cost	0.28	0.15***	1.86	1.84	0.07
Fertilizer cost	-0.14	0.16	-0.87	-0.88	0.37
Pesticide cost	-0.00	0.03	-0.03	-0.06	0.95
n = 56, R^2 = 0.85, F static = 54.01* *: sig at 1%; **: sig at 5%; ***: sig at 10%					

Table 3.27: Returns to scale of rainy season sorghum and competing crops

Crop	Returns to scale
Sorghum	1.37
Chickpea	1.24
Soybean	1.10

It is heartening to note that the returns to scale were more than one in case of three study crops (Table 3.27). But it is surprising that sorghum yielded the highest returns to scale, relegating soybean to third place. Chickpea occupied the middle position in between them. The most profitable crop, soybean, recorded the lowest returns to scale.

Estimation of inefficiencies in sorghum cultivation

The results of stochastic production function for sorghum for Maharashtra are presented in Table 3.28. The expenditures on labour, machinery and seed had positive impacts on efficiency, while those on manures and fertilizers had negative effects on efficiency and production. The household network index (NWI) impacted production efficiency positively. Crop diversification index (CDI) did not show any significant influence on sorghum production. There is no significant differences in technical efficiencies among the three study regions. Other social variables such as age, education did not showed any impact on the sorghum efficiency.

Table 3.28: Stochastic Frontier Production function for estimating inefficiencies

Variable	coefficient	Standard-error	t-ratio
beta 0	2.59	0.99	2.62
Area	0.08	0.16	0.51
Labour cost	0.29*	0.11	2.60
Bullock cost	0.06	0.06	0.95
Manure cost	-0.02*	0.01	-2.18
Machinery cost	0.32*	0.06	5.66
Seed cost	0.33*	0.16	2.04
Fertilizer cost	-0.05*	0.02	-2.36
Plant protection cost	0.02	0.01	1.52
delta 0	-0.30	0.11	-2.66
Age	0.00	0.00	1.12
CDI	0.16	0.22	0.74
NWI	0.45**	0.26	1.74
Marathwada	0.03	0.08	0.40
WMH	-0.02	0.08	-0.22
Education	0.11	0.09	1.30
sigma-square	0.12	0.01	9.28
Gamma	0.00	0.01	0.05
log likelihood = 0.62			
* Significance at 1% level ** Significance at 5% level			

Table 3.29: Average technical efficiency by farmer category

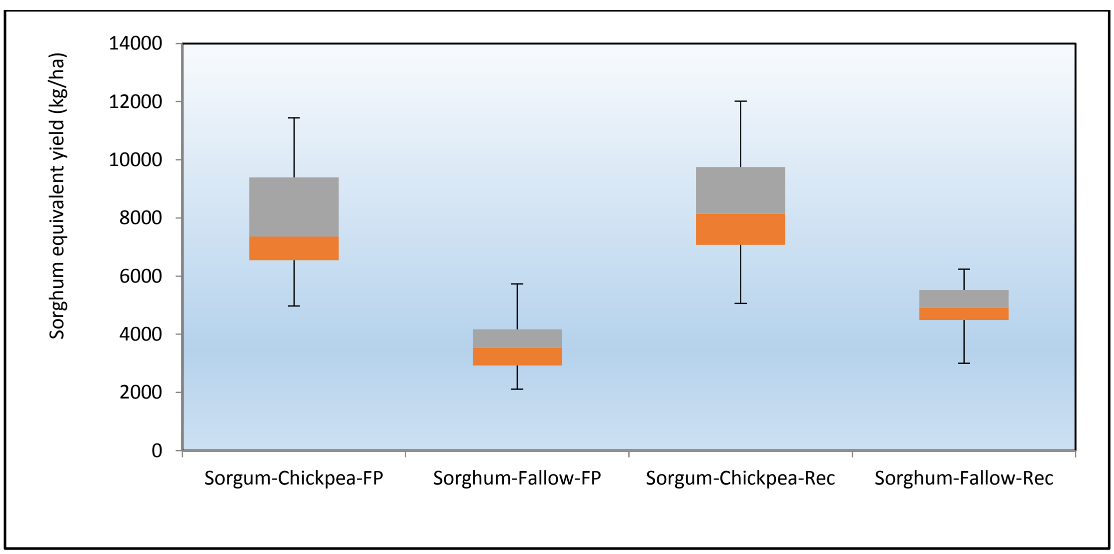
Farmer type	Marathwada	Western Maharashtra	Vidarbha	Average
Large	0.89	0.91	0.92	0.90
Medium	0.90	0.93	0.89	0.91
Small	0.86	0.90	0.90	0.88
Average	0.88	0.92	0.90	0.90

The technical efficiency of sorghum growers across three regions are estimated using stochastic frontier production function and summarized in Table 3.29. The estimates of production efficiency for sorghum in different regions of Maharashtra were fairly high (Table 3.29). Production efficiency was relatively higher in Western Maharashtra region in a relative sense. It was lower in Marathwada, with Vidarbha occupying the intermediate position. Medium sized farms in Marathwada and Western Maharashtra and large sized farms in Vidarbha were relatively more efficient. Small farms were least efficient on an average when compared with the other two groups.

3.2.6 Possible agronomic interventions for enhancing sorghum yields

Sorghum-fallow system was less efficient than sorghum-chickpea system (Fig.3.17). So, it is better that the farmers take-up chickpea after sorghum, wherever possible. In case of both sorghum-fallow and sorghum-chickpea systems, farmers would be better-off by following improved practices (application of recommended dose of nitrogen, 80 kg/ha) than sticking to their traditional practices (40 kg/ha).

Fig. 3.17: Sorghum performance under management practices (FP/IMP)



Case 3: Pearl millet in Maharashtra

Pearl millet in Maharashtra state was selected as a third case in the present study. Pearl millet was one of the dominant rainy season crops in Western Maharashtra and Marathwada regions until early 2000s. It has lost significant cropped area during the last one decade because of severe competition from cotton and maize crops. Due to low market demand and changes in food consumption habits limited its cultivation in the state. However, it has due recognition and importance in selected parts of the state (like western region) because of its high demand for grain consumption and fodder for livestock. It would be another interesting case to highlight the issues of intensification and sustainability in the state.

3.3.1 Primary and secondary data sources analysis

As discussed earlier, both primary and secondary data sources of information was used in assessing the agricultural intensification and sustainability in case of pearl millet in Maharashtra. The sample for the study covered 360 households from 60 villages and 20 tehsils in 9 districts of Maharashtra state[3] (see Table 3.30). The selected sample villages and districts across Maharashtra are also depicted in Fig 3.18.

Table 3.30: Primary sample of mandals

S.no	District	Mandal	S.no	District	Mandal
1	A.Nagar	Sangamner	11	Dhule	Sindkheda
2	A.Nagar	Pathardi	12	Jalgaon	Parola
3	A.Nagar	Shevgaon	13	Nashik	Malegaon
4	A.Nagar	Rahuri	14	Nashik	Sinnar
5	Aurangabad	Aurangabad	15	Nashik	Baglan (Satana)
6	Aurangabad	Gangapur	16	Nashik	Chandwad
7	Beed	Patoda	17	Pune	Shirur
8	Beed	Majalgaon	18	Pune	Purandhar
9	Beed	Parali	19	Sangali	K.Mahankaal
10	Dhule	Sakri	20	Satara	Man

[3] *For more details refer Kumara Charyulu D. et al. 2015b*

Fig 3.18: Selection of districts and villages for primary survey in Maharashtra, 2012

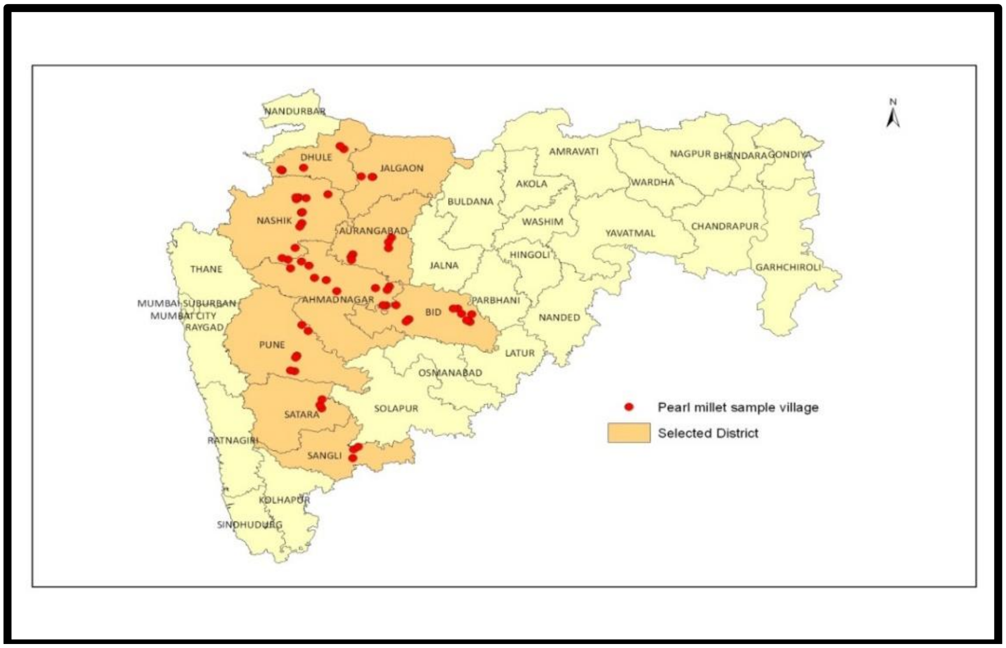


Fig. 3.19: Share of pearl millet in net sown area of Maharashtra

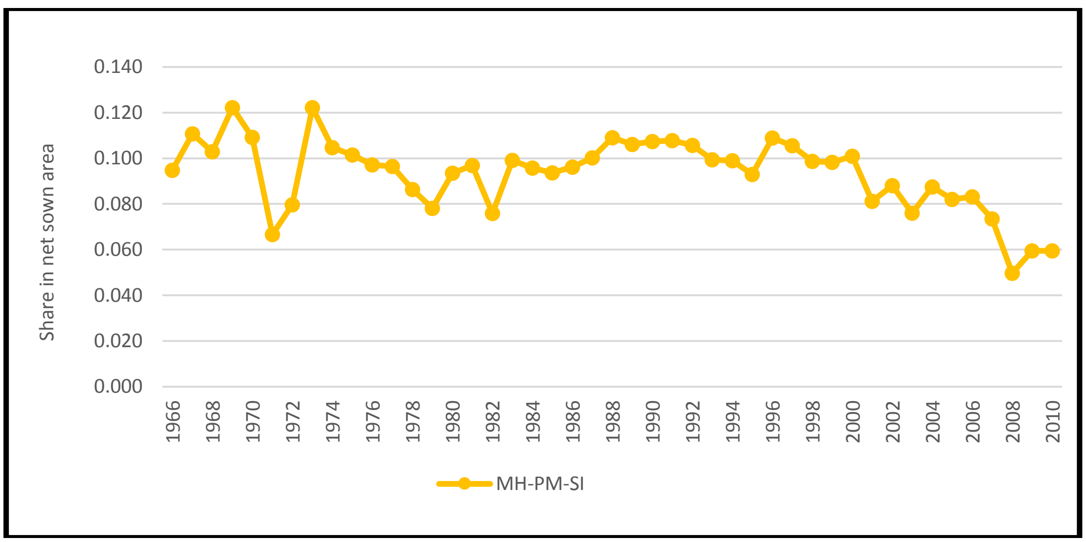
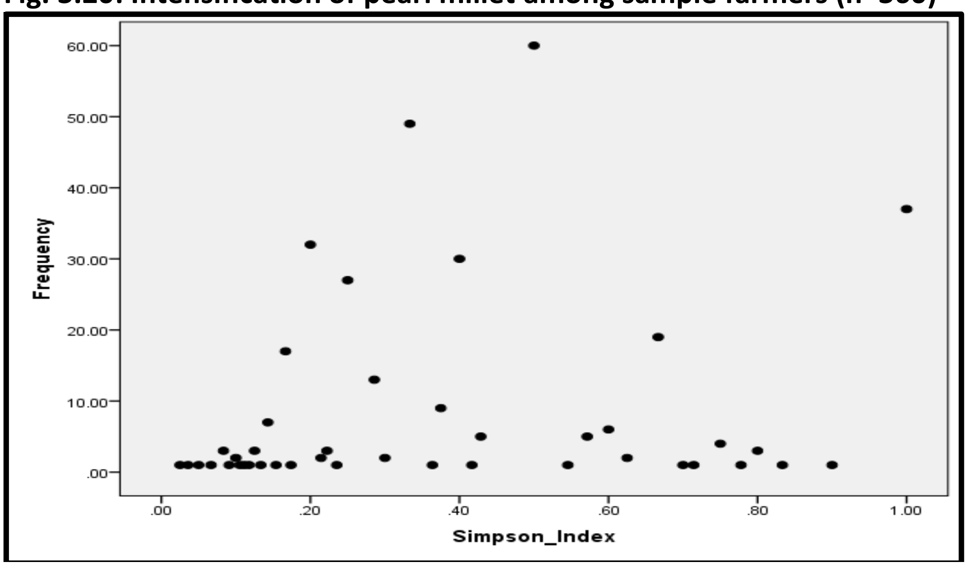


Table 3.31: Share of pearl millet in net sown areaof selected districts in Maharashtra

Triennnium	A'nagar	Auran	Beed	Dhule	Jalgaon	Nashik	Pune	Sangli	Satara
1990-92	0.293	0.259	0.208	0.219	0.134	0.405	0.202	0.162	0.185
1999-01	0.239	0.207	0.281	0.316	0.079	0.396	0.149	0.139	0.146
2007-09	0.166	0.165	0.191	0.258	0.049	0.223	0.071	0.084	0.101

Just as in case of rainy season sorghum, pearl millet also lost area under it over the years. The area share of pearl millet in the net sown area of Maharashtra has shown a decline (Fig. 3.19). In 1966, it had a share of 9.5 per cent and it initially went up to 12 per cent by 1969. Its share was 12 per cent in 1973, but steadily dropped over time to reach 5.5 per cent in 2008 before recovering to 6 per cent in 2010. In all the nine important pearl millet growing districts of Maharashtra, the area share of pearl millet dropped over time (Table 3.31), with the exception of Dhule district. The share of pearl millet was 29.3 per cent in Ahmednagar district during the triennium of 1990-92 (average), which fell to 23.9 per cent in the triennium of 1999-2001 (average) and further to 16.6 per cent in the triennium of 2007-09 (average). In Nashik district, pearl millet had a high share of 40.5 per cent in 1990-92 (average), but it came down to 22.3 per cent in 2007-09 (average). The declining trend was visible in six other districts as well. It fell from 25.9 per cent to 16.5 per cent in Aurangabad district; from 20.8 per cent to 19.1 per cent in Beed district; from 13.4 per cent to 4.9 per cent in Jalgaon district; from 20.2 per cent to 7.1 per cent in Pune district; from 16.2 per cent to 8.4 per cent in Sangli district; and from 18.5 per cent to 10.1 per cent in Satara district. But in Dhule district, the area share of pearl millet in net sown area increased from 21.9 per cent in 1990-92 (average) to 31.6 per cent in 1999-2001 (average), but fell to 25.8 per cent in 2007-09 (average).

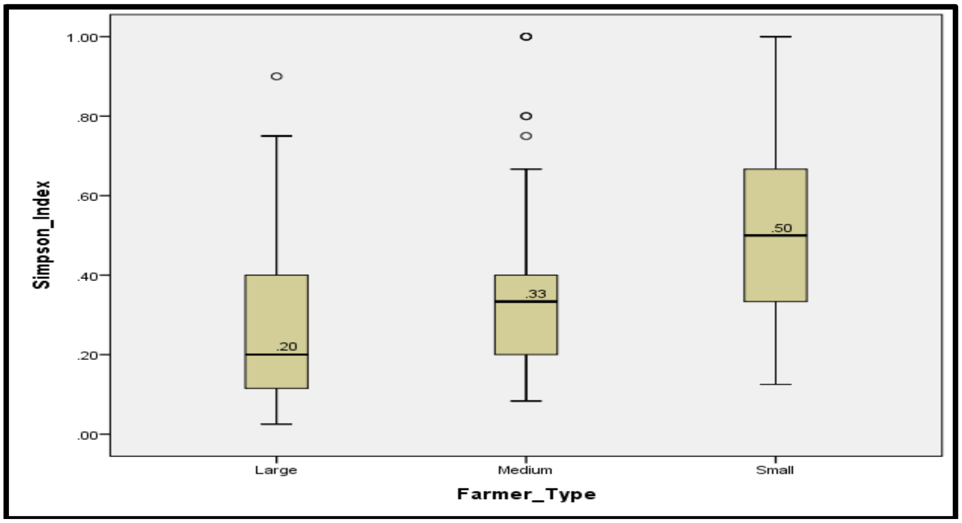
Fig. 3.20: Intensification of pearl millet among sample farmers (n=360)



The results of Simpson index (Fig. 3.21) have shown that the area share of pearl millet was as low as 20 per cent in case of the large farmers (average). The medium sized farms in the sample, on an average, had allocated a share of one third to pearl millet. But small farmers, owing to their subsistence requirements continued to allocate about one half of their net sown area to pearl millet. The scatter diagram of the shares allocated by sample farmers showed that the bulk of the farmers allocated less than 20 per cent of their net sown area to pearl millet (Fig

3.20). But, in a few cases, the area shares allocated by sample farmers touched up to 60 per cent.

Fig. 3.21: Intensification of pearl millet by category of farmers (n=360)



3.3.2 Assessment of pearl millet sustainability using simulation models

Due to the lack of a well calibrated model for pearl millet in Maharashtra, crop simulations were not attempted to assess sustainability. However, sustainability analysis was attempted using data collected at the sample farmers' level.

3.3.3 Economic sustainability of pearl millet

In Marathwada region, maize-fallow and cotton-fallow systems compete for land with pearl millet-fallow system (Table 3.32). Maize-fallow system was the most profitable system, with the returns over variable cost reaching up to 50 per cent of the total expenditure. This ratio was 0.26 in case of cotton-fallow system and was only 0.04 in case of pearl millet-fallow system. Farmers were just able to recover the variable costs in case of pearl millet, while maize and cotton returned reasonable profits. Pearl millet scored marginally better only in case of fodder availability per acre but lesser than maize-fallow competing system. The share of cereal consumption in total food production was also slightly higher in case of pearl millet over them. But, even the nitrogen-phosphorous ratio was unfavorable in pearl millet. Perhaps, only nitrogen was applied to it, while the competing crops received more balanced use of fertilizers. Overall, pearl millet scored very low in terms of profitability, while the sustainability indicators gave mixed signals.

Table 3.32: Economic indicators of pearl millet sustainability in Marathwada region

Parameter	Pearl millet-fallow	Maize-fallow	Cotton-fallow
ROVC ($ per ha)	85.9	906.6	468.8
Pearl millet equivalent fodder availability per acre (Qtl)	23.0	44.0	-
Share of ROVC in total expenditure (%)	0.04	0.50	0.26
N/P ratio	2.5	1.7	1.2
Share of cereal consumption in total food production (%)	25	25	20

The results were similar in case of Western Maharashtra region also (Table 3.33). Pearl millet was the least profitable one, while maize was the most profitable one, with cotton occupying the middle position. Pearl millet was just able to return the variable costs with negligible surplus of eight per cent. Cotton gave a return of 18 per cent, while maize gave a decent return of 35 per cent in the total expenditure. Even the pearl millet equivalent fodder availability per acre was higher in case of maize than in pearl millet. Pearl millet was only able to give a desirable nitrogen-phosphorous ratio than the two competing crops. The share of cereal consumption in total food production was higher with maize than with pearl millet. Thus, pearl millet was least profitable and did not have superiority even in case of sustainability indicators.

Table 3.33: Economic indicators of pearl millet sustainability in Western Maharashtra region

Parameter	Pearl millet-fallow	Maize-fallow	Cotton-fallow
ROVC ($ per ha)	146.2	607.6	306.0
Pearl millet equivalent fodder availability per acre (Qtl)	22.0	26.5	-
Share of ROVC in total expenditure (%)	0.08	0.35	0.18
N/P ratio	0.45	2.2	0.56
Share of cereal consumption in total food production (%)	26	35	22

3.3.4 Resource-use efficiency and returns to scale

The explanatory power of the production function for pearl millet was rather poor, while those of cotton and maize were moderate (Tables 3.34 (a) to (c)). The expenditures on human labour, bullock labour, machine labour and fertilizers had statistically significant and positive effect on production in case of pearl millet. In case of cotton, the expenditures on human labour, seed and pesticides did have positive and significant influence on production, while the expenditure on bullock labour impacted production negatively. The expenditures on bullock labour, machinery and seed had positive and significant impacts on maize production, while the expenditure on irrigation had a negative effect.

Table 3.34a: Resource-use efficiency in pearl millet cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.924	1.738		-.531	.596
Area	.034	.099	.026	.344	.731
Labour cost	.586*	.154	.314	3.809	.000
Bullock cost	.033***	.019	.122	1.736	.085
Machinery cost	.580*	.092	.454	6.281	.000
Manure cost	-.010	.015	-.043	-.687	.493
Seed cost	.038	.232	.010	.162	.872
Fertilizer cost	.085***	.049	.122	1.737	.084
n =167 , R2 = 0.41, F static = 15.9**: sig at 1%; **: sig at 5%; ***: sig at 10%					

Table 3.34b: Resource-use efficiency in cotton cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-4.867	2.547		-1.911	.062
Area	.194	.120	.190	1.616	.113
Labour cost	1.379*	.272	.718	5.060	.000
Bullock cost	-.119*	.041	-.300	-2.869	.006
Machinery cost	.149	.181	.091	.825	.414
Manure cost	.005	.020	.025	.261	.795
Seed cost	.518**	.242	.219	2.144	.037
Fertilizer cost	-.235	.164	-.157	-1.431	.159
Pesticide cost	.056**	.029	.209	1.953	.057
n =55 , R2 = 0.62, F static = 9.4**: sig at 1%; **: sig at 5%					

Table 3.34c: Resource-use efficiency in maize cultivation

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-5.354	3.464		-1.545	.133
Area	.013	.145	.013	.089	.929
Labour cost	.147	.314	.100	.467	.644
Bullock cost	.098*	.032	.694	3.068	.005
Machinery cost	1.267*	.226	1.323	5.608	.000
Manure cost	.011	.015	.102	.732	.470
Seed cost	.378***	.215	.279	1.760	.089
Fertilizer cost	.146	.116	.218	1.258	.218
Irrigation cost	-.066*	.022	-.633	-3.037	.005
n =39 , R2 = 0.61, F static = 5.9**: sig at 1%; **: sig at 5%					

Table 3.35: Returns to scale in case of pearl millet and competing crops

Crop	Returns to scale
Pearl millet	1.35
Cotton	1.95
Maize	1.99

In case of all the three crops, pearl millet, cotton and maize, the returns to scale were increasing (Table 3.35). They were significantly higher than one at 1.35 in case of pearl millet, while they were too high and close to two in case of the competing crops, cotton and maize.

Estimation of inefficiencies in pearl millet cultivation

The expenditures on human labour and machinery contributed to production efficiency of pearl millet positively and significantly (Table 3.36). The dummy variables for crop diversification index (CDI) and network index (NWI) and region (Marathwada /Western Maharashtra) had positive and significant values, suggesting that these variables had higher intercept values, while the dummy variable for education had a negative and significant value, implying that the educated farmers had a lower intercept value.

Table 3.36: Stochastic frontier production function for estimating inefficiencies

Variable	Coefficient	Standard-error	t-ratio
beta 0	3.00	1.26	2.38
Area under crop	0.28	0.21	1.35
Labour	0.61*	0.11	5.49
Bullock	0.02	0.02	0.81
Machinery	0.35*	0.07	5.03
CP	-0.01	0.02	-0.52
Seed	-0.22	0.21	-1.04
Fertilizer	0.05	0.03	1.55
delta 0	-29.15	8.85	-3.29
Age	0.28	0.07	4.00
CDI	20.81*	6.14	3.39
NWI	8.31*	3.14	2.65
Region	3.80*	1.33	2.86
Educated	-11.72*	2.65	-4.42
sigma-s	25.24	6.72	3.75
gamma	1.00	0.00	93.95
Log likelihood = 0.20 * Significance at 1% level ** Significance at 5% level			

Table 3.37: Average technical efficiency in Pearl millet production by farmer category and region

Farmer type	Marathwada	WMH	Average
Large	0.50	0.67	0.63
Medium	0.53	0.61	0.59
Small	0.56	0.54	0.54
Average	0.54	0.58	0.57

The average values of technical efficiency attained in pearl millet production by region and farmer category are furnished in Table 3.37. Among the regions, Western Maharashtra had attained slightly higher levels of technical efficiency than the Marathwada region. Among the farm size categories, large farmers attained higher levels of technical efficiency in pearl millet production, while the small farmers were far behind in efficiency.

3.3.5 Possible agronomic interventions for enhancing pearl millet productivity

Due to lack of well calibrated crop model for pearl millet, these simulations were not attempted in case of pearl millet crop in Maharashtra.

4. Farmer perceptions and drivers of agricultural sustainability

Perceptions of the farmers were recorded to know about the drivers (socio-economic, bio-physical etc.,) and incentives required to motivate farmers to adopt agriculturally sustainable agricultural practices in different systems.

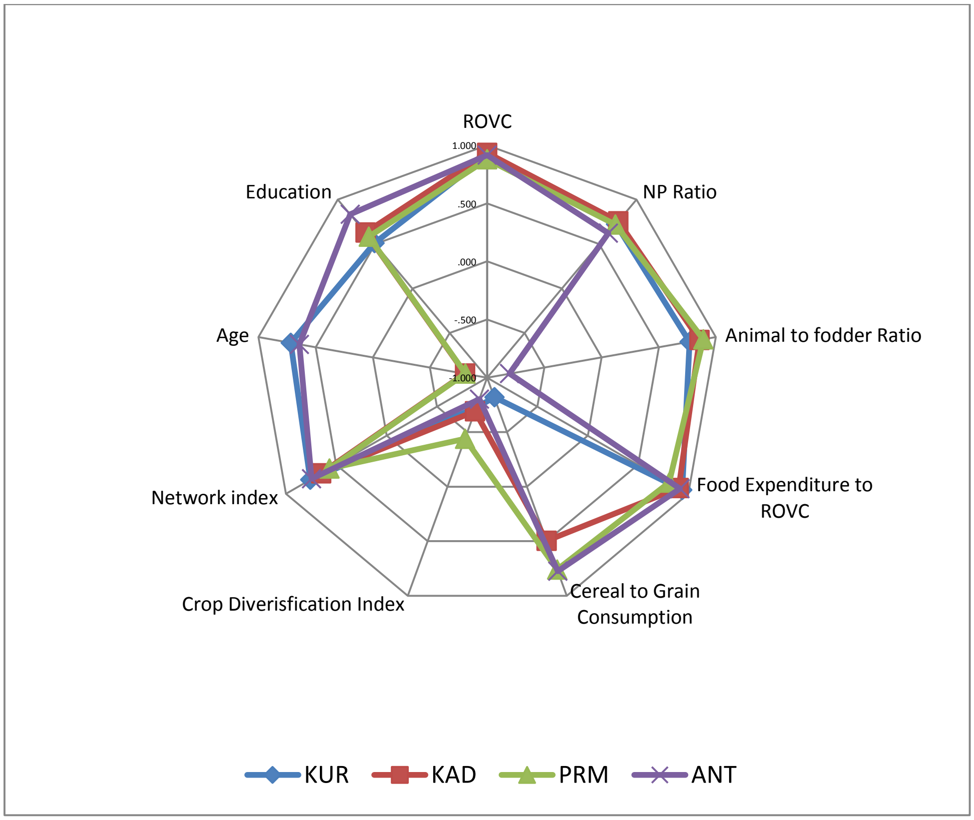
4.1: Chickpea in Andhra Pradesh state

The intensity of input use in terms of expenditures incurred on various inputs was measured over a period of one decade (Table 4.1). The cost of input use one decade ago was inflated to the present day to make the comparisons. The input use intensity has increased in all the districts with respect to virtually in all the inputs. The pooled data for fertilizer use reflected a 61 per cent increase over the past decade. The practice of giving irrigation support has gained ground. The expenditure on irrigation has increased by 688 per cent. The own land allocation has increased from 7 to 12 acres, while that of leased land allocation quadrupled from 3 to 12 acres. Many farmers leased-in land for increasing the scale of operation in chickpea cultivation. The expenditure on mechanization reported a 42 per cent increase. Similarly, the expenditure on pesticides has increased by 55 per cent. Very few farmers invested on soil and water conservation. Those who invested made substantial investments to the tune of Rs. 15000 per farm. This expenditure was a paltry Rs. 33 a decade ago. The pattern of input use reflected a massive intensification in chickpea cultivation in Andhra Pradesh. Both the own land as well as leased land allocation increased several fold as chickpea cultivation was profitable to the farmers.

Drivers of chickpea sustainable intensification across study districts (PCA Coefficients)

Some drivers of sustainable intensification of chickpea in the four study districts of Andhra Pradesh were noted through the web diagram drawn (see Fig 4.1). The returns exceeding the variable cost was an important driver for intensification in a specific geographic location. Food expenditure to returns over the variable cost, animal to fodder ratio, Nitrogen-phosphorous ratio and cereal to grain ratio were the other factors driving sustainability. But, the specialization in chickpea has led to reduced crop diversification index. The socio-cultural variables like network index, age and education also had limited impacts on intensification. The specific sustainability perceptions of farmers in chickpea cultivation in Andhra Pradesh were not collected in the primary household survey.

Fig. 4.1: Drivers of agricultural intensification of chickpea in study districts



4.2: Rainy sorghum in Maharashtra state

In Maharashtra, farmers reduced their own land allocation to rainy season sorghum over the last one decade (Table 4.2). The pooled data revealed that the farmers have cut their land allocation by one half. It was quite rare for the farmers in Maharashtra to lease-in land for cultivating sorghum in the rainy season. Only four per cent of the sample farmers leased-in land for sorghum cultivation but they increased the leased-in area by one-third. Apart from land allocation, farmers have intensified the input use even in case of rainy season sorghum. Due to the universal use of hybrids, the seed rate decreased from 5 kg to 3 kg per acre. But the fertilizer use per unit area nearly doubled in the pooled sample. The use of fertilizer was relatively higher in Western Maharashtra than in the other two regions, Vidarbha and Marathwada. Irrigation support is rarely provided to rainy season sorghum. But, in Marathwada, this practice is gaining popularity. Some farmers in Western Maharashtra are also providing it, while it is rarely practiced in Vidarbha region. But whoever provided the irrigation support had incurred higher expenditures than a decade ago. The pooled data showed that the irrigation expenditure went up by 129 per cent. Mechanization has become the order of the day and the farmers are spending twice the amount for it now when compared with a decade ago. The expenditure on pesticides has gone up by 38 per cent. A substantial number of sample farmers are making investments on soil and water conservation. The expenditure on this count also has gone up by 76 per cent. Thus, the farmers have, in general, increased the input use to realize higher yields, even when the crop is not much profitable. But, the farmers are reducing area under the crop over time as it is relatively less profitable.

It is very difficult and costly to assess the sustainability of resources like land and water, which are critical to agriculture. A number of tests have to be carried out to know about the long term sustainability of agriculture and they require huge financial and manpower resources. In the absence of those resources, the survey included questions on some indicators of sustainability. The farmers' perceptions were recorded and some broad conclusions were drawn about the agricultural sustainability on the basis of the analysis of the farmers' perceptions (Table 4.3).

Many of the perceptions are ringing danger bells to agricultural sustainability. The average size of holding has decreased; the availability of fodder/grazing pastures has declined; the livestock population has fallen; land allocation to food crops has decreased; application of farm yard manure or other organic matter has decreased; and the soil fertility status has worsened. The intensity of cropping and use of legumes in crop rotation have improved and the application of inorganic fertilizers has gone-up. These positive features failed to stem the decline in the fertility status of the soil. Use of farm machinery and pesticides has also increased and this can only have deleterious effects on agricultural sustainability. One positive feature was the increase in investments for soil and water conservation, but it has also failed to arrest the soil erosion problem. Many other aspects like cultivation of green manure crops, micro-nutrient application and frequency of soil testing remained at the same level as earlier. The overall impression one gains after reviewing the farmers' perceptions is that agricultural sustainability is at risk. The farmers growing rainy season sorghum perceive threat to long-term productivity and soil fertility.

Table 4.1: Adoption of chickpea improved technologies and change in input-use behavior over last decade

Indicators	Anantapur		Kadapa		Kurnool		Prakasam		Pooled	
	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation
Fertilizer application cost	685 (134)	1055	884 (124)	1413	926 (349)	1467	1091 (107)	1877	898 (714)	1442
Irrigation expenditure	0 (1)	13000	0	0	0	0	1015 (2)	1500	677 (3)	5333
Leased-in land allocation	3.5 (15)	16	0 (7)	11	3 (69)	12	2 (45)	11	3 (136)	12
Mechanization	1747 (134)	2175	2162 (124)	2789	1522 (342)	2178	1645 (106)	2952	1695 (706)	2401
Own land allocation	7 (26)	13	6 (14)	11	8 (134)	14	3 (40)	6	7 (214)	12
Pesticide application cost	687 (134)	994	726 (124)	1087	866 (349)	1343	860 (107)	1434	807 (714)	1247
Soil & water conservation expenditure	0 (3)	10000	0 (1)	20000	0 (3)	28000	146 (2)	700	33 (9)	15044

Note: Figures in the parentheses represent no. of respondents
* Costs are inflated to 2009-10 prices

Table 4.2: Adoption of sorghum (rainy) improved technologies and change in input-use behavior over last decade

Indicator	Marthawada		WMH		Vidarbha		Pooled	
	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation
Fertilizer application cost (Kgs/acre)	66 (144)	125	62 (62)	146	61 (61)	113	64 (267)	127
Irrigation expenditure (Rs/acre)	425 (19)	1353	932 (9)	1422	400 (1)	0	581 (29)	1328
Leased-in land allocation (acres)	2 (5)	4	7 (1)	5	3 (2)	2	3 (8)	4
Mechanization (Rs/acre)	541 (151)	1147	554 (75)	995	508 (68)	972	536 (294)	1068
Own land allocation (acres)	4 (118)	2	4 (49)	2	5 (49)	2	4 (216)	2
Pesticide application cost (Rs/acre)	141 (119)	191	149 (28)	259	120 (47)	144	137 (194)	189
Seed rate (Kgs)	5 (123)	3	5 (52)	3	4 (57)	5	5 (232)	3
Soil & water conservation exp. (Rs/acre/year)	393 (80)	803	332 (41)	454	335 (41)	510	363 (162)	640

Note: Figures in the parenthesis represents no. of respondents
* Costs are inflated to 2010-11 prices

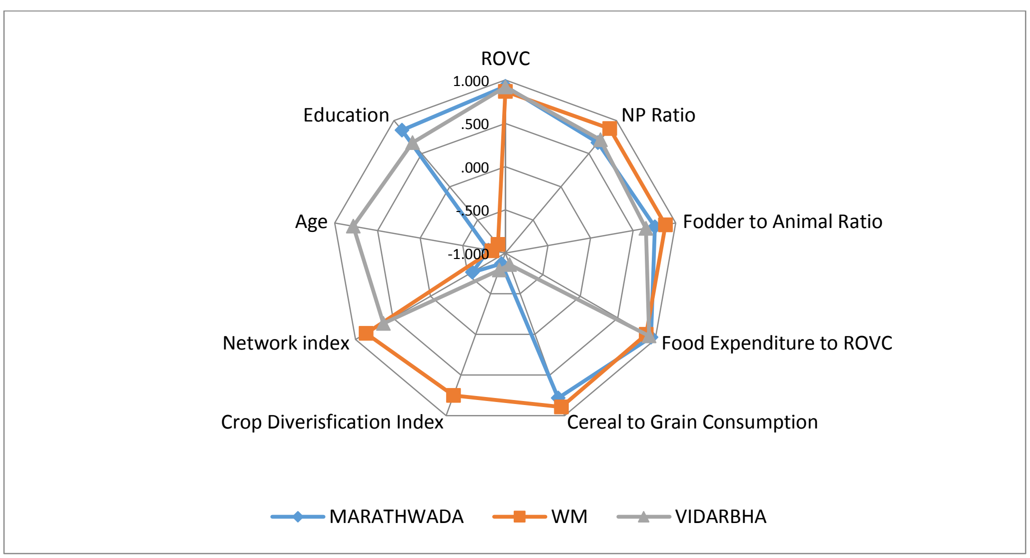
Table 4.3: Perceptions of sample farmers about agricultural sustainability (N=360)

Indicator	Pooled (% of HH)		
	Increased	Constant	Decreased
Livestock population (No. per Hh)	1.7	7.8	90.6
Availability of fodder/grazing pastures	0.8	17.5	81.7
Area under green manure crops	16.4	81.4	2.2
Land allocation for food crops (acres)	0.6	45.0	54.4
Average land holding size of farm (acres)	1.4	19.2	79.4
Land-use intensity (no. of crops per year)	69.2	30.0	0.8
Use of legumes in crop-rotations /inter-cropping	54.2	16.4	29.4
FYM/other organic matter application rate (Qtl/acre/year)	3.6	8.1	88.3
Soil and water conservation investments per acre (private and public)	53.3	46.4	0.3
Soil loss due to erosion	91.9	2.8	5.3
Soil fertility status (organic carbon and NPK levels)	0.3	5.0	94.7
In-organic fertilizers (N, P, K – application rate)	83.6	12.8	3.6
Micro-nutrient application (kg/acre)	26.7	73.1	0.3
Frequency of soil testing and use of fertilizers based on recommendations	24.7	75.0	0.3
Expenditure on plant protection chemicals (Rs/acre)	71.1	26.7	2.2
Expenditure on farm mechanization (Rs/acre)	100.0	0.0	0.0

Drivers of sustainable Intensification of sorghum in Maharashtra (PCA Coefficients)

Among the three regions of Maharashtra, Western Maharashtra seems to be better placed in terms of crop diversification index**,** nitrogen-phosphorous ratio**,** fodder to animal ratio, cereal to grain consumption and network index (Fig 4.2)**.** Marathwada seems to be better placed with respect to education and food expenditure to return over variable costs. Vidarbha scored in age. All the three regions seem to be at par with respect to the returns over variable costs. All these factors are influencing the agricultural intensification.

Fig. 4.2: Drivers of sorghum agricultural intensification across regions



4.3. Pearl millet in Maharashtra state

Just as in case of rainy season sorghum, the sample farmers in both Marathwada and Western Maharashtra have reduced the own land allocation to pearl millet from 3 to 2 acres per farm (Table 4.4). Leasing-in land to cultivate pearl millet is rather unusual in both Marathwada as well as in Western Maharashtra. Only a couple of farmers have leased-in land to cultivate pearl millet and they have also reduced the leased-in land allocation to pearl millet. Farmers are adopting mostly hybrids due to which the seed rate was reduced from 4 kg to 2 kg per acre. But, input use intensity has increased in case of fertilizer, machinery use and pesticide application. The expenditure on fertilizer increased by 147 per cent, while that on machinery increased by 64 per cent. The cost of pesticide application has increased by 184 per cent. A dozen farmers invested in soil and water conservation. They have increased the investments on soil and water conservation by twenty times.

Table 4.4: Adoption of pearl millet improved technologies and change in input-use behavior over last decade

Indicators	Marathwada		Vidharbha		Pooled	
	Old allocation*	Current allocation	Old allocation*	Current allocation	Old allocation*	Current allocation
Fertilizer application cost (Rs/acre)	647 (86)	1510	527 (238)	1336	559 (324)	1382
Leased-in land allocation (acres)	0 (1)	1	15 (1)	10	8 (2)	6
Mechanization (Rs/acre)	1147 (82)	1762	919 (230)	1545	978 (312)	1602
Own land allocation (acres)	3 (31)	2	3 (88)	2	3 (119)	2
Pesticide application cost (Rs/acre)	236 (2)	350	149 (12)	475	161 (14)	457
Seed rate (Kgs)	4 (30)	2	3 (146)	2	4 (176)	2
Soil & water conservation exp. (Rs/acre/year)	0 (6)	1200	138 (6)	1668	69 (12)	1433

Note: Figures in the parenthesis represents no. of respondents
*all costs are inflated to 2010-11prices

In contrast to the perceptions of farmers growing sorghum in the rainy season, pearl millet farmers indicated that the indicators of sustainability have largely improved over a period of time (Table 4.5). About 56 per cent of the sample farmers opined that their soil fertility status has improved. Many of them were able to increase the use of farm yard manure and other organic manures, besides the application of inorganic fertilizers and, hence, were able to perceive an improvement in the status of soil fertility. They have increased the use of farm machinery as anywhere else. A good proportion of them invested more in soil and water conservation but yet the soil loss due to erosion continued to increase. Pearl millet farmers, by and large, perceived constant status with respect to several indicators like livestock population, area under green manure crops, use of legumes in crop rotation/inter-cropping, average size of holding, land use intensity, land allocation to food crops, micro-nutrient application, availability of fodder/grazing pastures, frequency of soil testing, expenditure on other plant protection chemicals etc., Despite some indicators showing weakness, the pearl millet sample farmers in Maharashtra perceived that, by and large, sustainability indicators are showing an improvement over time.

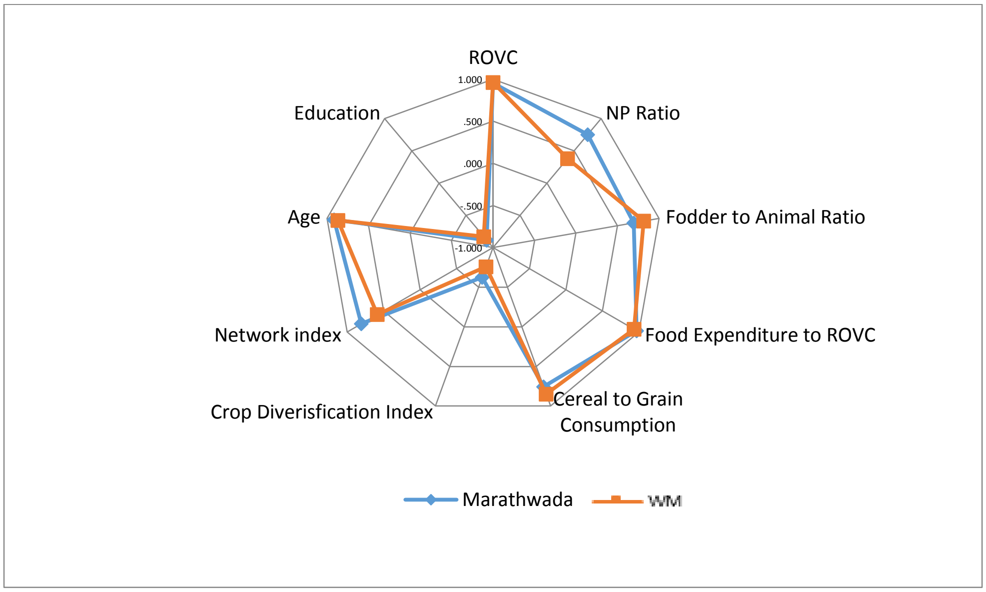
Table 4.5: Perceptions about agricultural sustainability (N=360)

Indicator	Pooled (% of HH)		
	Increased	Constant	Decreased
Area under green manure crops	1.9	64.2	33.9
Availability of fodder/grazing pastures	32.5	42.2	25.3
Average land holding size of farm (acres)	3.3	68.1	28.6
Expenditure on farm mechanization (Rs/acre)	92.5	6.4	1.1
Expenditure on plant protection chemicals (Rs/acre)	30.0	49.4	20.6
Freq. of soil testing and use of fertilizer based on recommendation	25.3	54.4	20.3
FYM/other organic matter application rate (Qtl/acre/year)	55.3	32.5	12.2
In-organic fertilizers (N,P,K) application rater (Kg/acres)	76.4	20.6	3.1
Land allocation for food crops (acres)	10.0	50.3	39.7
Land-use intensity (No. of crops/year)	29.2	61.4	9.4
Livestock population (No./HH)	20.3	46.1	33.6
Micro-nutrient application (Kg/acre)	11.9	77.2	10.8
Soil and water conservation investment per acre(pri.+Publ)	29.2	52.8	18.1
Soil fertility status (Organic carbon and NPK levels)	56.4	21.9	21.7
Soil loss due to erosion	15.8	26.4	57.8
Use of legumes in crop-rotation/inter-cropping	13.6	64.2	22.2

Drivers of pearl millet agricultural intensification in Maharashtra

Among the different indicators of agricultural sustainability, both the study regions scored poor with respect to crop diversification index and education (Fig 4.3). Marathwada scored better with respect to network index and nitrogen-phosphorous ratio. Western Maharashtra was better placed with respect to cereal to grain consumption and fodder to animal ratio. Both these regions were at par with respect to returns over variable costs and food expenditure to returns over variable costs.

Fig. 4.3: Drivers of sustainable intensification across regions (PCA Coefficients)



5. Conclusions and way forward

This study tried to look at the scope for sustainable intensification in Semi-arid Tropics of India, with three data sets relating to i) chickpea in Andhra Pradesh, ii) rainy season sorghum in Maharashtra and iii) rainy season pearl millet in Maharashtra. The very concept of sustainable intensification involves synthesis of two opposite forces. Intensification relates to the more intensive use of inputs to enhance the yields further. Sustainability looks at the longer term productivity of resources like land and water, which by its nature, applies brakes on the efforts to increase production by intensifying the use of inputs due to the fear that they may adversely impair the longer term productivity and resource quality/quantity. There may be a limited scope for increasing the use of inputs for realizing higher yields without impairing the longer term productivity of the critical resources. Sustainable intensification precisely looks at these limited opportunities. Its scope is specific to a given region and a given cropping system. It may be possible to exploit opportunities for sustainable intensification by altering the cropping systems. Or new technologies may enhance this scope for sustainable intensification.

A number of developmental agencies have tried to define sustainable intensification in a variety of ways. One may choose a definition relevant to the problem in hand. But the common concern is about meeting the rising needs of people by intensifying the input use in such a way that it will not harm the quantity and quality of resources such that the interests of the future generations are not jeopardized. The innovative technologies and cropping systems may aid this process of sustainable intensification and support the population growth for some more time. The present study looked at the three examples and assessed the scope for sustainable intensification.

The first case of chickpea in Andhra Pradesh provides an ideal scenario for sustainable intensification. Chickpea is more productive than the competing crops of maize and sorghum during the post-rainy season. At the same time, it has also scored better with respect to sustainability indicators like water-use-efficiency, nitrogen-use-efficiency, organic carbon dynamics etc., But, it may have met other sustainability indicators like fodder availability, food security etc., only partially. Because of the productivity and sustainability of chickpea, the area share of chickpea went-up in almost all the important chickpea growing districts of Andhra Pradesh. Some more scope might exist for extending the process of sustainable intensification of chickpea. But the availability of water retentive heavy soils might be getting exhausted in the chickpea growing districts to limit the scope for sustainable intensification.

But the two other cases of rainy season sorghum in Maharashtra and rainy season pearl millet in Maharashtra present the evidence in the opposite direction. They are neither productive nor profitable when compared with the competing crops or cropping systems. Being cereal crops, they do not contribute to the sustainability indicators like water-use-efficiency, nitrogen-use-efficiency, nitrogen-phosphorous ratio, organic carbon dynamics etc., The evidence with respect to other sustainability indicators like fodder availability and food security is mixed. No wonder, these crops are fast losing area shares in all the important districts of Maharashtra growing them. The future trends may not be different from the declining trends observed in the past. Unless the research system comes up with more sustainable cropping systems, the fortunes of rainy season sorghum and rainy season pearl millet may not be reversed in the near future. The perceptions of the sample farmers also endorsed that the sustainability indicators are showing declining trends in case of rainy season sorghum, while they were mixed in case of rainy season pearl millet. These two cases in Maharashtra do not indicate any scope for their sustainable intensification. While policy distortions had their own share in reducing the profitability of sorghum and pearl millet, the process of change cannot be reversed even if policy makers are sincere in correcting the policy bias against these coarse cereals.

The methodology of assessing the sustainable intensification is still evolving and the approaches used in the present study have scope for further development and application in varied cropping systems in the SAT region. Some additional indicators can be developed and employed and more innovative definitions and approaches can be tried in the future.

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