Drivers and major changes in agricultural production systems in drylands of South Asia: assessing implications for key environmental indicators and research needs

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Abstract

The South Asian dryland (arid and semi-arid) ecosystems have been exhibiting considerable agricultural production system changes. In fact, today, there are scientific consensus that this nature of agricultural production system enables it to capture market, technologies and environmental opportunities. Pressing concerns are, however, adverse environmental trade-offs that these changes are experiencing and therefore the challenges toward a resilient agricultural production system. This is particularly important in arid and semi-arid ecosystems which are resources constrained and thus more vulnerable: for example to climate change. To stimulate and revive a debate in agricultural research circles, this paper demonstrates the magnitude of major changes, their drivers and environmental implications in context to agricultural production systems in drylands of South Asia. As an example we selected districts representing different dryland agricultural production systems in western Rajasthan, Andhra Pradesh and Karnataka states of India. Taking crop, livestock and trees as major enterprises, we characterized agricultural production systems of the sample districts. Key operational resources, demographic and external agents were illustrated as examples of drivers of changes. Then major emphasis was given to material and environment related livelihood outcomes and their dynamic as agricultural production systems evolve over time. Despite a remarkable improvement in material outcomes of agricultural production (> 100% increase in cereal grain yields taking 1966 as a base year), the long term environmental dimension tends to be compromised by short term needs: as demonstrated by perpetual soil nutrient stock mining, ground water depletion and instability of cereal grain yields (28-110% CV). Based on these empirical evidence, we debate as to where a system research should focus and what policy circles need to do to address emerging problems and contribute to advances toward a sustainable agricultural production systems in dryland.

Key words: Drylands, Intensification trajectories, Environmental and material outcomes, Sustainable ecosystems, Resilient system

1. Introduction

Globally dryland (arid and semi-arid) ecosystems occupy more than 3 billion hectares and are home to 2.5 billion people: the size equivalent to 41% of the earth's land area and more than one-third of its population (ICARDA 2011). In view of their extent (area) and current intensive use, dryland ecosystems and their associated agricultural production systems in South Asia are of great importance. For example, in India alone, dryland ecosystems contribute about 40% of the total food grain production and support two third of livestock population (Wani et al. 2009; CRIDA 2011). One of the growing concerns is, however, that the continues increase in human population and concomitant demand for livestock and crop products will exert additional pressure to already resources poor and overstretched dryland ecosystems.

The dryland ecosystems are also commended for encompassing several globally important centres of origin and diversity of plant and animal species (Mortimore et al. 2009). Dryland, particularly in South Asia, has large productivity gaps, where relatively quick wins would be possible to meet the livelihood outcomes with minimum adverse environmental consequences.

Efforts to close these yield gaps go back to mid-1960: the time of green revolution (Singh 2000). In some areas there were achievements, but with various environmental consequences (Singh, 2000); while in major part of the dryland these potentials are not yet crafted. Here we hypothesize that a systematic evaluation of post-intensification’s adverse environmental consequences and understanding impeding factors, to close the yield gaps, will help to focus future agricultural production system’s research in dryland.

One of the major reasons why research has not delivered more in this regard is that it has been conducted on single components of an agro-ecosystem, while farmers and communities operate in complex systems, with high levels of integration of many components (White et al.

1996). For example, the commonly recognized yield gap is only of a single component and hardly includes gap related to synergies and complementarities of system components under the 'right mix' scenarios. Changing behaviour of agricultural production systems, in response to increasingly diverse exogenous and endogenous factors acting on and interacting with system components (White et al. 1996), is also less comprehended and therefore pertinent policy and technical measures to straighten system intensification trajectory, in a way to meet features of sustainable agricultural production, is hardly put into practices (Ison et al. 1996).

The overarching objectives, here, were to stimulate the debate in agricultural research and policy circles by highlighting key indicators: as to how the current agricultural production systems structured and functions and how they are evolving and what this implies for environmental sustainability and therefore pertinent research questions.

2. Approaches

2.1. Study areas and data sources

Study areas were chosen based on vulnerability maps (NRA/CRIDA 2011), available geospatial information [rainfall, population, soil etc. (ICARDA 2012)], and expert opinion. The most vulnerable dryland districts in India include parts of Rajasthan. Therefore here three districts representing the major farming systems (in arid ecosystem), including the small ruminants based crop-livestock in Barmer and Jaisalmer and millet base crop-livestock system in Jodhpur), were selected. As a cluster representing dryland systems in semi-arid ecosystems in peninsula India, systems including cereals based crop-livestock system in Bijapur (Karnataka) and groundnut based crop-livestock system in Anantapur and pulses based crop-livestock system in Kurnool districts (Andhra Pradesh), were identified.

In the present work, we primarily used multiple years' district level census data on livestock and crop production, farm size and number of holdings and land use. Additional data on key environmental indicators were acquired from district contingency plans and literature (e.g. Haileslassie et al. 2012). Trends of Land Use Land Cover Changes (LULCC) were acquired from remote sensing (2000-2010). Expert opinion and discussions with farmers in these districts helped to triangulate information from the different sources mentioned above (Haileslassie and Craufurd, in press).

2.2. Perceptions of agricultural system and adopted analytical framework

2.2.1. Perception of agricultural production system

Agricultural system was perceived as an assemblage of components (livestock, tree and crop) which are united by different degree of integration and interaction (depending on whether the comparative advantage is crop or livestock) and which operates within a prescribed 'open-boundary' to achieve specified agricultural objectives (Jodha, 1986; FAO 1997). Agricultural production systems is also viewed as a fundamentally dynamic process influenced by endogenous and exogenous agents and being dependent on the passage of time, ex-ante, and their outcomes are uncertain (White et al. 1996; Ison et al. 1997).

Mixed crop-livestock production systems are major production systems in these areas (Jodha, 1986). But the comparative advantage of crop over livestock and *vice versa* is dependent on prevailing biophysical settings. For example most system in western Rajasthan are livestock based, while in Anantapur, Kurnool and Bijapur crop production plays a major role.

But generally, in the study areas, drawing a boundary line among the different agricultural production systems and their components can be argued as scale dependent. For a large-scale study, which customarily does not take heterogeneity in human decision into account and considers agricultural production systems as a 'black-box', such distinction can be made. At lower scale, however, where we most often interested in interventions and within and between systems interactions are much more important and cannot be ignored. For example, a farm located in one of the livestock based systems in-Jaisalmer villages (West Rajasthan), having access to ground water or be able to harvest rain water, maximize their income through integration of crop and livestock. In another scenario a farm in the same village having no access to these resources may be compelled to depend on livestock management [e.g. common property resources (Jodha 1986)] and off farm labour. As such, agricultural landscapes in the study areas are understood as mosaics of smaller interacting systems (Haileslassie et al. 2011).

2.2.2. Analytical framework

For a consistent flow of information, primarily, analytical framework depicted on Figure 1 was developed. The framework proposes interrelated focus areas (structure, enabling environment, system changes, system functions and feedback) in analysing agricultural system. In line with this, first we characterize how the current agricultural production systems, in the study areas, are structured by showing key system components and their major interactions (e.g. Haileslassie and Craufurd, in press). Secondly we discuss the dynamic of key operational/enabling resources taking land holding and LULCC as an example and demonstrate how this influences the trajectories of agricultural system intensification and what it implies for agricultural research. In fact, the impacts of operational resources on agricultural production systems are not liner: there are interactions with exogenous forcing agents such as climate and demographic forces. Examples of these relationa are also highlighted.

Changes in agricultural production systems, in turn, influence the diversity and landscape of livelihood outcomes and agricultural production systems sustainability. Then, thirdly, key indicators of sustainability [e.g. stability and trends of material outputs and environmental health (e.g. soil nutrient stock and water)] were considered to illustrate whether the enduring intensification trajectories are sustainable or not and where agricultural system research should focus to meet the features of sustainable agricultural production.

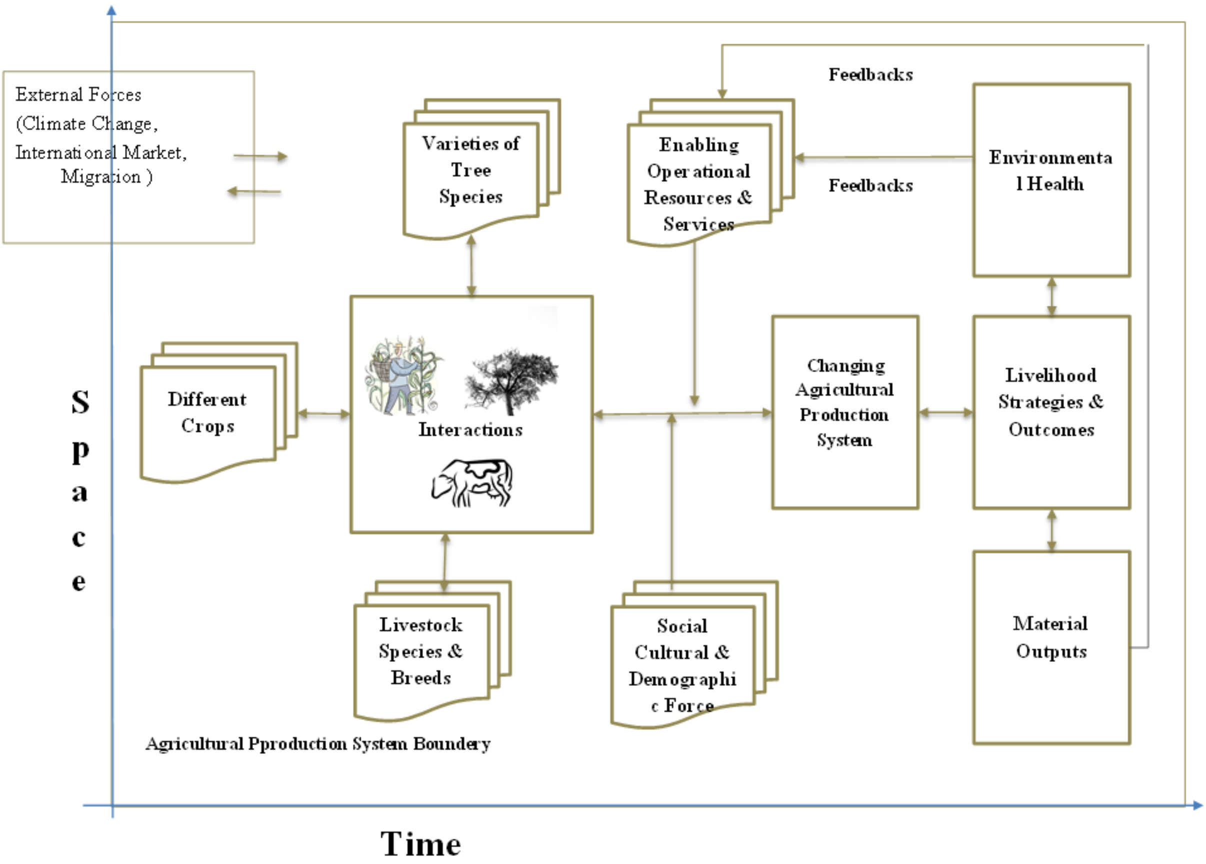

Figure 1: A simplified analytical framework illustrating agricultural system components driving factors, livelihood outcomes and feedbacks: synthesized from FAO (1997) and Rufino et al., (2006).

3. The structure of agricultural production systems

3.1. Agricultural production systems in arid eco-systems of West Rajasthan

Crop or livestock based mixed crop-livestock production systems are major sources of livelihood in arid ecosystems of west Rajasthan. Jodha (1986) described the agricultural systems in western Rajasthan as crop and livestock based and emphasized the comparative advantage livestock farming enjoys over crop farming. Census data and discussion with farmers indicates that small ruminants [sheep (*Ovis aries*), goat (*Capra hircus*)] based crop-livestock production system is the main traditional system in the western Rajasthan (e.g.

Jaisalmer and Barmer). Distinct features of this system includes low (~<250mm) and erratic rainfall, and herd management that involves seasonal or permanent mobility within and between districts in search of feed and market. Here along the West-East rainfall gradient, crop [pearl millet (*Pennisetum glaucum (L.) R. Br.* , Cumin *(Cuminum cyminum (L.)* and mustard (*Brassica juncea (L.)*] based large ruminant [cattle (*Bos indicus)* and *(Bos taurus taurus,* buffalo (*Bubalus bubalis*)] production system are also common. Traditionally trees on permanent pasture lands in these systems are major ingredient of system structure and sources of browse for small ruminants: but their role is increasingly declining due to major conversion of range lands to crop land (Jodha 1986).

One of the major defining factors of the structure for agricultural production systems in *small ruminants based crop-livestock* (in Barmer and Jaisalmer) and *millet base crop-livestock system* (in Jodhpur) is availability of sufficient water. For example with increasing extraction of ground water there is a tendency for change in the traditional livestock herd composition. Experts also ascribe this change to increasing local and global demands for livestock products. District level census data over the last decade shows an increase in total livestock population. Buffalo became an important herd constituent along West-East rainfall gradient while a tendency to shift in composition of small ruminants was observed for the drier, more western part *(i.e. small ruminants based crop-livestock systems).* An important research issue here could be to understand as to how existing feed resources complement these evolving interests in livestock enterprises. How these dynamics in system structure does relate to vulnerability of smallholders?

3.2. Agricultural production systems in semi-arid ecosystems of peninsula India

The semi-arid ecosystems selected for this study are dominated by *groundnut based crop-livestock* (in Anatapur)*, pulses based crop-livestock* (in Kurnool) and *cereals based crop-*

livestock agricultural production systems (in Bijapur). These three production systems have one common feature: crop production plays important economic role compared to livestock and >75% is rainfed based agriculture. In response to divergent biophysical factors (e.g. soil and climate), the major structural difference among the production systems lies in cropping season, crop types and their combinations. The cropping season in *groundnut based crop-livestock* (Alfisols ~78% of the district area) systems of Anantapur is predominantly Kharif (June to October rainfall) based and is particularly groundnut (*Arachis hypogaea (L.*) dominated. It is usually intercropped with pigeon pea (*Cajanus cajan*) or sunflower (*Helianthus annuus (L.*). In addition to pigeon pea and groundnut on its Alfisol areas the *pulses based crop-livestock* systems in Kurnool district produces Rabi (post rainy season November to April) chickpea *(Cicer arietinum (L.)* on is its black soil (vertisol) areas.

Depending on soil depth, cropping seasons of the *cereal based crop-livestock* systems in Bijapur can be Kharif, Rabi or both (extended Kharif). The major field crops cultivated in the Kharif include pigeon pea, sunflower and pearl millet (*Eleusine coracana (L.*). Sorghum [(*Sorghum bicolor* (L.) *Moench*.)] and chickpea are major Rabi season crops. Both small and large ruminants are integrated into crop production in all production systems of the semi-arid ecosystems: i.e. the crop provide major feed sources while livestock recycle nutrients and provide traction services for crop production.

Between 1996 and 2007 there was a sharp increase in the total livestock population and in terms of livestock head, small ruminants became important elements of the herd (e.g. *groundnut based crop-livestock* in Anatapur). Arguably, the market driver - demand for milk - is the same for the two major system clusters (arid and semi-arid) and which is why buffaloes have increased relative to cattle (1966-2007). The overall change in structure of the system from the livestock number perspective contrasts with feed supply which farmers state as a major constraint. With an increasing decline in area and quality of grazing land, crop residues became an important feed ingredient. On the one hand, livestock compete with other biomass uses and users (e.g. conservation agriculture) but on the other hand such crop-livestock interactions are commended for their notable increases in resource use efficiencies (e.g. Haileslassie et al., 2012). A key research issue here is identifying an optimum mix of system components over spatial and temporal scales to exploit synergies and complementarities and investigating mechanisms to catch market opportunities with minimum risks to the environment.

4 Enabling resources and trajectories of system changes

4.1 Interplay of demography and operational resources: what for a system change?

Agricultural land is a key input for function of an agricultural production system and from society's point of view supply of land is perfectly inelastic, i.e. fixed in quantity. But from individual point of view, its supply is relatively elastic. Alauddin and Quiggin (2008) and Gajendra et al. (2005) suggest that the interplay among demographic factors (population growth, law of inheritance, land reform measures, rural indebtedness) and land resources are one of the major causes of changes in agricultural production system function. However empirical evidence demonstrating the major determinants among these factors is not available. Therefore population growth is invariably referred as the major driver of changes of operational land holding size (e.g. Singh 2000).

Figures 2A-F illustrate examples of trends in number of operational land holdings (by holding size) across years in the study areas. Apparently, for the observation period, there were remarkable increases in the total number of holdings in *groundnut based crop-livestock* system in Anantapur and the *cereals based crop-livestock* system in Bijapur. Similar trend was observed for holdings under marginal (<1 ha) small (1-2 ha) and semi-medium (2-4 ha) farms. Contrastingly, the number of holding size for medium (4-10 ha) and large (>10 ha) farms dropped. Although weak, the *millet based crop-livestock* system in Jodhpur and *small ruminants based crop-livestock* system in Jaisalmer showed similar trends. Perhaps the differences between the arid and semi-arid ecosystems largely depend on the areas of alternative land resources such as the availability or access to more common property resources (e.g. *small ruminants based crop-livestock*) and also to differences in the minimum areas of a holding below which a reasonable economic return is not possible.

As expected, land holding sizes reflects these changes observed in land holding number with increasing smaller holding and declining larger holdings (Fig. 3A-F). It shows a sharp drop in areas under large and medium farm holdings for *groundnut based crop livestock* system in Anantapur. In fact, this was attended by a proportional growth in total areas under marginal, small and semi-medium farms. Systems in arid ecosystem did show only mild changes in this respect. The issue here is to comprehend what these changes suggest for system function in terms of livelihood outcomes, resources use efficiencies and future options of intensification across farm typologies.

Generally fragmentation of holding is often cited as a reason for increased costs of production. Mahendra (2012) argues that marginal and small farms are labour intensive and thus, compared to large farms, the ratio of inputs to outputs is less affected. Here we argue that the efficiency of marginal farm is contextual and as intensification is gaining a momentum there will be likelihood for increasing need of external inputs and thus high probability of shift in values of ratio of inputs to outputs. For example the majority of large farmers in different parts of dryland systems have access to canal irrigation, while marginal and small farmers are most often using bore-wells or have no access to water. In this case small farm, for example with disjointed three plots, must sink three wells which are economically not feasible or alternatively buy water from adjacent farms. Irrigation might be delayed as the bore owner's own crop fields get priority for watering. Discussion with farmers, in west Rajasthan, also suggests that the bore well owners normally limit the size of land that a neighbouring farm can irrigate from their water sources. This challenges arguments regarding efficiencies of small and marginal farmers earlier.

At a point where land holding reaches a cut-off level beyond which it will neither accommodate family labour nor provide sufficient food, family members may exit that strategy and join alternatives if there are any. Most farmers have also other sources of livelihood that supports their farming until they can exit agriculture all together. A good question is whether intensification by marginal and small farmers depends on this other investment or can be generated some other way and this needs examining farm size from livelihood assets perspective and such approach will help to target systems and livelihood for priority research and development

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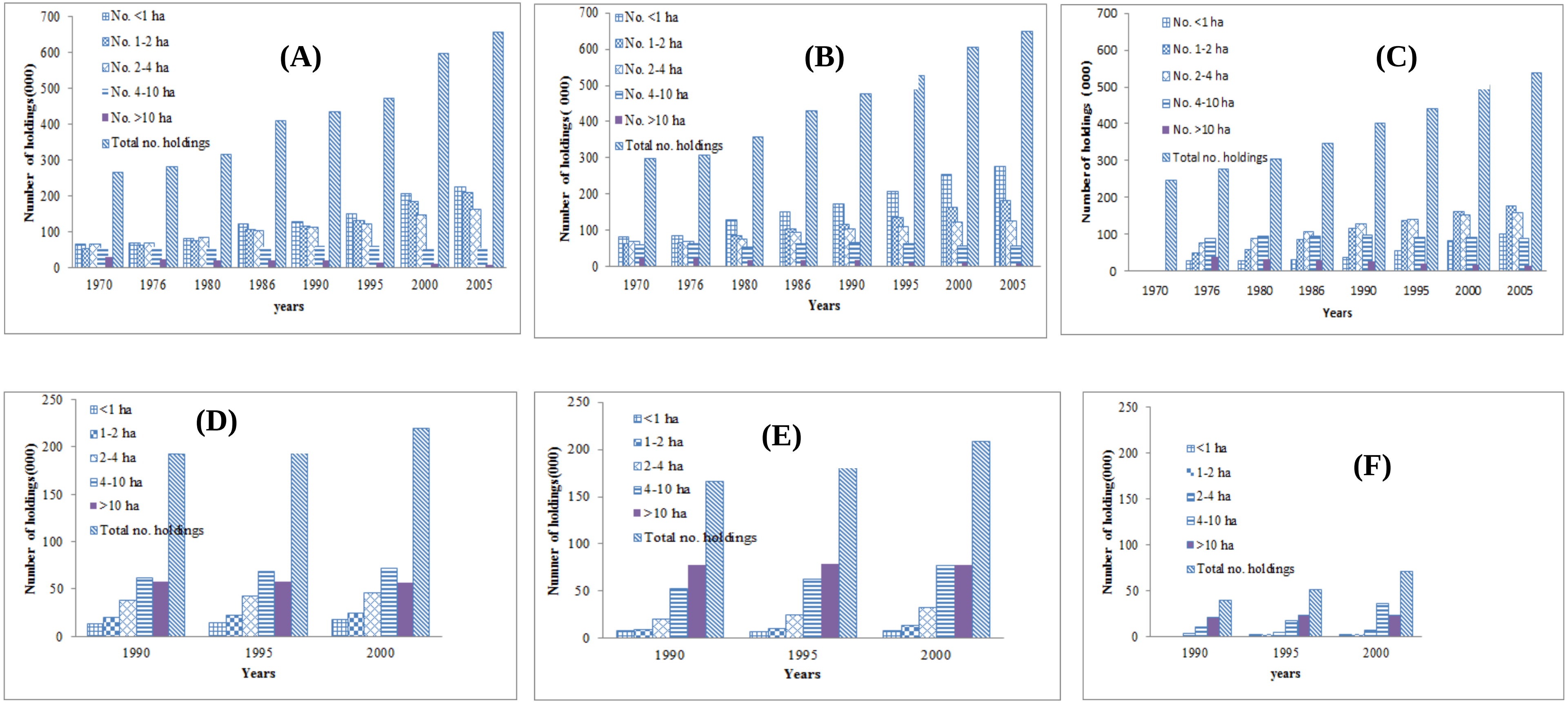

Figure 2A-F: Examples of trend in number of operational land holding by holding size across years in g*roundnut based crop-livestock* production systems in Anantapur **(A)**; *Pulses based crop-livestock* production systems in Kurnool **(B)** C*ereals based crop-livestock* production systems in Bijapur **(C)**; M*illet based crop-livestock* production systems in Jodhpur **(D)** S*mall ruminant based crop-livestock* production system in Barmer (E) and S*mall ruminant based crop-livestock* production system in Jaisalmer **(F)**

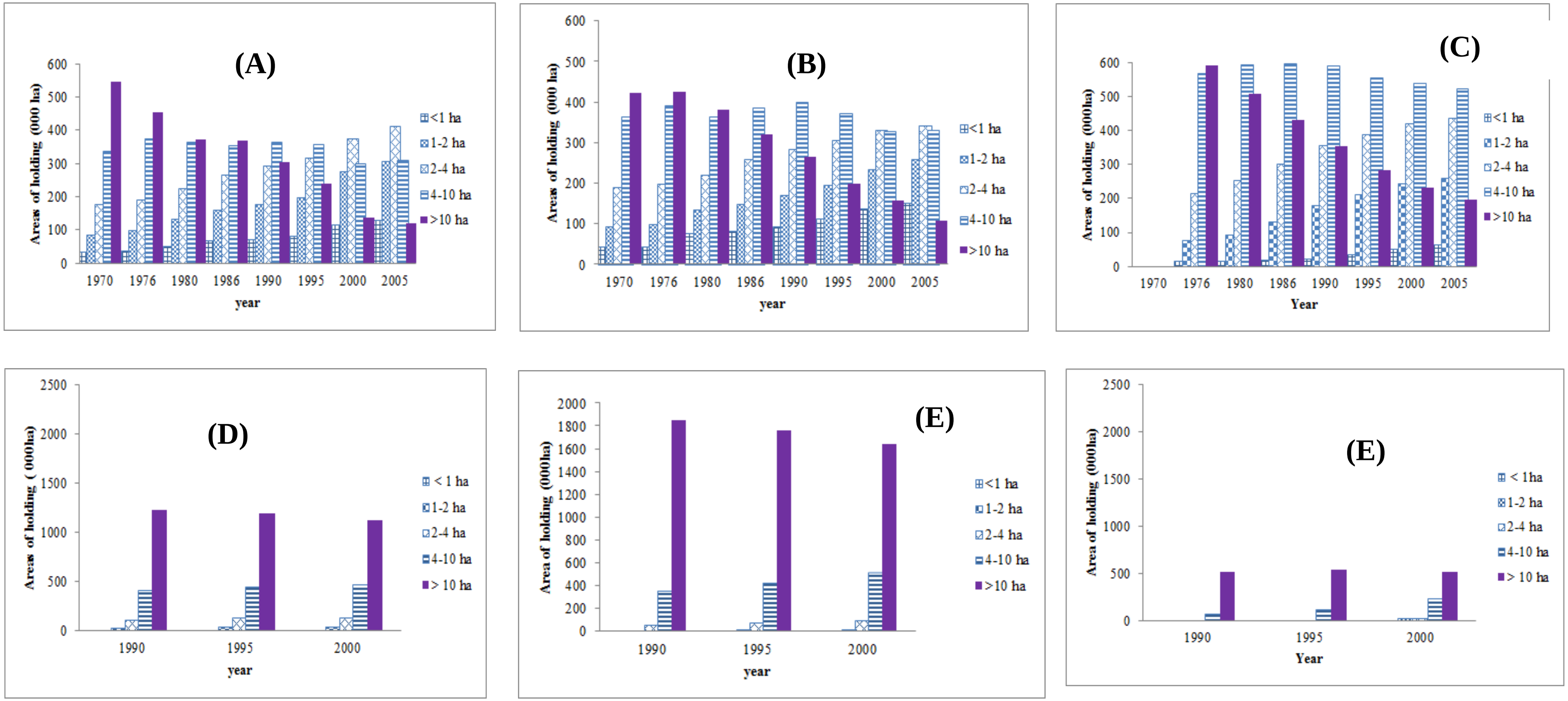

Figure 3A-F: Examples of trend in area of operational land holding by holding size in *groundnut based crop-livestock system* in Anantapur **(A)**; *Pulses based crop-livestock* production systems in Kurnool **(B)** C*ereals based crop-livestock* production systems in Bijapur **(C)**; M*illet based crop-livestock* production systems in Jodhpur **(D)** S*mall ruminant based crop-livestock* production system in Barmer **(E)** and *small ruminant based crop-livestock* production system in Jaisalmer **(F)**

4.2. **Land use and land cover changes : effects on system structure and function**

Other than population pressure agents such as climate change, international and local market and enabling environment (e.g. policy and availability of inputs like water) for alternative uses of land are frequently mentioned as an important agent of LULCC (Chaudhry et al. 2011). Regardless of the type of driving agent production systems in arid and semiarid ecosystems are experiencing a persistent LULCC and this has both environmental and livelihood implications (Chaudhry et al. 2011).

Figure 4A-B and Table 1 illustrate examples of LULCC in the study areas. In the *groundnut based crop livestock system* and *pulses based crop livestock systems*, major LULCC, during last decade, were conversion of range land to crop land. Additionally conversion from rain fed to irrigation also accounts for an important proportion. When we refer back to historical data (Figure 5), for these systems, more important changes were change in cropping pattern. For example many of the system moved clearly from traditional cereals based farming (millet and sorghum) to other crops (e.g. in Ananatpur). In absence of grazing land, quality of feed resources from the new crop determines the feed demand and supply. While economically these changes can be efficient, the dominant mono cropping (e.g *ground nut based crop livestock system*) practices can be debateable: as it damages the soil ecology and increases crop vulnerability to opportunistic insects. The result is a more fragile ecosystem with an increased dependency on pesticides and artificial fertilizers.

Quite interesting here are the negligible areas of grazing lands in both livestock and crop dominant systems and a significant conversion of range lands and waste lands to crop lands. Generally wasteland and range lands are common property resources ((Jodha, 1986) and they are important livelihood sources for landless community who completely dependent on livestock.

Table 1. Examples of Land Use Land Cover Changes (LULCC) between 2000 and 2010 for ground nut based crop livestock system in Anantapur and pulses based crop livestock system in Kurnool

	Extent of changes (ha)	
Types of LULCC	Kurnool	Anantapur
Rangelands to Rainfed-single crop	15,425	27,300
Rangelands to Irrigated- single crop/double crop	1,088	556
Irrigated-single crop to others	1,725	931
Irrigated-single crop to Irrigated double crop	11,813	450
Rainfed-single crop to Irrigated single or double crop	8,213	1,113
Rainfed-singe crop to others	19,125	7,081

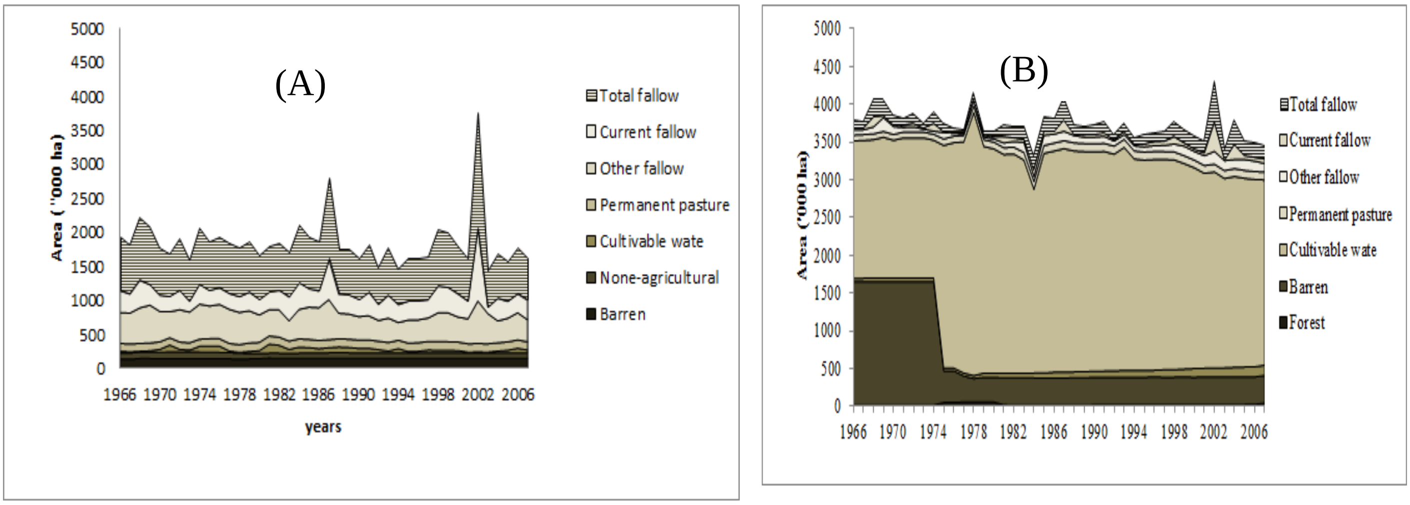

Figure 4 A-B: LULCC in *millet based crop-livestock* production systems in Jodhpur **(A)** and S*mall ruminant based crop-livestock* production system in Jaisalmer **(B)**

In arid areas it is in response to the need for unrestricted mobility of livestock that the common property resources or common access resources emerged as the dominant forms of resources ownership and usage by village and communities in this region (Jodha, 1986). In view of these trends it can be argued that these changes restrict landless community to access these resources for their livestock grazing (Jodha 1986). On the other hand this system-transition is an opportunity for these individuals who are enjoying increased in productivity as the results of improved input (irrigation and fertilizer) at least in the short term.

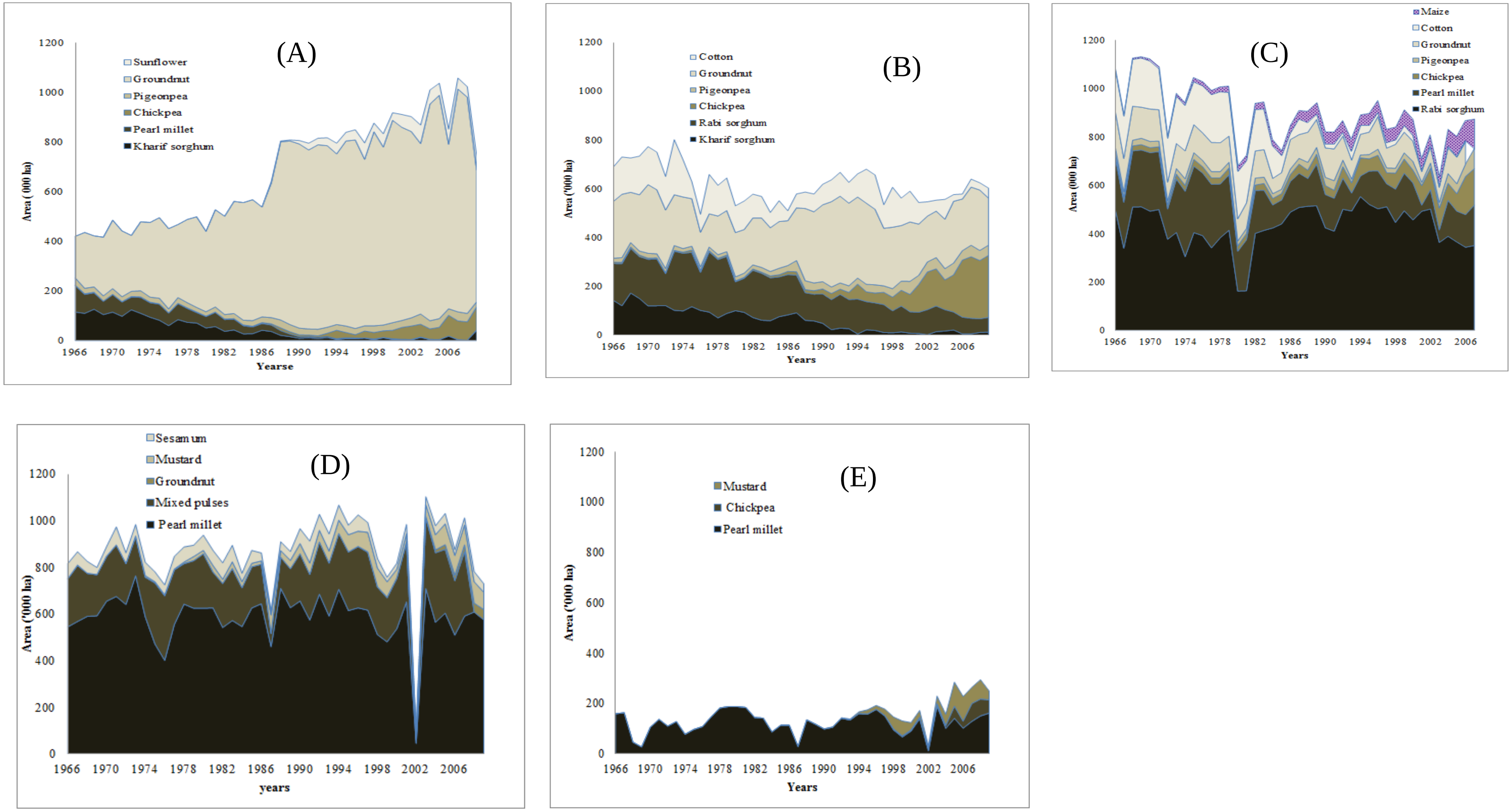

Figure 5A-E: Examples of trends in cropping pattern in *groundnut based crop-livestock system* in Anantapur **(A)**; *Pulses based crop-livestock* production systems in Kurnool **(B)** C*ereals based crop-livestock* production systems in Bijapur **(C)**; M*illet based crop-livestock* production systems in Jodhpur **(D)** and S*mall ruminant based crop-livestock* production system in Jaisalmer **(E)**

5. Livelihood outcomes: quest for features of sustainable agriculture

Apparently intensification of agricultural production has improved food which is one of the livelihood outcomes. Figure 6A-E depict trend in major crops productivity across years in across the studied dryland production systems. Apparently in the *groundnut based crop livestock system*, *pulses based crop livestock system* and *cereals based crop-livestock system* yield for major cereals has increased. While for the millet based crop livestock system and small ruminants based millet system the yield for major cereal crop tends to stagnate. Improvements in productivity of other crops were not spectacular for all systems. For example the productivity of groundnut in system where it cover major area, tends to decline/stagnated.

Quite interesting issue revealed from Figure 6 was also the huge intersystem and intrasystem variation of productivity. A coefficient of variation (CV) for major crops across and system ranges between 24 and 140% and the highest value was for cereals in the small ruminant based millet system. Perceptibly the intersystem variation can be explained by the differences in biophysical factors. Intrasystem disparity across years, as illustrated by wide range of CV, is an indicator of lack of system stability and therefore its poor sustainability (FAO 1997). The point here is to understand as to what drives such instability and decline in productivity of some of these crops and what research can deliver to mitigate impacts.

A closer monitoring of some of the environmental sustainability indicators (e.g. soil nutrient) suggest that years of cultivation and unbalanced nutrient input depleted soil nutrient stocks in the mixed crop livestock systems of dryland ecosystems. For example Haileslassie et al. (2012) reported that about 79% of farmers' fields in semi-arid areas in Karnataka are deficient in organic carbon (OC) and 74% of the fields showed deficiency in S. Fields used for pulses were the most deficient in P (45.28 % of the fields) and Zn (60.4% of the fields), while B deficiency was observed on 64.10% of fields used for oil crops. In fact this is an interaction of combination of factors: low input to counter balance the nutrient lost through erosion, leaching, and product outputs. The authors argue that the effect of such dwindling ecosystem production services provision goes beyond crop production. It affects livestock development mainly in terms of low feed availability; low feed quality associated with multi-nutrient deficiencies. When the historical LULCC, that consistently pushes the grazing land, is taken into account this, in fact, is ‘a tip of an iceberg’. Future system research needs to consider nutrient as an interface of system components (i.e. soil-plant-livestock).

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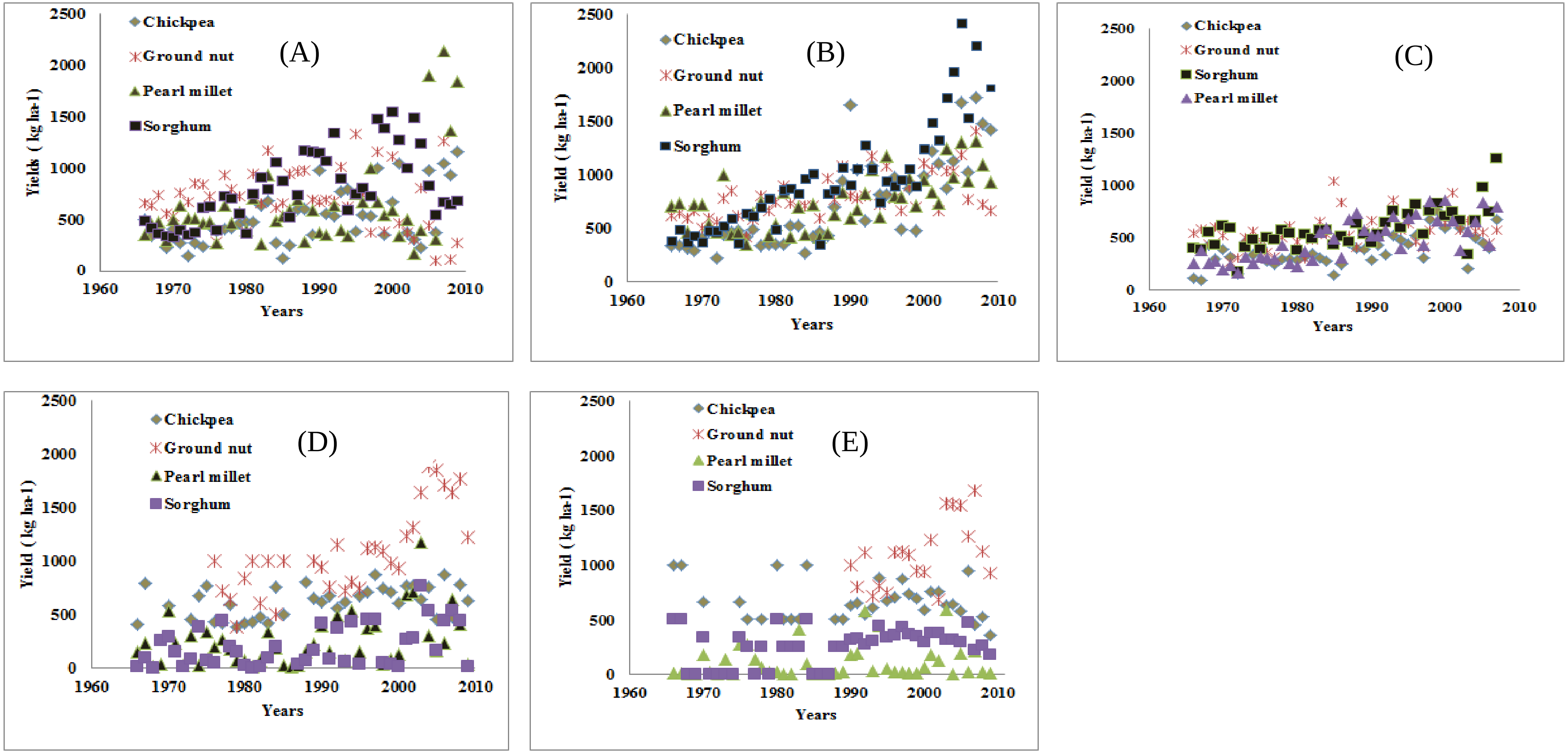

Figure 6A-E: Examples of trend in yields of selected dryland crops in *groundnut based crop-livestock system* in Anantapur **(A)**; *Pulses based crop-livestock* production systems in Kurnool **(B)** C*ereals based crop-livestock* production systems in Bijapur **(C)**; M*illet based crop-livestock* production systems in Jodhpur **(D)** and S*mall ruminant based crop-livestock* production system in Jaisalmer **(E)**

Another important areas of concern related to environmental health is the trends in ground water exploitation in the dryland ecosystems. Practices of traditional rain water harvesting (e.g. Khadien) are declining due to limiting biophysical factors or decline of institutions that have nurtured them, or have lost their relevance in the modern day context (Agarwal and Narain 1997). Nearly a third of India's groundwater blocks were defined in 2004 as critical, semi-critical or over-exploited (Rodel et al., 2009)., Similarly in the study systems, what is more often emerging as challenges to a sustainable water use, is the ground water over exploitation. Analysis of public ground water data for the study sites shows over exploitation of ground water in many areas (e.g. *Cereals based crop livestock systems* in Bijapur). Discussion with farmer suggests that a remarkable proportion of the bore wells is drying out (Ananatapur, Kurnool and Bijapur) and thus substantiate the empirical evidences. Number of scholars ascribes the trend to imprudent use of water (Rodel et al., 2009). In general this has a negative feedback to the enabling resources frontier and thus complicating prediction of future directions to where agricultural production system evolves.

6. Sustainable trajectory for agricultural development: the role of research

Despite lack of a comprehensive yield gap assessment (integrating nutrient, water, variety and values of synergies between system components) many literature illustrates huge crop yield gaps in drylands and an example is provided on (Table 2). These are evidence revealing opportunities to improve the performances of agricultural development both in terms of: environmental indicators and livelihood outcomes. Apparently if water, the major production limiting factor in semiarid and arid ecosystem, was included in the analysis these yield gaps could have been even higher.

Table 2: Examples of nutrient and variety limited yield gaps arid ecosystems

District	Rain fall (mm yr^{-1})	Yield (kg ha^{-1})			
		Farmers practice	Farmers practice + improved varieties	Balanced nutrient + improved varieties	SED (5%)
Tonk	288	1150	1930	3160	280
Udaipur	570	2530	3090	6320	590
Mean of 5 Districts		1810	2550	4320	

Similarly examining livestock performances in terms of milk yield and weight gain under different feeding regimes demonstrate disparity between farmers' practices and improved management. Haileslassie et al. (2011) illustrated a significant increase in livestock products and services when feed sourcing (good quality feed), feeding techniques and livestock management are improved. When these feed sources are water productive the impact could be even multiple: improves livelihood and saves water and therefore ensures positive feedback to the enabling resources.

In summary there are key questions that a system research should ask and pursue answers for it, to contribute towards efforts to achieve sustainable agricultural production in dryland. These include:

- What is the nature and the level of vulnerability and potentials of the different production systems
- What are respective technical (e.g. components mix) and institutional measures (e.g. for common property resources management) needed to increase resilience and close the yield gaps and what are the potential trade- offs?
- Which biophysical and social landscapes (e.g. marginal, large farmers) should be targeted and what respective incentive measures are needed to enable farmers to pursue judicious uses of resources?

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Reference

Agarwal, A.; Narain, S. 1997. Dying Wisdom: Rise and Fall of Traditional Water Harvesting Systems, Centre for Science and Environment. New Delhi, India: Centre for Science and Environment.

Alauddin, M.,and Quiggin, J. 2008. Agricultural intensification, irrigation and the environment in South Asia: Issues and policy options. Ecological Economics 6 5: 1 1 1 – 1 2 4

CAZRI 2009. Trends in arid zone research in India Eds (Amal kar, B.K. Garg, M.P. Singh and S. Kathju) 481 pp

Chaudhry P., Bohra K. N., Choudhary, K. R. 2011. Conserving biodiversity of community forests and rangelands of a hot arid region of India Land Use Policy Land Use Policy 28: 506–513

CRIDA (2011. VISION 2030, Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, India, pp:31

FAO 1997. Farm Management for Asia: a Systems Approach. Farm Systems Management Series 13. Food and Agriculture Organization of the United Nations. Rome

Gajendra S. Niroula, Gopal B. Thapa 2005. Impacts and causes of land fragmentation, and lessons learned from land consolidation in South Asia Land Use Policy 22 (2005) 358–372

Haileslassie A. Blümmel M., S.P.Wani, K.L. Sharawat, G. Pardhasaradhi, Anandan Samireddypalle 2012. Impacts of extractable soil nutrients on the feed quality traits of crop residues in the semiarid rainfed mixed crop-livestock farming systems of Southern India. Journal of Environment, Development and Sustainability DOI 10.1007/s10668-012-9403-3

Haileslassie, A. Blummel, M., Clement, F., and Ishaq, S., Khan, M.A., 2011. Adapting livestock water productivity to climate change. International Journal of Climate Change Strategies and Management Vol. 3: 156-169

ICARDA 2012. Integrated Agricultural Production Systems for the Poor and Vulnerable in Dry Areas. A Proposal Submitted to the CGIAR Consortium Board.

Ison, R., L., Maiteny, T., P., and Carr, S. 1997. Systems methodologies for sustainable natural resources research and development. Agricultural Systems 55:257-272

Jodha, N.S. 1986. The decline of common property resources in Rajasthan, India. Pastoral Development Network. Network Paper 22c. Overseas development Institute, London

Mahendra, Dev, S. 2012. Small Farmers in India: Challenges and Opportunities. Indira Gandhi Institute of Development Research, Mumbai WP-2012-014

Mortimore, M., Anderson, S., Cotula, L., Davies, J., Faccer, K., Hesse, C., Morton, J., Nyangena, W., Skinner, J., and Wolfangel C. (2009). Dryland Opportunities: A new paradigm for people, ecosystems and development, IUCN, Gland, Switzerland, 86p.

Rodel, M., I. Velicogna, and J. S. Famiglietti. 2009. Satellite-based Estimates of Groundwater Depletion in India. Nature 460:999-1002.

Rufino, C.,M., Rowe, C., E., Delve, J.R. Giller, E.K. 2006. Nitrogen cycling efficiencies through resources poor African crop- livestock systems. Agriculture Ecosystem and Environment 112:261-282.

Singh R.B. 2000 . Environmental consequences of agricultural development: a case study from the Green Revolution state of Haryana, India. Agriculture, Ecosystems and Environment 82: 97–103

White, D.,H, , Howden, M., S. and Nix, A.,H. 1996. Modelling agricultural and pastoral systems under environmental change. Economical modelling 86:213-217

Wani, S.P., J. Rockstrom and T. Oweis. 2009. Rainfed agriculture: unlocking the potential. Comprehensive Assessment of Water Management in Agriculture. CABI, Wallingford, United Kingdom.