Annals of Arid Zone 51(3&4): 1-8, 2012 (Proof)

Challenges in the Dryland Agricultural Production Systems of South Asia: Research Priorities and Strategies

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Abstract: Dryland (arid and semi-arid) ecosystems occupy more than 41% of global land area and are home to 2.5 billion people. More than 50% of South Asia's dryland ecosystems are located in India. Drylands contribute about 40% of the total food grain production and support two thirds of livestock population. Despite these important roles, agricultural production systems in the drylands are facing numerous challenges that threaten their resilience and future sustainability. This paper demonstrates some of the challenges and draws implications for priorities research and strategies. As an example, we selected districts representing different dryland agricultural production systems in western Rajasthan, Andhra Pradesh and Karnataka states of India. First we focus on the present performance of the major agricultural production systems by highlighting their structure (e.g. farm size) and key indicators of their function and state (e.g. production). We discuss major problems in terms of their cause and effect on these systems' structure and function. Finally we synthesize lessons as to where system research should focus and what strategies are needed to produce a more resilient and dryland sustainable agricultural production system in in the future.

Key words: Sustainability, livelihood, resilient production system, land use, land cover, nutrient depletion, cropping system.

In response to increasing vulnerability and declining productivity of agricultural production systems in the drylands, advocacy to improve their management has been more prominent recently in international research debates, and the establishment of a Dryland Systems CRP is evidence of this. Global dryland (arid and semi-arid) ecosystems support the livelihood of more than 2.5 billion people and are centers of origin and diversity of many domesticated and wild plant and animal species (ICARDA, 2010; Mortimore *et al*., 2009).

In view of their extent (area) and current intensive use, dryland ecosystems and their associated agricultural production systems in South Asia is of importance. For example, in India alone drylands contribute about 40% of the total food grain production and support two thirds of the livestock population.

In efforts to satisfy the livelihood outcome of the continuously growing human population, a significant proportion of dryland agricultural production systems have experienced changes related to climate and population - most often with a number of adverse environmental consequences (Singh, 2000). Nonetheless, a major part of the dryland agricultural production systems still offer opportunities to satisfy livelihood outcomes and safeguard the environment; as illustrated by successful programs to reduce crop and livestock yield gaps (Wani *et al*., 2009; CRIDA, 2011).

Agricultural production systems can be analyzed in terms of structure (i.e. system components and their spatial and temporal organization farm size, extent of degradation, land use change, etc.), function (i.e. crop and livestock production, biodiversity, water-use) and state (stable or undergoing change). Systems analysis also needs to be considered across scales to recognise the importance of interactions between components.

The future research focus and strategies that can nurture agricultural production systems needs to be built on a systematic diagnoses of these problems in terms of their short- and long-term effects on the system structure, function and state, and how they could be modified or replaced to achieve higher level of performances.

The objectives of this paper were to illustrate some of the major changes and challenges in

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agricultural production systems in drylands today and there from draw implications for research priorities and strategies.

Approaches

Study areas and data sources

Study areas were chosen based on vulnerability maps (NRA/CRIDA, 2012), available geospatial information [rainfall, population, soil, etc. (ICARDA, 2010)], and expert opinion. The most vulnerable dryland districts in India include parts of Rajastan. 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 based crop-livestock system in Jodhpur, were selected. As a cluster representing dryland systems in semi-arid ecosystems in peninsula India, systems including cereal based crop-livestock system in Bijapur (Karnatka) and ground nut 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, land use and population. Additional data on key environmental indicators were acquired from district contingency plans. Expert opinion and discussions with farmers in these districts helped to triangulate information from the different sources mentioned above.

Analytical steps

In the present study we compared different systems/regions and assessed the comparative performance over different periods of time and key problems embedded therein. In these kinds of exercises one should use assessment criteria based on the relationship between structural and functional components of a system. In this kind of comparative study, the focus structural and functional elements depend on the availability of data, scale and potential audience. This study focuses on large (district) scale - and key indicators. First we elaborate system structures in the study areas and then illustrate system components by focusing on crop, livestock and trees. Secondly, we highlight system functions in terms of key inputs (e.g. access to land, land use), outputs (e.g. productivity) and show how input: output relations adversely affected or contributed to the livelihood outcomes and therefore the state of the system. In presenting these structures, functions and state of the systems we elaborate inherent or human induced problems in each of these. We then discuss how they may affect future sustainability and ask what research could deliver for a more resilient and sustainable agricultural production system in the drylands.

The Structure of Agricultural Production Systems

Agricultural production systems in arid eco-systems of West Rajasthan

Crop or livestock based mixed crop-livestock agricultural production systems are major source of livelihood in the study areas. Jodha (1986) described the agricultural system 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 include low (~<250 mm) 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*. 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 demand 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.

Agricultural production systems in semi-arid ecosystems of peninsula India

The semi-arid ecosystems 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. 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 or sunflower. 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 (*Cajanus cajan*), sunflower (*Helianthus annuus (L.*) 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 systems 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. The degree of integration varies among systems and mainly depends the level of intensification.

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 a livestock number perspective contrasts with feed supply which farmers state is a major constraint. With an increasing decline in area and quality of grazing land, crop residues have become 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 and investigating mechanisms to catch market opportunities with minimum risks to the environment.

Interplay of Land and Demographic Factors: Implications for System Function

Land holding number and size vis a vis system function

Agricultural land is an important 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

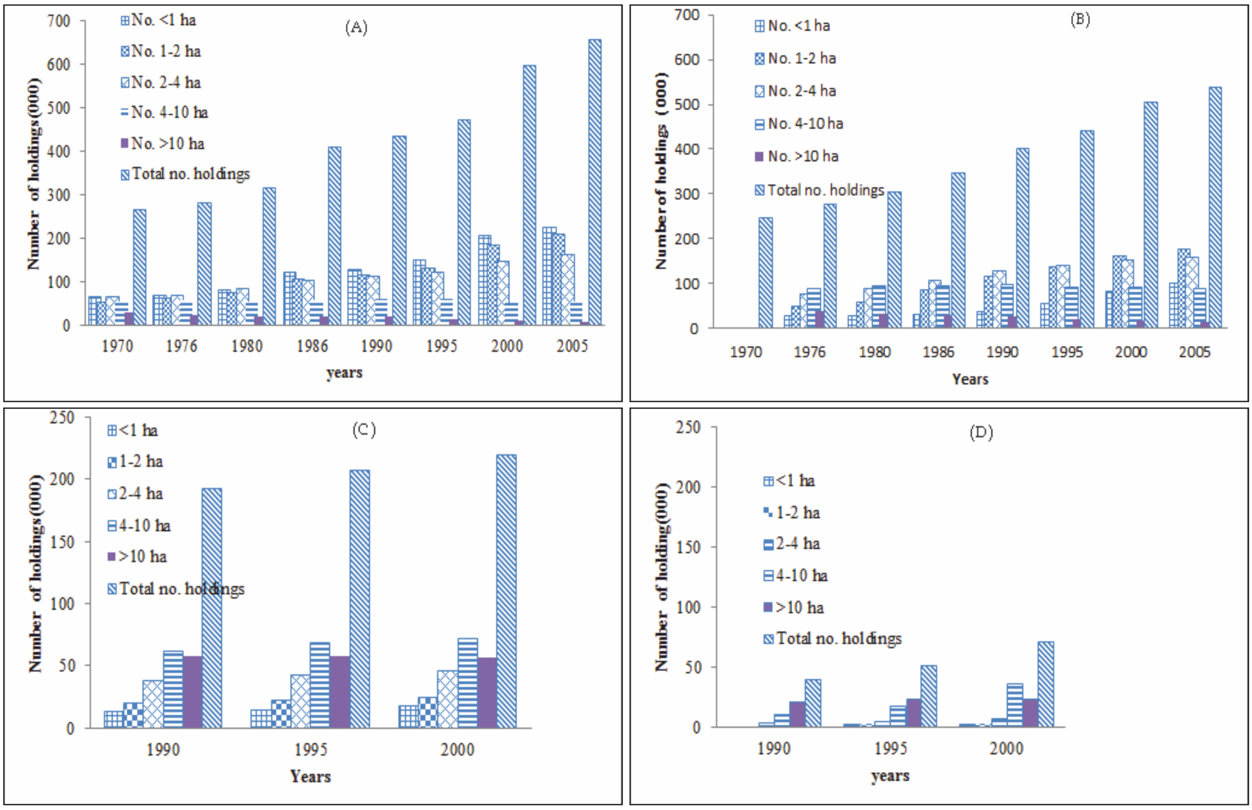

Fig. 1. A-D. Examples of trend in number of operational land holding by holding size across years in groundnut based crop-livestock production systems in Anantapur (A); cereals based crop-livestock production systems in Bijapur (B); millet based crop-livestock production systems in Jodhpur (C) and small ruminant based crop-livestock production system in Jaisalmer (D).

is not available. Therefore population growth is invariably referred as the major driver of changes of land holding size (e.g. Singh, 2000).

Figure 1 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 was a remarkable increase 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 had 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 reflect these changes in land holding number with smaller holding and few larger holdings (Fig. 2). It shows a sharp drop in areas under large and medium farm holdings for groundnut based crop livestock system in Anantapur. In fact, attended by a proportional growth in areas of marginal, small and semi-medium farmers. Systems in arid ecosystem did show only mild change in this respect. The issue here is to comprehend what this implies for system function in terms of outputs and resources use efficiencies across farm typologies.

Fragmentation of holding is often cited as a reason for increased costs of production. Mahendra (2012) argues that marginal and small farms are labor intensive and thus the ratio of input to outputs is less affected

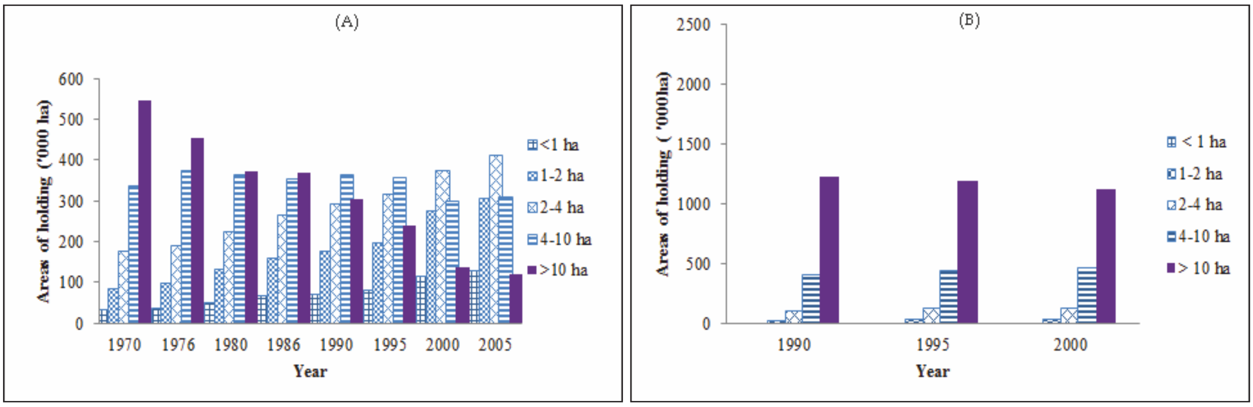

Fig. 2. A-B. Examples of trend in area of operational land holding by holding size in groundnut based crop-livestock system in Anantapur (A); millet based crop- livestock system in Jodhpur (B).

compared to large farms. In reality, however, the majority of large farmers 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 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. In fact when this is considered there is a high probability of shift in values of input to output ratio for marginal and small farmer.

Gajendra *et al*. (2005) and Mahendra (2012) argue that these vulnerable to such kind of system structure and function changes are the marginal and small farmers who, after all, could not afford these costs and thus may exit from these enterprises. But from the general rural livelihood perspective land is only one form of livelihood asset and therefore the contemplation related to vulnerability of small and marginal farmers can be a simplification of the complex livelihood settings and thus needs further research work. In fact there is one general truth: diminishing holding size has a cascading effect and discussion with farmers in the study areas underscores that agricultural labor supply has became one of the major impediments of agricultural production process.

In conclusion, at a point where land holding reaches a cut-off level beyond which it will neither accommodate family labor nor provide sufficient food, family members must exit that strategy and join alternatives if there are any. Two challenges are facing farmers in this respect: extending the cut-off point through intensification and finding alternatives livelihood to their family. 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 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.

Land use and land cover changes: Effects on system structure and functions

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 drivers of Land Use Land Cover Change [LULCC (Chaudhry *et al*., 2011)] and the structure and function of agricultural production system. Regardless of the type of driving agent, production systems in arid and semi-arid ecosystems are experiencing a persistent LULCC (Chaudhry *et al*., 2011).

Figure 3A-B illustrate examples of LULCC in the study areas (in millet based crop-livestock production systems in Jodhpur (A) and small ruminant based crop-livestock production system in Jaisalmer (B). Quite interesting here is the negligible area 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

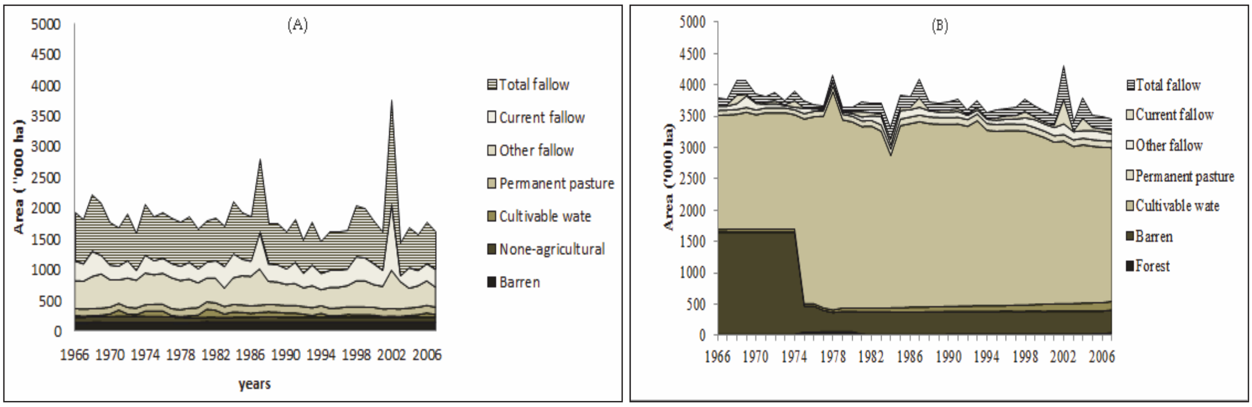

Fig. 3. *A-B. Examples of LULCC across years in millet based crop-livestock production systems in Jodhpur (A) and small ruminant based crop-livestock production system in Jaisalmer (B).*

(Jodha, 1986). And they are important livelihood sources for landless community segments who are mainly dependent on livestock. 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 we argue that these changes restrict landless community to access these resources for their livestock grazing (Jodha, 1986). On the other hand this transition in system structure created an opportunity for these individuals who are enjoying increased in productivity as the results of improved input (irrigation and fertilizer) at least in short term. Apparently change in structure of the system (e.g. land use, cropping pattern Fig. 4 A-B) has improved its function (e.g grain production) but not without price. For example a closer monitoring of some of the environmental sustainability indicators suggest that years of cultivation and unbalanced nutrient inputs depleted soil nutrient stocks in the mixed crop livestock systems in arid and semi-arid ecosystems

For example Sahrawat *et al*. (2007) and 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 farmers' fields showed deficiency in S. Fields used for pulses were the most deficient in P (45% of the fields) and Zn (60% of

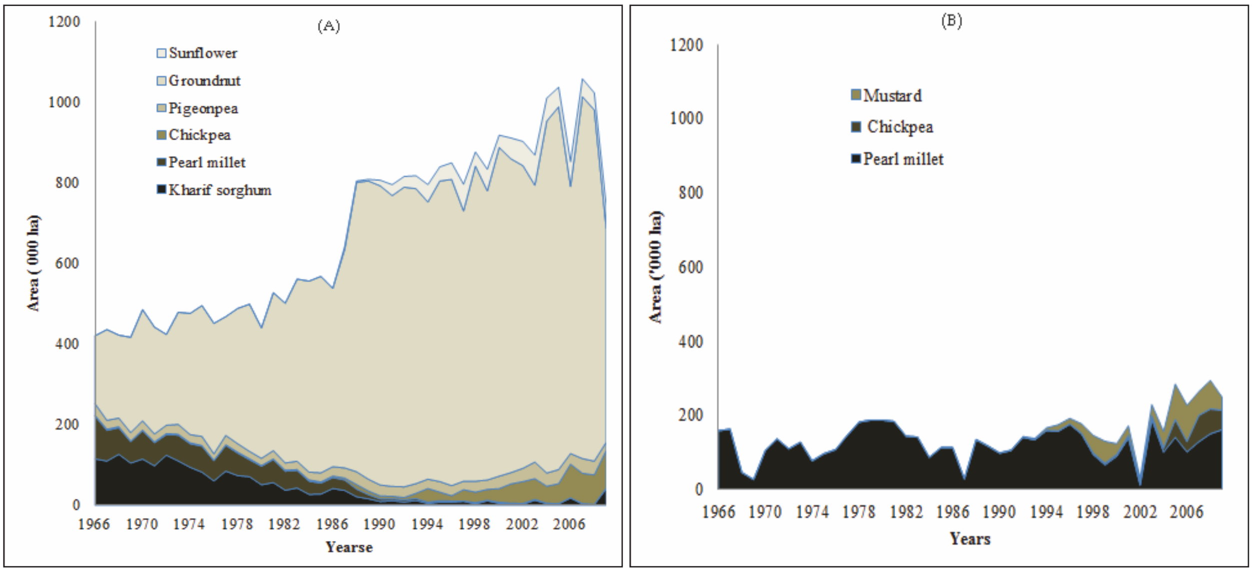

Fig. 4. *A-B. Examples of trend in cropping pattern across years in groundnut based crop-livestock production systems in Anantapur (A); small ruminants based crop-livestock production systems in Jaisalmer (B).*

the fields), while B deficiency was observed on 64% of the fields used for oil crops. In fact this is interplay of combination of factors: low input to counter balance the nutrient lost through erosion, leaching, and product outputs. The authors argue that the effects 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 is in fact 'a tip of an iceberg'.

Despite huge seasonal and regional variations, India should have ample water for agricultural, industrial and household use. But what is more often emerging as a challenge to a sustainable water use in these systems, is the ground water over exploitation (e.g. Rodel *et al*., 2009). Analysis of public ground water data for the study sites shows over exploitation of ground water in many areas of arid and semi-arid ecosystems. Discussion with farmers suggests that remarkable proportions of the bore wells are drying out (e.g. in groundnut based crop-livestock, pulses based crop-livestock and cereals based crop-livestock systems) and thus substantiate the empirical evidences. 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.

Sustainable Trajectory for Agricultural Systems: Research Issues and Strategies

Despite lack of a comprehensive yield gap assessment (integrating nutrient, water and variety) much literature illustrates a large crop yield gap in arid and semi-arid production systems. Similarly examining livestock performance in terms of milk yield and weight gain under different feeding regimes, demonstrate disparity between farmers' practices and improved management (e.g. Blummel *et al*., 2010). 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 greater: improved livelihood and saved water and therefore ensuring positive feedback to the enabling resources. Technologies such as drip and sprinkler irrigation are widely reported to be profitable and water saving both for marginal, small, and medium and large farms. These are evidence revealing opportunities to improve the function of dryland agricultural production system both in terms of: environmental indicators and livelihood outcomes.

The one of the major limitations, to get these technologies and ideas on farm and thereby straighten intensification trajectory in a way to meet features of sustainable agricultural production, lies not only in where research should focus, but also how research engages the eventual users and promoters.

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 are the best strategies to involve and reach diverse partners and add value to local efforts?
- 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?

Acknowledgement

This paper presents synthesis of findings from inception phase of the CGIAR-dryland agricultural production and livelihood research in South Asia. The authors are grateful to the dryland system CRP for financial support.

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