# Research and Developmental Issues in Dryland Agriculture

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## 1 Introduction

Drylands cover more than 40 % of the terrestrial land surface and are not on the margins of the 'economically productive' world; rather, they are vast areas often lying right in the center, and contribute about 40 % to global net primary productivity (Grace et al. 2006; GLP 2005; MEA 2005). Dryland ecosystems are extremely diverse and include the Mediterranean systems, the cold deserts of Chile and Mongolia, the Sahel and Sahara of Africa, the Arctic Circle, and the high altitude drylands of Afghanistan and Iran (Fig. 1). More than two and a half billion people (40 % of Africans, 39 % of Asians and 30 % of South Americans) inhabit of dryland areas, which is more than 38 % of the world population (GLP 2005; MEA 2005).

The term 'dryland agriculture' is often used interchangeably with 'rainfed agriculture'. However, rainfed agriculture is synonymous with non-irrigated agriculture which includes rainfed drylands and rainfed wetlands. Therefore, dryland agriculture is component of rainfed agriculture (Stewart et al. 2006).

Drylands are defined in terms of water deficit, as areas where mean annual precipitation is less than half of the potential evapotranspiration (FAO 1993, 2004). These areas include hyper-arid, arid, semi-arid and dry sub-humid areas (FAO 2004) and receive less than 200 mm, less than 250 mm, 200–500 mm of total annual rainfall and 500–700 mm total annual rainfall, respectively (Table 1, FAO 2004). In

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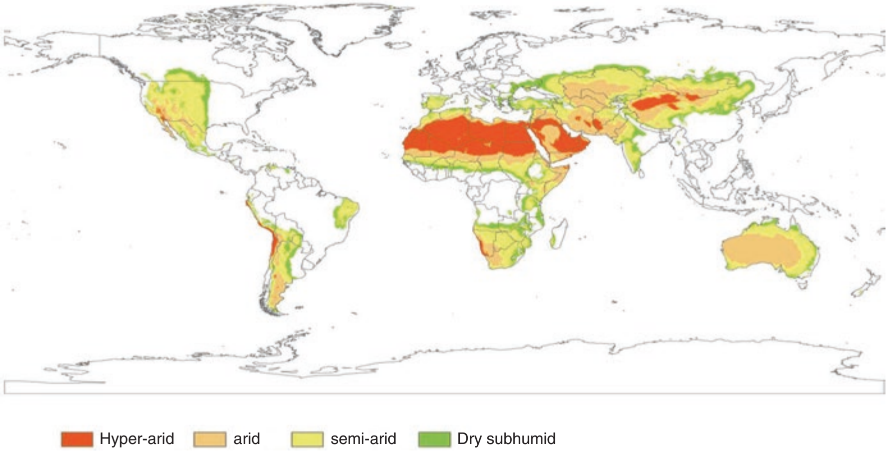


**Fig. 1** Global distribution of drylands (Source: USAID (2014))

**Table 1** Major indicators and characteristics of drylands

| Climate type | [a]Aridity index | Average annual rainfall (mm) and variability | Growing season (days) and typical crops | Pastoral systems | Examples of biomes |
|---|---|---|---|---|---|
| Hyper-arid | < 0.05 | 150 mm | 0 days (unless irrigated) | Very limited, fodder available only for short periods (<4 months) | Desert |
| | | Inter-annual variability 100 % | No rainfed crops | | |
| Arid | 0.05–0.20 | 150–250 mm | < 60 days | Marginal pasture, available for short periods. Mainly small stock and cattle in transhumance systems | Desert, xeric shrub-land, desert scrub |
| | | Inter-annual variability 50–100 % | No rainfed crops | | |
| Semi-arid | 0.20–0.50 | 250–500 mm | 60–119 days | Large and small stock | Savanna, steppe |
| | | Inter-annual variability 25–50 % | Bulrush millet, sorghum, sesame | | |
| Dry sub-humid | 0.50–0.65 | 500–700 mm | 120–179 days | Large and small stock | Open woodland, savanna, steppe |
| | | Inter-annual variability < 25 % | Maize, bean, groundnut, pea, barley, wheat, tef | | |

Source: FAO (2004)
[a]Precipitation (P)/Potential evapotranspiration (PET)

addition to water deficit, drylands are characterized by erratic distribution with common periodic droughts (Zurayk and Haidar 2002). Dryland soils, characterized by moisture deficit, and low levels of soil organic matter and biological activity, often havepoor fertility (USAID 2014). When inappropriately used for agriculture, these soils are prone to rapid fertility loss, erosion, desertification, and salinization.

Drylands span all continents (Fig. 1) in areas where rainfall is highly variable, droughts are common and water is the principal limiting factor for agriculture. The global population is expected to reach ten billion by 2050. This increase, together with diet changes to include more animal products, is projected to i increase food demand by up to 70 % (UNESCO 2012). Dryland agriculture can play a role in meeting this enormous challenge (Stewart et al. 2006). In this chapter, the challenges for dryand agriculture are discussed, and researchable issues to improve the productivity of drylands on a sustainable basis are suggested.

## 2 Challenges for Dryland Agriculture

Dryland ecosystems, are characterized by recurrent but unpredictable droughts, high temperatures, variable rainfall and low soil fertility. Therefore, agriculture in dryland areas is fragile. The stress on land resources to meet the basic demands of humans is expected to further increase as population increases in the coming decades. In this context, the challenges for dryland agriculture are discussed in this section.

### *2.1 Water Deficit*

Water deficit is the most critical determinant of the success or failure of crop production in drylands (Falkenmark et al. 1990). Reduced plant available soil moisture occurs as a result of a low quantity of water supplied (rainfall) or changes in rainwater partitioning (reduced in infiltration and water retention in the soil). The variability of rainfall in time and space is a common feature of drylands (Falkenmark and Rockström 2004; Adnan et al. 2009).

Generally, dryland production is possible where the growing season does not fall under the temporal distribution of water deficit i.e. precipitation during the growing season is sufficient to meet the crop's water requirement. However, water deficit becomes severe in cropping systems and growing season where precipitation is less than evaporation (Baumhhardt and Salinas-Garcia 2006; Adnan et al. 2009). The difference between evaporation demand and precipitation received determines the crop water deficit. It is argued that in dry sub-humid and semi-arid areas, the amount of rainfall is not the limiting factor rather its extreme variability, such as high rainfall intensity, few rainy days, and uneven spatial ortemporal distribution (Klaij and

**Table 2** Types of droughts and underlying causes in semi-arid and dry sub-humid tropical environments

| | Dry spell | Drought |
|---|---|---|
| **i. Meteorological drought** | | |
| Frequency | Two out of three years | Once every 10 years |
| Impact | Yield reduction | Complete crop failure |
| Cause | Rainfall deficit of 2- to 5-week periods during crop growth | Seasonal rainfall below the minimum seasonal plant water requirement |
| **ii. Agricultural drought** | | |
| Frequency | More than two out of three years | Once every 10 years |
| Impact | Yield reduction or complete crop failure | Complete crop failure |
| Cause | Low plant water availability and poor plant water uptake capacity | Poor rainfall partitioning, leading to seasonal soil moisture deficit for producing harvest (where poor partitioning refers to a high proportion of runoff and non-productive evaporation relative to oil water infiltration at the surface) |

Source: Falkenmark and Rockström (2004)

Vachaud 1992; Hatibu et al. 2003), In arid and hyper-arid regions, absolute water scarcity is the prevalent limiting factor due to the crop water demand being higher than the rainfall (Hatibu et al. 2003).

Drought is a recurring phenomenon in drylands (Table 2). Agricultural drought is linked with meteorological characteristics including erratic rainfall, soil moisture deficits, differences between actual and potential evapotranspiration, and lower groundwater tables and/or reservoir levels (Stewart and Peterson 2015). Such events are likely to increase with the current climate shift (IPCC 2007; Adnan et al. 2009). Although agricultural droughts are observed in all regions, the impact of drought on drylands is usually more severe as the amount of rainfall received is far below that of potential evapotranspiration (Stewart and Peterson 2015). However, there are management-induced dry spells and droughts where the rainfall received is not stored and utilized in a productive way. This cases can be prevented by improved management practices than blaming on droughts (Rockström 2003).

## 2.2 *Weather Variability*

Weather variability is a major issue in the drylands and includes the unpredictable nature of various weather elements such as precipitation, temperature and winds. This variability is directly related the availability of water for crop use, its temporal and spatial distribution, and the success of crop production.

The changing climate may increase the intensity and the frequency of current risks and the probability of extreme events and new hazards (Nicholls and Lowe 2006). For instance, climatic studies have predicted a decline in overall rainfall with increased episodes of drought (Rockström 2003; Peterson et al. 2006) and increased high-temperature events (Peterson et al. 2006) in the drylands in the future.

Climate change is dictating the changes in climate variability and the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC 2012). Increasing episodes of drought and heat stress are projected for the rest of this century, which are expected to have adverse effects over and above the impacts due to changes in mean variables alone (IPCC 2012). Key ecosystem processes are seasonally sensitive to climate variability and the timing of climate variability may be just as important as its magnitude for plant productivity (Craine et al. 2012). For instance, in drylands, crop production occurs in areas receiving sufficient precipitation to support crop production. However, precipitation is usually unpredictable between years and within growing seasons, such that crops can fail due to inadequate water, even with good management (Peterson et al. 2006). Droughts, desertification, and water shortages are permanent features of life in drylands and under such conditions, any increase in evapotranspiration has a severe impact on agriculture, horticulture, forestry and human activities (Sen Roy and Singh 2002). The vulnerability of arid regions is further accentuated by low levels of socio economic development, as is the case in India (Singh and Gurjar 2011).

### *2.3 Erosion*

Soil erosion is a leading cause of land degradation in drylands. For instance, in Sub-Saharan Africa soil erosion and degradation are considered a bigger problem than climatic variability and drought (Peterson et al. 2006). Possible factors responsible for severe soil erosion includes, injudicious land usage for crop production, monoculture and lack of crop rotation, excessive tillage and clean fallowing, disconnecting arable farming from livestock, intensive livestock grazing without knowledge of the grazing capability of rangelands and inappropriate removal of forest vegetative cover (Grimm et al. 2002; Irshad et al. 2007).

Soil erosion is a form of land degradation leading to the removal of topsoil (typically the layer with the most effect on plant production and thus food production) by water and/or wind. Topsoil contains organic matter, provides micro- and macronutrients to plants, and is responsible for soil structural stability—the determining factor for the provision of water to plants (Rojas et al. 2016). The soil is eroded in two steps i.e. soil detachment and soil transport. Raindrops are the main reason for soil detachment—also known as sheet erosion (Lal 2003). However, it is hard to identify soil erosion at the starting phase. By the time farmers identify soil erosion, the land has most likely lost its productivity (Lal 2003). Soil transport mainly happens through the wind or air (McCarthy et al. 1993).

Wind erosion reduces crop yields in drylands and large and unprotected fields (e.g., through soil being mobilized and relocated from farmland and 'sandblasting' of standing crops) (Rojas et al. 2016). Sometimes soil reaches as much as 100 t $ha^{-1}$ due to extreme events, i.e. storms (Grimm et al. 2002; Verheijen et al. 2009). In the

Mediterranean region, soil erosion in some areas is so severe that some soils are close to being rendered unproductive.

Erosion reduces soil fertility by physically removing organic matter and nutrients from the soil. Soil degradation has a negative impact on water infiltration thereby reducing crop production and soil sustainability. Globally, management factors for soil degradation in dryland regions are often similar (Peterson et al. 2006). The impact of soil erosion on crop production varies across soils and ecoregions and depend on soil management, cropping systems, soil conservation measures and technological inputs. The resistance of soils to degradation (soil resilience) and the degree to which soils degrade (soil erodibility) also differ by soil type (Scherr 1999).

The sustainable development of agroecosystems is at risk due to accelerated soil erosion resulting from the pressure of environmental degradation and human intrusions of land exploitation. Soil erosion disturbs the natural balance and reduces production potential (Pimentel et al. 1995). Accelerated soil erosion causes loss of biodiversity which further fuels erosion and the soil becomes devoid of beneficial production factors such as carbon recycling (Chapin et al. 1997). Loss of biodiversity is a reason for the reduced replenishment of resources and such soils are more prone to irreversible changes (Chapin et al. 1997).

## *2.4 Nutrient Mining*

The deficiency of nutrients in drylands is the second main reason for low yield output as, fertilizers are not applied after sowing in dryland agriculture and the rate of fertilizer application is quite low due to weather vulnerability. Crop residues are removed from the fields to feed livestock and not incorporated, resulting in widespread nutrient deficiencies in the soils of dryland agriculture (Rojas et al. 2016).

Nutrient mining is the removal of soil nutrients by continuous cropping without adequate supplementation of inorganic and/or organic fertilizers and manures. Nutrient mining reduces crop yields in drylands due to soil fertility losses and is a key link to environmental damage and land degradation (Henao and Baanante 2006). Over time, developing countries face the net depletion of macro nutrients stock while more developed areas that replenish soils with macronutrients unintentionally cause excessive micronutrient mining (Emmett et al. 1997). The situation in drylands with marginal soils is even alarming, which are already under pressure due to various environmental impacts and increased human intrusions (Rojas et al. 2016).

In the case of Africa, dryland soils are depleted of nutrients and soil organic matter due to inappropriate practices of cultivation, deforestation and overgrazing, continuous cropping and non-judicious and inadequate fertilizer use (Hartemink 1997; De Jager et al. 2001). Nutrient balances which consider system inputs and outputs have been used to estimate the magnitude and extent of nutrient mining. From 2002 to 2004, 85 % of agricultural land in Africa had annual nutrient mining rates greater than 35 kg (N, P and K) $ha^{-1}$ and 40 % had annual rates greater than 60 kg $ha^{-1}$ (Blum 2013).

### 2.5 Institutional Role

Institutional challenges are a hurdle in the sustainable development of dryland agriculture; there are three types, *viz*. institutional, policy and legal related issues (Liniger et al. 2011). Institutional issues include inapplicable local and national political agendas, absence of operational capacity, unclear and overlapping delineation of responsibilities, bad governance (Liniger et al. 2011), the lack of a credit system for growers and the agro-based industry (Pinto 1987; Bevan et al. 1999) and the lack of weather forecasting systems (Odjugo 2010). Legal framework/policy constraints may arise due to the non-implementation of sustainable land management laws because law implementation is costly, difficult, and may cause hostile interactions between land users and law enforcement agencies (Liniger et al. 2011).

To improve and manage the dryland regions, an institutional setup is needed to deliver laws and policies regarding the sustainability and management of these areas. Financial provision to the institutes for research and development of natural resources or ways to protect these dryland regions from further degradation is also needed (Rosegrant et al. 2002).

## 3 Researchable Issues in Dryland Agriculture

Drylands are fragile ecosystems. Major researchable issues in dryland agriculture include building resilience and reducing vulnerability of the people living on marginal lands, improving crop varieties and livestock breeds, integrating crop–livestock systems, conservation agriculture, the diversification of food production systems, management of natural resources especially the water, increasing investment in institutional support and agricultural research, and taking an integrated agroecosystem approach to these actions. These researchable are discussed below.

### 3.1 Rainwater Harvesting and the Efficient Use of Water

As rainfall is very low and erratic in dry areas is a recurrent problem, increasing the availability of water in the root zone of the crop is paramount for sustainable agriculture production in the drylands (Lal 2001). This approach has a positive effect and helps to improve the yield per unit of rainfall in dryland areas (Kurukulasuriya et al. 2006).

Rain water capture, infiltration into the root zone, and the efficient use of available water are necessary pragmatic strategies for improving crop yields in dryland areas. However, there is a broad spectrum of integrated land and water management options to achieve these aims (Rockström et al. 2010; Table 3). For instance, some techniques focus on capturing more water, e.g. external water harvesting systems,

**Table 3** Rainwater management strategies and corresponding management options to improve yields and water productivity

| Rainwater management strategy | | Purpose | Management options |
|---|---|---|---|
| Increase plant water availability | External water harvesting systems | Mitigate dry spells, protect springs, recharge groundwater, enable off-season irrigation, permit multiple uses of water | Surface microdams, subsurface tanks, farm ponds, percolation dams and tanks, diversion and recharging structures |
| | *In situ* water harvesting systems, soil and water conservation | Concentrate rainfall through runoff to cropped area or other use | Bunds, ridges, broad-beds and furrows, microbasins, runoff strips |
| | | Maximize rainfall infiltration | Terracing, contour cultivation, conservation agriculture, dead furrows, staggered trenches |
| | Evaporation management | Reduce non-productive evaporation | Dry planting, mulching, conservation agriculture, intercropping, windbreaks, agroforestry, early plant vigor, vegetative bunds |
| Increase plant water uptake capacity | Integrated soil, crop and water management | Increase proportion of water balance flowing as productive transpiration | Conservation agriculture, dry planting (early), improved crop varieties, optimum crop geometry, soil fertility management, optimum crop rotation, intercropping, pest control, organic matter management |

Source: Rockström et al. (2010)

while others, such as mulching and drip irrigation, aim to increase water productivity directly as a good crop canopy can help reduce water loss through soil evaporation (Rockström 2003).

Water harvesting is a hydro-agronomic term which comprises techniques and methods to collect and conserve water from surface run off and rainfall (Siegert 1994). Water harvesting may involve the capture of local farmland rainfall (*in situ* water harvesting) or the capture of rainfall received away from the farmland (*ex situ* water harvesting) (Oweis and Hachum 2001). Water harvesting differs from conventional water conservation practices as it does not deprive the farmland of its share (Reij et al. 1988). Rain-water harvesting allows water to be conserved for later use during dry spells in the cropping season (Rockström 2003; Awulachew 2010). Water harvesting has been practiced successfully for millennia in parts of the world, yet the potential of water harvesting remains largely unknown, unacknowledged and unappreciated. Water harvesting offers opportunities for the drylands in the developing world (Rockström 2003).

Rainfall is the most important natural resource in drier environments. Low rainfall, water scarcity and land degradation severely inhibit the production capacities of agricultural lands in arid and semi-arid environments. Improving the efficiency of rainwater use is, therefore, critical in these water-scarce areas with rapidly expanding, poor populations living in a fragile environment and facing food insecurity and depleted natural resources bases. Water harvesting has become increasingly important for improving the management of water resources in such dry environments. The ultimate goal of *in situ* water harvesting is a sustainable and environmentally-friendly system of agricultural production is to complement rather than replace the existing water use system. Improved systems must be socially acceptable as well as more productive. Water harvesting interventions form part of a plan for integrated land and water resources development which takes into consideration the necessary technical, agronomic, socioeconomic and institutional aspects and inputs (Oweis et al. 2001).

Supplemental irrigation systems should be promoted in drylands, especially for small-scale farmers (Fan et al. 2000; Fox et al. 2005). Policy frameworks and institutional structures similar to those for irrigated systems will be needed to implement supplemental irrigation systems successfully in the drylands.

### *3.2 Crop Diversification*

Traditional monocropping may be a risky option in light of the predicted climatic changes, eventually leading to a severe decline in agricultural productivity (Huggins et al. 2015). In this regard, crop diversification has the potential to increase the sustainable intensification of agriculture in dryland areas. Crop diversification widens the variety of crops in a system or extends its niche. It helps to save the system from various risks such as crop failure and pest attack (Lin 2011). An alternative crop or species must be adapted to the chosen environment or agroecosystem i.e. the crop or species must be able to tolerate the harsh environment and climate, variation specifically the water deficit.

Crop diversification is an excellent opportunity to enhance income and improve the social and overall livelihood of people living in dryland areas (Lin 2011). In dryland areas, the inclusion of legumes in a cereal system may be a good option for improving system sustainability (Peterson et al. 2006). While diversification is an effective way to mitigate risks and increase incomes in dryland ecosystems, the prevailing global eating habits, market scenarios, dwindling economies, unpredictable climatic changes, and traditional cultivation has shifted the scope of agriculture from diversification to intensified monocropping, particularly in the drylands. This requires extensive research on biological and socio-economic perspectives.

## *3.3 Conservation Agriculture*

Conservation agriculture (CA) —a suite of three key technologies *viz*. minimum soil disturbance, stubble retention and diversified crop rotation—offers a system for sustainable agriculture production (Farooq et al. 2011). CA is a good option for successful crop production in drylands because it improves soil organic matter and conserves water making it available for the plant when it is needed (Lyon et al. 2004; Thomas et al. 2007; Bayala et al. 2012).

CA is practiced in different dryland agro ecosystem - and has the potential to reduce the threat of food insecurity in the Middle East, North and Sub-Saharan Africa, and West and Central Asia (CGIAR 2013). Losses such as soil degradation through erosion and water through runoff can be reduced by adopting CA practices such as reduced tillage and maintaining soil cover (Serraj and Siddique 2012). CA benefits farmers in economic terms by reducing costs (plowing, labor), improving water use efficiency and water availability in the root zone and reducing water loss due to soil evaporation because the soil is covered with residues from the previous crop. In CA, the inclusion of legumes in the rotation and mulch (previous crop residues) helps to restore the fertility status of soil (Marongwe et al. 2011).

Constraints to the successful adoption of CA include mindset of the famers, unavailability of appropriate seeding machinery, poor farmer knowledge on CA benefits, weeds and disease issues during initial stages, and the lack of collaboration between farmers, extension workers and institutions (Farooq and Siddique 2015). Generally, CA systems are better adapted to the drylands because CA triggers increase in infiltration resulting in more effective rainfall use, less surface runoff, less soil erosion and improve in soil water-holding capacity. In CA systems, crops are more likely to produce better yields than those under conventional tillage (Stewart 2007; Friedrich et al. 2012).

## *3.4 Mixed Crop–Livestock Systems*

Livestock production plays and will continue to play an important role in dryland agriculture. In this regard, ruminant production in dryland areas is expected to expand with the increased in the demand for animal protein production in the coming decades. The importance of mixed crop–livestock systems and grazing of annual forages varies between regions and climatic conditions (Thornton 2014). However, with an increase in the total annual rainfall from 200 to more than 500 mm, grazing and production of drought tolerant crops (such as sorghum and millets) is replaced with other crops like maize and wheat (Schiere et al. 2006).

Most dryland systems in Sub-Saharan Africa integrate crop and livestock production with the productivities of livestock, croplands and rangelands intricately linked in these systems (Powell et al. 2004). Maintaining a balance between the food and feed supply, nutrient inputs and outputs, and human and livestock populations is critical for sustaining the productivity of livestock, croplands and rangelands. In addition to the biophysical response of crops and livestock to additional nutrient inputs, the innovative approaches must be evaluated to ensure that they are accessible and affordable to growers, and to determine how these and other inputs can help to reduce the risks associated with erratic weather variability (Powell et al. 2004).

Ruminant production is the predominant form of livestock production in Sub-Saharan Africa. Despite it being a risky business. Although, options to manage the risk are available, they tend to be specific solutions for specific factors causing risk rather than integrated and innovative approaches that simultaneously manages and reduces all of the risk factors associated with the uncertainties of animal production in dryland (Martínez et al. 2014). One innovative solution to sustainable livestock production in rangelands involves an integrative approach, combining shrubs and native plants in silvopastoral systems with strategies to promote self-herding (or traditional herding) and careful selection of animal genotypes. This approach needs to be refined for each system and location, underpinned by sound principles, to ensure that the interaction between genotype, environment and management is optimized to maximize productivity and minimize the impact on the environment.

### *3.5 Policy Options for Improvement*

Agriculture in dryland regions is facing several policy management issues, agriculture research problems, and institutional challenges. The collaboration of researchers with practitioners is desired as both have to adopt an integrated approach because social and ecological issues are interlinked (Reynolds et al. 2007). Short-term policies to solve ecological issues are not beneficial because they do not have potential to resolve problems faced by the inhabitants of dryland regions (CGIAR 2013).

Policies are needed which address market availability problems faced by farmers. Markets need to be located in the vicinity of farmers. There is poor market policy support for dryland crops (CGIAR 2013). Policies should be formulated to address serious problems such as land degradation, water scarcity, and food insecurity. Failing to resolve these issues will lead to more poverty and poor nutrition, loss of biodiversity, and more land degradation. A long-term and unified action plan by all of the stakeholders is desired (Bantilan et al. 2006).

The United Nations Convention established a policy to alleviate desertification and suggested diverting funds at the national and global level for the betterment of livelihoods in dryland areas (UNCCD 2007). However, efforts should be initiated to improve the social condition of the inhabitants of drylands.

### *3.6 The Ecosystem Approach: Collaboration for Integration*

Dryland agriculture is considered as agro ecosystem, comprised of grassland, forest and arable land. Ecosystem management in dryland regions will only be beneficial and successful if it protects and improves the sustainability and profitability of the ecosystem. An ecosystem approach involves decision making with more efficient tools and policies for dryland crop production, and the provision of stakeholders with knowledge on the benefits of policies and risks of investment, development and management for drylands (White et al. 2002).

An ecosystem approach to dryland agriculture may help to monitor, assess and address the actual needs and requirements of the dryland population. This should provide indicators to stakeholders regarding the integrated socioeconomic and environmental impacts for the assessment of development, investment domains and management options for dryland regions.

Each dryland ecosystems ha several native microbial, plant and animal species equipped with special strategies to cope with the extreme weather conditions in these ecosystems. Such adaptive traits may have some global implications in the context of predicted climate change (Bonkoungou 2007). However, research efforts should be initiated to develop balanced ecological strategies for sustaining the productivity of dryland ecosystems.

## 4 Conclusion

Dryland areas occupy almost half of Earth's land surface and are central to the provision of most pulses and some cereals. Drylands also meet our protein needs through legumes and livestock, as these regions provide pasture and natural vegetation without additional input costs. However, dryland agriculture is deteriorating day by day due to increased human activities, climate extreme, growing needs for food and through natural such as wind and water. The main challenges which threaten reduce yields or cause total crop failure include moisture deficits, unpredictable weather, soil fertility losses, policy negligence and nutrient deficiencies. To resolve these challenges, a collaborative interdisciplinary ecosystem approach of the researchers, extension agents, farmers, and research and policy institutions is desired. The formulation and implementation of appropriate policies for drylands may help to improve farm income on a sustainable basis. In this regard, campaigns for CA, rain water harvesting and mixed crop–livestock systems may be helpful. Installation and provision of weather prediction systems may also help to avoid climatic calamities.

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