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Making rainfed agriculture sustainable through environmental friendly technologies in Pakistan: A review

Mirza B. Baig[1], Shabbir A. Shahid[2], and Gary S. Straquadine[3]

Abstract

Pakistan is an agricultural country spreading over an area of about 79.6 million hectares (Mha) with an arid and semi arid climate. Of 79.6 Mha, about 23 Mha is suitable for crop production and nearly 25 percent of the total cultivated area is designated for rainfed agriculture. Unfortunately, rain-fed agriculture is constrained with multifarious problems such as moisture stress, soil erosion and crusting, nutrient deficiency, depletion and poor nutrient use efficiency, and weed infestation limiting the yield potential of these lands. In addition, deforestation and poor crop husbandry techniques are commonly noticed features. To meet the food requirements, farmers bring all the available pieces of lands under plough including steep slopes. Farming on steep slopes if not managed on scientific lines, results in severe erosion. The problems faced by the farmers are due to the unsustainable practices they adopt to practice dryland agriculture, limiting the productive potential of these important ecosystems. However, their potential can be improved by adopting suitable rainwater harvesting techniques; employing scientific soil and water conservation methods and using sustainable agricultural practices. This paper highlights some important issues associated with the rainfed agriculture of Pakistan. Working strategies for realizing optimum and sustainable yields have been outlined while conserving both land and water resources.

Key Words: Arid agriculture, Sustainable technologies, Rainwater harvesting, Agronomic practices, Extension Education

1 Introduction

Pakistan is predominantly an arid country with 80 percent falling in the arid and semi-arid regions (Shah et al., 2011). Today Pakistan stands among the most arid countries with an annual rainfall of below 240 mm (Farooq et al., 2007). In general, climate is characterized primarily as desert or near desert, half of the country receives less than 250 mm rainfall per annum. The country spreads over a geographical area of 79.6 million hectares (Mha), only 23 Mha is cultivated. About 75 percent of the cropped area is irrigated and the rest (4.0 Mha) is rainfed (PCST, 2005a) playing an important role in the national economy (Adnan et al., 2009). Forests cover an area of 4.0 Mha, which is 5.0 percent of the total area in the country (PCST, 2005b; Siddiqui, 2007). In addition, with an area of 28.5 Mha the rangelands occupy about one-third (32.4 percent) of the total land mass (Economic Survey, 2010-2011) as shown in Table 1.

In Pakistan, drylands, arid lands and rainfed areas are the terms being used interchangeably to designate the lands not irrigated by canals or tubewells where agriculture relies solely on rainfall. However, drylands are generally defined as arid, semiarid or dry sub-humid lands receiving less than 500 mm annual rainfall with an aridity index between 0.05 and 0.653 (the aridity index is the ratio of Precipitation [P]/Potential Evapo-transpiration [PET]. In Pakistan, most parts of Sindh, Balochistan, southern parts of Punjab and Khyber Pakhtunkhwa receive

[1] Prof., Dr., Department of Agricultural Extension and Rural Society, College of Food and Agricultural Sciences, King Saud University, Kingdom of Saudi Arabia. Corresponding author: E-mail: mbbaig@ksu.edu.sa

[2] Dr., International Centre for Biosaline Agriculture, Dubai, United Arab Emirates. E-mail: s.shahid@biosaline.org.ae

[3] Prof., Dr., Ohio State University, Columbus, OH, USA 43210. E-mail: straquadine05@osu.edu

less than 250 mm annual rainfall. These areas receive very scarce, erratic rainfall during a short rainy season; however, these regions remain relatively dry during the rest of the year. Due to high temperatures and high rain intensity much of the rainfall is being lost through evaporation and runoff. In dry areas, water remains the most limiting factor for flora and fauna (Intercooperation Pakistan, 2006). Rainfed areas are concentrated in the Pothwar Plateau, northern mountains and north-eastern plains of the country (NCA, 1988). The rainfall in these areas varies from less than 100 mm in the hot desert to over 1,500 mm in the outer Himalayas. According to Rashid et al. (2004), the pattern is bimodal with 60 – 70 percent of rainfall occurring in the summer from July to September and the remainder occurs in the winter.

Table 1 **Area under different land uses in Pakistan (MINFAL, 2002)**

Land uses	Area (Mha)	Percent (%)
Culturable Commanded Area (CCA):		
Designated for perennials	8.3	10.3
Designated for perennial irrigation	5.3	6.6
Subtotal:	13.6	16.9
Other Cultivated Area:		
Irrigated (from wells, streams, tanks, etc.)	0.7	0.9
Rainfed (Barani)	3.2	3.9
Riverain	1.2	1.5
Subtotal:	5.1	6.3
Culturable Waste and Forest:		
Culturable waste	9.7	12.0
Estimated forest area	1.2	1.5
Subtotal:	10.9	13.5
Total Suitable for Agriculture & Forestry	29.6	36.7
Unsuitable for Agriculture and Forestry:		
Mountains and deserts	40.5	50.2
Unrecorded, towns, water area, etc.	10.5	13.1
Total Unsuitable for Agriculture and Forestry	51.0	63.3
Total Area of Pakistan	80.6	100

A large fraction of Pakistan is in the arid and semi-arid climatic zones. Pakistan is well known as an agricultural country and its agriculture sector continues to play a pivotal role in the economy. It is still considered to be the second largest sector, accounting for over 21 percent of Gross Domestic Product (GDP), and remains by far the largest employer, absorbing 45 percent of the country's total labor force. Nearly 62 percent of the country's population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood (Economic Survey, 2009 – 2010).

In the past, resources were allocated for the development of irrigated areas (high potential) whereas less importance was given to agriculture on rainfed areas (low potential) due to its intrinsic risks (Zia et al., 1997). However, rainfed areas are very vast natural resource contributing a very significant share to the national economy. In Pakistan, dryland agriculture is synonymous with rainfed (barani) conditions (Rashid et al., 2004). It sustains 80 percent of the livestock population and contributes 12 percent of wheat, 27 percent of maize, 69 percent of sorghum, 21 percent of millet, 25 percent of rape and mustard, 77 percent of gram, 90 percent of groundnut, 53 percent of barley and 85 percent of pulses (Zia et al., 1996). On the country level, a big yield gap exists for various crops between the average yields and the potential yields (PCST, 2005a). Unachieved potential for wheat, rice, maize and sugarcane yields has been determined as 66, 79, 78 and 71 percent respectively and depicted in Table 2 (PSPB, 2005). The critical review of yields realized in the last few decades, suggests substantial improvement in crop yields is quite possible in rainfed areas (Zia and Baig, 1997).

Table 2 **Potential yield and yield gaps of various crops ($t\ ha^{-1}$)**

Crops	Potential yield	National average	Yield gap	Yield gap (%)
Wheat	6.4	2.2	4.2	66
Rice	9.5	2.0	7.5	79
Maize	6.9	1.5	5.4	78
Sugarcane	160.0	46.0	114.0	71

Source: Pakistan Statistical Pocket Book 2005, Government of Pakistan, Statistics Division, Federal Bureau of Statistics, Islamabad, Pakistan.

Rainfed agriculture, therefore, is quite capable with an appreciable potential for meeting the increasing food requirements of the rising population of the country. For this purpose, the factors which affect the productivity of rainfed agriculture need to be properly looked into and managed. In this paper, an effort has been made to present an account of problems associated with the rainfed agriculture and innovative sustainable management strategies have been presented keeping in view the intrinsic production potential of the rainfed areas.

Present study employs the qualitative interpretive research paradigm. The information relevant to the paper topic have been collected and analyzed by employing qualitative analysis techniques. The research findings presented below were a result of the application of the content analysis method.

2 Status and scope of rainfed agriculture

It has recently been reported (Adnan et al., 2009) that agriculture practiced on the rainfed areas remains 17% of the total area brought under crop production. Rainfed areas are concentrated in the Pothwar Plateau, northern mountains and north-eastern plains of the country forming the largest contiguous block of dry-land farming in Pakistan. In Pakistan, the terms rainfed and dryland are used interchangeably. Rashid et al. (2004), also viewed dryland agriculture synonymous with rainfed (barani) agriculture. Drylands are the areas receiving less than 500 mm annual rainfall. In Pakistan, about 75 percent of the area receives less than 250 mm annual rainfall (Intercooperation Pakistan, 2006). With the population of 30 million people (Intercooperation Pakistan, 2006), land resources of the rainfed areas are characterized by fragmented land holdings (Rashid et al., 2004). Based on constraints associated with these areas, agricultural activities contribute only about 10% of the total agricultural production (PCST, 2005a; Qureshi et al., 2010).

In terms of crop production, rainfed lands have more often been underestimated. For example, as high as some 1,200 kg $acre^{-1}$ wheat yield has been reported in these areas, which is an indicator of the production potential of rainfed areas. However, water deficit remains the biggest limiting factor and the greatest challenge for sustainable agricultural development in these areas. In the country about one-third of the wheat crop is grown under rain-fed conditions every year; the area under wheat is greater than all the crops raised in rain-fed areas, yet the production is not sufficient to meet the total requirements of the population in this area. Wheat crops in rain-fed areas depend upon rain for soil moisture. If the rains are received at the proper time, the farmer can harvest reasonable yields. On rainfed areas, the farmers mostly obtain about 27 percent yield of maize, 56 percent of sorghum and millet, 52 percent of barley, 90 percent of guar seed, 77 percent of gram, 84 percent of pulses, 24 percent rape and mustard seeds, 83 percent groundnut and 100 percent of castor seed, as compared to yields obtained in irrigated agriculture (Supple et al., 1985; Zia and Baig, 1997).

Numerous desert plants, vegetables, and fruits having lower water requirements for their growth can be successfully raised on the rainfed areas of the country. The rainfed areas of the Punjab Province also support some 65 percent of the livestock population of the country; while 80 percent of the livestock are sustained by arid lands in the province of Baluchistan. Similarly, rainfed areas of the provinces of Khyber Pakhtunkhwa (KPK) and Sind sustain a substantial livestock population. The economy of the dry land areas of Pakistan depend heavily upon the crop and livestock sectors.

About 60% of the rainfed areas are used for growing winter season crops like wheat, barley, gram, lentils, rapeseed, and canola mustard while among the important summer crops; millet, sorghum, maize, pulses, guar, groundnut, and watermelon are planted on nearly 40 percent of rainfed lands. Alam (2000) is of the opinion that production levels of the food crops and livestock can reasonably be enhanced by rainwater harvesting and timely use. Due to uncertain rains and risks involved in crop production, the best viable option to ensure livelihood remains livestock husbandry (Irshad et al., 2007). The prime species sustained by the rainfed ecosystems include sheep and goats followed by cattle and camels, whereas buffalo rearing is the most common activity in the sub-humid low rainfall areas. The occurrence of rainfall in the rainfed areas is erratic, with high spatial and temporal variation. Most of the rainfall occurs during the monsoon period of July to September. Due to the uncertainty of rainfall, farmers normally apply lower amounts of inputs to their crops, so that losses are minimized in case of crop failure due to drought (Rashid et al., 2004). Although production levels of the rainfed areas of Pakistan are low at this time i. e. 1-1.5 t ha^{-1}, yet crop yields can be doubled provided one or two supplemental irrigations are applied at the critical growth stages of growing crops (Oweis and Hachum, 2001). There is a high potential for the development and management of water-resources. Crop yields could be greatly increased by adopting suitable and appropriate water-resource development, harvesting and management practices (PCST, 2005a; Qureshi et al., 2010).

3 Shortcomings and problems faced by rainfed agriculture

The wide diversity of climate, soils, relief, topography and anthropogenic changes cause numerous constraints and problems, there are several other serious threats being faced by rainfed areas. According to Rashid et al. (2004), today most rainfed areas are farmed using the old, traditional and primitive soil and crop management practices. The major constraints are moisture stress and/or uncertainty, credit scarcity, soil erosion, and nutrient depletion. Due to rain uncertainty, agriculture on the rainfed area remains a high-risk and low-input enterprise for resource-poor farmers. Low yields on the areas could be attributed to factors like: poor quality seed, inadequate and imbalanced fertilizers, and poor crop management practices. Excessive losses of water as runoff, old traditional land and water management practices and fragmented land holdings can cause low efficiency of water use (Rashid et al., 2004; Shah et al., 2011). Consequently, crop yields are much below their demonstrated achievable potentials. In addition, inappropriate soil conservation measures, excessive cultivation of steep slopes, brief fallow periods, and cultivation in fragile regions, shallow tillage, imbalanced fertilizer use and irrational irrigation measures can negatively impact the productivity of land resources (Irshad et al., 2007). The challenges and problems faced by rainfed agriculture are discussed in the following sections.

3.1 *Water shortage, moisture stress and droughts*

In rainfed agriculture, soil moisture has always been a major factor limiting crop yields. In a majority of the rainfed areas, seldom is natural precipitation sufficient and adequately distributed during growing season to sustain economic crop yields (Baig et al., 1999; Adnan et al., 2009). Alam (2000) states that about 50% – 60% of the annual rainwater is lost through runoff, causing moisture shortage and erosion on the rainfed areas receiving medium to high rainfall. Thus, it is necessary to store rain water to supplement plant water requirements (Papendick, 1989; Zia et al., 1996; Zia et al., 1997) through rainwater harvesting, moisture conservation and the construction of small dams (Zia et al., 1996; Baig et al., 1999; Rashid et al., 2004).

3.2 *Soil erosion*

In Pakistan, soil erosion caused by water and wind remains a serious problem, significantly affecting rainfed agriculture. Over 76% of the total land mass of the country is affected by wind and water erosion; water erosion is affecting some 36% of the area whereas 40% of the lands are suffering from wind erosion. According to Khan et al. (2012), rainfed tracts are severely suffering from erosion due to inappropriate land uses, uncontrolled grazing and illegal cutting of trees and associated vegetation. Irshad et al. (2007), are of the opinion that severe soil erosion on rainfed areas and the possible factors responsible for this menace include inappropriate land uses for growing unsuitable crops, livestock grazing without considering the carrying capacity of rangelands and illegal indiscriminate removal of forest vegetation cover. Approximately one billion tons of fertile soils are eroded annually, and being deposited in dams and carried into the Arabian Sea (Anjum et al., 2010).

Water erosion is mostly prevalent in high rainfall areas having steep slopes, particularly in the Potohar region (Shah and Arshad, 2006). In these rainfed areas, almost 50% of rain water is being lost as runoff (Anjum et al., 2010). The main areas affected by water erosion are Pothwar, Bannu, Peshawar valley, Piedmont plains and the Himalayan Mountains. The most commonly observed forms of water erosion are: sheet, rill, gully and riverbank erosion. A considerable part of the area has been gullied and steeply dissected, while pinnacle erosion, piping and slumping are also quite pronounced (Baig et al., 1999; Farooq et al., 2007). Soil loss caused by water erosion is quite high in Khyber Pakhtoonkhawa (KPK) Province, and is followed by the Northern Area (NA), Baluchistan and Punjab provinces. In northern mountainous areas with steep slopes, water erosion is low if covered by closed canopy forests, whereas water erosion increases on steep slopes when cultivated with arable crops. These areas with uneven terrain receive rainfall from 250 – 1,000 mm per annum (Irshad et al., 2007). Irshad and his co-workers (2007) believe that such landscapes absorb less water and are quite vulnerable to the loss of soil and water. This loss of rainwater in the form of runoff could be about 50%. If the country could save half of this rainwater, it would be equal to about 6 million acre-feet (MAF). This much water is equal to 2/3 of the storage capacity of Tarbela Dam (the world's biggest earth-filled reservoir), and it may be enough to meet the irrigation requirements of crops grown on 4 million acres. On the other hand, soil loss due to wind erosion is at its maximum in the Punjab Province, followed by Sindh, Baluchistan and KPK. Overall the erosion problem is severe in KPK, followed by Punjab, Baluchistan and Sindh provinces (NCS, 1992; Zia et al., 1996; Baig et al., 1999).

Wind erosion is prevalent in low rainfall sandy desert areas, such as the Thal and Cholistan deserts in Punjab, the Thar deserts in Sindh, the Kharan desert in Baluchistan and the Bannu area in KPK (Irshad et al., 2007; Anjum et al., 2010). Wind erosion affects depend mainly on soil type, vegetation cover, wind velocities at different times of the year, soil moisture conditions and land relief. Drifts formed by creeping soil, and shifts through suspension and saltation of soil particles are common forms of wind erosion occurring in sandy areas (Alim and Javed, 1993; Zia et al., 1996; Irshad et al., 2007).

3.3 *Soil crusting and compaction*

On the rainfed areas, soil crusting remains a deleterious phenomenon causing soil erosion and making crop husbandry and agronomic practices difficult to accomplish. Generally, low organic matter and a high proportion of fine silt, sand and sodium in the rainfed areas result in the formation of surface soil crusts (Zia et al., 1996; Rashid et al., 2004). Excessive ploughing and high intensity rains further accentuate the problem. Soil crusting and compaction are known to reduce water infiltration and increase runoff and cause soil erosion in rainfed areas of Pakistan (Nizami and Shafiq, 1988; Zia et al., 1996; Baig et al., 1999; Shafiq et al., 1994), and at the same time could minimize gas exchange between soil and atmosphere and restrict seed germination. Nizami and Khan (1991) maintain that crust formations result in unfavourable physical conditions, directly affect crops; reduce crop stand, plant population, grains yields and growth.

3.4 *Nutrient depletion, low fertilizer use efficiency and imbalanced fertilizer use*

The soils of the rainfed areas have been cultivated for centuries and consequently their fertility levels have declined to the extent where they adversely affect crop yields. In addition, low input (low rates of fertilizers) agriculture is being practised by the farmers in rainfed areas because of the high risk due to climatic uncertainties (Razzaq et al., 1990; Rashid et al., 2004; Irshad et al., 2007). Actual use of nitrogen for rainfed wheat is 32 kg ha^{-1} as compared to the optimum use of 71 kg ha^{-1}. The actual use of phosphorus is only 9 kg ha^{-1} while the optimum use is 48 kg ha^{-1} (MINFAL, 1993). Actual fertilizer use in the rainfed areas is far less than the optimum use. Crops remove more nutrients than the nutrients returned back in the soil, causing a negative nutrient balance and making soils of rainfed areas deficient in N, P, and K (Irshad et al., 2007). In rainfed areas, almost 100% of agricultural soils have been found to be nitrogen deficient. Some 90 percent of soils are Phosphorus (P) deficient while about 20-40 percent of soils are low in Potassium (K) (Shah and Arshad, 2006). Boron, Zinc and Iron deficiencies are prevalent in 60%, 67% – 71% and 21% – 25% soils respectively (Rashid, 1994).

Excessive cultivations can destroy the soil structure and because of this, soils are unable to hold enough moisture to support the growing crops (Irshad et al., 2007). On the country level, about 96% of soils brought under plough do not have the optimum levels of organic matter to support good agriculture practices (MELGRD, 2001) Some 77 percent of soils have organic matter contents as low as <0.80 percent and only 4 percent of the soils have organic matter content >1.2 percent. The possible reason for low organic matter contents of soils could be attributed to the prevalent climatic conditions (arid to semiarid) and agricultural practices (Qureshi, 2003). Crop residues are known to improve the physical conditions of the soils and intend to enhance organic matter contents; however, instead of incorporating crop residues and animal wastes into the soil, these are mostly used as fuel and fodder (Baig et al., 2005).

Fertilizer use efficiency in rainfed agriculture is lower than in irrigated areas (Saleem et al., 1986). For irrigated grain crops, it generally varies from 50 to 60 percent for N and from 15 to 20 percent for P (Ray and Chandra, 1979). The main factors responsible for low fertilizer use efficiency in rainfed agriculture are poor fertilizer management practices, moisture stress at critical growth stages, severe weed problems in high rainfall areas and poor crop management practices adopted by the farmers of the dry areas (FAO, 1981). Imbalanced fertilizer application is considered as one of the most important factors responsible for low fertilizer use efficiency and it may cause a 20-50 percent reduction in efficiency (Zia et al., 1997; Zia et al., 1998; Rashid et al., 2004). Results of 96 experiments on rainfed wheat revealed that application of N alone increased grain yield 87 percent over control. But, when P was also applied, the increase in yield over control was almost doubled (161 percent). A further increase was achieved by a balanced application of K alone with N and P (SFSSTI, 1980 – 1982). Besides fertilizer management practices, good crop management practices play an important role in realizing potential yields (Zia et al., 1996; Zia and Baig, 1997). Studies reported by Indian workers (Sekhon, 1976; FAO, 1981) reveal that various production factors if not properly managed would cause significant reduction in fertilizer use efficiency.

3.5 *Deforestation and weed infestation*

Despite the presence of thin cover of forests in Pakistan, their productive, protective, regulative and socio-cultural functions and benefits cannot be denied. The indirect benefits of forests in terms of soil conservation, water production, and regulation of stream flow and maintenance of ecological balance are much more than their direct benefits (Khan and Mahmood, 2003). Against deterioration of soils and environment, forests act as the first line of defence. Such deteriorations may lead to desertification and erosion resulting in silting of reservoirs (Irshad et al., 2007). They also act as a biological defence against land degradation issues like erosion, salinity and waterlogging. Although a desirable range of a country's land under forest is 20% – 25%, only 5.0 percent of Pakistan's total area is under forests (Siddqui, 2007). According to Khan et al. (2012), all the major forest types and vegetation cover have been affected severely in recent years due to factors like: ruthless and indiscriminate removal of forests; poor, unplanned and unscientific management; overgrazing; and ecological changes, and anthropogenic activities. Whereas according to Ahmed and Zia (2003), key factors responsible for the degradation of forest resources in Pakistan include: shallow soils on steep slopes, unsuitable soil structure, degradation in soil productivity, inadequate irrigation, poor quality planting stock, low survival rate of new seedlings, poor regeneration and low stocking in coniferous forests, low intensity of cultural practices and defective and inappropriate logging practices. The country experiences deforestation on around 7,000 – 9,000 ha annually, that is almost equal to 0.2 percent loss in the forest cover per year.

Both rangelands and forests are deteriorating due to uncontrolled roaming and grazing livestock. The productivity of rangelands has been reduced to 15 – 40 percent of their potential resulting in acceleration of soil erosion and loss of biodiversity. Anjum and his co-workers (2010) report that the disappearance of many trees from the rainfed areas has created the issues like land degradation and declining of soil fertility. Fear remains if these rangelands and forests are not managed along scientific lines for regeneration and rehabilitation, more environmental degradation will take place (Government of Pakistan, 2007). Crop yields are severely hampered due to the heavy infestation of weeds, a serious problem experienced in high rainfall areas of rainfed agriculture. Weeds are known to compete strongly with the main crop for moisture, nutrients, space and light and take a heavy toll of crop production. In high rainfall areas, it is practically impossible to grow summer season crops (when heavy down pours received) without proper weed management making rainfed agriculture difficult and expensive (Baig et al., 1999; Rashid et al., 2004; Irshad et al., 2007).

4 Innovative technologies and strategies suitable for rainfed areas towards sustainable land management and crop yields

Rashid et al. (2004) identified various corrective measures to improve crop productivity and soil improvement including: effective rainwater harvesting, land consolidation, improved credit facilities, better soil and water conservation, use of good quality seed, balanced nutrient management, and weed control. In the context of crop production, rainfed lands are known as low potential areas and most often are underestimated. However, these areas can produce more than double what is being realized now, an indication of their high potential for crop-production. According to Adnan et al. (2009), although water remains the only limiting factor for agriculture development in these areas, the adoption of appropriate water-resource development measures and management practices can greatly increase crop yields.

4.1 *Conserving rainwater through better water harvesting techniques*

Rainfed areas receive sufficient rain and if rainwater is collected through innovative techniques, it can be used for crop production (Baig et al., 1999; Adnan et al., 2009). Shah et al. (2011) argue that supplemental irrigation plays a critical and essential role in dryland agriculture if practiced on scientific lines. Among the rainwater collection techniques, two important are (i) in-situ and (ii) catchment based water harvesting. In situ water harvesting consists of conserving as much rain as possible at places where it falls. For this purpose, some land and soil treatments are applied. However, the excess water that cannot be conserved within the root profile is collected and recycled to the donor catchment itself. This practice is more useful in moderate rainfall areas receiving 240 – 400 mm of average annual rainfall. Retention of all incident precipitation in such areas may be achieved by holding water on the surface until it is absorbed by the soil. This can be accomplished by making contour furrows, terraces and run-off recycling. In catchment-based water harvesting for sustained crop production, rainwater is allowed to run on the upper reaches of the catchment and collected at lower reaches. The under lying principle is to reduce infiltration and maximise run-off on catchment slopes for greater water harvest on adjacent areas. The run-off can be increased by vegetation removal, compaction or chemical soil sealants. In areas, where runoff water can be stored and used, cost effective small dams can be developed for supplementing the water requirements of rainfed area.

Practices adopted to reduce surface runoff not only combat and diminish the erosion risk but also improve moisture reserves in the soil. Such remedial measures include: proper bunding (putting strong earthen boarders around the fields), levelling and deep ploughing, which help hold water so that most water infiltrates into the soil, while levelling (preferably laser) ensures the equal distribution of moisture over the whole field (Baig et al., 1999; Rashid et al., 2004). Each millimetre of saved water could increase yield of wheat by an average of about 10 kg ha^{-1}. The adoption of these conservation practices for a Kharif (summer) season increased crop yields by 14%. However, for light-textured and sandy soils, water-harvesting is known to increase surface runoff and it can be collected at appropriate places to meet domestic, livestock and agricultural needs.

4.2 *Role of conservation agriculture*

Conservation tillage includes minimum tillage, no till, direct drill, mulch tillage, stubble mulch, trash farming and strip tillage for increasing infiltration and reducing run off. Thus, it helps to reduce soil erosion. Deep tillage, ripping or sub soiling can also be beneficial, either to increase the porosity of soil or to break a pan (compact cemented layer) that really reduces permeability. Under these conditions, deep tillage increases water infiltration, reduces run-off and checks soil erosion (Baig et al., 1999). Other practices which are helpful in conserving moisture in rainfed areas include use of suitable mulches and addition of organic materials and planting cover crops. In describing the benefits of mulches, Qureshi et al. (2010) observed that mulches have good potential in increasing crop production by conserving soil moisture. Mulches create the conducive environment for growing plants, making soils conditions favourable by reducing evaporation, suppressing weed infestation, enriching soil with nutrients and preventing runoff and hence halting erosion problems (Irshad et al., 2007). Relatively small amounts of crop residue (1.0 t ha^{-1} wheat straw) which could provide 50 percent surface cover is effective in enhancing water infiltration by reducing runoff, erosion and crusting. In one study where straw was used, available water capacity in soil increased by about 45 percent and total pore volume by 7.5 percent (Voss, 1988). Similar useful effects of wheat straw mulch on moisture conservation and wheat yield have been reported in Pakistan (Chaudhary et al., 1990; Hussain, 1991).

Appropriate tillage practices are important for realizing sustainable crop yields on rainfed areas. However, inappropriate tillage practices result in erosion, soil compaction, reduced soil aeration, water infiltration, and microbial activity (Ahmed and Zia, 2003). The role of tillage in moisture conservation in rainfed agriculture has been somewhat controversial in the past. Currently there is significant interest and an emphasis on a shift to minimizing tillage intensity in North America, Europe and Australia (Hamblin, 1984; Sprague and Triplette, 1986). Farmers of the rainfed areas practice shallow tillage for increasing organic matter, water conservation, weed control and infiltration (Sidiras and Rotli, 1987; Ahmad and Zia, 2003). However, continued shallow ploughings develop a hard pan under the plough layer. The practice prevents rainwater infiltration into the soil and restricts the emergence and root development of rainfed crops (Qureshi, 2003). Khaliq and Cheema (2007) consider deep tillage an important practice in ameliorating plough pans, hard pans or naturally occurring dense soil layers. Deep tillage as compared to normal shallow cultivation loosens the soil, increases infiltration and recharges the underground water resources during rainfall. Thus, deep tillage helps to conserve the moisture in the soil. Zia and Nizami (1993) have conducted an extensive review of the role of tillage for the rainfed areas of Pakistan. They demonstrated that more moisture was conserved in soil tilled with a moldboard plow as compared to one tilled with cultivator. Cover crops are known as the best practical means of providing the organic matter needed to maintain and improve the tilth, health, fertility and productivity of soils (Baig et al., 1999). Parr et al. (1990) reported that cover crops are highly effective in improving water conservation by supplying organic matter, controlling certain weeds and reducing evaporation.

4.3 *Construction of small dams, and dug wells*

It has been estimated that about 11 Billion Cubic Meter (BCM), which is equivalent to 9 MAF, of water is lost annually as surface runoff from the rainfed regions. If 50% of this runoff is retained in small/mini dams, water equivalent to more than half the capacity of the Tarbela dam could be stored. There are many potential sites for the construction of small/mini dams in northern areas of the country as well as in the Pothwar region. The government of Punjab has constructed 31 small dams in the region. Besides supplying water for irrigation, these dams have many indirect benefits, such as groundwater recharge, domestic and municipal uses, soil-erosion and flood control in hilly and plain tracts, developing fish culture, and providing recreational activities. However, there are several issues relating to these dams that need to be addressed, such as development of the areas to be irrigated, low water-conveyance and application efficiencies, reduction in reservoir-capacity due to sediment-deposition and vegetation growth, and evaporation and seepage losses. Reports compiled by the International Water Management Institute

(IWMI) and National Engineering Services of Pakistan (NESPAK) reveal that presently only 23% of the stored water is being used, with a cropping intensity of 60% against a projected figure of 130%. It is interesting to note that small/mini dams are being constructed by many progressive farmers in the Pothwar Region and have been very successful in generating income comparable to that of farmers in the canal-irrigated areas (PCST, 2005a). Large-scale water resources through mini and small dams involve large capital investment. Moreover, these reservoirs need special attention, in terms of operation and maintenance. Since these dams are mostly public owned, disputes over water rights and the sharing of maintenance cost also arise. Small-scale on-farm water-resource development and management activities, however, can play an important role in increasing the income of farmers. Individual farmers or a micro community own these systems; therefore, they make best use of the water-resource available and disputes over water are eliminated.

The Rainfed Master Plan reports that there is considerable potential for development of open wells in the cultivable lands of the Pothwar plateau. The aquifers in the Plateau are generally in sandstone formations with low transmissivity values. It is considered that dug wells up to 20 m (66 feet) deep can safely yield 3-6 litres per second (lps) water to irrigate small fields, besides meeting domestic requirements. However, the design of such wells needs to be based on aquifer transmissivity and recharge characteristics and capacity of the aquifer. The development of a typical dug-well can provide water for about 2 ha of flood-irrigated, 4 ha of sprinkler-irrigated or 6 ha land with low-pressure drip, typically for high-value orchards. At present, there are nearly 10,000 open wells in the Pothwar region, constructed either by government support through several micro-water resources development projects or by farmers themselves. There is still potential for further development; however, sustainable assessment is needed to be carried out before initiating any further activity (PCST, 2005a).

4.4 *Pressurized irrigation systems*

Due to water scarcity, only 25% of the total rainfed area is under cultivation. The farmers use obsolete methods of irrigation resulting in poor application and distribution efficiencies. In most of the area, the land is highly undulated and precision land levelling is not an economically justified option under the prevalent topographic conditions, gravity irrigation is also not possible in these areas. Therefore, it is of utmost importance that the scarce water resources in the region are used most appropriately and efficiently with minimum losses. Highly efficient sprinkler and trickle irrigation techniques have been successfully introduced on a small scale in Pakistan, and are particularly well suited to the water scarce rainfed areas (Khan et al., 2012). Application efficiencies of these systems can be very high (75% to 85%) thus, permitting almost full use of the scarce water supplies. An additional advantage, as compared with other methods of surface irrigation, is that efficient irrigation can be carried out even where topography is undulated and soil is of light texture, as is the case in much of the rainfed areas. Rain-gun sprinkler with mobile units and drip irrigation system components have been locally developed, which are comparatively less expensive and have proved successful and potentially promising (PCST, 2005a).

4.5 *Soil and water-conservation practices*

Rashid et al. (2008a) through the addition of gypsum have been able to successfully conserve soil moisture. In addition, gypsum application at the rate of 2.5 t ha^{-1} was helpful in increasing wheat yield by 46% in low rainfall years. Their experiments in the rainfed areas showed that such practices have the potential to mitigate the adverse effects of drought (Rashid et al., 2008a). Khan et al. (2012) called the adoption of integrated engineering, cultural and biological measures for soil and water management practices. They also advised that ecologically suitable cropping systems be devised and applied on these areas. In addition to these, other innovative technologies include: contouring, strip cropping, terracing, improved tillage practices, and construction of soil and water-conservation structures. In contouring, tillage operations are carried out as nearly as practical on contours. On gentle sloping lands, contouring reduces the velocity of overland flow. If ridge cultivation is practiced, the storage capacity of furrows is increased, permitting the storage of large volume of water. It has been shown that contour cultivation of a good piece of land with grass at the beginning of the rainy season can reduce watershed runoff by 75% to 80% (Baig et al., 1999). Strip cropping consists of a series of alternate strips of various type of crops laid out so that all tillage and management practices are performed across the slope or on the contours. Strip cropping is not a single practice rather it is a combination of several good farming practices such as crop rotation, contour cultivation, proper tillage operations, stubble mulching and cover cropping. Cover crops can also be highly effective for controlling erosion (Zia et al., 1996).

Terracing involves constructing broad channels across the slope of rolling land. The prime function of terracing is to decrease the length of hillside slope, thereby reducing sheet and rill erosion, and preventing the formation of gullies. Terraces not only check erosion but also increase retention of rainwater in the soil for successive crop. This also helps maintain soil fertility and enhance crop production significantly(Baig et al. ,1999). Technological support would be required to have deep ploughing, chiselling and sub-soiling where required and to improve the existing cultivated terraces to have increased water infiltration, absorption and to check and minimize runoff on the rainfed areas(Khan et al. ,2012). Tillage practices have been the most common practice adopted for improving soil physical conditions for crop production. Deep tillage enhances the yield by lowering the soil strength and by increasing evapo-transpiration. Deep tillage also increases the moisture reserves in the soil by retaining rainfall. Before the monsoon begins, the soil should be tilled across the slope rather than parallel to the slope. This practice retains maximum rainwater, conserves the soil, and prevents erosion(Khaliq and Cheema, 2007).

To control soil erosion and to conserve soil moisture, various types of structures can be constructed at appropriate locations to dispose of excess runoff including retaining walls, water disposal outlets, spillways etc. (Rashid et al. ,2008b). These low-cost water conservation structures/technologies that are developed and evaluated by researchers(Rashid et al. ,2008b) have been evaluated for their cost-benefit ratio by Shah et al. (2012). The evaluators believe that these technologies are of low cost providing more benefits and they are to be taken to the farming communities of rainfed areas by the governmental departments. Other practices and measures like: making strong borders made of mud around the fields to keep the water in the same field for preventing runoff(locally called watbandi), contouring, water disposal outlets, range improvement and forestation have been proved useful. Rehabilitation of eroded lands through earth moving machinery, gully plugging and construction of mini and check dams have been very successful in soil and water conservation, as carried out by various organizations in Pakistan. Along with these, other workers(Zia and Nizami, 1993; Baig et al. ,1999; Rashid et al. ,2004) also suggested some additional measures like cover cropping, rotation with perennial pastures, maintenance of fertility, stubble mulching, minimum tillage, strip cropping, construction of drop structure and flood retarding structures. The combination of these practices would certainly help conserve soil and water, and result in sustainable crop yields while addressing erosion issues. FAO(1987) has also presented a detailed account of soil conservation measures that could be very effective for rainfed ecologies and ecosystems. Appropriate crop rotations enrich soils with the addition of organic matter, improving the fertility status through adding nutrients through the addition of essential nutrients. Organic matter is known to improve soil structure and soil infiltration, which ultimately could reduce soil erosion. Surface mulching provides protective cover at a time when crop cover is not practical, as it improves infiltration and reduces soil erosion hazard(Zia et al. ,1996; Baig et al. ,1999).

The national scientists at PARC have successfully designed an integrated approach by using a mixture of crops, forage, trees and forest plants for managing watersheds and plugging gully lands. Such an approach has proved quite useful to rehabilitate eroded areas and for making the best use of degraded lands(Zia et al. ,1996; Baig et al. ,1999; PARC, 2001). Wind erosion is also an important constraint in some rainfed areas, especially on sandy soil with low moisture contents. Many researchers like Alim and Javed(1993), Baig et al. (1999), and Zia et al. (2004) presented remedial measures for combating the wind erosion menace, and salient points of their suggestions are presented below:

Certainly the wind-erosion hazard can be minimized by adopting cultivation techniques that maximize residue-conservation and reduce soil-pulverization. For cultivation, tined implements are thought to be better than disc plowing, as the latter results in more soil-pulverization of the surface-residues. To minimize wind erosion, soils should be less exposed to disturbance by employing less frequency of cultivations. Implements, such as blade and chisel plows, with steep points which go deeper into the soil and produce good clods, should be used. In order to conserve the soil and check erosion, at least 50% of the soil-surfaces must be covered with soil-clods greater than 2 cm in size. Similarly vegetation cover can trap eroded soil-particles and reduce their erosive power. Vegetation adsorbs the wind force and consequently reduces wind-speed at the ground level by creating a shield against the wind forces and preventing wind from removing soil. To stop erosion, it is important to keep at least half of the ground covered with vegetation, otherwise, wind erosion can take place.

Vegetation can greatly reduce erosion. To keep the vegetative cover in good condition it is important to control grazing and to control the uprooting, cutting and burning of natural vegetation. Among the viable options to halt wind erosion through vegetation include: strip-cropping; growing of hedges around cultivated fields exposed to winds and those located near active sandy ridges; and establishing windbreaks around erosion-vulnerable areas to reduce wind velocity.

4.6 *Managing steep slopes*

Steep sloping lands cover about 10.5 Mha and occur mainly in northern and western mountains and, to some extent, in Pothwar. Because of steep slopes, geological erosion is active in most of the area. However, the process has been accelerated by deforestation, and by the expansion of cultivation and by over-grazing. Landslide, sheet erosion and stream erosion are serious problems. In the western mountains, 90 percent of the area consists of rock outcrop with a very thin soil cover, which can support only poor vegetation. In the Pothwar uplands, steep sloping land occurs in the form of eroded and gullied lands. Cultivation of steep slopes (over 30 percent) is a major source of erosion. Soil erosion affects irrigation systems in the plains and reduces the functional and operational life of reservoirs. Loss of topsoil results in loss of nutrients, thus affecting productivity of the eroded lands (Baig et al., 1999; PARC, 2001).

Steep sloping lands mainly occur in northern and western mountains. Improvement measures like building stone bench-terraces in the cultivated areas have been proven useful. Further expansion of the cultivated areas with the slopes greater than 15% results in erosion and should be avoided. Sloping soils should be covered with a mixture of legumes and grasses for forage-production instead of just growing maize. On the sloping lands, it is important to improve the existing bench-terraces and install water-disposal system with, grass waterways and water drop-structures (Zia et al., 2004). Such cost-effective water control structures for the storage and disposal of rain-water have been developed by the Soil and Water Conservation Research Institute (SAWCRI). They were installed at various locations in the rainfed region and an increase of 20% – 25% in crop production has been realized due to these structures (Rashid et al., 2008b).

4.7 *Strategies for enhancing the fertilizer use efficiency*

Many researchers have reported the low fertilizer use efficiency for rainfed agriculture. Since most of the rainfed areas are being exposed to higher temperatures, the warmer conditions speed the natural decomposition of organic matter and at the same time also increase the rates of other soil processes that affect fertility. Additional application of fertilizers may be required to realize enhanced crop growth (Bhatti and Khan, 2012). However, various researchers have shown that fertilizer use efficiency can be enhanced to realize higher yields through rainfed agriculture, if applied in the correct doses, in the appropriate combination and at the proper time. It is common in Pakistan and elsewhere that nitrogenous fertilizers are generally applied at the time of sowing of the crop. Nevertheless, the efficiency is improved if the fertilizers are applied in split applications (Spratt and Chaudhry, 1978). With deep tillage, rainwater moved to a lower soil depth improving the N use efficiency for wheat (Meelu and Rekhi, 1976). Foliar application of N using 1.5 percent concentration of urea increased wheat yield by about 15 percent (Chaudhry and Shafiq, 1988). Using rhizobium inoculum on leguminous crops improved the use of N fertilizers. According to Amin (1990), chickpea yield was increased by 16.1% by applying chickpea inoculum. In another study, soybean yield was increased from 29% to 39% with the use of different rhizobium strains. Yield was further increased 49 percent when a mixture of rhizobium strains was used (OSP, 1990).

Phosphatic fertilizers are extremely important for their role in improving crop yields (Zia et al., 1996). The yield of rainfed wheat was significantly improved with the application of phosphatic fertilizer, maximum yield increases of 100% to 106% were obtained with the application of 60 kg P ha^{-1} (Rashid et al., 1992). Efficiency of phosphatic fertilizers can be substantially improved by proper placement methods and soil management techniques. In another study, pod yield of groundnut was increased by 69%, from 1,343 kg ha^{-1} by broadcast to 2,270 kg ha^{-1} by drilling of 23-69 kg ha^{-1} N -P205 ha^{-1} (BARD, 1990). In case of mungbean and chickpea, band placement of P fertilizer for producing maximum grain yield saved 71% to 73% fertilizer over its broadcast application (Rashid, 1992). For rainfed wheat, P application in deep tilled soil with moldboard saved 21% to 37% fertilizer over its application in soil tilled with cultivator (SCAN, 1993).

4.8 *Strategies for controlling soil crusting and its compaction*

The issue of soil crusting can be addressed and its harmful effects offset by employing appropriate tillage practices; application of organic amendments; use of a mechanical soil crust breaker; use of soil conditioners; and planting seeds of various crops by proper sowing methods at appropriate planting depths (Prihar, 1974; Page and Quick 1979; Nizami, 1989; Zia et al., 1996).

4.9 *Use of organic and farm wastes*

Addition of organic manures improves the physical-chemical conditions of the soils by improving pore space and water and nutrient holding capacity (Baig et al., 2005). It was observed that hoeing and use of poultry waste were equally effective to control soil-crusting problems. On the Balkassar soil series, use of poultry manure was best in controlling soil-crusting problems. On the Guliana soil series, hoeing was superior to the use of organic manures in controlling soil-crusting (Nizami, 1989). There is a need to find suitable leguminous or green manure crops like alfalfa, berseem, sesbania and groundnut that could improve the organic contents of soils and reduce the erosion hazard (Khan et al., 2012).

4.10 *Sowing seeds at shallow depths*

Crust formation, soil compaction and resultant poor seed emergence are very pronounced and visible phenomena on the rainfed areas of Pakistan. In soils where there is a greater possibility of crust formation, planting the seed at deeper depths reduces the chances of seedling emergence due to the hardness of the soil crust, therefore, seed planting at a shallow depth would ensure greater seed emergence and higher plant population (Hadas and Stible, 1977; Nizami, 1989; Baig et al., 1999).

4.11 *Tillage practices*

Excessive plowing (ten times) resulted in crust formation in three rainfed soils. For Guliana and Missa soils series (silt loam texture), only 6 plowings were required to get the maximum corn yield, whereas in the case of soil which is fine sandy loam in texture, excessive plowing was harmful and the highest yield of maize was obtained with two number of plowings (Nizami, 1990).

4.12 *Managing weed infestation*

Competing with the main crop for moisture, nutrients, space and light on the areas receiving high rainfall in rainfed agriculture, fast growing weeds cause serious problems by taking a heavy toll of crop production. In the rainy season (summer), it is nearly impossible to grow crops without the eradication of weeds. Weeds can be eliminated by hoeing (hand weeding), tillage operations and/or proper use of herbicides. However, use of chemical herbicides remains the most effective, workable and economical option to control weeds (Zia et al., 1996). In one study, grain yield of maize was increased from 1.41 to 2.48 t ha^{-1} (76 percent increase) by using Prim extra (BARD, 1988). Similarly Shad et al. (1993), also reported that eradication of weeds manually produced a 66 percent increase in maize grain yield compared to 93.4 percent with the use of Prim extra (1.5 kg ha^{-1}). Weeds were also better controlled with deep tillage using a moldboard plow as compared to conventional cultivation (Razzaq et al., 1990). The efficiency of weedicides for rainfed wheat was improved by applying them in deep tilled soil (PARC, 1990). However, an integrated approach consisting of agronomic practices, application of weedicides and manual eradication is suggested to realize economic yields. The combination of all such measures can only prevent their multiplication.

4.13 *Bringing forest cover back*

Various proposed steps to bring the forest cover back and measures for realizing afforestation are:

- Identify areas needed afforestation.
- Patches and areas with thin and sparse vegetation in the forests must be replanted on a priority basis.
- Rehabilitation of riverain forests may require additional irrigations.
- Conservation and management of private forests would enhance forested areas and must be encouraged.
- Dedicated efforts need to be made to plant trees along canal banks, railway tracks.
- In order to combat land degradation processes, plantations are needed for sand dune stabilization and to control salinity.
- Trees should be planted in and around all governmental buildings and compounds of all official institutions should be planted with trees.
- More trees and green areas can be established by popularizing the Social Forestry programmes; such initiatives also ensure their after care.

4.14 *Rehabilitation of rangelands*

Rangelands of Pakistan, covering an area of 50.9 Mha (63.9%) are a very precious resource base for livestock, however it is diminishing, leading to low livestock production and loss of productivity (Farooq et al., 2007). More than 60% of rangelands are degraded and producing less than one-third of their potential due to overstocking beyond their carrying capacity. Over-grazing of rangelands has brought their productivity levels to as low as 15% – 40% of their potential (Anjum et al., 2010). In addition, aridity and prolonged droughts have further adverse impacts on their vegetation (Farooq et al., 2007). Such deteriorated rangelands are difficult to rehabilitate. In this situation, it would be wise to devise and launch an integrated rangeland management approach for afforestation and livestock production (Intercooperation Pakistan, 2006). Some important and useful initiatives may include:

- There is a need to develop grazing systems in the rainfed areas, which close and re-open at appropriate times.
- Rangelands can be made more productive by re-seeding them with palatable grasses and leguminous species.

4.15 *Cultivation on the sloping lands*

Sloping Agricultural Land Technology (SALT) farming techniques have been developed with the collaboration of the scientists of Pakistan Agricultural Research Council and the International Center for Integrated Mountain Development (ICIMOD). The technology evolved was well received by the vast majority of the farmers residing in Himalayan foothills of Pakistan. Today by adopting these farming techniques, farmers are successfully realizing sustainable crop yields from their lands which were considered vulnerable in the past. They are not only growing various crops but also are conserving the soil resources and enhancing the fertility levels of the sloping soils of Pakistan (Khan et al., 2012).

4.16 *Integrated land and water conservation approach*

In rainfed areas, moisture is the most prevalent limiting factor. An integrated land and water conservation approach has been developed by the Pakistan Agricultural Research Council (PARC). Researchers of the organization have developed a model and applied it in the Pothowar Plateau of northern Punjab near the Fatehjang area. In the model the problem area is being used according to its land-capability and ability to sustain crops, pasture, fruit trees, and other tree-planting. The model involves the formation of grassed waterways for making the water flow to desired places to check erosion and runoff, plugging of gullies and construction of ponds for storage of water. By employing the "integrated land and water conservation approach" the farmers of the rainfed areas are putting their lands under crops, pastures, orchards, and forest trees. Such practices have also been replicated in the neighboring villages, with similar topographic features and climatic conditions (Zia and Rashid, 1995; Shah et al., 2012; Khan et al., 2012).

4.17 *Gully land management*

National scientists after conducting research on severely eroded lands for a period of 10 years have developed bio-engineering technology for the rehabilitation of gullies on areas severely affected by erosion. The technology was able to address the issue and completely reclaimed the area. Land-development operations were kept at the minimum. Every possible effort was made not to disturb or remove the soil from its position. The intervention applied in the form of planting forest and fruit trees are producing handsome returns. Today the model inspires other farmers of the area and technologies have trickled down even to the level of small and subsistence farmers. By adopting this model, farmers are making the best use of their degraded lands and at the same time, have been able to elevate their income levels reasonably by practicing sustainable agriculture (Zia and Rashid, 1995; Khan et al., 2012).

4.18 *Adoption of zero-tillage*

Pakistan Agricultural Research Council (PARC) in collaboration with provincial research and extension system developed zero-tillage for the major rice-wheat and cotton-wheat systems of the country. These technologies were used for wheat sowing and preparing the seed bed for planting. The technologies were able to contribute significantly in improving crop productivities particularly on saline soils by providing a comfortable environment and avoiding germination issues, improving crop-stand establishment, enhancing fertilizer use efficiencies and water resource conservation. Now a sizeable segment of the farming community has put zero-tillage technology into practice in the rainfed and saline areas (Khan et al., 2012).

4.19 *Integrated land use model for Barani areas*

For the Barani (rainfed) areas an integrated land use model has been developed by the Soil and Water Conservation Research Institute (SAWCRI). The organization has developed low-cost water conservation structure technologies to protect lands from water erosion and to conserve soil moisture in an efficient manner for realizing better crop production in the rainfed Pothwar areas. The installations of these structures helped conserve moisture, increasing cropping intensity and realizing sustainable high value crops production. These technologies are well-received by farmers in the up-scaling phase in other watershed management related projects presently under implementation in rainfed areas. Water distribution structures have also been developed for rod-kohi system (Spate irrigation) to practice agriculture on 2 million ha. These structures helped in diverting flood water, increasing moisture availabilities and combating the effects of cyclical droughts. Farmers of the rod-kohi areas are actively employing this system of irrigation for practicing agriculture as it is economically feasible, socially acceptable and environmentally sound, bringing it under the definition of sustainable agriculture (Rashid, et al., 2008b; Khan et al., 2012).

4.20 *Development of rangelands*

For the rehabilitation of degraded rangelands, the national range scientists have been able to develop technologies like: micro-catchment water harvesting technologies such as ridge formation for shrub establishments, V-shape plant rehabilitations structures, fodder reserves development for winter grazing through plantation of drought tolerant shrubs (*Atriplex and Acacia* species), reseeding of species of grasses like Chryso and Symbo in the provinces of Balochistan and Punjab. The nomads believe that all the natural resources including rangelands are meant for them and their grazing animals, hence, research or developmental initiatives that restrict their animals from free grazing under rotational grazing systems, meet failures. The technologies aimed at the development of the rangelands did not meet the desired level of success and their use still remains limited and only on a small scale. In order to make them popular among the graziers and pastoralists, planned participatory efforts are needed through the social mobilization and active involvement of the community. To realize the real outcomes of participatory approach, it is extremely important that all the afore-mentioned stake-holders including the implementing agencies do participate in the initiatives aiming at the development of the degraded rangelands (Inter-cooperation Pakistan, 2006; Khan et al., 2012).

The brief information on the technologies adopted and the extent of their use is presented in Table 3.

Table 3 Examples of some of the prominent sustainable agricultural practices adopted on the rainfed areas

Category	Practices and technologies	Extent
Soil and water conservation management	Terraces and other physical and biological structures to control erosion and water runoff	Adopted on large areas
	Water harvesting techniques	Adopted on large areas
	Contour planting	Practiced on small scale
	Hedgerows and living fences and barriers	Practiced on small scale
	Conservation tillage	Practiced on small scale
	Mulches, cover crops including nitrogen fixing legumes	Adopted on large areas
Soil fertility management	Manures, Composts, Organic wastes	Adopted on large areas
	Green manures like Sesbania, Berseem	Adopted on large areas
	Agroforestry	Practiced on small scale
	Integrated soil fertility management	Practiced on small scale
	Integrated plant nutrient management (IPNM)	Practiced on small scale
Crop establishment	Intercropping	Practiced on small scale
	Alley cropping	Practiced on small scale
Controlling of weeds, diseases and pests	Inter-cropping and rotations	Adopted on large areas
	Integrated pest management (IPM)	Practiced on small scale

Modified after Tripp (2006).

5 Implications for extension, education and capacity building

In order to realize the benefits of agricultural and livestock sectors, Agricultural Extension could be of great and valuable assistance and can certainly play a pivotal role. Agricultural Extension has a prime role in the over-all process of sustainable development of rainfed areas by highlighting the issues and popularizing the beneficial farming technologies. It is imperative to create awareness and educate the rural masses on the prevailing issues, potential sustainable technologies available to mitigate these issues towards improving the situation. There is a need to educate the rural policy-makers, planners, government officials, and NGOs etc. Initiatives on capacity building, organizing of workshops, training courses, support from electronic and print media are important endeavours. Rich opportunities do exist to realize sustainable development in rainfed areas if all the stakeholders play their roles with dedication and devotion.

6 Conclusions and recommendations

Pakistan is predominantly an agricultural country. Rainfed agriculture contributes a significant share towards national agricultural production and GDP of the country. However, due to the problems and sustainability issues associated with rainfed agriculture, crop yields are quite low. The deteriorating situation of rainfed areas needs immediate attention of the researchers and policy makers for devising an appropriate, sustainable and implementable technology for the rehabilitation of these areas. In addition, a big yield gap exists between the potential yields and yields realized at the farm level. The erosion hazard keeps on washing away the fertile top soil at an alarming rate. Factors like: arid and dry climate and severe water deficits make agriculture difficult to be adopted and practiced on these areas. Range management and livestock rearing businesses can be very successful on areas having limited scope for agriculture. The problems like extreme scarcity of water, over-grazing, deforestation, and water erosion are quite common in the rainfed areas and can be managed through the following measures/techniques.

- Water harvesting techniques should be adopted on the mass-scale as a promising way of collection of run-off water;
- Conservation of water by adopting latest irrigation techniques such as Sprinkler irrigation, Drip irrigation etc. should be put into the practice to use each drop of water for realizing higher crop production;
- Present crop pattern can be replaced with the drought tolerant crops having lower water requirements and other desirable traits as an alternate farming system.

Pronounced wide spread nutrient deficiencies result in nutrient imbalances in soil, one of the major reasons of low productivity in rainfed agriculture. Proper nutrient management can go a long way in improving the productive potential of these areas.

The use of rhizobium inoculum can substantially improve the yields of leguminous crops and economize the use of N fertilizers. Balanced fertilizer applications and appropriate application methods can restore soil health and result in sustainable crop yields. For example, application of N fertilizer in deep tilled soil and/or in split application help in improving the efficiency of N fertilizer. Efficiency of P can be significantly improved by band placement. Good crop management practices such as proper seed bed preparation, proper seeding and sowing, appropriate crop variety planted at the right time, an adequate plant population, eradication of weeds and employment of measures against insect pest attacks are some important management strategies for realizing potential yields in rainfed areas. Masses of arid lands are in dire need to adopt a holistic approach that comprises developmental initiatives and conservation measures to protect precious natural resources, especially soil and water. A significant and considerable potential for development of agriculture and livestock sectors exist in these areas. In the overall agricultural scenario, the bulk of rainfed areas are an important and precious resource of the country, constrained with numerous problems and issues. However, if rainfed agriculture is practiced along scientific lines and improvement strategies are adopted, tangible and encouraging crop yields can be achieved on a sustainable basis.

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