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Dr. Sanjay Rana

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WATER PARADIGM: RAINWATER HARVESTING IN ARID REGIONS FOR AGRICULTURE

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ABSTRACT

In many developing and developed countries including India and the USA, water scarcity is a major problem, and it has considerable impact on policy-decision making for use and distribution of water, which affects government, public, scientists, and farmers in particular. The water challenges are severe in arid and semi-arid regions, where uncertain rainfall and lack of irrigation water affects the public and agriculture most harshly. Even in irrigated regions, seasonal variability in rainfall affects agricultural economy substantially. In terms of water use, 70-80% of water consumption is for agriculture. Any shortage of water, however, affects not only agriculture but also whole ecosystem including water quality, public health, and aquatic and wildlife resources.Developing improved resilience against water scarcity is crucial for enhancing the sustainability, specially when the incidences of climate extremes including the frequency and longevity of droughts are increasing. To improve water resources in arid and semi-arid regions, a range of strategies, which involves improving existing rainwater harvesting approaches, runoff retention from agricultural land, and enhancing water use efficiency are needed. In this study we assessed challenges and potential opportunities in rainfed farming system, and also evaluated the benefits of rainwater harvesting system in rainfed system. As an example, on-farm rainwater harvesting reservoirs, which are used for rainwater in rainy seasons, were found to be useful for improving the farm income in rainfed agriculture. These water harvesting systems not only improve the localized water quantity by enhancing the retention and conservation of rainwater but also will likely to have positive impacts on downstream water quantity, and water quality by controlling the *transport of non-point source pollution such as pathogenic bacteria, excess nutrients, and pesticides from agricultural land to ambient water bodies including natural streams and lakes.We anticipate that this paper will provide a general overview of rainfed farming, challenges, scope for improvement, and various strategies to improve farming in rainfed system.*

KEYWORDS:*water resources; rainwater harvesting; water quality; pollution; agriculture; economy*

INTRODUCTION

More than 9 billion people are expected to live in this world by 2050 (Sposito, 2013), which will likely to result in increased food demand substantially. To meet the future demand of food,crop production has to be increased by 50 to 100% in coming 3- 4 decades (Sposito, 2013; Tilman et al., 2011). One option for increasing the global crop production is to enhance the crop yield in rainfed regions such as arid and semi-arid regions (Pandey et al., 2013; Pandey et al., 2011). Currently, more than 80% of the total global cropped land is rainfed, which contributes to global food production considerably(Falkenmark and Rockström, 2006). Considering the contribution of rainfed farming in food production, it is critically important to enhance the crop production and sustainability of rainfed farming systems.

In terms of land resources, currently considerable competition exists for land need for agriculture and residential and industrial purposes. It is likely that the increase in crop production will have to come from increase in crop yield rather than from increased crop land (Sposito, 2013) primarily because of increasing demand for land resources for non-crop purposes (Gregory and George, 2011). Rainfed agriculture can help achieving this goal. The rainfedfarming is needed not only to meet the global food demand but also to reduce the increasing water stress (due to excessive water mining for irrigation) in ground water and aquifer system. To enhance the sustainability of rainfed farming, and meet the sustainable food supplies; however, additional water resources capable of providing supplemental irrigation during prolonged dry seasons are required in arid regions. The lack of water for supplemental irrigation during dry seasons reduces the crop yield substantially in rainfed farming system.

Despite relatively poor crop yield, the distribution of rainfed farming system is considerably all over the world. As an example, arid and semiarid regions include all of the Middle East, half of India, and about 70% of Africa (Sposito,, 2013; Boelee, 2013). In general, more than 95% of people in developing counties live in rainfed or mixed rainfed systems [in mixed rainfed system livestock are raised with crops, and rainfall is the only source of irrigation] (Herrero et al., 2012). In sub-Saharan Africa, 400 million depends on rainfed farms against 6.4 million depends in irrigated system

(Herrero et al., 2012). Considering the fact that the rainfed farming is widely used, identifying the practices which have a potential to improve the rainfed farming productivity is crucial for improving the crop yield in ranfed system as well as global food production.

POTENTIAL CHALLENGESIN ARID AND SEMI-ARID REGIONS

Major challenges of rainfed system includes uncertainty in rainfall, lack of water storages systems for conserving the rainwater during monsoon seasons, lack of water for crop irrigation during dry seasons, and prolonged dry spells. During rainy seasons, millions of lives are affected because relatively larger areas are inundated with water. On the other hand, millions of livelihoods are compromised because of no availability of water during dry seasons. The productivity of rainfed farming systems is often directly linked with climate variability, droughts, and monsoon. In addition to water resources, issues such as desertification, poor soil quality, and land degradation are considerable challenges of rainfed farming system (Boelee, 2013; Sposito, 2013).

As many of the world's poorest lives in rainfed areas, the advance practices, which requirea large investment, cannot be afforded by farmers. Nevertheless, implementation of cost effective methods, which can help in improving the crop yield can help millions of farmers and will result in multiple benefits (Boelee, 2013). The improvement in the crop yield is required for improving the farm income, particularly in rainfed regions because majority of the people's livelihood in these regions entirely depends on agriculture. Increasing crop production in rainfed areas, however, is challenging primarily due to the lack of water. In many rainfed regions such as in India, during monsoon season there is plenty (i.e., surplus) of rainfall that results in flooding during monsoon seasons. During dry season limited water availability results in diminished crop yield. Very few options exist for availing irrigation water during dry seasons. Such scenarios are common not only in India but also in many other parts of the world. The lack of water during dry seasons results in substantially less crop yield in rainfed farms than that of irrigated farms.

Currently, agriculture in rainfaed regions of tropical savannah and subtropical agro-ecosystems is carried out below the potential (Bhatt et al., 2006) mainly due to the lack of water for irrigation. Previous studies reported that water storage of around 200 mm annual can help in increasing crop yields substantially in rainfed regions (Rockström et al. 2007). In principle, crops are able to avail approximately 100 mm of water from water stored in soil profile. An additional 100 mm of water is needed to achieve the crop yield potential (Pieter van der Zaag and Gupta, 2008). The main sources of this water in rainfed regions are either rainfall or some sorts of supplemental irrigation. In the lack of rainfall or supplemental irrigation, crop yields are substantially low, and in many cases crops are dried in the field without any grain output. To meet the water demand of rainfed farms, additional water resources, which can provide supplemental irrigation, are required. Rainwater harvesting can be an alternative approach to conserve the water during rainy season, and subsequently it can be applied as supplemental irrigation during the dry seasons. Previously, a range of approaches including on-farm reservoir system, water storage tanks, Caggsytem, the Zay system, Jessour system, small earth dam,Bunds, and Cistern(Oweis et al., 2006; Pandey et al., 2006; Pandey et al., 2011) [Figure 1] have been found to be useful for rainwater harvesting and improving water resources in arid and semi-arid regions.

RAINWATER HARVESTING POTENTIAL IN ARID AND SEMI-ARID REGIONS

To enhance water resources in arid and semi-arid regions, additonal water storage facilties are needed

Figure 1: Rainwater harvesting system for improving water resources in arid and semi-arid regions (data source: Pandey et al., 2003; Oweis et al., 2006; Agriwaterpedia, 2016).

(Dey et al., 2006; Keller et al., 2000; Pandey et al., 2011). In general, both large-scale reserovoirs and small-scale farm reservoirs (i.e., water reservoir, Jessours, bunds, cistern, on-farm reservoirs) [Figure 1] are applicable for enhancing water resources, however, large reservoirs requires relatively larger inveestment, and extensive desing and feasibility studies, which often hinders the implementation. Further, negatively environmental impacts of large-scale reservoirs are well reported (Pahl-Wostl, 2002; van der Zaag et al., 2008). In such circumstances, farm-scale reservoirs (i.e., small reservoirs) can be more viable option to meet the water demand for supplemental irrigation in arid regions than large reservoirs.

In rainfed regions, availing additional 100 mm/year of water can results in substantial increase in crop yield, which can be met through the rainwater harvesting approach (Rockström et al., 2009; Pandey et al, 2013). On the other hand, large-scale reservoirs are more useful, when irrigation requirement is greater than 500 mm/year. Further, hydroelectric power generation is another purpose of large-scale reservoirs (Pandey et al., 2013). Previous studies have shown that small-scale decentralized reservoirs are potentially useful for deficit/supplemental irrigation, particularly, when less than 200 mm irrigation is needed in arid and semi-arid regions (van der Zaag and Gupta, 2008). These small reservoirs have been used for supplemental irrigationfor centuries in many countries in SoutheastAsia,Middle East, and Africa. In these systems, rainfall and runoff is collected in farmlands, and pasture land and subsequently water storages is used as supplemental irrigation to rainfed farms (Molden, 2007; Barron et al., 2003; Palanisami and Meinzen-Dick, 2001; Balasubramanian and Selvaraj, 2003). In addition to irrigation, these rainwater harvesting systems have been used for aquaculture purposes, which often results in increased farm income and provide additional source of nutrition by fish culture (Pandey et al., 2006).

RAINWATER HARVESTING FOR AQUACULTURE

The use of on-farm rainwater harvesting reservoirs for fish culture is a viable option [Figure 2]. In general, these small-scale reservoirs are constructed either in farmland or near farmlands. In terms of irrigation

Figure 2: On-farm reservoirs for fish culture between July and October in eastern part of India

requirement, it is highly unpredictable in rainfed regions. As an example, monsoon season in many part of India starts from June-July, and during the first crop season, water is often available through rainfall. The second crop season starts from November-December. The irrigation water is highly sought between December and February. In many occasions, there is ample opportunity to store water in these reservoirs between July and November (approximately 4 months). Having stagnant water for four months provides excellent opportunities for raising fish in these reservoirs. Subsequently, during the second crop seasons these reservoirs can be emptied to supply supplemental irrigation to crops.

A study by Pandey et al. (2014) conducted an extensive field study to understand the feasibility of aquaculture in on-farm reservoir systems constructed in rice fields. The water stored in the reservoirs was used for fish culture for more than 120 days. The growth of four Indian major carps (*Catlacatla, Labeorohita, Cirrhinusmrigala, and Tilapia*) was assessed. The results showed that the approach was useful for both fish culture and supplemental irrigation. Economic analysis showed that the reservoirs which were used for fish culture as well as supplemental irrigation produced substantially higher benefits over the reservoirs which were used only for supplemental irritation. As an example, the internal rate of return (IRR) for unlined and lined reservoirs with fish culture was 13 and 26% compared to the IRR of 9.5 and 9% for unlined and lined reservoirs without fish culture, respectively (Pandey et al., 2014). Detail analysis of water quality in reservoirs was found to be suitable for fish culture indicating the suitability of environment.

RAINWATER HARVESTING FOR SUPPLEMENTAL IRRIGATION

Both field and modelling studies have shown that on-farm reservoirs (Figure 3) are suitable for storing the water during rainy seasons, and this water can be eventually used for supplemental irrigation (Pandey et al., 2011; Pandey et al., 2013). The water storages in different sizes of reservoirs (1%, 5%, 10%, 15%, and 25%) were estimated. Results showed that the benefits of these reservoirs considerably depend on soil type, climate, OFR size, and depth of reservoirs. As an example, when water balance was simulated for two regions: eastern part of India, and Fort Worth, Texas, USA; the water storages was considerably higher in rainfed regions of India (West Bengal) than the water storages in the reservoirs in the rainfed regions of the USA (Fort Worth, Texas). The primary reason for greater water availability in reservoirs of eastern part of India was relatively higher annual rainfall compared to rainfed of Texas. The economic analysis showed that the benefits of these on-farm reservoir systems exceeded the benefits of a large reservoir (Pandey et al., 2011).

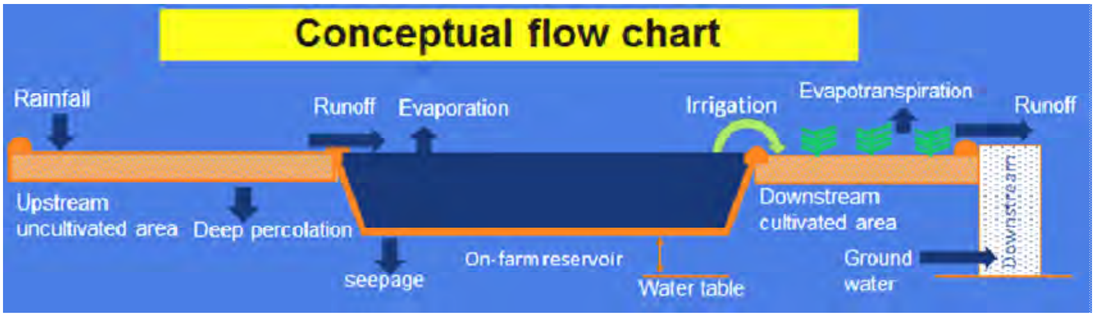

Figure 3: conceptual flow chart of on-farm reservoir for supplemental irritation and water balance(data source: Pandey et al., 2013).

Conceptual water balance model used in these studies are shown in Figure 3. Various parameters including rainfall, runoff, evaporation, evapotranspiration, percolation, downstream water availability were simulated. Results of the study showed that in a season when supplemental irrigation was critically needed, crop yield was increased by 4.2 times compared to the rainfed system, where no supplemental irrigation was available. Predictions showed that approximately 8% of farm area can be allocated for designing such reservoirs system for optimal benefits (Pandey et al., 2013). Further, these reservoirs have positive influence on downstream water balance. The use of on-farm reservoirs increased the downstream water availability by 29% (Pandey et al., 2011).

CONCLUSIONS

In many countries, 60-90% of agriculture land is rainfed. Despite poor crop yield in rainfed farming system, crop production of rainfed farming system contributes significantly to global food production. On average 80% of global cropland is rainfed, which produces 60-70% of world's food supply. One major hindrance in rainfed farming system is the uncertainty of rainfall and the lack of water for supplemental irrigation during dry seasons. Improvement in crop yields of rainfed farming system is needed to meet the future global food demand. Results of modeling and field scale studies showed that the crop yield of rainfed farming system can be increased substantially by facilitating the farm-scale water storage structures, which can conserve rainwater during rainy (or monsoon) seasons. The water storages in these reservoirs can be utilized for supplemental irrigation to improve crop yield. Further, these farm-scale reservoirs can be used for aquaculture to enhance the income and produce additional nutrient source (i.e., fish).

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