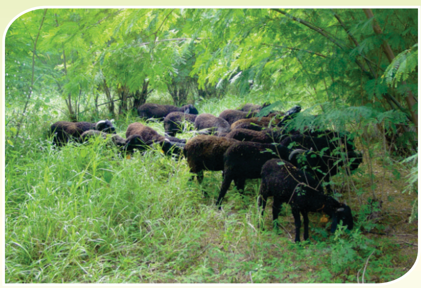
Training Programme on

Efficient Watershed Management in Rainfed Agriculture

(Sponsored by Watershed Development Department, Govt. of Karnataka)

September 19-23, 2017



CRIDA

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TRANSFER OF TECHNOLOGY
ICAR - CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE
Hyderabad-500059

A Compendium of Lectures
Training Programme on

Government of India

"Efficient Watershed Management in Rainfed Agriculture"

Edited by

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Citation: K. Ravi Shankar, K. Nagasree, G. Nirmala, Jagriti Rohit, R. Nagarjuna Kumar, P.K. Pankaj and K. Sammi Reddy 2017. Compendium of lectures on "Efficient Watershed Management in Rainfed Agriculture". ICAR- Central Research Institute for Dryland Agriculture, Hyderabad – 500 059 (Telangana), pp-91.

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Acknowledgement

The present publication entitled “Efficient Watershed Management in Rainfed Agriculture” is a result of collective efforts, experience and knowledge and wisdom of several authors. We wish to place on record the cooperation and support received from all the authors and staff at CRIDA who contributed in various ways for timely publication of this book.

The compendium of lectures has enlightened the Nutrient management strategies, Zero Tillage technologies, Conservation Agriculture, Soil Carbon sequestration strategies, Soil Health management, Integrated nutrient management and other related topics.

The feedback obtained from post- evaluation of relevant subject matter training programme has indicated a need for a ready reference in a compendium form which can impart latest technologies as well as information which can serve as documentary guide while working in the field conditions. This has motivated us to compile the diversified work which can serve the need of different stakeholders. We are highly thankful to the funding agency, Watershed Development Department, Govt. of Karnataka and also the line departments for deputing participants for the programme.

We profusely thank Dr. K. Sammi Reddy, Director CRIDA for the constant support and encouragement. We also thank all authors who have contributed and Dr. P. Vijaya Kumar, PC, AICRPAM, Dr. M. Maheshwari , Head DCS, Dr. K. Sammi Reddy, Head, DRM, Dr. G. Nirmala, Head, TOT, Dr. C.A. Rama Rao, Head, SDA and Dr. Ravindra Chary, PC AICRPDA for their constant encouragement and support.

Crops and cropping systems strategies in rainfed agriculture

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Introduction

Rainfed agriculture with nearly 55% (78 M ha) of the net cultivated area contributes 40% of the country's food basket. 85% of coarse cereals, 83% of pulses, 70% of oilseeds and 55% of rice is produced from rainfed areas, further, supports livelihoods of 80% of small and marginal farmers, about 68% of rural population, 81% of rural poor and 66% of the total livestock. Even after realization of full potential of irrigation, nearly 40% of the net cultivated area will remain under rainfed farming. Much of the acreage under pulses cultivation (84%) is rainfed (DAC, 2014). In view of this, rainfed farming is crucial to country's food security and economy.

The estimated undernourished population would be around 70 million which would account for 5% of the population assuming that dietary energy supply would rise from current 2500 kcal/person/day to 3020 kcal/person/day by 2050.The total cereal demand is projected to grow by 1048 mt (45% from maize; 26% from wheat; 8% from rice; and the rest from minor millets and other coarse grains).The high levels of malnutrition, especially among poor, needs immediate attention as this affects their contribution to the national GDP. Output of cereals has increased at a much faster rate than population during the post green revolution period till mid-1990s, peaking to 501 g/day in 1995-96 and then declining slightly. However, output of pulses has remained almost stagnant for a long time resulting in protein malnutrition. Another issue is to meet the growing demand for pulses and oilseeds. With growing affluence, the per capita edible oil consumption is likely to rise sharply leading to further surge in imports (CRIDA, 2015).

Another major development likely to influence rainfed areas is the changing demand profile for different food commodities. With rising incomes, the demand for high energy food (milk, meat, eggs and oils) will increase. For instance, milk and meat demands in India by 2050 are estimated to be around 110 and 18.3 mt respectively meaning more production of livestock and poultry. The major challenge is also for green fodder production. The projected domestic demand indicates that other cereals will be in acute shortage. Out of 59mt shortfall, most of the produce will constitute maize which would go for animal/poultry feed and the net deficit would be primarily for oilseeds, fruits, vegetables and pulses. There is urgent need for synergy between natural resources endowment and cropping patterns, particularly in rained areas in the country. In rainfed areas, the present cropping patterns do not fit well which are otherwise driven due to changing food habits influenced by urbanization, globalization and accentuated by government policies. Therefore, how these food habits change in the long run will have implications on use of natural resources. For example, increasing consumption of livestock products may lead to higher use of water. Improving water use efficiency and expanding the access to water are critical to achieve the targets. It is an irony that areas with less rainfall are net exporters of agricultural produce to areas with sufficient rainfall and untapped groundwater potential (CRIDA, 2015).

An average food grain yield of 2 t/ha from the current level of <1.0 t/ha will be required from drylands to feed the projected population of 1500 million by 2025 AD. More than the calories, ensuring protein security will become an important issue in view of the predominantly vegetarian habits of the populace and the dwindling availability of vegetable (pulses) proteins whose current supply is about 25 g/head/day against the minimum dietary need of about 70 g. Based on the present growth in productivity trends, attaining a goal of 2 tonnes of food grains/ha is well within the reach in rainfed areas. The strategies for enhancing food production in rainfed areas lies primarily in increasing the productivity of cereals, pulses, oilseeds and vegetables per unit area through efficient crops, cropping systems, agri-horti systems and integrated farming systems and through better natural resource management. This will further likely to contribute to enhanced production of fruits, milk, eggs etc.

Strategies for enhancing the food production in rained areas

The coarse cereals, millets, pulses and oilseeds are primarily rainfed crops impacted by intra-seasonal and inter-seasonal weather aberrations, poor soil resource base and poor crop management leading to large yields gaps. Hence, the challenge would be to enhance productivity levels of the rainfed crops/cropping systems, rainfed agri-horti systems integrated with optimal use of natural resources. The various strategies for enhancing the productivity of rainfed crops are presented in this chapter.

Efficient crops and varieties

Sowing of right variety of right crops at right time under right landuse conditions makes a significant difference towards attaining higher yields. The choice of crops and varieties is more relevant under highly complex rainfed production systems and areas frequented with weather vagaries. The choice of the crops and variety for an agro-ecosystem could further be narrowed down by matching crop requirements with prevailing location specific climatic and soil information. The analysis of long-term climatic data on onset and withdrawal of monsoon, intermittent dry spells and effective cropping period etc. serve as a good guide to select crops and varieties. While, intrinsic soil properties *viz.*, soil depth, texture, slope and available water holding capacity etc. reflects capability of a soil to mitigate the impact of weather events, and thus are of great use for macro and micro-level crop planning (Velayutham, 1999). Further, few agro-ecosystems frequently experience extreme of moisture (drought or floods), temperature (heat or cold) and wind (cyclone or hail storms). Farming under such situations is highly uncertain and challenging. These events have usually very short life, but long-lasting impact on standing crop and many times results into complete failure of crops. These ecosystems require highly elastic crop and varieties which could give higher yields under normal conditions and also withstand the natural calamities effectively. Understanding their special needs of such agro-ecosystems, a number of crop varieties has been developed and evaluated for their suitability at different parts of the country.

In rainfed production systems, generally, the crop should be of short duration with early vigour, deep root system with ramified roots, dwarf plants with erect leaves and stem, moderate tillering in case of tillering crops and varieties, resistance/tolerance to biotic stresses, lesser period between flowering and maturity so that the grain filling is least affected by adverse weather, resistance/tolerance to abiotic stresses, low rate of transpiration, less sensitive to photo-period and wider adaptability. Thus, under changing climate conditions, introduction of high yielding, drought resistant/tolerant varieties hold the promise for getting higher yields.

As a general rule, rainfed crops are sown early with the onset of monsoon to realize higher yields. And any delay in monsoon beyond normal period affects sowing of many crops of longer duration or narrow sowing window. The crops with wider sowing windows can still be taken up till the cut-off date without major yield loss and only the change warranted could be the choice of short duration cultivars. Beyond the sowing window, choice of alternate crops or cultivars depends on the farming situation, soil, rainfall and cropping pattern in the location and extent of delay in the onset of monsoon. For example, pulses and oilseeds are preferred over cereals with respect to water requirement and for delayed *kharif* sowing. Clusterbean, mothbean and horsegram are better choice for low rainfall areas as compared to other *kharif* season pulses. For cultivation on conserved soil moisture during *rabi* season, chickpea and lentil are preferred over peas and french bean. Similarly among oilseeds, groundnut, castor sesame and niger perform well under rainfed conditions during *kharif* season. In the rapeseed-mustard group, taramira is the best choice for light textured soil with low moisture storage capacity, followed by Indian mustard. Among the *kharif* cereals, coarse cereals (millets, ragi and sorghum) are better choice over maize and rice. Similarly in *rabi* season, barley does well under conserved soil moisture than wheat. Among the millets, setaria is most suited for late sown condition without any serious effect on productivity. The resilient crops and varieties to cope with delayed monsoon in various rainfall and soil zones are given in Table 1.

Table 2. Suitable varieties of rained crops under delayed onset of monsoon

Location/ MCSR (mm)	**Crop**	**Suggested contingency crops and cultivars**		
		Delay by 2 weeks	**Delay by 4 weeks**	**Delay by 6 weeks**
Anantapur (Alfisols)/ 352 (*kharif*), 144 (*rabi*)	Groundnut	-	Kadiri- 9, Prasuna, Narayani	Kadiri- 9, Prasuna, Narayani
	Pigeonpea	Palnadu, LRG-41, LRG-30, Lakshmi, PRG-158	Palnadu, LRG-41, Lakshmi, LRG-30, PRG-158	ICTP 8203, ICMV-221, ICMH-451
	Sorghum	PSV-15, 19	CSH-9, 14, CSV-12	CSH-9, 12, 13, 14, CSV-12, NTJ-1, 3
	Castor	Kranthi, Jyothi, GCH-4, 6	Kranthi, Jyothi, GCH-4, 6	Kranthi, Jyothi, GCH-4, 6
	Cotton	Narsimha, MCU-5, LRA-5166, NHH-44, NDLHH-240	Narsimha, MCU-5, LRA-5166, NHH-44, NDLHH-240	Narsimha, MCU-5, LRA-5166
Bangaluru (Alfisols)/ 517 (*kharif*), 241(*rabi*)	Fingermillet	MR-1, 6, L-5	MR-1, 6, L-5, HR-911	Fingermillet: GPU-28 Little millet: CO-2, PRC-3 Foxtail millet: RS-118, K-221-1
	Maize	Deccan-103, NAC-6004, Ganga-11	NAC-6002, 6004	DHM- 2, Ganga-11, Deccan-103
	Groundnut	JL-24, K-134, GPBD-4, K-134	TMV-2, JL-24	JL-24, K-134
	Pigeonpea	BRG-2	BRG-2	K-134, VRA-2
	Cowpea	TVX-944-2E, KBC-1, 2	TVX-944, IT-38956-1	-
Bijapur (Vertisols)/ 388 (*kharif*), 134 (*rabi*)	Pigeonpea	GS-1, BJ-221, Maruthi, Asha, TS-3, ICPC-87	GS-1, BJ-221, Maruthi, Asha, TS-3, ICPC-87	Durga, GC-11,39, WRG-1, Maruthi, TS-3 R, ICPC-87
	Sunflower	KBSH-1, 44, DSH-1, RSFH-1, MSFH-17, SH-41	KBSH-1, 44, DSH-1, RSFH-1, MSFH-17, SH-41	KBSH-1, 44, DSH-1, RSFH-1, MSFH-17, SH-41
Akola (Vertisols)/ 688 (*kharif*), 82.3 (*rabi*)	Soybean	Samrudhi, JS-335, JS-93-05	JS-335, JS-93-05	-
	Pigeonpea	BDN 708, AKT-8811	AKT-8811, Vipula, PKV-Tara, BSMR-736	AKT-8811, Vipula, PKV-Tara, BSMR-736

Parbhani (Vertisols)/ 800.5 (*kharif*), 110.5 (*rabi*)	Sorghum	CSH – 9, 14	CSH-9, 11, 14, 16, PVK-401, 809	CSH-9, 11, 14, 16, PVK-401, 809
	Pigeonpea	Vaisali	BSMR-736 853, BDN-708, 711	BSMR-736, 853, BDN-708, 711

MCSR: Mean crop seasonal rainfall; *Source:* Annual Reports - AICRPDA-NICRA 2011 to 2015

In addition, the sustainability of few varieties was also tested under various rainfed ecosystems for wider adoption (Table 2.).

Table 2. Performance of improved varieties of rainfed crops with high sustainability

AICRPDA Centre	**Crop**	**Variety/ Hybrid**	**SYI**	**Agro-climatic zone/ climate /soil type**
Arjia	Maize	PEHM-2	0.41	Southern zone of Rajasthan (Semiarid Vertic Inceptisols)
Bangalore	Fingermillet	MR-1	0.77	Southern dry zone of Karnataka (Semi arid Alfisols)
Indore	Soybean	NRCS 37	0.50	Malwa Plateau zone of Madhya Pradesh (Semiarid Vertisols/Vertic Intergrades)
Phulbani	Rice	Vandana	0.79	Easternghat zone of Odisha (Subhumid Oxisols)
Anantapur	Groundnut	Narayani	0.49	Scarcity zone of Andhra Pradesh (Arid to semiarid Alfisols/Aridisols)
Akola	Soybean	JS335	0.55	Western Vidarbha zone of Maharashtra (Semiarid Vertisols)

Source: AICRPDA Annual Reports; SYI- Sustainable yield index

Efficient cropping systems

The true concept of cropping system gained momentum during sixties for bring self sufficiency in food through enhanced cropping intensity besides breaking technology and policy barriers. And the advent of high yielding, photo-insensitive, input responsive varieties of rice and wheat totally revolutionized the Indian agriculture in less than a decade and brought paradigm shift in farming with respect to tillage, planting time and method, fertilizer use, irrigation, pest control and harvesting. This resulted in major shift towards cereal based cropping systems by relegating less productive, risk prone legumes and oilseeds to marginal lands especially in irrigated ecosystems. Although, the transformation brought self-sufficiency in food, but caused many second generation farming problems. This necessitated designing alternate cropping systems by considering potential and specific needs of different regions under changing socio-economic and climatic situations. AICRP for Dryland Agriculture (AICRPDA) network centres located across rained agroecologies developed location specific doable cropping systems with higher productivity.

However, many of the conventional cultivation practices and strategies may no longer be relevant under changing climate scenarios. This necessitated need of technologies responding to climate change effects and giving more resilience against such shocks. Under changing climate scenario, many conventional practices and cropping systems are becoming redundant and ineffective, and thus need revalidation and modification in accordance to changing climate and soil-site conditions, This also calls for critical examination of important modifies of cropping systems *viz.*, soil type, rainfall pattern, length of growing season, temperature regimes etc. so that available farm resources are effectively used. Accordingly, identified potential rainfed cropping systems for varying range of rainfalls, soils and agricultural drought situations (CRIDA, 1997) (Table 3).

Table 3. Potential cropping systems based on rainfall and soil types

Mean annual rainfall (mm)	Major soil order	Growing season (weeks)	Suitable cropping system
350-650	Alfisols, shallow Vertisols, Aridisols and Entisols	15	Single rainy season
350-650	Deep Aridisols and Inceptisols	20	Either rainy or post-rainy season crop
350-650	Deep Vertisols	20	Post-rainy season crop
650-800	Alfisols, Vertisols, Inceptisols	20-30	Intercropping
800-1100	Deep Vertisols, Alfisols and Entisols	30	Double cropping
>1100	Deep Alfisols, Oxisols etc	30+	Double cropping

Source: Modified from CRIDA (1997)

Intercropping systems

Mixed cropping is a widespread traditional practice in rainfed agriculture to distribute the risk of uncertainties among different crops, but the practice is hardly productive. Therefore, mixed cropping was gradually advanced to scientific and rational intercropping systems where two crops of different durations are planted in definite row ratios to minimize the risk and simultaneously enhance the productivity and resource use efficiency. A good intercropping system gives optimum productivity and higher LER in normal/good seasons, while brings reasonable yield for either of the crop in poor seasons as an insurance against weather aberrations (Ravindra Chary *et al*., 2012). Generally, these advantages are more pronounced in stress environments. In addition, it helps to spread labour peaks, maintain soil fertility (with inclusion of legume) and stability in production. It embodies the protective cover of mixed cropping and at the same time increases production. Furthermore, greater efficiency of resource utilization is expected from intercropping in a wide range of environments. In general, intercropping with additive series was found better than replacement series under most of drought situations (AICRPDA, 2003). The mean LER of additive series was 23% higher than replacement series in 54 out of 59 experiments taking sorghum, maize, pearl millet, pigeon pea, safflower and wheat as base crop. However, intercropping systems were more favourable in *kharif* than *rabi* season in Indian rainfed regions probably due to replenishment of soil moisture during *Kharif* season (AICRPDA, 2003). Agroclimatic-zone wise and soil zone wise efficient intercropping systems in major rained production systems are given in Table 4.

Table 4. Agroclimatic zone and soil zone-wise efficient intercropping systems

Soil zone/ Agroclimatic zone/State	Intercropping system
a. Vertisols and Vertic Inceptisols	
Malwa plateau, Madhya Pradesh	Soybean + pigeon pea (4:2)
	Sorghum + pigeon pea (2:2)
Western Vidharbha, Maharashtra	Cotton + greengram (1:1)

Southern Rajasthan	Maize + blackgram (2:2) Groundnut + sesame (6:2)
Northern Dry zone, Karnataka	Pearl millet + castorbean (3:1) Pearl millet + pigeonpea (4:2)
Northern Saurashtra, Gujarat	Groundnut + castorbean (3:1) Groundnut + pigeonpea (3:1)
Southern Tamil Nadu	Cotton + blackgram/greengram (2:1)
b. Inceptisols and related soil zone	
Western plateau, Jharkhand	Pigeon pea + rice (2:3) Maize + cowpea (2:2)
Alfisols/ Oxisols zone	
Eastern Ghat zone, Odisha	Maize + pigeon pea (2:2) Fingermillet + pigeon pea (4:2)
Alfisols zone	
Southern dry zone, Karnataka	Groundnut + pigeon pea (8:2) Fingermillet + pigeon pea (10:2)
Southern zone, Telangana	Sorghum + pigeon pea (2:1)
Scarcity zone, Andhra Pradesh	Groundnut + pigeon pea (7:1)
Aridisols zone	
Northern zone, Gujarat	Castor bean + cowpea (1:2) Pearl millet + cluster (2:1)

Source: AICRPDA (2003).

Double cropping systems

Traditionally, double cropping including relay cropping is practiced in rainfed regions with sufficient rains (usually >750 mm) and good soil moisture holding capacity (>150mm). However, some more areas could bring under double cropping through use of available dryland technologies *viz.*, rainwater management, choices of crops, short duration varieties and agronomic practices. Out of the two crops, one could be short durations (usually legumes) and another, medium duration (usually cereals) for optimum use of available growing season. For example, a second crop could successfully grown in high rainfall regions of Odisha, Eastern Uttar Pradesh and Madhya Pradesh by replacing medium to long duration (>120 days) rice variety with short duration (<100 days) rice variety; while another crop of chickpea or safflower could be taken in Malwa (MP) and Vidarbha (Maharashtra) regions by substituting sorghum variety of 140-150 days with 90-100 days cultivars. Similarly, relaying a short duration and fast growing crop in standing principle crop provide good opportunity for efficient use of growing period. For example, relay cropping of castor in 40-45 days old greengram crop is practices in about 35000 ha areas of North Gujarat. Castor is either named dibbled sown between two rows of greengram using animal drawn seed drill (Venkateswarlu *et al.*, 2009). Some efficient double cropping systems are suggested in Table 5.

Table 5. Efficient double cropping systems

Agroclimatic zone/state	Moisture availability period (days)	Double cropping system
Malwa plateau, Madhya Pradesh)	210-230 190-210	Soybean-wheat/wheat, Maize-chickpea/safflower Sorghum – safflower/chickpea, Soybean-safflower
Baghealkhand, Madhya	210-230	Rice-chickpea/lentil

Pradesh)	190-210	Sorghum-chickpea, Blackgram/greengram-wheat Groundnut-chickpea
Bundelkhand, Uttar Pradesh)	190-220	Sorghum-chickpea, Blackgram- mustard/safflower, Fodder cowpea- mustard
Vidarbha,Maharashtra	190-210	Groundnut-safflower, Sorghum-safflower
	170-190	Green gram-safflower
Southern Maharashtra	160-180	Greengram- sorghum/safflower
Southern Rajasthan	160-180	Greengram – safflower
Central Karnataka	130-150	Cowpea – sorghum, Greengram – safflower

Source: AICRPDA Annual Reports

Pulses in rice fallows

On an average, 30% of the area under rice production during *kharif* season in India remains fallow in the subsequent *rabi* due to number of biotic, abiotic and socio-economic constrains. A large area (11.6 m ha) of rice fallows under rainfed conditions can be brought under pulses provided available land and water resources (soil moisture, crop residue, water harvesting structures, etc) are scientifically and innovatively managed (Kumar *et al*., 2013a). Out of 10.5 m ha rice fallows of eastern (Uttar Pradesh, Bihar, West Bengal, Assam), Central (Chhattisgarh) and southern states (Andhra Pradesh, Karnataka, Tamil Nadu), 2.5 m ha can be utilized by expanding lentil, Greengram and blackgram cultivation (Ali and Gupta, 2012). Pulses are the ideal crops that can be grown in the areas vacated after rice, because of their property to establish with the surface seeding and suitability for relay/para cropping and resistance against soil moisture and temperature stress. Pulse crops suitable for rice fallow areas are lentil, lathyrus, urdbean, mungbean and chickpea.

Crop planning as per climate-soil-site suitability

Agriculture is mainly a land based activity, and thus requires better land resource management for higher productivity and conservation of resources. Efficient resource management has become more relevant in recent time to address the twin problems of unabated land degradation and impact of changing climate on land productivity. Further, the natural resources have profound influence on cropping pattern and crop productivity. Since each plant species need specific soil-site conditions for its optimum growth. As a result, soil-site based landuse planning has capacity to double the yield under many rainfed conditions. Therefore, soil-site suitability for crops needs to be determined to grow most suitable crop(s) in each land use types. Plant requires a reasonable moisture and nutrient supply, linked to a sufficient rooting depth and a good energy regime for photosynthesis and biomass production. And the adaptability of crops in an area is the interaction between existing edaphic conditions and fitness of the cultivar under those conditions. Further, the productivity and profitability of agriculture are largely determined by field preparation and harvesting conditions, while workability and traffic ability factors may also have to be considered for some land utilization types.

Real Time Contingency Planning

During 1972-73, large scale scarcity of rainfall was experienced all over the country, particularly in the scarcity region of Maharashtra, Karnataka and Andhra Pradesh. Roving seminars were organized by the ICAR at different locations, at the end of which *new phrases* were coined *viz. contingent crop planning* *and mid-season correction.* As a follow up, the AICRPDA centres at Solapur and Bijapur collected data on these two aspects and after analysis of weather data for the past 100 years, listed the weather aberrations: (*i*) delayed onset of monsoon, (*ii*) early withdrawal of monsoon (*iii*) intermittent dry spells of various durations, (*iv*) prolonged dry spells causing changes in the strategy and (*v*) prolonged monsoon (AICRPDA, 1983).Contingency plans, for each region, was a conceptual approach unique from AICRPDA project in developing location specific contingent crop strategies which were first published in 1977 (Ravindra Chary *et al.*, 2012) and with further refinements and updating in crops and varieties, the first document was brought out by AICRPDA in 1983 on "Contingent crop production strategy in rainfed areas under different weather condition". The AICRPDA network centers developed crop contingency plans for each centre's domain (Subba Reddy *et al.*, 2008; Ravindra Chary *et al*., 2012). Further, during 2009-10, AICRPDA centres prepared contingency measures considering weather aberrations, seasons, and the predominant *kharif* and *rabi* crops with appropriate crop management strategies. Central Research Institute for Dry land Agriculture (CRIDA)with information available at AICRPDA centres and SAUs, prepared district level agriculture contingency plans for more than 614 districts in collaboration with Department of Agriculture and Cooperation (DAC), Ministry of Agriculture, GoI, ICAR institutes, State Agricultural and allied universities, Krishi Vigyan Kendras (KVKs), and the State line departments. These plans essentially suggest coping strategies/measures in agriculture, horticulture, livestock, fisheries and poultry sectors in the event of delayed onset of monsoon, seasonal drought, unseasonal rainfall events, floods, cyclones, hail storm, heat/cold wave (Venkateswarlu *et al*., 2011).

In view of the frequent weather aberrations impacting agricultural production round the year in some part of the country, the need was felt to implement contingency measures on real-time basis to minimize the losses in agriculture and allied sectors and to improve the efficiency of the production systems,. Thus, Real Time Contingency Planning is considered as "Any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (Srinivasarao *et al*., 2013).The real-time contingency measures aim to (*i*) to establish a crop with optimum plant population during the delayed onset of monsoon; (*ii*) to ensure better performance of crops during seasonal drought (early/mid and terminal drought) and extreme events, enhance performance, improve productivity and income; (*iii*) to minimize damage to horticultural crops/produce; (*iv*) to minimize physical damage to livestock, poultry and fisheries sector and ensure better performance) to ensure food security at village level and (*vi*) to enhance the adaptive capacity and livelihoods of the farmers.

Summary

There is a growing demand for food in the country besides changing food demand profile. Since rained areas contribute 40 % of country's food basket, there a need for enhancing the productivity of rained crops from this region. Besides this, the climate change risks and impacts on agriculture production and productivity are evident in rainfed araes.The focus thus would be on upscaling of doable cropping systems technologies and real-contingency measures in target domains. A well-planned complementary cropping systems and intercropping have great potential to reduce the risk and uncertainties in production through effectively exploiting differential performance of crops to moisture and temperature stresses, intermittent and terminal droughts in different agro-ecological settings. In addition, the sustenance of small and marginal land holdings will also depend on better integration and utilization of resources from unit piece of land. Similarly, double and relay cropping systems with suitable component crops/varieties with resource conservation technologies have greater scope for climate resilient agriculture. Further, breeding resilient crop varieties that fits in emerging cropping systems is very important for enhancing adaptation capabilities. Resilient varieties not only cope with multiple weather aberrations but also enhance crop productivity. Thus, it is essential to characterize agroecology/resource domain (climate and soil) of these varieties for wider adoption. However, all these efforts will have little significance if it is not supported with real-time strategies to handle farming emergencies emerging due to enhanced weather vagaries. The important issues include developing rainfed agroecology specific resilient cropping systems along with associated management practices; agroforestry based cropping systems, evaluation of crop varieties in cropping system mode and demonstration of proven systems in cluster approach for large scale adoption.

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Application of soil and water conservation practices in watershed area

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Introduction

Agriculture is one of the major sectors of Indian economy which provides livelihood to vast majority of Indian population. Rainfed agriculture defined as the cultivation on natural precipitation. A major component of the Indian agriculture is rainfed which is practices in 55% of net cultivated area. Rainfed agriculture in India contributes 40% to the national food basket, inhibits 40% population, and contributes 80% and 60% of horticulture and livestock respectively. Major part of pulses, oilseeds and cotton are grown under rainfed region. The rainfed agriculture in terms of crop and livestock are seen as a huge potential in raising overall agriculture growth in order to achieve the sustained food security. It is understood that future food production needs of the country would come from rainfed system as productivity of irrigated system reached a plateau. The rainfed agriculture spread over several agro-ecological regions and mostly characterized low productive and non remunerative. The other socio-economical constraints small and fractured land holdings distributed over rugged terrain and limited scope to adopt intensive agriculture.

Management of watershed area is a complex and dynamic activity and subjected to vary with time. It involves various hydrological, morphological, physiographical and above all socio-economical aspects. These require sound knowledge and understanding of different discipline and blending of these for overall development of watershed. The management of watershed essentially implies in holistic utilization of land and water resources for optimum production with minimized hazards to natural resources. Therefore watershed management essentially is a adoption of soil and water conservation principles in watershed.

The Watershed

A watershed represents land area usually contains a well-connected stream network, minimal spatial variability in hydrological parameters and well defined outlet or discharge point, where the representative area drains when rainfall occurs.

Watershed management

Theoretically "watershed" is a hydrological unit of an area draining to a common outlet point. Watershed concepts are primarily used for agricultural development purpose. Watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary. Features of a watershed that agencies seek to manage include water supply, water quality, drainage, stormwater runoff, water rights, and the overall planning and utilization of watersheds. Watershed is an appropriate unit as it allows measurement, conservation and utilization of water resources, critical inputs for agricultural production. Soil and water conservation including water resource development and management is the basic activities for any watershed development program. The watershed management aims to establish operational framework for the integrated use of resources, regulation and development of land and water resources in order to increase the productivity and overall social upliftment. The major objective of watershed management depends on the priorities and needs of local population. However, typical objectives includes

- To control damaging runoff and degradation and thereby conservation of soil and water.
- To manage and utilize the runoff water for useful purpose.
- To protect, conserve and improve the land of watershed for more efficient and sustained production.
- To protect and enhance the water resource originating in the watershed.
- To check soil erosion and to reduce the effect of sediment yield on the watershed.
- To rehabilitate the deteriorating lands.
- To moderate the floods peaks at down-stream areas.
- To increase infiltration of rainwater.
- To improve and increase the production of timbers, fodder and wild life resource.
- To enhance the ground water recharge, wherever applicable.

Physiographic Characteristics of Watershed

Physiographic characteristics of any watershed are the description of watershed in terms of area, slope, shape, drainage density, aspect, relief, land use and soil characteristics etc. Physical properties of watersheds significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses. These characteristics watershed are described below in details.

Area of the Watershed

The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. The runoff from watershed is generated after the interaction of precipitation with the watershed area. The amount of runoff generated is however, depends on some other parameters as well as will be described later. Thus the drainage area is the most important parameters to the hydrological models to estimate the volume of runoff. This parameters is required as input to almost all hydrological models ranging from simple linear prediction equations to complex computer models. The area of watershed is delineated either manually using toposheets or through digital elevation model derived using geographic information system (GIS). Once the watershed has been delineated, its area can be determined using planimeter or can be approximated using GIS.

Length of Watershed

Length of water is defined as the longest distance between outlet and any point on the perimeter. This length is usually measured to compute the time dependent parameters of watershed such time of concentration (time taken to reach the runoff generated from remotest point of watershed to outlet), time dependent parameters are watershed are useful in determining time for peak flow required to establish the hydrograph of the watershed which can be termed as watershed signature. The watershed length is therefore measured along the principal flow path from the watershed perimeter to the outlet. Since the channel does not start from the watershed boundary, it is determined by extending the main channel to the boundary and then measuring the length of the channel.

Slope of Watershed

Watershed slope affects the momentum of runoff along with time to peak and quantity. Both watershed and channel slope are of interest because watershed slope determines runoff with surface erosion and channel slope determines the channel erosion and transportation and deposition of sediments. Higher watershed slope demands on field soil conservation measures such as trenching and bunding etc whereas higher channel slope demands conservation measure for permanent gully control structures such as drop structures. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the highest and lowest elevation of the point of the watershed divided by watershed length.

Delineating watershed boundary from toposheet

Toposheet map of scale 1:50,000 are supplied by survey of India. These maps contains the information of drainage network, settlements, contour line at interval of 10m, 20m and 50m, land use and soil type. For watershed delineation the feature under interest are contour line and drainage network. For delineation the first step to identify the outlet and point this for reference. Locate the main channel from chosen outlet to the starting point. From this point look at the nearby contour and read the elevation and seek other contour having higher elevation value near to this contour and repeat this unless highest elevation contour are found. Determine the direction of drainage by putting arrows perpendicular to the contributing contour (higher elevation) along the contour at small interval. Again put arrow perpendicular to the receiving contour (lower elevation than the previous contours) In next step this receiving contour will be contributing contour to subsequent lower elevation contour. Follow this process until contour near to the outlet is addressed. Mark breakpoint on each contour. The breakpoint if the point on the contour from where half of the flow contributes to the indentified outlet. Finally connect these breakpoint to delineate the watershed under consideration.

It is important to note that while manually delineating watershed using toposheet, the drainage divides are located by analyzing the contour lines. Arrows representing the flow directions are drawn perpendicular to each countour in the direction of steepest descent. Manually locating these points are difficult process and errors are unavoidable. However. the extent of error depends on the individual skill and so different worker may produce different result. This problem is more serious when delineating relatively flat micro-watershed watershed (Area between 500-1000ha) from 1:50,000 toposheets. The contour interval in these toposheets are 20 m and usually 2-5 such contours are fall in the micro-watershed which is extremely difficult to pinpoint the drainage divide. Thus for such conditions, raster based image containing DEM (digital elevation model) data are most suited for accurate watershed delineation.

Automatic delineation of watershed

The watersheds can also be delineated automatic ally using modern computing tools such as GIS. GIS needs digital elevation map (DEM) for automatic delineation of watershed. In this case the contour feature from toposheets are scanned and accordingly digitized using either screen digitizer or table digitizer. Respective elevations are assigned to the digitized contour. After elevations are assigned, the outlet are defined using latitude and longitude. The GIS calculated the flow direction map, slope map, flow accumulation map and compute drainage network and finally delineate watershed. However, watershed delineated using GIS should be cross checked with the toposheet. Nowadays DEM are available at various website as a free resource such as SRTM (Shuttle radar topographic mapping) or ASTER (Advanced Spaceborn thermal emission and reflection) and can be downloaded and use to delineate the watershed. The DEM from SRTM or ASTER source usually has 1 meter elevation interval and 30 and 90 meter resolution in grid form. The 30 meter resolution suggest singular elevation value for 0.09 ha (30mX30m) and similarly 90 meter resolution suggest singular elevation value for 0.81 ha (90mX90m). These. Though the automatic delineation is free from human intervention and error and produces same result every time, these has limitations as well. For instance, 90 m resolution DEM data, the delineation assumes singular elevation value means there is zero slope in 0.81 ha and 0.09 ha area respectively for 30 meter resolution. Thus in DEM based watershed delineation, accuracy is largely dependent on resolution (Higher the resolution, greater the accuracy). Higher resolution data requires higher computing and data transfer infrastructure alongwith highly skilled personnel as well which may significantly increase the cost of delineation.

Soil and water conservation approaches

In order to get better plant growth, the top soil layer must be protected from eroding capability of wind and water. Measures taken for protecting the top soil layer are called soil conservation measures. These measures protect top soil either through reducing the impact of erosive agents (water and wind) or by improving the soil aggregate stability or surface roughness. These can be achieved either by mechanical or agronomical measures. Mechanical measures can be divided into two broad classification (1) excavation of earth in such as trenching etc. or accumulation of earth such as bunding etc. The biological measure essentially utilizes the plant resource in for of grass, shrubs and bushes and trees. Bioengineering approaches combine the structural practices with live vegetation (either herbaceous or woody species) to provide erosion protection particularly for hillslopes and stream banks. The bioengineering methods are different than biological measure in the sense that later method is applied mostly in the agricultural field where cultivation are part of the conservation measures.

Biological control of soil erosion.

In this, erosion is controlled through crops or vegetation. However, improper cultivation practices leads to severe soil erosion. A permanent vegetative cover is the best protection for soil. Studies have shown that bare ground allows four times more soil erosion compared to permanent plant covered ground. Therefore, vegetation plays an important role in controlling soil erosion and can be used as effective erosion control measure. The vegetation enhances the surface roughness by binding the soil particle which increases of the resistance to soil erodibility. There are several ways to control soil erosion through biological means. The choice of biological means however depends upon the soil type, geomorphological characteristics of the terrain and also prevailing cultivation practices. It means that cultivation should be done in suitable way by adopting measures, which shall minimize erosion. In this method it is needed to plant such species, which are capable of holding soil strongly and can survive in very adverse soil condition. The main puroposeof biological control remains to prevent high velocity erosing agents and conserve water within the soil in case of water erosion. The biological control measures include mulching, contour farming, strip cropping, shelterbelts etc for arable land. The details of different biological measures are presented in following sections.

Mulching:

Mulching is done for dual purpose of soil conservation as well as in-situ moisture conservation and nutrient supply to some extent. Mulching is very effective in dryland agriculture where annual rainfall is less than 750 mm. The method involves the covering of the soil surface with previously cultivated crop residues such as gliricidea, straw, maize stalks etc. The quantity of the mulch usually varied between 5-10 t/ha. However, this depends upon the local soil conditions. These cover protects the soil from the rain drop impact and reduces the velocity of runoff and wind. It is also useful as an alternative to cover crop in dry areas where a cover crop should compete for moisture with the main crop. Fig. 3.1 shows application of mulch in agriculture.

Figure 1 Application of mulch in maize crop
(source: http://www.flickr.com/photos/cimmyt/4777735545/)

Contour Farming

In contour farming, the crops are planted as per the contour lines in such a way that the flow direction intersects perpendicular to the contour (Figure 2). Contour farming also known as cross faming in some part of the world. The contour farming is normally practiced to the area where slope is varying between 2 to 10% and receiving 24-hour rainfall of 160 mm or lower with 10 years return period(NRCS conservation practice standard, 2007). The basic objectives of the contour farming is to reduce the sheet and rill erosion from agricultural field and thus to reduce transport of sediment and increase the infiltration.

Figure 2 Contour farming of cotton
Courtesy: AICRP on Dryland Agriculture, Akola centre, Dr.PDKV, Akola

Strip cropping

In strip cropping, the erosion prone crops are succeeded by erosion resistant crops such as maize and groundnut. The crops are grown in the strips of 2-5 meters. In intercropping different crops are grown in ratio of rows. Strip cropping is a combination of closely sown crops with such as pegeon pea, millets with row crops such as maize, soybean, cotton, castor etc. This can be practiced on leveled field or contour. The main objective is to reduce soil erosion and transport of sediment like contour farming (NRCS conservation practice standard, 2007). Strip cropping is practiced in the area where slope is higher and too long.

Shelterbelts

Shelterbelts are plantation of tree in a row such that it breaks the wind velocity to protect the area from soil erosion. It is more common in desert area to protect agricultural land from excessive wind erosion. This are usually planted along the field bunds across the wind direction and facing the wind speed.

Mechanical control of soil erosion

Mechanical control involves construction of structure either temporary or permanent to arrest the flow velocity of eroding agents i.e. water. Mechanical measures acts like breaking the flow velocity of water before it achieve the eroding capacity of the soil. The example of mechanical control are trenching, bunding, vegetative barriers and terracing

Trenching

Trenching is done by digging the earth to check the runoff velocity before it could achieve the eroding capability. The overflow of runoff from the specific trench is again checked in subsequent trench down the slope and thus controls the soil erosion. Trenching is one of the most important activities of any watershed management program. There are several types of trenching existing in practice. These include continuous contour trench and Staggered trenching.

The trenches are essentially constructed according to the prevailing slope. The trenches constructed such a manner that it envelops the entire contour is called continuous contour trenching (Figure 3). The contour interval of contour trenching depends on the soil erodibility factor, prevailing land slope and rainfall intensity. In staggered arrangement of trenches, these are split into several pieces and arranged in a manner shown in figure 4. The trenches are constructed in the area where prevailing slope is 1:1 to 3:1(H:V) and good infiltration capacity of the soil. The cross-sectional area of the trenches are varied between 1000 to 2500 cm^2 (Central ground water board, 2007) with the depth limited to 50 cm.

Figure 3 Picture explaining the continuous contour trenches and staggered trenches
Source: http://www.indiawaterportal.org/

Bunding

Like trenching, bunding is done for soil conservation. In bunding however, the soil are accumulated as small embankment unlike trenching where soils are excavated. The bund dimension are usually 30 cm height and 30 cm top width and side slope depends upon the soil type. The placement of bunds are followed more or less the same principal as for trenching. The bunding is primarily constructed for soil conservation and thus there is limited scope of runoff water storage trenching. There are several type of bunds are in practice, those includes block bunding or compartmental bunding, contour bunding and graded bunding.

The block bunding or compartmental bunding are mostly practiced in rainfed paddy area where these are used to impound water and arrest soil from the above field. Contour bunding involves construction along the contours with vertical interval of 1 to 1.5 meter. The size, cross-section and spacing of bunds depends upon the rainfall, soil and slope characteristics of the area. Graded bunding is practiced in the area of high rainfall where the drainage of excess runoff to avoid water logging conditions are equally important to soil conservation .

Bioengineering measures

Bioengineering methods are adopted mostly in slope stabilization, gully control and preventing streambank erosion. These methods are low cost and require lower maintenance cost and strengthen over time as the root system develops. The method become handy in the sites with environmental issues and limited accessibility. Application of this method requires information on site topology, geology, vegetation alongwith hydrology. Some of the bioengineering measures are presented in the following sections (soil resource management, 2013).

Contour wattling

This method breaks the long slope into smaller slope by means of bundle of live branches placed in shallow trenches (usually 50 cm deep). These branches are typically 20-25 cm in diameter and are secured with time. After the branches are filled the trenches are backfilled to look like bunding. These are used in hill slope restoration.

Brush layering

In this method the 75-80% of the branches are buried in the shallow trench. Exposed tip of the branch layer helps in reinforcing the fill that improve further as the branches develop roots throughout the fill area. Thus the series of reinforced benches are created. These are useful in stabilizing loose soil slopes.

Coir matting

Coir matting of various specification are used to protect hill slope erosion, guiding flow of water in hilly terrain and plantation of shrubs on highly eroded hill top. Jute matting are also utilized for these purposes.

Interplanting rip rop

Conventionally, Rip rop are used to protect streambank from water erosion. The rip rop are composed of various size of irregular stone pitched on soil surface where water contact the soil. The plantation of shrubs in the gap of stone placement further improve the soil strength and live vegetation later presents a more natural look.

Crop planning & traditional/current crop

Many part of the country receives sufficient rainfall and have rich natural resource base for successful agriculture, but poor management of these resources and land use planning leads to agriculture and livelihood unsustainable. In these situations, crop diversification for cultivating low water requiring high value crops may be the best option for drought mitigation and increased productivity. The major objective of crop planning is to ensure the proper utilization of each piece of land to enhance resource use efficiency. Crop planning is dynamic in nature and can change temporarily. The crop planning involves the selection of crops and cropping system based on the analysis of agroclimatic characteristics coupled with socio-economic constraints and prospects. The probability analysis of rainfall, wet-dry spell analysis, onset and withdrawal of effective monsoon and climatic water balance are the major factors that influence the crop planning in the specific region. Crop planning also explores the scope for crop diversification to make agriculture sustainable. For example, crop diversification in rainfed rice areas may be bery useful in drought mitigation with increased productivity and rainwater efficiency.

In-situ moisture conservation

In arid and semi-arid regions, where precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of rainwater during the wet season for use at a later time, especially for agricultural and domestic water supply. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in situ*. To increase the moisture availability to the agricultural crops, it is necessary to adopt in-situ moisture conservation techniques in addition to the large scale soil and moisture conservation and water harvesting structures in the watershed. The principle behind the recommendation of different practices is to increase the infiltration by reducing the rate of runoff, temporarily impounding the water on the surface of the soil to increase the opportunity time for infiltration and modifying the land configuration for inter plot water harvesting. Several in-situ moisture conservation techniques are practiced depending on the crop type and field conditions. Some of those includes Contour farming, Broad base furrow, Stubble mulching, Contour bunding, Graded bunding, Contour trenching and Water absorption trench

Farm pond technology

Farm pond is a dug out structure with definite shape and size having proper inlet and outlet structures for collecting the surface runoff flowing from the farm area. It is one of the most important rain water harvesting structures constructed at the lowest portion of the farm area. The stored water must be used for irrigation only. Inadvertently, some people use the farm ponds as ground water recharge structures which is not correct as per the definition. For recharging the groundwater, the structures require high capacity and are generally located in the soils having high infiltration rates and are called percolation tanks. Percolation tank is meant for only recharge purpose and not for irrigation. Such structures conceptually differ in their hydrology and physical location. A farm pond must be located within a farm drawing the maximum runoff possible in a given rainfall event. A percolation pond can be dug out in any area where the land is not utilized for agriculture.

Farm ponds have a significant role in rainfed regions where annual rainfall is more than or equal to 500 mm. If average annual rainfall (AAR) varies between 500 to 750mm, the farm ponds with capacity of 250 to 500 m^3 can be constructed. If AAR is more than 750 mm, the farm ponds with capacity more than 500 m^3 can be planned particularly in black soil regions without lining. It was observed from the field experience and if present rainfall pattern changes; atleast two to three rainfall events producing considerable runoff are possible in a season making farm ponds an attractive proposition. In high rainfall semi arid regions, these structures can be made as multiple use enterprises like protective/supplemental irrigation, fish culture or duck farming integrated with poultry. These structures provide localised water and food security by enhancing the crop productivity and climate resilience. Moreover, farm ponds conserve the natural resources like soil and nutrients apart from water and acts as flood control structure by reducing peak flows in the watersheds or given area of catchment. Depending on the source of water and their location, farm ponds are grouped into four types:

1) Excavated or Dug out ponds
2) Surface ponds
3) Spring or creek fed ponds and
4) Off stream storage ponds.

Selection of crops and varieties

Traditional rice/paddy system in several parts of the country have become unsustainable in the current scenario of changed climate, high variability of rainfall and distribution, low water flow in the river like Krishna Godawari etc, depletion of ground water. Recommendations on suitable alternate crops and tolerant varieties have been developed in different agro-ecological sub-regions. Important recommendations in this direction are,

1. Diversify paddy area to low water consuming crops with pulses and oilseeds.
2. Within paddy area, following water saving rice system.
3. Promotion of intercrops in place of solo crops.
4. Combination of traditional crops and emerging crops like cotton and maize.
5. Stress tolerant crop cultivars etc.

Better Agronomic Practice for higher water use efficiency

In soil and water conservation programmes, the agronomical practices are considered to substantiate the mechanical or engineering measures which are employed to arrest the soil erosion immediately. The role of agronomic measure is more economical, long-lasting and effective. The agronomical measures are referred by the practices of raising vegetation on mild slope to cover them and to control the erosion. It affects by several ways such as by enhancing infiltration rate and runoff velocity to scour the soil particles to reach into the channels or reservoirs. Several agronomic practices for soil conservation can be adopted depending on the regional physiological characteristics.

Soil amendments

Soil amendments improve the soil aggregation, increase porosity and permeability and improve aeration, drainage and rooting depth vis a vis water and nutrient holding capacity and thus substantiate the objective of more crop per drop. Soil amendment is a material added to the soil to improve its physical properties and achieved by thoroughly mixed into the soil. Soil can be amended using several organic such as manuring using animal waste (FYM) or plant waste (green manuring) and inorganic materials such as lime and fly ash etc.

Tank silt application

Silt is fine granular material derived from rock or soil. Suspended as particulate matter in running water, it settles at the bottom of standing water bodies as fine sediment. In traditional Indian agricultural methods. Poor management practices of catchment have resulted in silting of most of thesewater bodies and significant reduction of storage capacity. Silt deposit has not only reduced the storage capacity but also groundwater recharge, eutrophication of tanks and most importantly higher release of carbon to atmosphere through silt mediated anaerobic decomposition of organic carbon. Continued mining by crops and reduced application of organic manures has resulted in deficiency of several nutrients particularly that of micronutrients. Recycling of tank silt provides a win-win situation to both, improvement in soil health and renovation of the tank. Silt gathered in village tanks and lakes are applied to the field to improve soil fertility. These are spread evenly on the field before sowing. Usually 20-25 tractor loads of silt applied per acre of land. The adhesive properties of silt allow it to mix with soil in the main fields during the first monsoon rains. As silt composition varies from area to area, it is necessary to test the silt quality before applying. Silt can be applied to soil once in 3 years in order to improve soil conditions. Advantages of silt application include increased soil fertility and, therefore, crop yields, increased moisture content of soil, improvement in water table due to increased filtration, among many others. The tank silt application is presented in figure 4.

Figure 4 Tank silt application at field

More Crop per Drop

The soil and water resources are finite and the mismanagement can have adverse effect on agricultural productivity including surface and ground water quality and availability. Thus there is a need to have focused attention on development of NRM practices that not only conserve soil and water resource but also ensure sustainable productivity in order to achieve “more crop per drop”. The adverse effect of agricultural practices take place where the land in fragile ecosystem such as semi-arid and arid regions with porous soil are used for intensify production system.

An excellent example is the decentralized, large scale, check dam rainwater harvesting movement in Saurashtra, Gujarat. The drought proofing benefits from small rainwater harvesting structures can very effectively distribute the available water when there is no drought or a limited drought. Rainwater harvesting structures can be very useful for semi-arid and dry, sub-humid regions especially as water scarcity is caused by extreme variability of rainfall rather than the amount of rainfall. Under such conditions, with high rainfall intensities, few rain events, and poor spatial and temporal distribution of rainfall, even if total rainfall is adequate, water losses are very high, thus leading to scarcity. Given that the frequency of dry spells and droughts is expected to increase with climate change, rainwater harvesting structures as extremely important for mitigating the impact on agriculture and increasing agricultural productivity. Addressing critical dry spells through supplemental irrigation of about 50 to 200 mm through groundwater and rain-water harvesting can stabilize yields in dry, sub-humid regions. Tanks lead to substantial rainwater harvesting at the local level, and the associated distribution system leads to water availability in large areas and to larger numbers of farmers. A significant benefit of percolation of rainwater is groundwater recharge and higher water table in the area. Other benefits include low cost fl ow irrigation, reduction in intensity of flash floods, concentration of silt and minerals to fertilize the soil in the command area, and reduction in soil erosion. The water harvesting structures has a substantial positive impact on the cropping patterns of farmers and crop yields.

Conclusions

An important avenue for achieving increased production goals is to enhance the productivity of vast areas under rainfed agriculture, which constitute nearly 60% of the net cultivated area of the country. These are areas where the green revolution technologies made limited or no impact. These are also areas where vast majority of the poor live and whose livelihoods are intimately linked to our ability to impact agriculture in these areas. Rainfed agriculture is practiced under a wide range of soil and climatic conditions. Rainfall regimes and soil characteristics are the key determinants of rainfed cropping potential. The amount and distribution of seasonal rainfall differ widely among regions as well as from year to year. Two major soil groups are found extensively in the rainfed regions: red and black soil. Rainfall in these areas ranges from 750 to 2000mm per annum. Soil depth varies but most soils are shallow and have low water-retention capacity. In the absence of cost-effective moisture retention and conservation technologies, the soil suffers from rapid water run-off and erosion reducing the productive capacity. Red soils have considerable agronomic potential but to achieve this potential there is need to popularize effective soil moisture conservation practices. Compared to the red soils, the black soils are deeper and heavier and hold more water. However, they are highly erodible and run-off can be as high as 40% or more depending on rainfall volume and intensity and on the slope. There is a large gap between actual and potential crop yields in these regions and there are significant opportunities for increasing production. With rainfall varying from 750 to 2000mm, effective water management is essential to control run-off and erosion to protect against dry season moisture stress limiting productivity. Realizing this potential essentially hinges on our ability to reverse the process of degradation–processes that will contribute to institutionalize water conservation, reduced run-off and erosion. Thus, resource conservation issues represent an essential prerequisite to achieve enhanced productivity. Over the past two decades, the Government of India has devoted considerable attention and resources in programmes of watershed development in rainfed areas. Issues of resource conservation have assumed importance in view of wide-spread resource degradation problems, need to reduce production costs, increase profitability and make agriculture more competitive and sustainable. Many of these technologies related rain water harvesting and efficient utilization are being upscaled under National Mission on Sustainable Agriculture (NMSA), one of the 8 mission under prime minister.

Application of GIS & Remote Sensing tools in Watershed Management

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1. Introduction

Geographical Information System (GIS) and Remote Sensing tools and techniques are part of the Geospatial methods used extensively for survey, planning, design, development and assessment of innumerable processes, phenomena and for program implementation. In 1980s the concept of GIS was rolled out as a consequence of development and improvement of computing skills. The advent of space satellites fuelled the possibility of space-based remote sensing at the same time. At present satellite data obtained from remote sensing satellites form an important input for analysing temporal change in natural processes like rainfall, temperature, normalized difference vegetation index (NDVI), land use-land cover change (LULC and LCCC), soil erosion, agricultural production, drought and flood, monsoon activity etc., besides many others. India has developed the capability of developing and launching its own remote sensing, telecommunication and weather satellites. Data obtained from these are being used extensively for various applications in the country. For this lecture a short study of use of GIS and RS tools and techniques for watershed development and management is being presented, as rainfed agriculture is dependent on judicious use of limited water available in the region for agriculture.

Rainfed agro-ecological regions (AER) which encompass the semi-arid tropics (SAT) and hot dry and moist sub-humid regions of India includes over 95.09 m ha (28.98%) under the semi-arid climate and 3.19 m ha or 1 % of the land area under the transitional climate. Watershed-based development has been accepted as the template for agricultural development and economic planning of this region. In peninsular India average annual rainfall is 500 mm (300-800 mm), which occurs in 45-50 rainy days. Over 50% of this rainfall occurs by way of thunderstorm that lasts for a few hours. Considering such a rainfall pattern, it is essential to harvest, store and use rainwater for undertaking agriculture and other allied activities for the rest of the year. Intensive rainfall events induce severe soil erosion in bare or sparsely vegetated land that is common in the region.

Watershed Development and Management Program was initiated during 1980s to address these limitations of the rainfed AER (Planning Commission, 2001). Soil and Water Conservation Structures (S&WC) viz., check-dam, stone weirs, contour bund, live bunds, vegetative cover, key-line plantation, grass way etc. were planned to provide impediments to overland - runoff which induce soil erosion and depletion of nutrients from agricultural fields. Structures were laid to guide runoff to designated farm ponds and tanks for water harvesting on the surface, besides impounding water for facilitating deep percolation for groundwater recharge. Thus, Watershed Development Program (WDP) was considered the most comprehensive program for achieving agricultural and ecological sustainability in the rainfed regions in India. As India envisages sustaining an agricultural growth rate of 4.0 to 4.5 per cent in order to reduce food insecurity and poverty, while increasing rural purchasing power, it is essential to strive for achieving sustainable development through watershed development.

2. Watershed Development Program (WDP) in India

One of the primary reasons, in favor of watershed-based development in rainfed AER, is the enormous cost of major water projects like the under-construction Narmada river-valley project. Hence emphasis was shifted to augmenting water resources through small and decentralized projects and the WDP for rainfed regions in rural India, have remained the accepted strategy for rural transformation. Watershed Projects have been undertaken under six major national programs, viz. Drought-Prone Area Program (DPAP), Desert Development Program (DDP), National Watershed Development Project for Rain-fed Area (NWDPRA), Watershed Development in Shifting Cultivation Areas (WDSCA), Integrated Watershed Development Project (IWDP) and Employment Assurance Scheme (EAS) etc. by four Central Ministries of Govt. of India namely, Ministry of Rural Development (MORD), Agriculture (MOA), Environment & Forestry (MOEF) and Water Resources (WR). Significantly, 70 per cent of funds for watershed development in India are being spent under these six major programs. There are also, a lot of commonality in the WDP undertaken by these four ministries, in view of which, a inter-ministerial sub-committee (1999) evolved a common approach and principles for undertaking of WDP in India. The Perspective Plan of India envisages an holistic and integrated development of rainfed areas in the country on watershed –basis to cover app. 63 million ha at an estimated cost of Rs. 76,000 c*rore* or USD 1520 m (Planning Commission, 2005). A Technical Committee Report submitted to the Department of Land Resources (MORD) in January 2006 (Parthasarathy, 2006), estimates that at current level of outlay, it may take 75 years to complete watershed treatment in India. The Committee opined that if S&WC measures needed to be completed by 2020, the Government must allocate Rs. 10,000 crore (USD 20 m) annually for the purpose till then.

3. Evaluation of impact of Watershed Development Program (WDP) in India

Most of the studies undertaken to evaluate the impact of package of practices implemented under WDP have been based on qualitative data with some quantitative information for which econometric analysis had to be performed. All the studies faced two major problems due to which their scope of analysis was restricted. Firstly, baseline information of watershed villages is extremely difficult to obtain from Project Implementing Agencies (PIA) as there were no systematic methods or process put in place to collect and archive them; hence meaningful evaluation was always difficult. Next, periodic monitoring of WDP was neither undertaken by PIA nor the funding agency. As a consequence, most evaluation studies were forced to report on qualitative information only. These problems had been widely discussed and in more recent WDP, amendments have been made and a definitive process has been put in place to avoid similar problems. P.K. Joshi *et al* (2005) undertook meta-analysis of over 311 watershed projects and documented efficiency, equity and sustainability benefits. The authors point out that mean B: C ratio of a watershed program in the country was quite modest at 2.14. Internal rate of return was 22 % that was comparable with many other rural developmental programs.

To address these lacunae with reference to evaluation of sustainability of watershed projects in India, two research projects were undertaken at CRIDA under the *Ad-hoc* scheme and the ICAR National Fellow Scheme of the author to develop a methodology (Kaushalya et al., 2013)and a toolkit for evaluation of watershed development projects in the peninsular region of India since 2004 (Kaushalya et al., 2006 a& b, 2007, 2009, 2010). For this purpose, tools of Geo-informatics like GIS, Remote sensing techniques, DGPS and Spectro-radiometer were used to supplement information generated from actual field survey, soil analysis and socio-economic survey conducted in the selected watersheds and villages. Databases were created in ***MS-Access*** and thematic maps were drawn using ArcGIS. Multi-spectral satellite data were procured from NRSA for pre-project period i.e., 1998 and post-project periods, i.e., 2004 to 2006. The satellite imageries were interpreted to understand the processes of change using various indicators. A methodology was thus developed to generate baseline information for pre-project period for various parameters from field and satellite data which were in turn, used as sustainability indicators to assess sustainability of watersheds projects. In Figure 1 the modular scheme of the evaluation study has been depicted. The impact of non-implementation of WDP was compared in an untreated watershed in the vicinity for a clearer understanding.

4. Pre-field Activity

For evaluation of Watershed Development Projects (WDP) it is essential to select watersheds based on some pre-determined criteria. For our study in the AESR 7.2, five treated and an equal number of untreated micro-watersheds were selected in the districts of Rangareddy and Nalgonda in AP. The watersheds are located in the rural-urban divide zone at a distance 70 km from Hyderabad Urban Center. The pre-field activities undertaken prior to evaluation of the watersheds have been described in brief here.

4.1. Selection of watersheds

Our objective was to analyse which programs and agencies had implemented a sustainable watershed project in the study area. Hence projects developed by various agencies like the Dept. of Agri, Govt. of AP, - a line dept., NGO, research organization like CRIDA, MANAGE, NIRD, etc. was chosen for the study. As each of these PIA lay emphasis on various aspects, the outcome of the projects are very different. To capture these variations leading to difference in outcome of WDP five treated micro-watersheds were selected in five villages namely - Chintapatla near Ibrahimpatnam in Yacharam Mandal, Pamana in Chevella Mandal and Dontanpalli in Shankarpalli Mandal, Channareddiguda in Manchal Mandal – all in Rangareddy district and Gollapalli in Chintapalli Mandal in Nalgonda District.

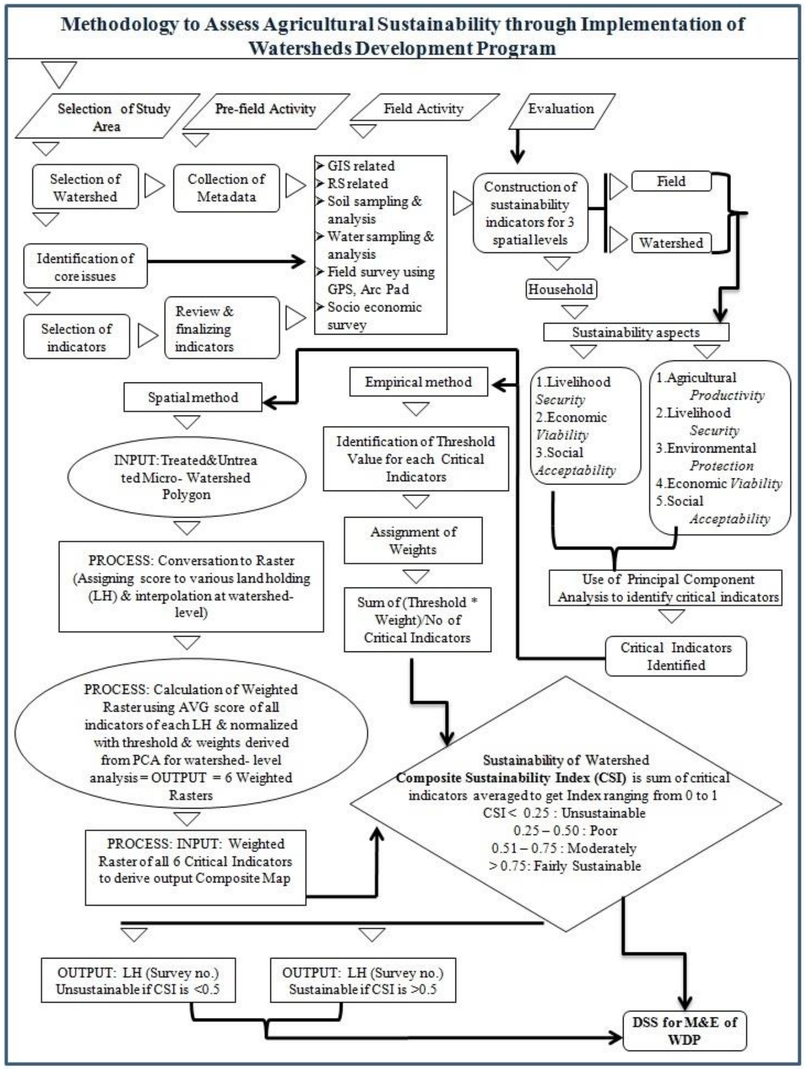


Fig.1: Methodology to monitor & evaluate sustainability of watershed projects.

4.2. Characterization of resource base in selected watersheds

The resources available in the various watersheds were surveyed and mapped using ArcGIS. Detail of this technique has been added in a later section in this paper.

4.3. Identification of core issues that affect agriculture in watersheds

After reconnaissance survey of selected watersheds and discussion with key informants, core issues that impact agriculture in the selected watersheds were identified. As these need to be addressed first to achieve sustainable development, the evaluation study and methodology is developed to address these issues

4.4. Identification and construction of relevant sustainability indicators

Based on the core issues, relevant indicators were developed to evaluate the various aspects of sustainable development. A set of fifty indicators was developed to evaluate the watershed projects under the NF scheme.

4.5. Methodology for identifying critical indicators

A methodology was developed to identify critical indicators for evaluating sustainability of watershed projects. The merits of this methodology are that it is helps in a quantitative evaluation that facilitates comparison of situation between two watersheds besides enabling mapping thus making the evaluation process easy, objective and useful. Wherever direct indicators were unavailable, surrogate indicators were developed and used for evaluation.

5. Field Activity

Fieldwork is an integral and crucial part of the study. At the initial stage a reconnaissance survey was undertaken in each of the watersheds identified for study. A transact walk was undertaken to survey the selected watersheds and villages for agricultural resource characterisation. A DGPS was used to geo-reference all resources and boundaries in the study area. Soil sampling sites and S&WC structures were also geo-referenced. Soil samples were brought to lab for analysis. In the next phase interviews of farm households were carried out using two structured questionnaires.

5.1. Watershed Survey - Transact Walk

5.2. Geo-referencing of sites using DGPS

A Trimble DGPS (Differential Global Positioning Systems) unit consisting of a base and a rover unit was used for geo-referencing the GCP, soil sampling sites, soil profile sites and S&WC structures in the study area. The unit was also used to update landholding boundaries that had changed owing to sub -division and fragmentation of land after mapping of the original cadastre (Photo 1).

Photo 1: Geo-referencing a check-dam in Pamana village near Chevella, RR District.

5.3. Measuring spectral signatures & collection of ground -truth information-

On an average more than a dozen visits was required to be taken for collection of ground truth information and for verification of the same in the field in each site annually during the study. Several of these trips were exclusively undertaken during cropping season for collection of spectral signatures of crops to facilitate interpretation of satellite data with reference to crop cover, change in land use and land cover and resultant NDVI conditions. A *Spectral Library* was developed to store typical spectral signature of various objects on ground during various seasons for facilitating interpretation of satellite data. Photo 2 indicates the use of a spectro-radiometer in the field.

5.4. Soil sampling

Mapping of soil fertility status is an essential requirement for analysing impact of improved practices implemented under watershed development projects. Over 450 soil samples were collected from various sites in the study area and analysed for 12 physico-chemical and biological parameters in the lab using standard methods.

Photo 2: Using a handheld spectro-radiometer (*Analytical Instruments Ltd*. USA) to collect spectral signature from paddy field at early growth stage in Gollapalli village.

5.5. Soil profile study

One typical soil profile was cut in each of the study site for establishing a baseline for facilitating long-term sustainability studies.

5.6. Socio-economic survey

Two questionnaires were specifically prepared for conducting socio-economic surveys at household and village-level in each of the study area. The questionnaire were structured in a manner so as to collect information for each for each of the sustainability indicator identified for the purpose. Wherever direct indicators were not available, information for surrogate indicators were collected.

5.7. Participatory Rural Appraisal (PRA)

A PRA was conducted specifically to identify core issues that affect agriculture in each of the watershed village.

6. Activities undertaken in Laboratory

The study involved several activities to be undertaken in the GIS, Soil Chemistry & Soil Physics Labs. While the interpretation and analysis of satellite data was undertaken in the GIS lab, storage and preparation of soil samples for analysis and finally batch-wise, analysis of soil samples was carried out in the Soil Physics and Soil Chemistry labs at the institute.

6.1. Applications in *ArcGIS* for analyzing sustainability of watershed projects -

One of the highlights of the research program was the application of GIS technique for evaluation of impact of LMP on rainfed agriculture. Watersheds were delineated and mapped using ArcGIS (ver. 9.0) software (Figure 2). All corollary data had to be collected and collated before preparation of map overlays for the study. Thematic maps for various aspects like slope, soil fertility status, cereal yield, etc., were prepared for deriving sustainability indicators (Figure 3). Map overlay of two or more themes helped in deriving numeric value for Sustainable Indicators. For instance, to evaluate impact of S&WC measures on soil fertility status and crop yield, overlay of maps of treated micro-watershed (TMW) with slope, soil macro - nutrient status. Correlation of location of S&WC measures with NDVI was deemed essential. Overlay of village cadastre over this outlay helped in quantifying the designated Sustainable Indicator. Other maps like NDVI derived from satellite data or land use and land cover maps helped in deriving and quantifying other sustainable indicator in a similar manner essential for evaluating NRM status in each land holding in the watershed.

6.2 Use of Geographical Positioning System (GPS)

An important highlight of the study likes the geo-referencing of various aspects of land management practices (LMP), natural resources management (NRM) and agricultural production systems (APS). After post-processing of GPS control points collected in the field, the data were imported and overlaid on the ArcGIS coverage and satellite data of the study areas. Using GPS points obtained using a *Trimble GeoXT* DGPS unit, a Digital Terrain Model (DTM) were prepared for each of the micro-watersheds. GPS units were used to update field boundaries in the village cadastre, to site S&WC structures in the watershed maps and satellite imagery and for preparing soil characteristic maps for the study. An important aspect of use of

DGPS unit was its help in creation of a geo-referenced database that is absolutely critical for undertaking long-term sustainability studies in future.

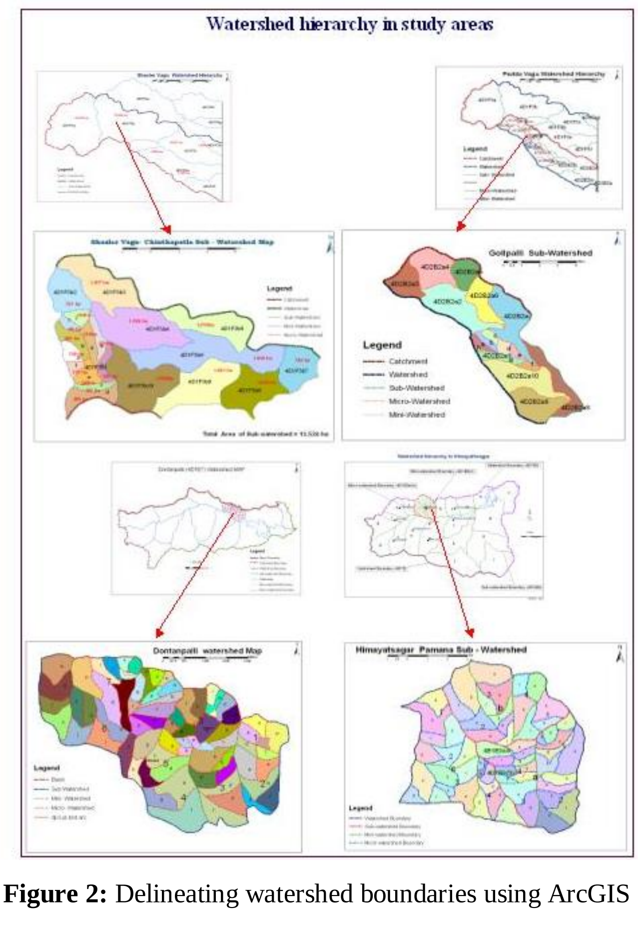


Figure 2: Delineating watershed boundaries using ArcGIS

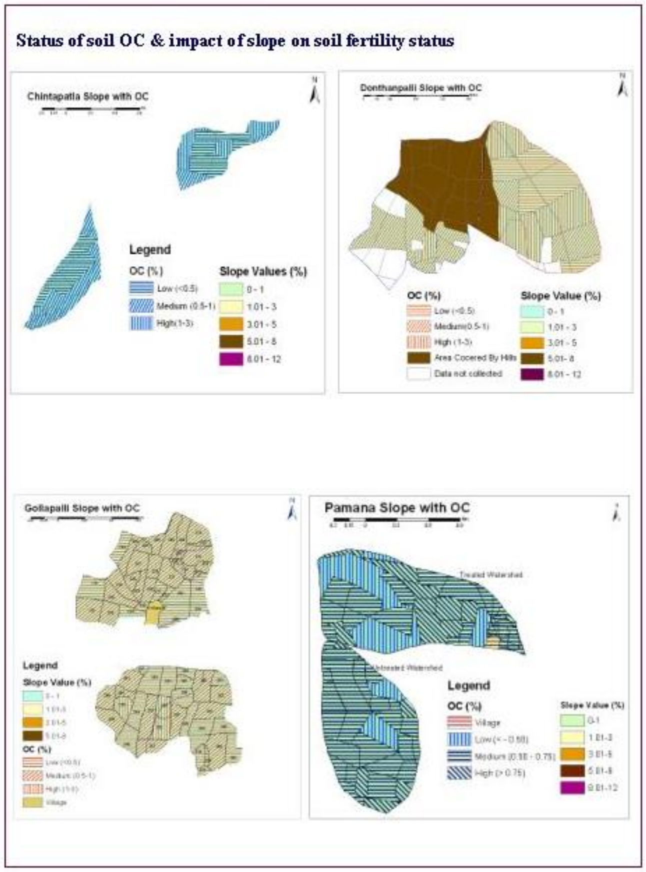


Figure 3: Map overlay to derive sustainability indicators of soil fertility and slope.

6.3 Interpretation of satellite data

For evaluating sustainability of watershed projects it was essential to compare the situation prevalent prior to implementation of WDP with the post implementation scenario. For this purpose, satellite data were procured from NDC, NRSC located in Hyderabad. Digital satellite data of IRS – 1D LISS III were procured for the pre–project period study for generating baseline info. As WDP were initiated in 1999 and 2000 in the study period, satellite data of two seasons viz., pre- and post monsoon data for 1998 and 1999 were procured from NRSA and interpreted using ERDAS *Imagine* (ver. 9.0). Analysis was undertaken to understand change in land use and land cover, drainage network, spread in extent of water bodies, NDVI, degradation of land, soil erosion, etc. The satellite data were also used to update maps that which had been mapped in 1970-71. The new road network, rail alignment and river network had to be mapped using *Virtual GIS* – a module of ERDAS software and incorporated into ArcGIS for preparing the DTM and for surface analysis of study area. The sustainability indicators pertaining to slope, NDVI, deforestation, change in land use and land cover, crop diversity etc., could be obtained only from the satellite data. Periodic study of the situation in subsequent years was facilitated in a similar manner. Satellite data of IRS 1D were procured for the period 2000 to 2004. For 2005 and 2006 IRS P6 LISS III data were procured. To analyse change that had occurred in 2006, satellite data of IRS P6 LISS 4 - MX with 5 m resolution was procured and studied. To facilitate interpretation of satellite data handheld portable spectro-radiometer was used to collect spectral reflectance in fields. Use of remote sensing technique in the present study was found to be absolutely essential not only for increasing our understanding of various nuances of agriculture, but also to interlink the impact of various aspects of NRM on agriculture (Kaushalya et al 2016 a, b).

6.4 Studies on soil fertility status

Over 450 composite soils samples collected from the farmers' field in the ten micro-watersheds during 2005 and 2006 were analysed for 12 physico-chemical parameters. Soil samples were shade – dried, ground and sieved with 0.5 mm sieve and a sample of 50-100 gm was taken and stored for carrying out analysis for OC content. The rest of the soil was again sieved with a 2 mm sieve and a sample of 250 gm was drawn for undertaking the rest of analysis. Soil physico-chemical parameters analysed were pH, EC, CEC, Organic Carbon content, major nutrients - N, P, K, micro-nutrients - Cu, Fe, Mn and Zn. Biological properties analyzed were Microbial Biomass Carbon (MBC) and Dehydrogenase assay (DHA).

6.5 Creation of Database for field and watershed - related data

As mentioned earlier, the entire study helped to generate a large volume of data that was required to be archived in a format that would be readily usable at a subsequent period. As a result, a digital framework was developed and the data generated from each of the sub-program was stored utmost case has been taken to a relive the data which would be critical for developing applications at a later date. The database consists of socio-economic, soils and land management related information that were used to prepare GIS coverage for socio-economic analysis and evaluation of LMP and WDP. The database is compatible with other national databases and could be easily shared and integrated.

7. Evaluation of agricultural sustainability in watershed projects

The methodology created facilitates evaluation of impact of WDP on state of agriculture, cropping pattern, soil fertility status, water availability, rural livelihood options and economic condition of farm households in treated micro-watersheds. The impact can be compared with the situation prevalent in an untreated micro-watershed in the vicinity. It was assumed that such a comparison would help in a rational understanding of impact of improver practices as extraneous advantages or disadvantages of geographical, topographical or economical situations to both or/ either of the micro-watersheds could be nullified.

7.1. Thematic mapping, overlay & analysis – *application of GIS*

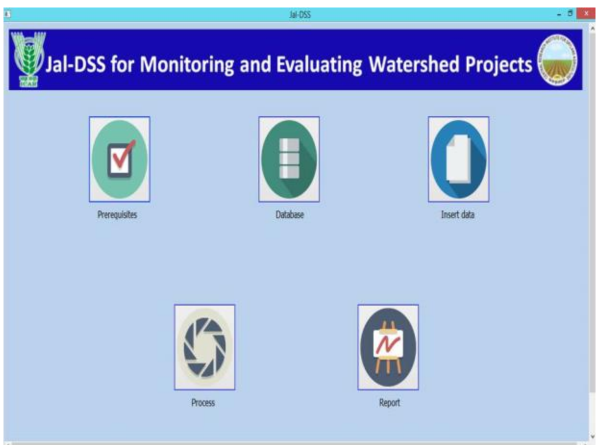
Various natural resources like soil, vegetation or agriculture pattern are depicted in maps prepared in GIS environment. Satellite data are used to study land use land cover pattern over a temporal resolution. Figure 3 indicates how natural resources are depicted in the form of thematic maps.

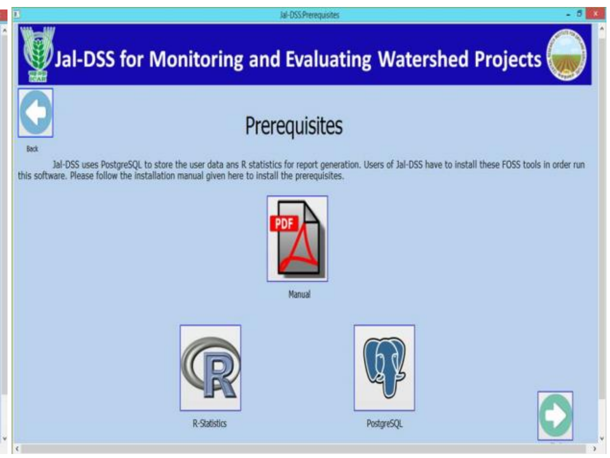
7.2. Land use and cover change studies (LCCS)

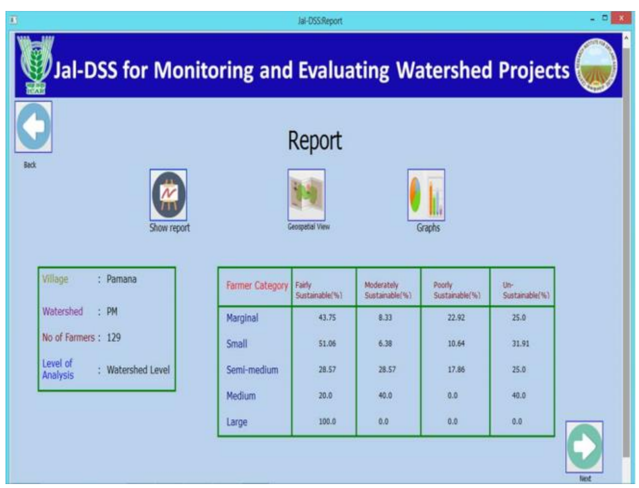
The land cover change were identified and mapped for deriving baseline data for constructing the sustainability indicators (Fig. 4).

8.0 Development of *Jal*-DSS for monitoring and evaluation of watershed projects

During the 3rd term of ICAR-National Fellow scheme awarded to me (2005-2016), we automated the methodology developed for spatial evaluation of watershed projects into a DSS for monitoring and evaluation of watershed projects. This is a first of its kind in India. The highlights of the DSS are that it has been developed using Open-Source GIS tools and R Statistics which essentially means that it can be used by anyone without access to proprietary GIS software. The DSS has been named Jal-DSS, meaning WATER Kaushalya et al 2016 (c). It uses multidisciplinary indicators to evaluate watershed projects while indicating the weak-links in a watershed project that could be corrected during implementation phase by the project implementing agencies. The DSS could be used by students and researchers to understand the working of watershed projects, by watershed project implementing agencies to monitor the performance of the project and take corrective measures when required and by funding agencies to assess the efficacy of watershed projects. Jal-DSS has been coded in Java and all necessary software have been bundled and a copy has been placed at CRIDA website <www.crida.in/Jal.DSS.zip/ for dissemination.







9.0 Conclusion

In order to evaluate sustainability of WDP, it is essential to undertake a multidisciplinary approach using the tools indicated in this document. Soil fertility status was evaluated in conjunction with socio-economic conditions prevalent in the selected watersheds. Application of GIS & Remote Sensing was found to be useful to geo-reference sustainability indicators and in construction of baseline information for pre- watershed development period so as to facilitate a comparison of progress made. Study of ten micro-watersheds in the five villages in AESR 7.2 undertaken during 2005-2015 indicated that watershed development program has positively impacted rainfed agriculture although marginally. It was seen that most villages are predominantly peopled by marginal and small farmers and any rural development programs including WDP must be fine–tuned for them, if agricultural sustainability has to be achieved. Automation of technology like Jal-DSS could help in implementing interventions in a short period of time which was not possible earlier. GIS and Remote Sensing tools and techniques facilitate robust and objective evaluation of impact of NRM interventions like watershed projects.

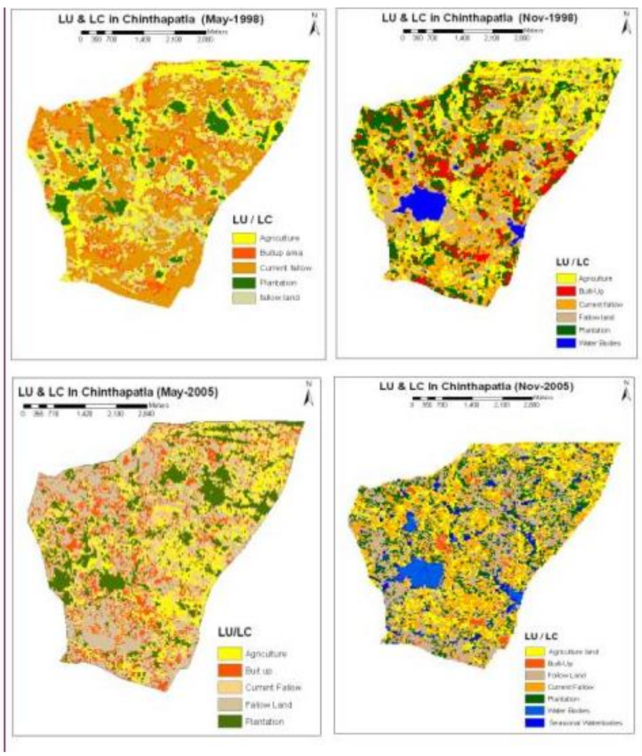


Figure 4: Land utilization pattern in Chintapatla village in pre-and post monsoon periods prior to, and after implementation of WDP in the village.

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Enhancing water productivity and profitability in semi-arid tropics using on farm reservoirs under diversified rainfed cropping systems

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Introduction

Food production for a growing world population would increase the global water demand. 80% of the world's physical agricultural area is covered under rainfed system and contributes 62% of the world's staple food (FAOSTAT, 2005). Farm lands of 93% of Sub-Saharan Africa, 87% of Latin America, 67% of Near East and North Africa, 65% of East Asia, and 58% of South Asia are rainfed (FAO, 2002a). Most countries depend primarily on rainfed agriculture for their grain food. Rainfed agriculture constitutes 55% of total net cultivable area in India and contributes to production of major coarse cereals, pulses and oil seeds. The environment of rainfed agriculture is enrolled with regular climate constraints like long dryspells, high intensity rainfall, high evaporation losses, soil degradation, etc. Moreover the annual average rainfall varies from less than 100 mm to 2500 mm in different rainfed agro-ecological regions of the country. Its distribution is erratic with CV varying from 30 to 80 % during crop growth period which varies in both space and time. The present level of land productivity in rainfed agriculture in India is about 1 t/ha, however, globally it varies from 1-2 t/ha (FAO, 2002b). Therefore, all the above vagaries of the climate necessitates for immediate measures towards adaption of rainwater harvesting technologies for climate resilience in rainfed agriculture to manage the drought. Rainwater harvesting technologies like check dams, drop spillways, gabion structures, percolation tanks, sunken pits, etc. have been implemented across the rainfed regions in India as a drought mitigation measure in the watershed programmes. These technologies have resulted in the increase of recharge potential of shallow wells and tube wells. However, in the hard rock areas and long distances for access to water by the farmers in the watersheds, it is imperative for rainwater harvesting through on-farm reservoirs (OFR) is necessary for enhancing the field scale water productivity to basin level.

Rainwater harvesting is the collection and storage of excess runoff generated from small scale farmers land, ephemeral streams and hill slopes in rainy season for productive purposes (Wang et al., 2011; Kahinda et al., 2007; Ngigi et al., 2005). Small and marginal farmers with farm holding size of 1-2 ha constitute 80% of total farmers engaged in agricultural activities in India (Dev, 2012). Enhancing the water productivity in rainfed areas using supplemental small-scale irrigation is an important tool to increase green water flows (Fraiture et al., 2007). Many researchers around the world mentioned that, the rainwater harvesting concept has become key component in production technology to enhance livelihoods of rainfed farmers and reduce the yield gap between irrigated and rainfed agriculture with water scarcity under changing climate conditions (Oweis and Hachum, 2006; Gunnell and Krishnamurthy, 2003; Pandey et al., 2003).

The optimal design of rainwater storage structure, catchment command area ratio for giving supplemental irrigation to different cropping systems, depends on runoff potential of farm and the amount of water that is needed for supplemental irrigation at critical stages of rainy season crops and deficit irrigation to vegetable and post-rainy season crops. A challenge in design and construction of on-farm water storage structures is to minimize water losses (mainly due to seepage and evaporation) by way of lining (Ngigi et al., 2005). Evaporation rate and water spread area directly relates to evaporation losses and it also depends on type of soil, climate and underlying formation material. The limited runoff collected in OFR may not allow full irrigation in rainfed conditions but it permits supplemental irrigation to mitigate long dryspells during critical stages of most rainfed crops. Excellent responses to supplemental irrigation have been reported from several locations (Gunnell and Krishnamurthy, 2003). The yield responses of crops to supplemental irrigation in different locations indicated that one supplemental irrigation at the critical stages of crop growth considerably increased crop yields (Singh and Khan, 1999).

Efficient use of limited water available in the OFRs requires crop diversification for more profits to the farming community. Across the world, rainfed farming communities require localized storage of run off water and the efficient methodology of water application to mitigate the long dry spells as well as to promote the on farm water conservation protecting the land erosion and nutrient losses. Maize and groundnut are widely grown used under rainfed conditions in south Asian and African countries. The information on catchment command area ratio, runoff coefficients for on farm rainwater harvesting on cropping system approach with net water availability, area could be supported with supplemental irrigation and different storage capacities of OFRs are seldom available for the design of the structures. Therefore, a systematic methodology and economic assessment under widely prevailing cropping system approach is presented in the paper.

Study area and climate

The field experiments were conducted from 2008 to 2015 in model rainwater harvesting through OFR in Gunegal Research Farm (GRF) of ICAR-Central Research Institute for Dryland Agricultural (CRIDA), Hyderabad, Telangana, India. The farm is located at 78°40’ N and 17º2’ E with mean sea level of 621 m. The daily climate data on rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed were recorded from an automated weather station (AWS) installed at the farm. The average annual and seasonal rainfall of the study area is 701.87 and 478.05 mm, respectively. The average temperature of study area is 25.5 ºC with average minimum and maximum of 8.94 and 42.06 ºC, respectively. The land is relatively flat with a slope of 2 per cent or less and it has deep to moderately deep well drained red soils. Soil texture was sandy clay loam with Sand (70.96 %), Clay (22.32 %) and Silt (6.72 %) with soil depth varying from 50 to 100 cm.

Rainfall runoff relation in semi arid alfisols

A rainfall and runoff relation was developed by busing 7 years data of observations in the research farm on rainfall and runoff collected in the OFR with different catchment areas varying from 1.5 to 14.5 ha. The water balance was worked out for both lined and unlined OFRs considering the evaporation and seepage losses in unlined OFR upto 2010 and only evaporation losses in lined OFR with HDPE 500 micron geo-membrane sheet.

Cropping systems

The long term data generated through field experimentation has been used in the present analysis for two cropping systems i) oil seed based with major crop of groundnut (GN) + okra (O)/ tomato (T) in rainy and carrot (C) in post-rainy seasons and ii) cereal based with major crop of maize (M)+O / T in rainy and C in post-rainy seasons which are commonly grown by the farmers of rainfed region in peninsular India. The experiments were conducted at the research farm with different crops and the yield data were obtained. During 2008-11, the groundnut based cropping system was tested and maize based cropping system was tested during 2012-15 under OFR imposing different supplemental irrigation (SI) depths at two critical stages of the main crops and weekly scheduling of deficit irrigation of 30 mm for vegetables in the alfisols.

OFR technology

Three dug out OFRs having top dimensions of 17×17×3m, 20×20×3m, and 26×26×3m for the capacities of 500, 750 and 1500m^3, respectively (considering suitability to small farm of less than 1.0 ha, medium farm of 2-4.0 ha and large farm of more than 4.0 ha, respectively in the rainfed areas) were considered in the present study with lining of HDPE 500 microns thick geo-membrane film. The structures were provided with inlet spill way, silt trap (1.5x1.5x1m) and rectangular outlet (1x1 m). The depth of maximum storage was of 3 m with side slopes of 1.5:1. On an average the evaporation losses were observed at 3 mm/day in rainy season and 5 mm/day in post-rainy season. The net water availability for critical irrigation in different OFRs were calculated by reducing the evaporation losses up to the critical stage of the groundnut and maize. The yield data for rainfed as well as SI were considered for two irrigation depths of 30 and 50 mm. The details of SI, acreage and cropping systems under different capacities of OFRs are given in Table-1. It was observed that, there is a chance of two fillings of OFRs for three out of five years after lining in 2010. Similarly, there is a chance of single filling of the OFR, four out of five years. It indicates that, the risk level is 20 % for single filling and 40 % for two fillings of OFRs. Post-rainy season crop was grown only after second filling of OFR. In single filling, the water available is sufficient to provide two critical irrigations for groundnut and maize along with vegetables (tomato/okra) with 30 mm of irrigation depth weekly once.

Catchment-Command Area (CCA) Ratio

A 30 year seasonal rainfall data has been subjected to probability analysis by using Weibulls technique (Crichley and Siegert, 1991) as given below.

$$p = \frac{(m-0.375)}{(n+0.25)} \quad \text{(Eq.1)}$$

p = probability % of m^{th} rank

m = rank of the observation

n = total number of observations

It is estimated that, the seasonal rainfall at 75 % probability of occurrence was 375 mm and taken as design rainfall (Reddy et al., 2012) for the experimental site. The average runoff coefficients and runoff efficiency were taken as 0.07 (7%) and 0.75 (75%) (micro-catchments) respectively for the alfisols which have good drainage, infiltration meeting the hydrological group B conditions. The catchment areas for 500, 750 and 1500 m^3 capacities of OFRs, are calculated by using the formula as given below:

$$Q = \frac{(A_{ca} \times RO_c \times RO_e \times R_d)}{1000} \quad \text{(Eq.2)}$$

Where, Q = OFR capacity, m^3

A_{ca} = catchment area, m^2

RO_c = runoff coefficient, (fraction)

RO_e = runoff efficiency, (fraction)

R_d = design rainfall, mm

The CCA ratios were calculated under different OFR capacities and cropping systems with different SI depths of 30 and 50 mm using equation 2 and the acreage as given in Table 1.

OFR construction and lining

The economics of OFR construction involves earth excavation, slope stabilization, digging of field channels, silt trap, inlet and outlet structures along with bund formation. Beside the earth excavation for digging of OFR, an extra of earth removal of 22%, 20% and 17% were added for 500, 750 and 1500 m^3, respectively. Based on the field experience of digging the OFR using machinery with big bucket having capacity of 1 m^3 can cost Rs. 30/m^3 as per the recent market prices of hiring the machinery. Lining of OFR with 500 micron HDPE black thick film is about Rs.100/m^2 plus labor charges for anchoring and laying of the film in the trench along the side bund of the OFR. The costs of the lining were: Rs. 30000, Rs.41500 and Rs.70000 for 500, 750 and 1500 m^3, respectively. The life of the lining film is taken as 5 years. The costs of the earth excavation were: Rs. 18300, Rs. 27000 and Rs. 52650 for 500, 750 and 1500 m^3 capacities of OFRs, respectively. These above fixed cost are annualized for 20 years of life of the structures by using the formula given below:

$$Annualized\ cost = p\frac{r(1+r)^{n}}{(1+r)^{n}-1} \qquad \text{(Eq.3)}$$

Where,

P = loan amount, Rs

r = interest rate (9%)

n = amortization period, years.

Water Application system

The cost of the water application system was estimated using two rainguns with one full circle and one half circle at an operating head of 30 m with 50% over lapping in the spray pattern and the discharge rate of 150 lph. One full circle would cover an area of 1258 m^2 by Hidra model of raingun. The life of the system was taken as 15 years for the 5hp monoblock diesel pumpset, HDPE pipes with accessories for 1 ha irrigation at a time (50 HDPE pipes at 4kgcm^{-2}). It was assumed that the plot size of 100 x 100 m^2 for all calculations of irrigation cost. The system was operated on shifts immediately after meeting the irrigation depth criterion. The time of irrigation estimated for 30 and 50 mm depths were 2.5 hr and 4.2 hr, respectively. The total market price of the system was estimated as [**]Rs 80,000/-. It is proposed to run the system on custom hiring basis with 100% benefit on annualized cost with 9% bank interest rate for loan repayment by the entrepreneur. The annual operation and maintenance cost of the system was taken as 12% over the annualized cost of the system including transport, etc. It is presumed that the system will be in operation for 840 hrs in the field in a year taking care of rainy season and post-rainy season irrigation from the OFR or any other water source in a cluster of 5-6 villages. The unit irrigation cost of the system was arrived at Rs. 350/hr. The cost of SI at two critical stages of crop growth at different levels of irrigation depths of 30 mm and 50 mm of water application was worked out as Rs 1900/ha and Rs 3204/ha, respectively under the custom hiring module using rainguns. It includes hiring charges of irrigation system and diesel cost with consumption of 0.5 l/hr of operation. On an average, the cost of the diesel was taken as Rs 60/litre.

Production economics

The selected crops GN, M, O, T and C were treated with 30 and 50 mm SI depths at 2 critical stages of the crop growth period. The average yields, costs of cultivation, market price are given in Table-2. In the present analysis, the cereal crop maize and oil seed crop, groundnut were taken as primary crops as commonly grown by the farmers of rainfed areas in southern region of India. The economic analysis was carried out in the combination of vegetables (O and T) with single filling and carrot in post-rainy season with second filling of the OFR. The analysis into the systems like monocrop M, M+O, M+T, during rainy season and M+C, M+O+C, M+T+C during rainy season and post-rainy season both spread over 2 seasons of the year, were carried out. Similarly, the second systems with oil seed crop, GN with the above combinations were tried in the experiment.

The sole crop of M and GN were experimented with both the SI depths of 30 and 50 mm at two critical stages (silking and tasseling, grain filling and development in M; flowering, peg initiation and pod development in GN). The combination of sole crop with vegetables like O and T were tested with 30 mm deficit irrigation from OFR as vegetable requires minimum 5-7 irrigations during its growth period. In the post-rainy season, C was grown with 7 irrigations of 30 mm from the OFR. The analysis was considered for three different capacities of 500, 750 and 1500 m^3. Under rainfed conditions, the average yields of GN and M are 700 and 2800 kg/ha with a cost of cultivation of Rs. 23000 and 25000/ha, respectively. In addition to the GN seed yield, the haulm of the GN added a benefit of Rs. 12500/ha under rainfed and Rs. 19000/ha under SI. The B:C ratios were 1.41 and 1.71 for rainfed GN and M, respectively.

Economic productivity and B:C ratio of different cropping systems were estimated under different SI depths for all the three OFR capacities. For estimating total water use for different cropping combinations, the effective rainfall at 75% probability of seasonal rainfall of 375 mm was considered by taking 57% of it as effective rainfall based on long term observations in the Alfisols. The SI depths applied for different crops as per Table-1 were also added to the effective rainfall for estimating economic productivity which is the ratio of annualized net benefit (Rs/ha) and total crop water use (m^3) by the system.

Rainfall and Runoff Relationship (RRR)

The relationship between rainfall and runoff in rainfed alfisols was developed through the regression analysis by using the data collected during experimental period and presented in Fig 1. From the all years of experimental data, it was observed that, there was a quadratic relation between rainfall and runoff with a coefficient of R^2= 0.82 in rainfed alfisols. Though the alfisols has high infiltration characteristics, the soils have the crust formation immediately after sowing having the runoff coefficient of 2 to 12% depending upon the antecedent moisture conditions of the catchment area and the rainfall intensity and its duration.

Irrigation scheduling of different cropping systems

Under three different capacities of OFRs with two levels of SI depths, an irrigation schedule was calculated based on the net water availability in the OFR at the time of critical stages of sole crop and for different combinations of O, T in rainy season and C in post-rainy seasons and the results are presented in Table-1.

For sole oilseed based cropping system, the GN can be irrigated in 0.8 and 0.5 ha with the SI depths of 30 and 50 mm for 4 and 4.11 hrs of irrigation time, respectively with the designed rain gun irrigation system under the OFR capacity of 500 m^3 with two critical irrigations. Similarly, for 750 m^3

capacity of OFR, GN can be grown in 1.16 and 0.7 ha with 30 and 50 mm critical irrigation depths for 5.7 and 5.8 hrs, respectively. For 1500 m^3 capacity of OFR, the areas under GN cultivation could be 2.23 and 1.34 ha with irrigation depths of 30 and 50 mm for 10.03 and 11.01 hrs of irrigation duration, respectively.

For the combination of GN and O, the areas under which GN could be irrigated with net available water are 0.25, 0.4 and 0.84 ha with 30 mm SI depth for the irrigation time of 1.25, 2.0 and 4.2 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. The areas under O are 0.25, 0.3 and 0.5 ha with five irrigations for duration of 3.13, 3.75 and 6.25 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively in combination with GN.

For the combination of GN and T, the areas under which GN grown are 0.4, 0.5 and 0.84 ha with 30 mm SI depth for the irrigation time of 2.0, 2.5 and 4.2 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. The areas under T are 0.1, 0.2 and 0.5 ha with six irrigations for duration of 1.5, 3.0 and 8.75 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively in combination with GN.

In post-rainy season, C crop was grown in addition to the above combination of crops in rainy season with the second filling of OFR. The area under C are 0.2, 0.3 and 0.55 ha with 30 mm SI depth and seven irrigations with duration of 3.8, 5.7 and 10.9 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. Except sole crop, the combination of crops are not possible with 50 mm level of irrigation depth under the OFRs looking into the water requirements of vegetables like O and T in rainy season and C in post-rainy season and the evaporative demand in the rainfed areas of semi-arid tropics.

Similar schedules were calculated for the M based cropping system with similar combination of vegetables like O, T in rainy season and C in post-rainy season (Table-1).

Catchment command area (CCA) ratio

The catchment areas estimated for alfisols with 7% average run-off coefficient are 2.55, 3.8 and 7.6 ha for 500, 750 and 1500 m^3 OFR capacities, respectively. In both the cropping systems with GN and M as sole crops, the CCA ratio was found to be same with progressive increase in OFR capacities from 500 to 1500 m^3. In 30 mm SI depth, both GN and M have the CCA ratio of 3.19-3.41 and it was 5.1-5.67 at 50 mm SI depth (Fig-2). In the GN-based cropping system, when C is planned in post-rainy season after second filling of the OFR, the minimum of CCA ratio was observed when both O/T in rainy season and C in post-rainy season are considered with 30 mm SI depth (Fig-2). It ranged from 2.13 to 2.28. The CCA ratio with sole GN under 50 mm SI depth is at par (5.1-5.67) with 30 mm SI depth with GN and vegetables (O/T) which indicates the benefit of deficit irrigation with 30 mm which may accrue more profits to a farmer under OFRs of different capacities. The same holds true for the M based cropping system too. While comparing both the cropping systems, the CCA ratio in GN+O/T+C under 30 mm SI depth (CCA=2.13-2.28) is less than M based system (CCA=3.64-4.02) as evidenced by 71.43, 76, 76.19% increase in M based cropping system over the GN in OFR capacities of 500, 750 and 1500 m^3, respectively (Fig-2).

The analysis of CCA ratio under different capacities of OFR indicates that for low sloppy land (less than 5%) particularly in the alfisols, the run-off coefficients are less, however, the CCA values may further decrease with increase in run-off coefficients in the moderate to high sloppy lands (more than 5%) in alfisols and also the vertisols even with low slopes.

Production dynamics under different SI

Average yield of the GN obtained were 1200 and 875 kg/ha under different irrigation levels of 50 and 30 mm, respectively. The corresponding rainfed yield was 700 kg/ha with average seasonal rainfall of 436 mm. For M, average yields were 4600 and 3930 kg/ha under 50 and 30 mm critical SI depths, respectively. The rainfed M yield was 2800 kg/ha. The average yields of O with five irrigations were 8500 and 5950 kg/ha under 50 and 30 mm depths, respectively (Table-2). For T, the average yields were 40000 and 28000 kg/ha under 50 and 30 mm depths, respectively with six irrigations. The post-rainy season C yields were 25000 and 17500 kg/ha under 50 and 30 mm depths of irrigation, respectively for seven irrigations.

SI showed a large potential to improve yield potential especially in semi-arid cropping systems with uneven rainfall variability and high intra seasonal dry spell occurrence (Pandey et al., 2003; Barron, 2004). Research results in Tigray (Araya et al., 2011) also showed that more than 80% of yield reduction and more than 50% of crop failure can be avoided when SI is employed during the critical growth stages of the crops. The importance of SI for different crops at critical growth stages is supported by various researchers in the world. In similar way SI was stated as one of the good crop water management options aimed to improve water availability and hence increase transpiration (Rockstorm and Barron, 2007). SI is a key strategy, still underused, for unlocking rainfed yield potential and water productivity (Rockstorm et al., 2010).

Economic assessment of OFR technology

The economic analysis has been done for two situations, viz., single filling of OFR with a risk of 20% (4 successful events out of 5 years) in rainy season and second filling of OFR with a risk of 40% (3 successful events out of 5 years) in post-rainy season in semi-arid regions with major soil group of alfisols. With the single filling in the oil seed based cropping system, three combinations using GN as a sole crop with 30 and 50 mm SI depths at two critical stages and GN+O or GN+T with the vegetable in the rainy season with the SI depth of 30 mm. Similarly, with the second filling of OFR, the carrot crop was taken in addition to the above combinations in post-rainy season with 30 mm SI depth.

While comparing the annualized net benefit with single filling of OFR in rainy season, it was observed that the net benefits with GN as a sole crop ranged from Rs. 11823 to 13506 per ha under the SI depth of 30 mm (Fig-3). However, there was an increase in the net benefit ranging from Rs. 21427 to 23168 per ha under the SI depth of 50 mm. Under the sole GN crop system, though the area increases (Table-1) with 30 mm SI depth, the response of crop yield is much more under 50 mm SI depth with less area giving increased net benefits. Under the cropping system of GN+O with 30 mm SI depth, the net benefits ranged from Rs. 24785 to 29399 per ha which is almost two times more than the net benefits with sole crop of GN. When T is taken instead of O, the net benefits ranged from Rs. 74451 to 128834 per ha which is five times more than the GN sole crop with the same SI depth of 30 mm. Also, when GN+T are compared with GN+O, the net benefits were increased by 2-5 times under different capacities of OFR with the same SI depth. Therefore, under oil seed based cropping system, GN+T is the best option followed by GN+O in the rainy season with the single filling of OFR.

In both the rainy and post-rainy seasons with second filling of OFR, the analysis was done for GN+C, GN+O+C, GN+T+C with the 30 mm SI depth and net benefits observed ranged from Rs. 71008 to 72936 per ha, Rs. 107043 to 110346 per ha and Rs. 141108 to 184940 per ha, respectively. It indicates that GN+T+C were the most profitable cropping system with two fillings of the OFR followed by GN+O+C.

In the cereal based cropping system with M as sole crop, net benefits ranged from Rs. 59193 to 60876 per ha, Rs. 66627 to 68668 per ha under 30 and 50 mm SI depths, respectively (Fig-4). With the introduction of O in the cropping system, the net benefits ranged from Rs. 50729 to 54968 per ha under

30 mm SI depth which is less than the sole crop as M. The decreases in net benefits were observed due to reduction in the area under the crop as well as crop yield response to the SI.

With the second filling of OFR, the net benefits ranged from Rs. 113720 to 115356 per ha, Rs. 126743 to 131719 per ha and Rs. 171616 to 204542 per ha for M+C, M+O+C and M+T+C, respectively. It indicates that M+T+C were the most profitable cropping system with two fillings of the OFR followed by M+O+C with 30 mm SI depth.

In rainy season with single filling of OFR, the GN (sole) based cropping system has B:C ratio ranging from 1.3 to 1.4, 1.47 to 1.53 under 30 and 50 mm SI depths, respectively (Fig-5). GN+O has the B:C ratio of 1.5, whereas GN+T has increasing ratio varying from 2.53 to 3.20 with 30 mm SI depth under different capacities of OFRs. In post-rainy season with second filling of OFR, the B:C ratio ranged from 2.86 to 2.95, 3.13 to 3.23 and 4.0 to 4.72 in GN+C, GN+O+C and GN+T+C, respectively indicating the option of T in rainy season with GN and C in post-rainy season under 30 mm SI depth has the maximum B:C ratio as compared to other cropping systems under three capacities of OFRs (500 to 1500 m^3). However, in cereal based cropping system with M as sole crop, the B:C ratio ranged from 2.5 to 2.6 and 2.4 to 2.5 under 30 and 50 mm SI depths, respectively and it is two times more than the sole GN (Fig 5 and 6). M+O gave the least B:C ratio (1.9 to 2.1) as compared to M+T (3.2 to 3.7) under 30 mm SI depth (Fig-6). However, in both the rainy and post-rainy seasons with second filling of OFR, the B:C ratio ranged between 3.4 to 4.7 with maximum in M+T+C (4.5 to 4.7) followed by M+C and M+O+C under different capacities of OFRs.

The economic productivity (EP) for different cropping systems were calculated by considering the total water used per ha by the system from the OFRs along with effective rainfall of 2138 m^3 and the annualized net benefits, Rs/ha of the cropping systems under different OFR capacities and SI depths of 30 and 50 mm. In GN based cropping system, the sole GN has the EP ranging from 4.32 to 4.93 Rs/m^3, 6.83 to 7.38 Rs/m^3, respectively under 30 and 50 mm SI depths (Fig-7). EP in GN+O declined from 6.94 to 5.85 Rs/m^3 as the capacity of OFRs increased. GN+T had the maximum EP over GN+O and sole GN ranging from 16.4 to 28.4 Rs/m^3.

When both farming seasons are taken into account with C in post-rainy season, GN+O/T in rainy season with 30 mm SI depth, GN+T+C had the maximum EP ranging from 21.3 to 27.9 Rs/m^3 over the OFR capacities of 500-1500m^3 followed by GN+O+C and GN+C with a declining trend as the OFR capacity increases.

However, the other cropping systems with M under different capacities of OFRs and SI depths, the EP increased 5 times more than that of sole GN based system (Fig-7 & 8) in rainy season except in the case of M+O with 2-fold increase. The maximum EP with progressive increase from 24.8 to 34.9 Rs/m^3 was obtained in case of M+T in rainy season with 30 mm SI depth (Fig-8). The EP was almost constant (23.51-23.84 Rs/m^3) in case of M+C with both cropping seasons under two fillings of OFR, however, M+T+C had the maximum EP (25.9-30.8 Rs/m^3) as compared to M+O+C and M+C when both the seasons are considered.

Conclusion:

OFR technology with different capacities and crop diversification will lead to reduce the yield gaps between irrigated and rainfed. Due to changing climate and rainfall patterns, principles of rainwater harvesting through OFRs within the farmers fields has the potential of enhancing the economic productivity of different crops in the rainfed regions without exploiting the ground water in hard rock regions like southern Telangana. Among the selected cropping systems with combination of different vegetables in rainy season and post-rainy season under two SI depths of 30 and 50 mm, the maize based cropping system with vegetables particularly tomato in rainy season and carrot in post-rainy season was found to be more profitable with high economic returns to the farmers. SI depth of 50 mm was found to be more profitable in the sole crop of M and GN, however, SI depth of 30 mm is not sufficient to induce the crop response to the profitable yield in the soils like alfisols which are thirsty with low water holding capacity leading to underutilization of soil nutrients as per the requirement of the crop. But, in the case of crop diversification with vegetables, like O, T and C with 5-7 irrigations, 50 mm SI depth can't be supported with the limited water storage in the OFRs upto 1500 m^3. Besides improving the economic productivity, OFR contribute intangible benefits of controlling soil loss and the nutrients from the farmers' fields and the limitation is only the area loss for construction of OFR within the farm field to an extent of less than or equal to 10% upto the capacity of 1500 m^3.

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Table-1. Command area under different combinations of cropping systems under differential rainfall and capacities of OFR

Seasons	Storage/SI depths	500 m^3 (CA=2.55)		750 m^3 (CA=3.8)		1500 m^3 (CA=7.6)		Storage/SI depths	500 m^3		750 m^3		1500 m^3	
		30 mm	50 mm	30 mm	50 mm	30 mm	50 mm		30 mm	50 mm	30 mm	50 mm	30 mm	50 mm
	Cropping system (Oil seed based)							Cropping system (Cereal Based)						
Rainy season	Acreage (ha)							Acreage (ha)						
	GN	0.8	0.5	1.16	0.7	2.23	1.34	Maize	0.8	0.5	1.16	0.7	2.23	1.34
	No of irrigation	2	2	2	2	2	2	No of irrigation	2	2	2	2	2	2
	Irrigation time (hrs)	4	4.11	5.7	5.8	10.03	11.01	Irrigation time (hrs)	4	4.11	5.7	5.8	10.03	11.01
	Acreage (ha)							Acreage (ha)						
	GN	0.25	*	0.4	-	0.84	-	Maize	0.3	-	0.4	-	0.84	-
	Okra	0.25	*	0.3	-	0.5	-	Okra	0.2	-	0.3	-	0.5	-
	No of irrigation							No of irrigation						
	GN	2	*	2	-	2	-	Maize	2	-	2	-	2	-
	Okra	5	-	5	-	5	-	Okra	5	-	5	-	5	-
	Irrigation time (hrs)							Irrigation time (hrs)						
	GN	1.25	-	2	-	4.2	-	maize	1.5	-	2	-	4.2	-
	Okra	3.125	-	3.75	-	6.25	-	Okra	2.5	-	3.75	-	6.25	-
	Acreage (ha)							Acreage (ha)						
	GN	0.4	-	0.5	-	0.84	-	Maize	0.4	-	0.5	-	0.84	-
	Tomato	0.1	-	0.2	-	0.5	-	Tomato	0.1	-	0.2	-	0.5	-
	No of irrigation							No of irrigation						
	GN	2	-	2	-	2	-	Maize	2	-	2	-	2	-
	Tomato	6	-	6	-	6	-	Tomato	6	-	6	-	6	-
	Irrigation time (hrs)							Irrigation time (hrs)						
	GN	2	-	2.5	-	4.2	-	Maize	2	-	2.5	-	4.2	-
	Tomato	1.5	-	3	-	8.75	-	Tomato	1.5	-	3	-	8.75	-
Post-rainy season (Second Filling)	Carrot							Carrot						
	Acreage (ha)	0.2	-	0.3	-	0.55	-	Acreage (ha)	0.2	-	0.3	-	0.55	-
	No of irrigation	7	-	7	-	7	-	No of irrigation	7	-	7	-	7	-
	Irrigation time (hrs)	3.8	-	5.73	-	10.91	-	Irrigation time (hrs)	3.8	-	5.73	-	10.91	-

*insufficient storage to irrigate in one filling of pond with combination of GN and vegetable; CA=Catchment Area in ha

Table 2. Average yield and cost details of different crops under different irrigation depths

Crops	Cost of cultivation (Rs/ha)	Present market price (Rs/kg)	Average crop yield (kg/ha)		
			50 mm	30 mm	Rainfed
Groundnut	23000	40	1200	875	700
Maize	25000	23	4600	3930	2800
Okra	40600	20	8500	5950	-
Tomato	61000	15	40000	28000	-
Carrot	35600	20	25000	17500	-

Fig-1: Rainfall and runoff relationship in rainfed alfisols during experimental period

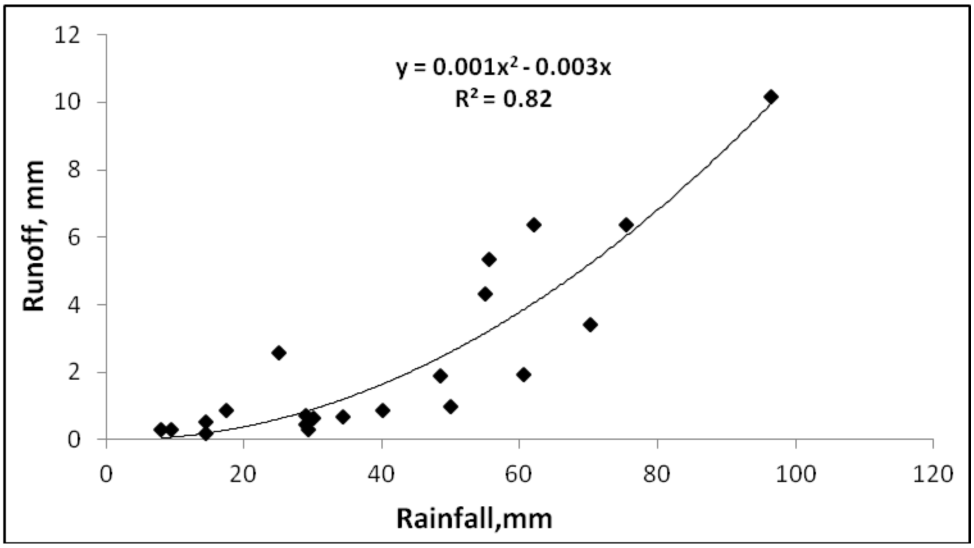


Fig-2. Catchment command area ratio for different cropping systems and OFR capacities

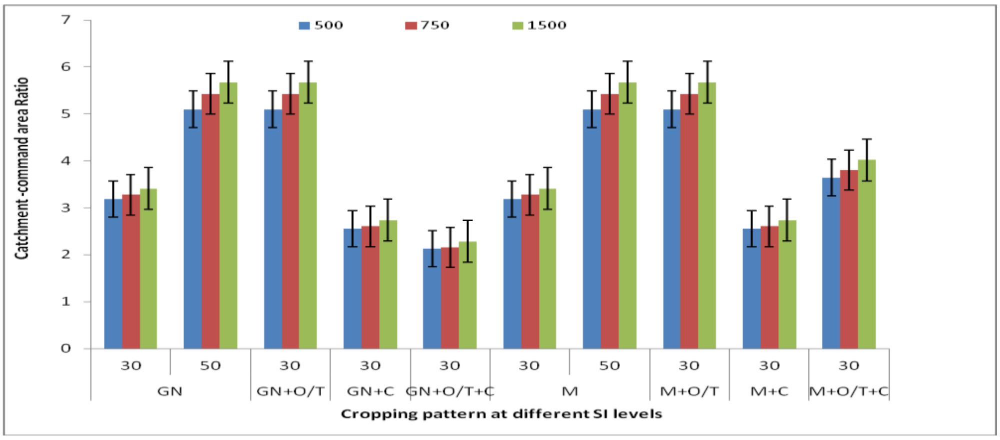


Fig-3. Annualized net benefits from oil seed based cropping system under different irrigation depths and OFR capacities

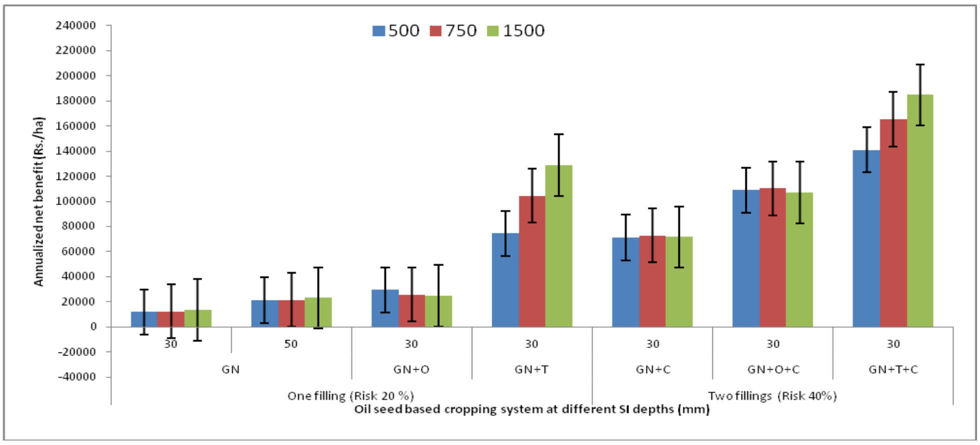


Fig-4. Annualized net benefits from cereal based cropping system under different irrigation depths and OFR capacities

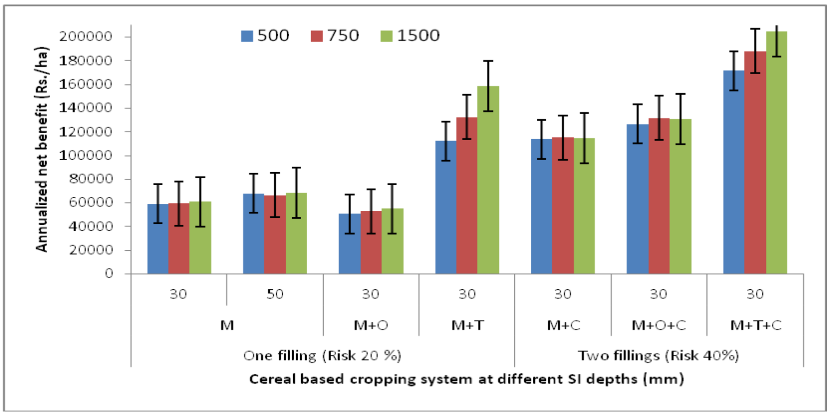


Fig-5. B:C ratio of oil seed based cropping system under different irrigation depths and OFR capacities

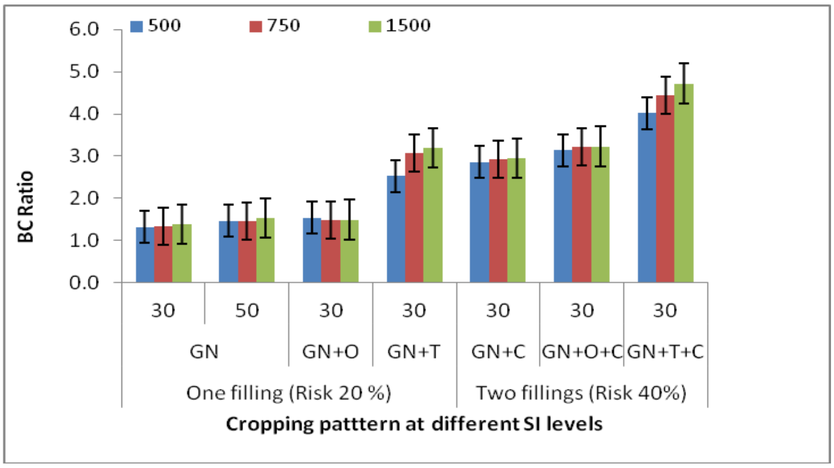


Fig-6. B:C ratio of cereal based cropping system under different irrigation depths and OFR capacities

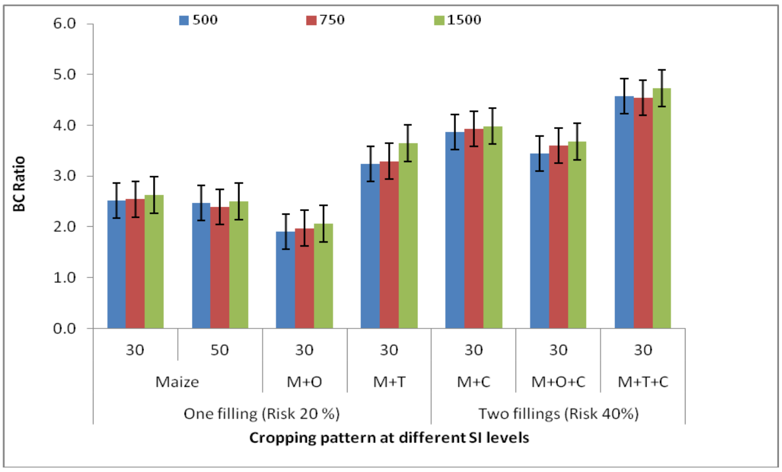


Fig-7. Economic productivity of oil seed based cropping system under different irrigation depths and OFR capacities

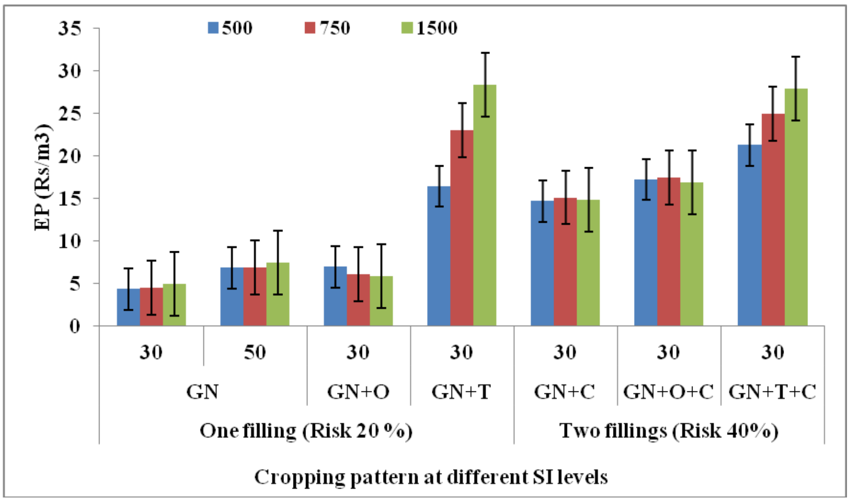
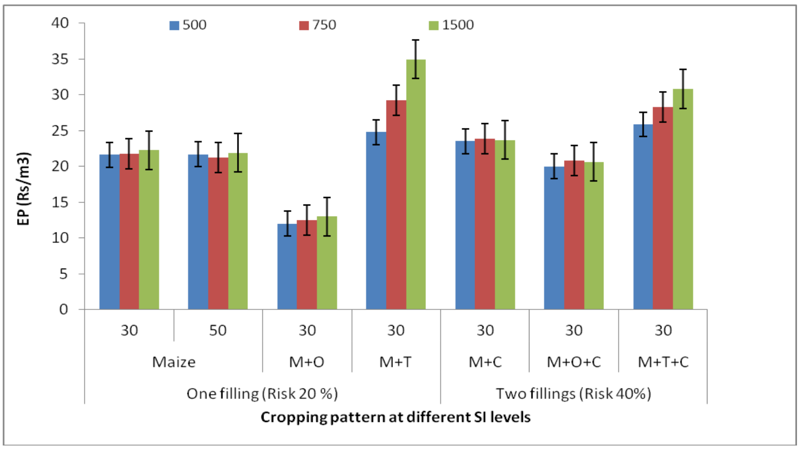


Fig-8. Economic productivity of cereal based cropping system under different irrigation depths and OFR capacities



Farm Mechanization to increase the productivity and profitability at farm level

I. Srinivas, Principal Scientist (Farm Machinery and power), CRIDA

Farm Power Scenario in India:

Experience has shown that there is a definite and positive relationship between farm power availability and farm production levels. Farm power availability to individual farms varies from 0.1 to 6 kw/ha depending upon the economic status and need of the farmer. Farm power availability of 1 to 1.5 kw/ha seems to be comfortable in completing all field operations in time and hence would help in attaining good crop yields. Therefore, there appears to be good scope in India to substantially increase the crop yields even with incremental increase in the levels of power availability, provided such power sources are utilized to optimum levels with good energy management. Improved farm implements and machinery with higher capacities and improved cultivation practices can play a vital role in achieving this target. Low power availability can considerably delay a farm operation thereby decreasing the yields. This could be overcome either by increasing the power availability, or by utilizing the existing power sources more efficiently. Field operations like tillage, sowing, fertilizer application, interculture, weeding, spraying and dusting (of plant protection chemicals), harvesting and threshing are very important and timeliness of these operations enhances and assures good crop yields. Delay in field operation has adverse effect on crop husbandry and results in reduction of yields from 10-80%. Availability of matching farm implements having high capacity is another factor. Timely availability of other inputs like seed, fertilizer, chemicals along with proper crop management are also equally important in crop production.
Mechanization brings timeliness in field operations, precision in placement of inputs, reduced input cost, increasing productivity, removing drudgery in farm operations and imparts dignity to farm work, breaking inhibitions of educated youth in farm operations. Total power availability on Indian farms has increased at an average compound annual growth rate of 4.58 percent from 0.293 to 1.841 kW/ ha during the past 40 years. Combined share of human and draught animals in India has reduced from 60.8 % in 1971-72 to 10.1 % during 2012-2013.

Off-late (2005-2010), innovations towards light weight and precision bullock drawn equipment like seed drills like drill plough, plough planter, 2,3,4 row seed drills, 6,9-row tractor drawn seed drills with inclined plate mechanism attracted the farmers and industrialists because of significant saving in seed by 20 % and fertilizer by 30% apart from increase in crop yields by 15-20%

The NATP mission mode project on dryland mechanization (2001-2004) helped in developing the complete package of crop based machinery at different centres which included crop-region combinations like Castor-Hyderabad, Maize-Arjia, Sorghum-Solapur, Rice-Varanasi, Fingermillet-Bangalore, Soyabean-Indore, Pearlmillet-Hissar, Cotton-Akola and Grounnut-Anantapur.. Products from this project like CRIDA 9-row multi crop planter, Castor sheller, Maize sheller, Groundnut digger, Cotton weeder, Ridger planter, Tractor drawn weeders, Orchard sprayer, Tree hole digger were upscaled through 14 Industries in 12 different States. It is observed that crop yields have increased by 12-35 % in addition to saving in crop production cost by 15-45 % in different cropping systems (Mayande, 2004). New model of workable farm machinery custom hiring centres backed by the local industries, met the crop specific machinery requirement of different cropping systems. This enabled easily availability of implements to the farmers at low rental cost. This intervention has in increasing the cropping intensity considerably. The same model was upscaled in the NICRA project in 100 KVKs in addition to 23 AICRPDA centres (Srinivasarao et al. 2013).

From above review, it was found that the mechanization play a vital role increasing the food production at the targeted rate. Now the following subheads deal with the specific machinery and methods of mechanization for different operations.

Animal drawn Tillage and seed bed preparation implements:

1. M.B. Plough
2. 3or 5 tyne cultivator
3. Disc harrows: They are equipped with 4-6 discs are widely used for secondary tillage. Output 0.12/ha
4. Leveller and land smootheners: Levelling blades, singh pata, ladders and patella harrows. Wide leveling plank helps in compacting soil aggregates in top layer which reduces the loss of soil moisture due to evaporation .(output 0.25-0.35ha/h)

Tractor drawn Implements:

1. M.B. plough
2. Disc plough
3. Shovel type cultivator
4. Duckfoot type cultivator
5. Disc harrows trailed or mounted type (tandom, off-set)
6. Ridger plough

Most of primary tillage implements such as m.b. plough, disc plough are two bottom type and are suitable for 25-35 hp size tractor. Three bottom implements are suitable for 35-45 hp size tractors. Field capacity varies from 0.2 to 0.3 ha/h for plough (for single bottom) and 0.4- 0.5 ha/h for disc harrows. Depth of operation is in the range of 100-150mm.

Levelling of field is mostly done by sing levelers or dumpers. In case the fields are leveled, the surface compaction is achieved by sing 2-3 M wide plank pulled by tractor.

The ridger bottoms mounted on a standard frame are mostly used for making ridges and furrows for planting of crops like potato and sugarcane. Single ridger bottom is used for making drains to remove excess rain water from the field. Field capacity of ridger varies from 0.4 to 0.5 ha/h.

Fig. 1: Animal drawn implements

Bed-furrow formers: Though animal drawn bed –furrow formers are available, their efficiency is very less. The tractor drawn be-furrow former is capable of forming alternate beds and channels. It saves 90 % of labour. These beds are suitable for planting crops like sorghum maize, cotton. This bed and furrow system is ideal for efficient irrigation management.

Rotavators and residue incorporation implements: Rotavators are best suitable for pulverization of the soil after primary tillage and also for incorporating the residue which is left in the ground as well as green residue if any grown on the surface of the soils. Field capacity of the rotavator is around 0.45 ha/hr. It is driven by the pto of the tractor. Blades with different shapes can be used in the rotavator. A 35-hp tractor can be sufficient enough to use these implements.

Fig.2.Rotavator

Planting and Planting Machinery:

The basic objective of sowing operation is to put the seed and fertilizer in rows at desired depth and seed to seed spacing, cover the seeds with soil and provide proper compaction over the seed. The recommended row to row spacing, seed rate, seed to seed spacing and depth of seed placement vary from crop to crop and for different agro-climatic conditions to achieve optimum yields.

Different types of furrow openers ate used to suit the varying soil conditions.

1. Double end pointed shovel
2. Pointed bar type
3. shoe type
4. Runner or sword

CRIDA has developed some of the implements with a special focus on Rainfed agriculture which are given below:

1. Plough Planter

Description: The planter is similar to the drill-plough operation except that it has an inclined plate mechanism to obtain uniform intra-row spacing which is crucial to minimize competition for water and nutrient. This unit is supported by two wheels; the pegged wheel at left, and the plain wheel at right. The metering plates are rotated by the power transmitted by drive wheel through shaft and bevel gears. The cells in the metering plate are cast to match the seed size and shape. The number of seed cells per plate is designed to obtain desired seed spacing within a row (Fig 2.).

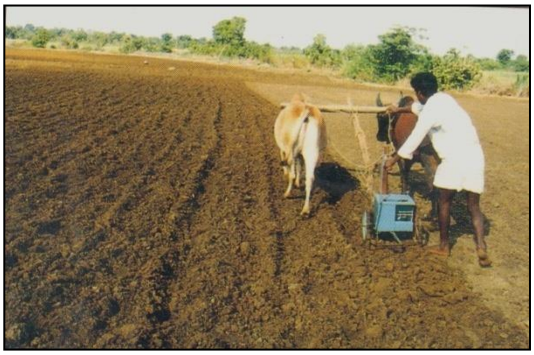


Fig 3. Plough planter

Advantages

- Optimum crop stand
- Suitability for all dry farming areas
- Compatible with country plough
- Precision seed metering and placement
- Uniform seed to seed distance
- Negligible maintenance cost
- Simultaneous application of seed and fertilizer

Two-row planter

Description: This is an upgraded model of plough planter with separate furrow openers for each row. It consists of a hopper box, rectangular frame, drive mechanism, guide wheels, two furrow openers, metering plates, seed tubes and other accessories. The inclined plate mechanism for seeding and agitator-orifice mechanism for fertilizing are used. The metering plates for groundnut, maize and other crops are designed to meet farmer's needs. The same metering plates can be used for single row, two row and four row planters. The gauge wheels with predetermined standard are used for depth adjustment. The row spacing is balanceable with lateral shifting of furrow openers on the frame (Fig.3). It is recommended to the regions where the average bullock height and draft power is less. It can also be used in hilly regions.

Fig.4.Two row planter

Advantages

- Two–row sowing and fertilizing at a time
- Row spacing and adjustable seed depth
- Uniform seed to seed distance
- Light weight
- Maintenance cost negligible
- Increased crop yield and profit

Suitability

It is suitable for all rainfed crops. A woman friendly machine and is useful to the regions where the average bullock height is less.

Three Row /Four-Row Planter

Description: The upgraded frame of earlier planter is made to accommodate three row or four row planter configuration. This planter (Fig.4) uses the inclined plate mechanism and is developed to meet the requirements of medium scale farmers. The depth of seeding is adjustable. The seed metering mechanism is based on inclined plate principle which is the same as for single or two row planters. It consists of a seed and fertilizer box which is mounted on a rectangular wheeled frame, guide wheels, drive mechanism, furrow openers, metering plates and seed tubes.

Fig. 5 Three row planter

Advantages

- Four- row sowing/fertilizing at a time
- Row spacing and adjustable
- Uniform seed to seed distance
- Adjustable seed depth
- Faster coverage
- Labour and seed saving
- Increased crop yield and profit

This planter was evaluated in the field by conducting various field studies and the data was given below in comparison to local method (Table. 1)

Table 1: Comparative performance of four row planter over local drill (Groundnut crop).

Seeding device	**Man (hrs/ha)**	**Bullock (hrs/ha)**	**Field coverage (ha/hr)**	**Plant stand/ha ('000)**	**Within row variation (CV %)**	**Yield (kg/ha)**
CRIDA planter	2.4	2.4	0.4	300	58	1875
Local drill	7.2	4.8	0.21	270	83	1562

Six-Row Planter

Description: There are many farmers in rainfed regions who own tractors. To suit their power availability six row planter (Fig. 5) was developed. The mechanism for seeding and fertilizing is similar to 4- row planter unit which was scaled up to match tractor powered tiller frame. The design consist of: hopper box for seed and fertilizer, drive mechanism, mounting frame, seed tubes and metering plates. The hopper box is mounted on available tiller frame. Row to row spacing can be maintained by adjusting the shanks on the frame as per the recommended spacing. A chain or wooden plank or a iron pipe can be fitted or hinged at the back to cover the furrows after seed and fertilizer placement if needed. The performance of six-row planter over traditional method is given in Table 2.

Fig. 6. **Six row planter**

Advantages

- Six-row sowing and fertilizing at a time
- Effective soil covering
- Uniform seed to seed distance
- Faster coverage
- Increased crop yield and profit
- Time saving by 80 % and labour saving
- 30 % saving in seed and fertilizer when compared to the conventional.

Table 2: Comparative Performance of CRIDA Planter over traditional method

Implement	**Area (ha)**	**Field capacity (ha/hr)**	**Plant stand (per ha)**	**Germination (%)**	**Yield (kg/ha)**	**Cost of sowing (Rs/ha)**
CRIDA castor planter	40	1.1	65000	88	430	600
Traditional method (behind country plough)	2	0.15	52000	79	350	2000

Nine-Row Planter for closed space crops

Description: This planter (fig. 6) is introduced to sow groundnut , soybean and other closely spaced crops with mechanical advantage and intercropping facility. The inclined disc plate seed metering mechanism will meet the precise seed to seed distance and maintains the recommended seed rate. The seed damage is negligible for the seeds like groundnut and other crops. The frame allows flexible row to row spacing because of which matching intercrops can be taken up.

Fig. 7.Nine row planter

Advantages

- Nine-row sowing at a time
- Suitable for all intercropping systems.
- Faster coverage
- Labour and seed saving
- Uniform seed to seed distance

Precision planter cum Herbicide applicator

Purpose: Precision planter cum herbicide applicator was developed to meet the timeliness and precision for sowing operation in all types of ecosystems with a special sfocus for undulated lands which are most commonly seen in rainfed ecosystem. Apart from sowing operation, the pre emergence herbicide can also be sprayed during the sowing operation which controls the weeds effectively.

Description: The machine mainly consists of rigid frame attached with individual seed cum fertilizer boxes on the top and spring loaded swinging type tynes with slit type furrow openers at the bottom to open the soil very narrowly in which the seed and fertilizer are dropped at the recommended spacing and depth (Fig.7). The seed is dropped with the help of a well controlled inclined plate seed metering mechanism and the fertilizer is dropped with a spring auger. The herbicide is stored in a tank mounted on the rigid frame. A pump with 150 w capacity gets the power from an inverter which in turn gets the power from the battery (Korwar et al., 2012). The nozzles mounted on a pipe behind the planter sprays the adjusted dose of herbicide all along the width of the planter. Specifications are given below:

Specifications

Fig. 8.Precision planter cum herbicide applicator

Advantages of technology

- High precision with considerable labour saving.
- It facilitates to apply the seed, fertilizer and pre-germination herbicide at a time.
- Reduce weed infestation.
- Faster field coverage enables completion of timely seeding.
- Precision placement of seed and fertilizer as their traveling distance is less
- It can do three operations at a time viz., seed sowing, fertilizer application and herbicide spraying.
    - It can work well in two way sloppy lands because of individually operated spring loaded tines.
- Separate seed and fertilizer boxes are available for inter-cropping.
- Separate seed metering plates are available for different crops.

Suitability

It is highly suitable to undulated lands and for the fields where reduced tillage is recommended. This can also be effectively used for precision sowing in all the soils.

Three row Ridger planter /BBF planter

Purpose: The ridger planter is specifically designed to meet the requirements of rainfed Agriculture in which the soil and water conservation plays a major role in crop production. This helps in in-situ rain water at on farm level during the season apart from sowing the seed and placing the fertilizer on the ridges at proper depth and placement. The broad furrows formed by the planter helps in conserving the rain water during the season and also works as drainage channels to drain out the excess water if heavy downpour occurs to save the crop during the initial drought and from excess flooding.

Description: It consists of a rigid frame with three point hitch mounting arrangement. Four ridgers were fixed on the frame with dimensions of 2500 x 750 mm. The ridger wings are adjustable to form a broad furrow of 35 cm to 65 cm wide according to crop geometry needs and the depth of conservation furrow can be made at 20-35 cm as per the soil conditions. The narrow headed furrow opener opens a small seed furrow on top of the ridge and the seed falls in to the furrow at proper depth based on the tractor hydraulic depth control. The depth of seed furrow varies 25-60 mm. The fertilizer will be delivered in to the furrow through spring auger mechanism (Srinivas et al., 2010). It forms three furrows during the tractor forward operation and the first ridger runs in the fourth furrow during its return to maintain the symmetry in formation of furrows and ridges based on the crop geometry requirement.

Fig. 9. Three row ridger planter cum BBF planter

Fig. 10. Three row ridger planter cum BBF planter

Advantages

1. It is used for in-situ water conservation
2. Precision seed and fertilizer placement on ridges along with conservation furrows.
3. It saves labour and energy by 80 % over convention method

Suitability

The ridger planter was successfully used for sowing the castor, groundnut, maize, sorghum and cotton. It can also be used as BBF planter where ever required with minor adjustment

II. Weeding and Interculture Equipment

Weeding is considered as most critical operation in rainfed agriculture. As the resources are limited, they compete with the main crop if not removed and effects the crop yields drastically. Apart from this, the limited moisture availability during the season reduces the number of optimum weeding days. To overcome this, CRIDA has developed improved manual, bullock drawn and tractor drawn weeders to match the different power sources and needs of farmers (Mayande et al., 2004). These tools create soil mulch apart from removal of weeds. These also proved in improving the efficiency of available power and make best use of available moisture while reducing the cost of operation.

1. Manual weeder

Description: This is manually pushed wheeled device followed by vertically adjustable sweep or blade mounted on a tool frame (fig.10). A long handle with wooden grip provides most comfort to men or women operating the tool. It is simple, low cost and easily adoptable equipment. It consists of 3 blades which can fixes as per the width of operation (fig.11)

Fig. 11 Weeding in vegetable crop

Fig. 12.. Close up view of Manual weeder

Advantages

- Low cost
- Compatible with operator
- Saving in time (72%)
- Saving in labour

2. Spike tooth type Manual Weeder

Description: The first model (fig. 12) of manual weeder consists of a spoked wheel (30cm diameter) made of either 16mm diameter rod or 24X3mm size mild steel flat. Two bent metal pipes of 18mm dia one ends are fixed to the wheel bushing using a small shaft on either side to function as a frame of the implement. Behind and close to the wheel, vertically adjustable shank of the weeding blade is fitted using bolt and nut to the frame .The other ends of the metal pipes are joined to a straight or crescent shape bent pipe to function as handle to the implement.

Fig. 12.. Spoked double ring weeder

Advantages

- These models are simple in design and could be easily replicated by rural artisans at low cost.
- Adoptable to wide range of vegetables as well as rainfed crops by replacing the soil working component ie blades.
- Suitable to both for women and men farmers alike in operation due to adjustable height in few inches to suite to stature of agricultural workers.
- Highly suitable to carry contract weeding job by agriculture based landless poor and small farmers during weeding season.

3. Bullock Drawn Weeder

A metal tool frame on which a single narrow shovel with shank is mounted at front center of the frame and at rear a blade matching to crop row spacing is mounted (fig. 13). A pipe beam is attached to frame, which is hitched by a pair of bullocks. The blades are either straight or V – shaped depending upon the field condition and weed intensity. Since all components are made of metal, it is long lasting with negligible maintenance. The tools, not only effective in removing the weeds but also creating a concave structure between the rows for capturing the rain water and also supporting the plants with soil mass. This requires one pair of bullock and one person.

Fig: 13: Bullock drawn weeder.

4. Tractor Drawn Weeder

Tractor drawn cultivator frame is used to mount different sizes of straight and V- blades depending on crop row spacing (fig. 14). This can cover 3-5 rows spacing at a time. This is most suitable in the field sown by tractor drawn planter. If the row to row spacing of crops is less, we can recommend to use the appropriate weeder along with tractor mounted with narrow width tyres (around 25 cm width) so that the plant damage can be avoided. Normally one to two weedings with this tool will create the weed free environment and the yields will also be improved.

Fig. 14.. Tractor drawn weeder

Advantages

- Faster coverage
- Efficient weed control
- Creating soil mulch
- Low cost of operation
- Effective earthing with good crop anchoring with adjacent soil

III. Spraying Equipment

Orchard Sprayer

Purpose: Orchard crops suffer from heavy attack of pest and diseases which cause about 20 to 40 per cent yield losses. This can be prevented by timely spraying of pesticides using orchard sprayer. Conventionally farmers used hydraulic sprayers in which liquid discharged from the spray nozzle does not reached the remote location in tree canopy. Identifying the problem, a air carrier sprayer is designed and developed to achieve the target spray for effective control of pest and diseases.

Description: It is a air carrier sprayer consist of the components like, blower assembly, pump, nozzle, nozzle adopter, spray liquid tank, power transmission system and mounting frame (fig. 15). The blower assembly consist of blower unit, inlet bell, outlet bell, diffuser and air outlets. Blower outlet can be adjusted according to the tree height. Axial flow blower is a turbo machine which transfer energy from rotating impeller to air. Sprayer produces fine drop lets (150 $x10^{-3}$ mm) of pesticide/insecticide to the target area so that it easily penetrates inside of stomata of leaves and hence increases pesticide use efficiency (Mayande et al., 2004) .

Field Performance of CRIDA Orchard Sprayer

The performance of air-carrier orchard sprayer was evaluated on 10 ha commercial mango orchard. The size and density of droplet is within the most desirable range for effective control of pests and diseases. The spray droplet distribution was uniform across the tree canopy locations. The spraying operation was done at a tractor speed of 2.39 km/hr. Spray application rate was 80l/ha. There is a saving of about 50 per cent in spray chemicals as the spray droplets are reaching target uniformly without much wastage. This covers area an 12-14 ha/day. The cost of operation per ha about 5 times low in air assisted sprayer. The comparative cost evaluation of conventional spraying and spraying with CRIDA orchard sprayer is given below. It indicates that the cost of spraying with CRIDA air assisted sprayer is about 20% of cost of conventional spraying.
Harvesters and combines:

Harvesting operation involves cutting/digging/picking/laying/gathering/curing/transport and stacking of the crops. In normal practice loss observed up to 5-10 % due to cutting and conveying losses. It can be reduced by using the precision harvesters and combines.
Types:
Reapers: Reapers are used for harvesting of crops mostly at ground level. It consist of crop-row-divider, cutter bar assembly, feeding and conveying devices. Reaper are classified on the basis of conveying of crops such as vertical conveying reaper, horizontal conveying reaper, bunch conveying reaper and reaper binders.
Strippers: Stripper is used for collection of matured seeds/pods from the plants or seed crops.
Diggers: For digging the groundnut and potato and other crops. Bullock drawn and tractordrawn diggers are available in the market.

Combine harvester: Various designs of combine harvester having 2-6 m long cutter bar are commercially available. The function of combine harvester is to cut, thresh, winnow and clean grain. It consists of header unit, threshing unit, separation unit, cleaning unit and grain collection . The function of the header is to cut and gather the crop and deliver it to the threshing cylinder. The crops are threshed between cylinder and concave due to impact and rubbing action. The material is shaken and tossed back by the straw rack so that grain moves and falls through the openings in the rack on to the clening show while the straw discharged at the rear. The grain is conveyed with collected in a grain tank.

PASTURE DEVELOPMENT AND INTENSIFICATION OF LIVESTOCK PRODUCTION IN WATERSHED AREAS

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Pasture development is the process of actively intervening the production of forage through resilient high yielding cultivars and their efficient utilization by livestock to maintain or improve production while sustaining the resources. Pastures not only provide the feed for the livestock production, but also improve soil fertility necessary to support the production of many crops and sustain the landscape. Efficient use of available pasture from the CPRs and PPRs in addition to crops residues available from agriculture is the central for profitable mixed crop–livestock farming in India. Livestock is an important livelihoods providing segment of traditional mixed farming systems and its contribution is substantial (about 23%) to the agricultural gross domestic product in the country. Traditional, resource-driven and labour intensive ruminant sector, which produces a multitude of services to subsistence agriculture in general and multi-faceted contributions to socioeconomic development of the watershed areas in particular. Increased human population growth and increasing urbanization, significantly driving the demand for animal foods thus necessitates the intensification of livestock production. This trend is also consistent with the fact that consumers have been obtaining an increasingly greater share of calories and protein from animal food products. Further, watersheds create opportunities for development of pastures through increased physical and economic access to groundwater.

PASTURE DEVELOPMENT STRATEGIES IN WATERSHED AREAS

The necessity for green fodder arises during rabi (post-rainy season) when the green fodder availability ceases. Hence, the idea of participatory evaluation of perennial and annual fodder species on farmers' fields was to introduce and sustain productivity of livestock even during rabi and summer. It aimed at increasing fodder supply through identifying and disseminating new varieties of fodder or dual-purpose crops in addition to conservation and efficient utilization of available feed and fodder resources. This involves participatory selection of fodders with an emphasis on genetically improved varieties and newer supplementary feed resources. Small fodder banks should be established with the surplus fodder from these cultivated fodders in addition to the collected fodder at monthly intervals from the common lands during rainy season. Encourage SHGs to cultivate fodder crops like maize, lucerne, cowpea, horsegram, sunhemp etc., on tank bed areas at the end of winter season. *Stylo hamata* should be sown on the available bunds in the village for strengthening of bund and also as leguminous fodder source for livestock**.**

Fodder production from arable lands: Non-availability of arable land has been severely affecting the area under fodder cultivation. As a result, the green fodder availability both qualitatively and quantitatively is much lower than requirement and leading to many nutritional deficiencies ranging from energy, protein to micronutrients like minerals and finally lowered production from livestock. Hence, each farmer should at least allocate 10% of their land for fodder production. The surplus fodder should be preserved as fodder bank in the form of hay or silage as fodder to the lean season requirements of the livestock in the village itself or for neighboring villages.

Fodder production from Tank beds**:** Due to silt deposition, tank beds are fertile and retain adequate moisture in the soil profile for cultivation of short season fodder crops like sorghum and maize fodder. Cholamarri village, Anantapur District has several tanks (45 tanks) but remained unfilled and was in the grip of severe drought during 2002 resulting in distress sale of livestock. This motivated the youth and organized the community for cultivation of fodder on the tank bed of Cholamarri village in early 2003. The farmers could produce substantial biomass worth Rs. 4.75 lakh by cultivating 184 ha of tank bed area and the fodder produced could support the livestock for entire summer (Ramana et al, 2007).

Perennial fodder production systems**:** The decreased availability of arable land in many areas and the need for more food from animals could encourage further integration of ruminants with trees in the form of silvopastoral (Forestry + Pasture + Livestock), agrisilvipastoral (Agriculture + Forestry + Pasture + Livestock) and hortipastoral systems (Orchards+ Pasture+ Livestock). Perennial deep rooted top feed fodder trees and bushes such as *Prosopis cineraria, Hardwickia binata, Albizia* species, *Zizyphus numularia, Colospermum mopane, Leucaena leucocephala, Azadirachta indica, Ailanthus excelsa, Acacia nilotica* trees and modified plants of cactus are highly drought tolerant and produce top fodder. Sowing of inter spaces of tree rows with drought tolerant grasses such as *Cenchrus ciliaris, Cenchrus setigerus* and *Lasirius sindicus etc*., further enhance forage production from these systems.

Alley Cropping**:** Alley cropping is a system in which food/fodder crops are grown in alleys formed by hedgerows of trees or shrubs (*Leucaena leucocephala, Gliricidia, Calliandra, Sesbania etc.*). The essential feature of the system is that hedgerows are cut back at planting and kept pruned during cropping to prevent shading and to reduce competition with food crops. The main objective of alley cropping is to get green and palatable fodder from hedgerows in the dry season and produce reasonable quantum of grain and stover in the alleys during the rainy/cropping season. This necessarily calls for cutting back (lopping) of hedge rows during the dry season fodder requirements. A welcome feature of alley cropping is its ability to produce green fodder even in years of severe drought. At Rajkot in 1985, rainfall received during the season was only 30% of normal precipitation. There was total failure of 3 legume crops tried in the system. In sole crop plots, production was limited to 0.5 – 1.7 t/ha of green fodder. However, in alley cropped plots, *Leucaena* hedgerows produced over 5t/ha of green fodder (Table 4). Similar was the experience at the Anantapur Centre in 1984. The cropping season rainfall was only 144 mm as against normal of 495 mm. All crops (groundnut, pigeonpea and sorghum) failed, and even stover production was severely affected. However, the *Leucaena* hedgerows produced 2t/ha of dry leaf material. Thus, alley cropping systems if properly planned, can remove a part of the risk faced by the small farmer in India.

Intensive irrigated fodder production systems**:** High yielding perennial (hybrid Napier varieties like CO-3, CO-4, APBN-1 etc.,) and multicut fodders varieties (MP Chari, SSG etc.,) could be choice of fodder crops under this system as it efficiently utilizes limited land resources and other agricultural inputs for getting maximum forage per unit area. It can be done where ever water is available and transported to deficit areas.

Intensive rainfed fodder production systems*:* Growing of two or more annual fodder crops as sole crops in mixed strands of legume (Stylo or cow pea or hedge Lucerne etc) and cereal fodder crops like sorghum, ragi in rainy season followed by berseem or Lucerne etc., in rabi season in order to increase nutritious forage production round the year

Hydroponic Fodder Production Systems: By this method, Fodder can be produced in large quantities within 8 days from seed to grass for all livestock. These include barley, oats, lucerne and rye grass. Growing grass fodder systems hydroponically is now becoming popular in drought prone areas. Hydroponic fodder production however requires large investment in the form of a commercial greenhouse, continuous supply of water and power. The state governments must encourage entrepreneurs to take up this activity in chronically drought prone areas. The department itself can establish some units to start with.

Increasing feed and fodder base at household level: *Azolla*, a blue green algae which is having more than 25 % CP and can be doubled in quantity within 5-7 days was encouraged to establish in pits at backyard depending on the number of milch animals of the farmer (Table 5). Large-scale production trials were taken up across the cluster villages to demonstrate the *Azolla* as alternative nutritious supplementary green fodder for livestock. Azolla yield is much more than the perennial fodder varieties like APBN-1/CO-3 etc and is around 1000 MT per hectare at the rate of 300 gm./sq.m/day even after taking into account wastage space between two Azolla beds. It is more nutritious than the leguminous fodder crops like lucerne, cowpea , berseem etc and can be fed to cattle, buffalo, sheep, goat and also poultry after mixing with concentrate mixture at the ratio of 1:1.

Fodder production through contingency plan*:* During early season drought, **s**hort to medium duration cultivated fodder crops like sorghum (Pusa Chari Hybrid-106 (HC-106), CSH 14, CSH 23 (SPH-1290), CSV 17 etc) or Bajra (CO 8, TNSC 1, APFB 2, Avika Bajra Chari (AVKB 19)etc.,) or Maize (African tall, APFM 8 etc.,) which are ready for cutting by 50-60 days and can be sown immediately after rains under rainfed conditions in arable lands during kharif season. If a normal rain takes place in later part of the year, rabi crops like Berseem (Wardan, UPB 110, etc varieties), Lucerne (CO-1, LLC 3, RL 88, etc.) can be grown as second crop with the available moisture during winter. In waste lands fodder varieties like Bundel Anjan 3, CO1 (Neela Kalu Kattai), *Stylosanthes scabra*, etc. can be sown for fodder production. Under irrigated conditions, Intensive forage sequences recommended for Southern region may be followed

STRATEGIES FOR INTENSIFICATION OF LIVESTOCK PRODUCTIVITY Feeding and nutrition are the major constraints to animal production in rural areas. Animal production within the mixed farming systems is predominantly dependent on the efficiency of use of the available coarse crop residues and grazing resources. The level of efficiency will dictate to a very large extent improved per animal performance and increased productivity from different livestock resources. Primarily four categories of feed and fodder resources exists in rural areas

a. Pastures on mostly grazing lands— these include native and improved grasses, herbaceous legumes and multi-purpose trees

b. Crop residues — these include such examples as coarse cereal straws, ground nut haulms and sorghum stover (the dried stalks and leaves of the crop)

c. Agro-industrial by-products (AIBP) — good examples are cereal bran, ground nut cake and cotton seed cake and

d. Non-conventional feed resources (NCFR) — this category includes diverse feeds that are not traditionally used in animal feeding; examples are palm press fibre, spent brewer's grains, sugar cane bagasse (the residue from crushing the canes) and sweet sorghum stalks.

The fibrous crop residues (FCRs), mostly sorghum, millet, paddy and maize straws, ground nut haulms and dry grass form the basis of feeding systems for ruminants in drylands. The green feeds available were weeds, forest grass, tree leaves, and cultivated forages such as napier, lucerne, and maize. Complementary to FCRs are those crop residues that have higher protein content, and can therefore be used judiciously to improve the overall diet. This category includes a variety of oilseed cakes and meals, such as ground nut cake, palm kernel cake, cottonseed cake, coconut cake and brans, damaged grains, and chuni (broken pulses with kernels) which are often used as dietary supplements.

Feeds are generally plentiful for use by various animals during rainy season, but chronic feed deficits exist during winter and rainy season in drylands. In order to ensure nutritional efficiency, priorities for use of the available feeds are important. With ruminant production systems, there are three categories: extensive systems; systems combining arable cropping (roadside, communal and arable grazing systems, tethering, and cut-and-carry feeding); and systems integrated with tree cropping (silvopastoral and hortipastoral). There will however, be increasing intensification and a shift within systems, especially from extensive to systems combining arable cropping, induced by population growth. The principal aim should therefore be improved feeding and nutrition, maximum use of the available feed resources, notably crop residues and low quality roughages, and various leguminous forages as supplements.

Management issues in rangeland-based systems: It is estimated that 60% and 5% of the total feed requirements of small ruminants and large ruminants respectively are met by the rangelands (Devendra et al., 2000). There are three major concerns about rangeland-based systems

- Appropriate strategies to use of common property resources (CPRs): As there is no control over the number of animals allowed to be grazed, causing severe damage on the regrowth of no. of herbaceous species in grazing lands (Table 2). Thus causing severe impact not only on herbage availability from CPRs but on the productivity of livestock
- Communal management of these lands: CPRs need to be reseeded with high producing legume and non-legume fodder varieties (Table 3) at every 2-3 years intervals as a community activity. Further, grazing restriction till the fodder grows to a proper stage as community decision would improve the carrying capacity of CPRs.
- Lean season feeding: It has severe impact on the productivity of livestock as the herbage availability comes to all most negligible during summer months. Hence, supplemental feeding becomes essential to maintain optimum productivity in livestock

Efficient feed and fodder utilization Strategies: Cost of feeding accounts for 60-70% of the total cost of production in any livestock production systems. The limited purchasing power forces farmers to manage livestock by carefully adjusting the resources and production factors of their farms. Hence, capacity development of the stakeholders about feeds and their efficient use should be imparted with self-reliance and on farm demonstration of different mixed farming systems. Potential promotion of linkages between rural and peri-urban areas in the use of production inputs, intensification, nutrient flows, and marketing of produce that is consistent with environmental integrity should be created. The final objective should be the development of sustainable all year round feeding systems that increase feed supplies to overcome shortages, seasonal constraints and expanded production systems. Examples of such approaches include food–feed cropping (Devendra et al., 2001), forage (para grass) production on rice bunds and under trees and alley cropping.

Based on the use of crop residues, combining or utilizing available resources at rumen level, e.g., supplementation with critical nutrients (bagasse/cakes/bran/minerals) or extracting more from existing resources by physical means (chopping/soaking etc.) and chemically treating (urea molasses treatment of straw) would help in meeting nutritional requirement of livestock and efficient utilization of available resources. Other technologies, such as modified cropping patterns (ley farming/perennial fodder cultivation in arable lands/Lucerne and horse gram cultivation in winter etc.,) might also contribute to increased feed availability and/or quality. Feeding interventions, such as use of concentrates, Leucaena leaves, urea-treated straw with limited concentrates, could benefit farms with crossbred cows. Tree leaf-feeding is feasible for farmers with access to tree leaves and slack labour, such as for tribal and landless farmers. However, urea-treated straw with limited concentrate supplementation may not be suitable for non-descript cows and/or landless farmers due to limitation of straw availability and low milk yield of the cows. The feed deficiencies can be corrected by adjusting the feeding practices. Feeding additional concentrates, such as bran plus urea/cakes, can compensate for both the TDN and CP deficiencies in all breeds. Urea treatment of straws can help to correct the CP deficiencies, particularly in the monsoon season and in zones where high amounts of straws are fed. The CP deficiencies in the dry season are too high to be corrected by feeding leguminous tree leaves/ cakes.

Health management:

Diseases reduce the production potential of livestock. There are a number of diseases such as foot and mouth disease (FMD), hemorrhagic septicemia (HS), black quarter (BQ), entero toxaemia (ET), blue tongue, peste des petitis ruminitis (PPR), sheep pox, pneumonia, calf scores, mastitis, brucellosis, tuberculosis etc., affect livestock production and cause enormous economic losses. An estimated livestock output worth more than Rs 50 billion is lost annually due to various diseases. Most of the diseases affecting livestock in general and small ruminants in particular were due to lack of awareness, supply constraints in availability of vaccines and deworming drugs and insufficient man power with animal husbandry department to tackle the problems in time. Hence, animal health camps and prophylactic vaccination campaigns needs to be conducted at regular intervals to create awareness among farmers regarding the adoption of better livestock health management practices and containment of endemic diseases. Capacity building of local youth as service providers and participatory involvement of stakeholders while streamlining the animal health services as community activity would better facilitate in this process. Further, developing linkages with animal husbandry and other rural developmental departments would help in promoting the innovative livestock health management practices and providing sustainable rural livelihoods.

Reproduction management:

Increased prevalence of reproductive problems especially in high yielders and crossbreds is becoming a potential threat to the profitability of livestock farming by bringing down the production and income. Reproductive problems like delayed onset of oestrus, anoestrus, abortion, failure of conception etc are more common in buffaloes and crossbred cows under village conditions because of deficiency of micro minerals and some fat-soluble vitamins due to under feeding and or sole feeding of roughages. The other reproductive disease conditions like prolapse, retained placenta and metritis in the early postpartum period, a sequel to the nutritional stress in the lactating animals will reduce the production efficiency and reproductive performance. Supplementation of top fodder, concentrate mixture, mineral mixture, vitamin premix, and synchronization of oestrus etc., in addition to the individual animal management practices like timely identification of oestrus and insemination will improve the life time productivity of livestock. In case of small ruminants, changing the breeding ram for every 2-3 years (ram lamb exchange from other district herd) or artificial insemination with proven breed semen will help in enhancing the productivity.

Breed improvement:

Cross breeding of indigenous dairy cattle and upgradation of buffaloes had tremendously improved the productivity of animals, augmenting milk production. This is an important development option for landless farmers *(*Patil and Udo, 2006). A case study of Gujarat farmers show that remote farmers with local cows under the assumed price conditions hardly benefit from feeding concentrates, however, farmers with better market access and crossbred cows may consider feeding of concentrates in all situations. This explains farmers' preference for crossbreds in conditions with a favorable milk/concentrate price ratio, and it illustrates the limitations of concentrate feeding where concentrates/milk ratios are unfavorable, due to prices, management and/or genetic potential.

Technology transfer issues:

Livestock development is affected by many factors, such as farmers' access to resources, availability of knowledge and skills, consumer demands, national and international policies and social aspects. As a result, a large number of technologies (Table 5) are not readily accepted by the stake holder. Indeed, low adoption rates of technologies by stake holders are at least partly due to differences among farmers in terms of their access to resources, such as land, water, livestock and credit and personal values, status, food habits, and to cultural barriers. Many development programmes lack a proper perspective on the local resources, the environment and the needs of the farmers (Van den Ban and Hawkins, 1988; Chambers *et al*., 1989; Röling, 1996). What is useful for one farmer may not be useful for another, and certain technologies can even have negative trade-offs. Hence, basket of technological options with site specific and problem targeted should be made available to the stake holders, so as to choose according to their resources and environmental conditions.

Policy issues:

There exist major opportunities for the use of improved policy issues. These relate to institutions, services and delivery systems that affect animal production systems. In view of the bio-physical focus among the ruminant production systems, despite the economic benefits of added value, integrated systems with trees remain underestimated. Policy interventions are required to stimulate more integration with animals, for example through tax incentives, and also encourage increased private sector investments. The market chain involves rural, urban and international markets. In an era of globalization and improved marketing, presently, the rural–urban market linkages are weak, and closer integration is very necessary. Rural markets are especially important to rural communities and their households, and are also used for the sale of live animals for slaughter in the urban areas. Appropriate policies are required to provide good links between rural and urban markets, infrastructural and communication facilities that must be in place, as also collection and processing centres. Horizontal and vertical coordination and the development of cooperatives are also important initiatives. Because of the greater market demand for animal products in urban areas, such facilities become more essential. Urban markets are the outlets for exports, and promote international trade, and have opportunities for foreign direct investments and growth benefits (Otte et al., 2005).

CONCLUSION

Capacity building and participatory involvement of stakeholders while streamlining the animal health services as community activity would better facilitate containment of animal diseases in rural areas. Animal health camps and on-farm trials creates awareness among farmers regarding availability of basket of options for productivity enhancement in livestock. Further, use of technological advances along with appropriate management practices would help in providing healthier livelihoods and income from large and small ruminants. Improved cultivars along with efficient fodder utilization practices and integrated systems would augment fodder resources substantially in rural areas and reduces distress sale of animals during lean season. Improvement in services and delivery system along with creation of market linkages and better polices would drive the stake holder for adoption of latest technologies. Thus results in higher productivity, more stable livelihoods and income.

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Indices for Weather based Insurance

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1. Introduction

Agriculture contributes to 14% of the Indian GDP and supports the livelihood of two-thirds of the population.In India around 61 % of cultivable area is under rainfed cultivation, which is most vulnerable to vagaries of weather. Despite tremendous technological developments, vagaries of weather continue to plague the agriculture production. Any shortfall in agricultural production will have its cascading effect on the economy of the country. In recent times, climate change and variability are confounding the troubles already faced by Indian agriculture and the farming community. Loss in crop production and farm income due to unexpected weather hazards is beyond the carrying capacity of resource poor farmers of the country. With the growing commercialization of agriculture, the magnitude of crop loss due to unfavourable weather hazards is increasing leading to suicides of farmers. The State and National governments on their part are coming to the rescue of farming community by implementing various relief measures like reduction or suspension of land revenue taxes, loan waiving, relief from calamity relief fund etc.

As agricultural yields are highly variable due to vagaries of weather, crops have to be covered under agriculture insurance for compensating yield losses and reduce the poverty of farming community. In India, since 1972 agricultural insurance has evolved as an adaptation strategy to mitigate / manage weather related risks in agriculture. However, experiences with traditional agricultural insurance schemes have shown that this approach is not often suitable in developing countries.In recent years, weather index insurance contracts in agriculture have emerged as an alternative to traditional agricultural (or crop) insurance.

2. Risks in agriculture

Though risks in agriculture are numerous, weather risks, biological risks and price risks are the most predominant ones in agriculture (Hess et al.,2002;Bryla et al.,2003 and Skees et al.,2005). Agricultural risks can range from independent (like localized hail storms) to highly correlated or covariant (example: Price risks or widespread drought). Weather risks are broadly of two types viz. sudden, unforeseen events (thunder storms) and cumulative events occurring over extended period (example: drought). The adverse impacts of either of these two types vary according to the crop, crop variety and time of occurrence of the event. Some of the weather risks in agriculture are: Drought, excess rainfall or floods, high temperature, low temperature events like frost and freeze, high winds and hail storms etc.

2.1 Weather risk management

Farmers in developing countries have always been exposed to weather risks, and for a long time have developed a variety of weather risk management (WRM) techniques for reducing, mitigating and coping with weather risks (Dercon, 2002). Traditional risk management covers actions taken both before (ex-ante) and after (ex-post) the risky event occurs (Siegel and Alwang, 1999). Mitigation,coping and transfer are the major strategies in agricultural risk management.

3. Agricultural insurance

Agricultural insurance is a means of protecting the farmers against financial losses suffered due to unforeseen and non-preventable weather risks (AIC, 2008). It is a financial mechanism in which loss of crop yields suffered by farmers in a particular area are borne by farmers in other areas (as premiums), so that burden of loss can be distributed among a large number of farmers. In agricultural insurance the reserves of premiums accumulated in good years are used to pay the indemnities in bad years.

3.1Crop insurance products

Crop insurance products can broadly be classified into two major groups: Indemnity-based insurance and Index insurance.

I.Indemnity-Based Crop Insurance:

There are two main products in the Indemnity - based crop insurance. They are:

***(i) Damage-based indemnity insurance* (or *named peril crop insurance*):** Damage-based indemnity insurance is the crop insurance in which the insurance claim is calculated by measuring the percentage damage in the field soon after the occurrence of the damage. The sum insured may be based on production costs or on the expected revenue. Where damage cannot be measured accurately and immediately after the loss, the assessment may be deferred until the end of the crop season. Damage-based indemnity insurance is best known for hail, frost, heat wave, deficit or excess rainfall.

(ii)*Yield-based crop insurance* (or *Multiple Peril Crop Insurance, MPCI*): Yield-based crop insurance is coverage in which insured crop yield is established as a percentage of the farmer's historical average yield. The insured yield is mostly between 50 to 70 percent of the average farm yield. If the realized yield is less than the insured yield, an indemnity (the amount payable by the insurer to the insured) is paid equal to the difference between the actual yield and the insured yield, multiplied by a pre-agreed value. Yield-based crop insurance protects against multiple perils, meaning that it covers many different causes of yield loss (it is generally difficult to determine the exact cause of yield loss).

II. Index-Based Crop Insurance:

Index based insurance products for agriculture represents an attractive alternative for managing weather risks. Currently there are two types of index insurance products viz., Area yield index insurance and weather index insurance (WII), as distinguished by Skees(2003)

(i) ***Area yield index insurance*:** In Area yield index insurance, the indemnity is based on the realized average yield of an area such as a block or district, not the actual yield of the insured farmer. The insured yield is established as a percentage of the average yield for the areaof the whole village or group of villages. An indemnity is paid if the realized yield for the area is less than the insured yield regardless of the actual yield on a policyholder's farm. This type of index insurance requires historical yield data of the area.

(ii)***Weather Index Insurance (WII)*:** In WII, the indemnity is based on realization of a specific weather parameter measured over a pre-specified period of time at a particular weather station. The insurance was structured to protect against realization of either very high or very low indices that are expected to cause crop losses. For example, the insurance can be structured to protect against either too much or too little rainfall. An indemnity is paid whenever the realized value of the index exceeds a pre-specified threshold (when protecting against excess rainfall) or when the index is less than the threshold (when protecting against deficit rainfall). The indemnity is calculated based on a pre-agreed sum insured per unit of the index.

Skees(2003) argues that weather based indices are usually preferred to yield based indices,as in developing countries the quality of historical weather datais better than quality of yield data, and weather events, especially deficit or excess rainfall, are the major sources of crop losses in many regions.

4.Main features of Weather index-based insurance

The essential feature of WII is that the insurance contract responds to an objective parameter (e.g. rainfall or temperature) at a referred weather station during an agreed time period. The parameters of the contract are set so as to correlate, as accurately as possible, with the loss of yield of a specific crop suffered by the policyholder. All policyholders within a defined area receive payouts based on the same contract and measurement at the same weather station, eliminating the need for in-field assessment of yield loss.

In order for the underlying index to be a sound proxy for loss, it has to be based upon an objective measure (for example, rainfall, wind speed, temperature) that exhibits a strong correlation with the variable of interest (in this case, crop yield). Additionally, the weather variable that can form an index must satisfy the properties: i) Observable and easilymeasured, ii) Objective, iii) Transparent, iv) Independently verifiable, v) Reported in a timely manner, vi) Consistent over time and vii) Experienced over a wide area.

Important features of a WII contract are:

- A specific meteorological station is named as the *reference weather station*.
- A strike or *trigger* weather measurement is set (e.g. cumulative rainfall), at which the contract starts to pay out.
- A *lump sum* or an *incremental payment* is made (e.g. Rupees per mm of rainfall above or below the trigger).
- A *limit or exit* of the measured parameter is set (e.g. cumulative rainfall), at which a maximum payment is made.
- The *period of insurance* is stated in the contract and coincides with the crop growth period; it may be divided into *phases* (Maximum three), with each phase having its own triggers, increment and limit.

4.1 Advantages and disadvantages of weather index based insurance

Though the development and application of weather index insurance (WII) is still in its early stages, the advantages and disadvantages of WII were well-documented (World Bank, 2005;USAID, 2006; IFAD and WFP 2010). Some of the relative merits and demerits of the WII are presented below (IFAD, 2010).

Advantages of WII:

In comparison to the traditional damage based agricultural insurance, WII has advantages on the following aspects:

Transparency:An Index Insurance contract usually allows the policyholder to have direct access to the information on which the payouts will be calculated. Hence, WII is more transparent to the clienteles.

No on-farm loss adjustment:This is the primary advantage of index insurance, as on-farm loss adjustment is quite complex and costly.

Lack of adverse selection: "Adverse selection" occurs when potential insured parties have hidden information about their risk exposure that is not available to the insurer, who then becomes more likely to erroneously assess the risk of the insured. As a result traditional insurance encourages high-risk producers to insure, while risk and premium are calculated on the average producer. However, in Weather Index based insurance all the insured farmers within the defined area have the same insurance payout conditions, regardless of their specific risk exposure (USAID, 2006). Hence, insurers and clients benefit from reduced adverse selection.

Lack of moral hazard: "Moral hazard" refers to a phenomenon that the insured person's optimal decision may change as a result of purchasing the insurance, because the insurance contract reduces the loss associated with the insured event. Such changes in behaviour will normally increase the probability of the insured event occurring or increased severity of loss (Ashan et al., 1982). In WII, individual farmers who are trying to influence claims will not get any benefit and all farmers in the defined area are treated equally for payment of pay outs or indemnity.

Addresses correlated risks: Index insurance works best where there are correlated and widespread risks like drought. In traditional insurance, perils such as drought are challenging to insure.

Low operational and transaction costs: Index insurance requires limited individual underwriting (Client assessment). It can be distributed, or sold out and claims can be settled, at relatively lower cost than in traditional insurance.

Rapid payout:Measurement of meteorological data from a reference weather station, with no field loss adjustment, allows for providing rapid payouts to the clients in WII than in traditional agricultural insurance.

Despite the merits of weather index based insurance mentioned above, acceptance WII by farmers is of slow due to the following disadvantages:

Disadvantages of WII:

Basis risk:Basis risk is a key constraint in WII and it has suppressed the growth of WII. Basis risk is the difference between the actual crop yield at farm unit level and yield projected by the weather index. As a result of basis risk a farmer experiencing yield loss, may not receive a payout, and a payout may be triggered without any loss being experienced. Index insurance works best where losses are homogeneous in the defined area and highly correlated with the indexed peril. Diaz Nieto et al.(2006) mentioned three important types of basis risk, which are mentioned as under:

- ***Spatial or geographical basis risk:*** A geographical basis risk represents the risk that result from the difference between weather patterns at reference weather stations and the locations of farmers. Local variations in the weather (e.g. rainfall) within the area surrounding a reference weather station are responsible for geographical basis risk.
- ***Temporal basis risk:***It results from **i**nter-annual variations in crop phases, and the insurance phases are not temporally aligned with the intended crop growth stage.
- ***Product or crop specific basis risk:***It means that the sensitivity to weather events varies across crop types due to different crop characteristics. Crop losses can be caused by many factors including weather. Where there is no clear-cut and strong relationship between yield loss and the indexed weather peril, risk can be high. WII is most likely to work, for rainfed crops and at severe levels of the risk event, when losses may be more widespread and homogeneous.

Limited perils: WII normally covers only one, or sometimes two, weather perils. Although this reduces the cost of operation compared to the multi peril crop insurance (MPCI), the product may not provide broader and enough coverage to more number of weather risks that are affecting the crop loss.

Replication or Scalability: The triggers, limits and increments of a specific product that were worked out for a reference weather station will not be valid for another reference weather station and they need to be adjusted to reflect the weather parameters of that new weather station. Different product designs are required for different crops (or at least generic crop types).

Requirement of Technical expertise:WII requires considerable technical work in its implementation and sustaining. Technical capacity and expertise in agro-meteorology are required, particularly during the initial design phase for new products, and also in operationalising the products.

Lack of weather data: WII depends on the availability of quality weather data, which drastically vary from country to country. In developing countries, the shortage of historical and real-time weather data is often a major hurdle for design of WII products.

4.2 Collection of weather data for weather index based insurance

The data used for constructing the weather indices should satisfy quality requirements, including:

- Reliable and trustworthy ongoing daily collection and reporting procedures;
- Periodic checks and quality control;
- An independent source of data for verification (e.g. surrounding weather stations).

The general criteria for weather data requirements for WII applications (ISMEA, 2006) are specified as follows:

- At least 20 years of historical weather data;
- Limited missing values and out-of-range values (preferably less than 3 per cent missing data from the entire dataset);
- Availability of a nearby weather station for fall-back verification purposes;
- Consistency of observation techniques – either manual or automated;
- Limited changes in instrumentation/orientation/configuration;
- Integrity of weather-data recording procedure;
- Little potential for measurement tampering.

Beyond the quality of data, definition of the boundaries of the area(s) covered by the weather station(s) is critical, so that WII contracts can be written for specific areas tied to a specific weather station. A general rule of thumb is to consider a specific WII contract marketable within a 20-km radius of the weather station; but in many cases the applicable area is smaller. The more the terrain varies, the more the acceptable distance from a station decreases.

Modalities must be defined for weather data collection and dissemination during the contract coverage period. Insurance and reinsurance industries tend to require the use of automated weather stations and availability of fallback verification measurements from nearby stations with comparable weather patterns. Manual measurement of weather variables (e.g. through manual rain gauges) is usually not regarded as sufficiently reliable and secure. As a result, low-cost, automatic weather stations are being implemented in some WII initiatives. Even if manual observation of weather risks are taken, all weather parameters should be taken at the same time for controlling hampering of weather data, as various weather variables are linked by specific relationship.

4.3 Collection of agricultural data

Agricultural information is the second most important component of the contract design equation of WII. The data on productivity (yield), and description of the agricultural production practices carried out in the areas is also necessary. Unfortunately, the availability of quality yield-data series of adequate length and at the appropriate spatial level is a major problem. However, lack of quality yield data does not pose as serious a problem as lack of good weather data, since it is still possible to find alternative approaches to estimate yield data. One possibility is to simulate synthetic yield-data series through crop growth simulation models. Information such as crop varieties adopted, planting dates, management practices, related costs, risk profiles, historical recollection of the impact of the peril, and the most sensitive phases in crop life are essential in designing a meaningful WII contract.

4.4 Technical issues concerned to thedesign of weather index

Diaz Nieto et al.(2006) mentioned the following technical requirements for the index insurance scheme to have a positive impact on farmers' livelihood.

- The weather index should be easily understood and well defined;
- It should takeaccount of crop sensitivity at different growth stages;
- It should take account of the relationship between soil texture and rainfall effectiveness;
- It should define a protocol that reflects the actual planting date as closely as possible;
- It should ensure that the insured pays the price of spatial variation in risk;
- It should enable accurate estimation of the probability of the risk event.
- Reliability of the institution providing the weather data;
- Transparency and absence of corruption;
- Adaptation of the product to farmers' needs;
- Communication and training for farmers and field staff.

5. Design and validation of weather index based insurance products

The objective of the contract design is to define a structure that effectively captures the relationship between the weather variable and the potential crop loss and to select the index that is most effective in providing payouts when losses are experienced, eliminating basis risk as far as possible. The set of possible index combinations is unlimited, and numerous structures have been developed in the relatively short history of WII. Weather index-based contracts can be classified according to many different parameters (Table 1).

Table 1 Examples of parameters used for WII contracts

Contract parameter	**Options**
Triggering values of weather variable	Cumulative
	Average
	Maximum
	Minimum
Period covered by index	Entire life cycle of crop
	Fractions of crop life cycle
Number of phases into which covered period is divided	Usually 1 to 3 phases
Start of coverage period	Fixed
	Dynamic
Payout structure	Incremental
	Lump sum (single value payout)

One of the most commonly adopted structures is that of a continuous payout triggered and limited by a cumulative measure of the weather variable (e.g. rainfall) for each of the different crop growth stages, is discussed as follows.

Payout parameters in a WII contract – an example

Using the drought coverage case represented in Figure 1 as an example, the parameters that characterize an incremental payout structure can be defined as follows:

- ***Trigger:***Threshold above or below which payouts are due. In this example, payments are due when the calculated value of the index is below the trigger level (300 mm).
- ***Limit:***Threshold above or below which no additional incremental payout will be applied. In this example, the maximum payout is paid if the calculated value of the index is equal to or below the exit threshold (100 mm).
- ***Tick:***Incremental payout value per unit deviation increase from the trigger. With a maximum payout (the insured sum) of ₹12000, a trigger of 300 mm and an exit of 100 mm, the monetary value of each deficit mm of rainfall below the trigger is: ₹12000 / (300 mm-100 mm) or ₹60 per mm

Contract design is probably the most challenging part of developing a pilot program and local insurance companies, usually have no expertise to carry out the design. WII pilot developed with the involvement of specialists of research organization is encouraged.

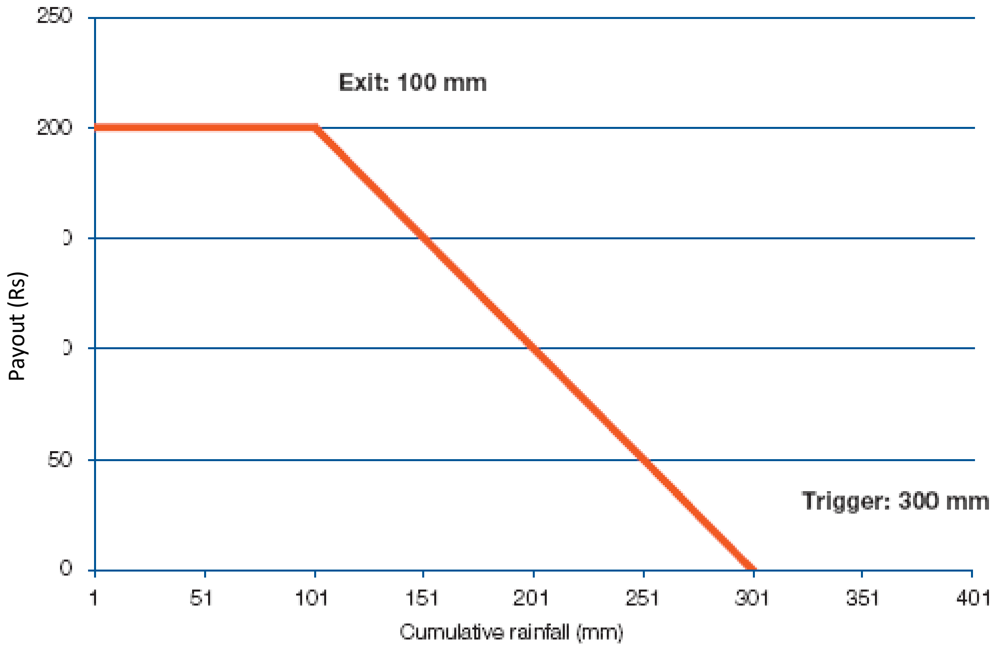

Fig. 1 Payout structure of a WII drought contract

5.1 Weather Index Insurance: Indian Experience

An impressive repository of historical weather data, high dependency of country's agricultural production on rains and huge pool of scientific resources place India in the forefront of piloting of weather index insurance.

Pilot Weather Risk based Crop Insurance

The first pilot on weather index insurance in India and also in the developing world was carried out in 2003 by ICICI Lombard. This which was followed by pilots on weather risk index-based insurance by Agriculture Insurance Company of India (AIC) and IFFCO-Tokio, both during 2004. Building on the existing weather risk insurance products, the Government asked AIC in 2007 to design the Weather risk-Based Crop Insurance Scheme (WBCIS) as a pilot. An example of the product for multi-phase deficit rainfall and consecutive dry days is presented in Table 2.

Table 2 Illustration of WBCIS in *Kharif* groundnut at Mahaboobnagar, Telangana during 2004

		Crop: Groundnut	Season: *Kharif*		
			PHASE-I	PHASE - II	PHASE – III
1 A.	Rainfall Volume	PERIOD	21st June to 15th July	16th July to 15th Aug	16th Aug to 30th Sept
		TRIGGER I (<)	80 mm	160 mm	80 mm
		TRIGGER II (<)	40 mm	80 mm	40 mm
		EXIT	20	30	20
		RATE I (Rs./ mm)	25	25	25
		RATE II (Rs./ mm)	75	60	75
		Max. Payout (Rs.)	2500	5000	2500
		TOTAL PAYOUT (Rs.)	10000		
1 B.	Rainfall Distribution (Consecutive Dry Days)	PERIOD	1st July to 31st August		
		TRIGGER DAYS (>=)	20	25	30
		PAYOUT (Rs.)	1500	3000	5000
			TOTAL PAYOUT (Rs.)	5000	
Rainfall of less than	2.5	mm in a day shall not be considered as a rainy day; and multiple payouts considered			
		Max. Payout (Rs.)	15000		

6. CRIDA's contribution to WII

AIC has signed a MOU for generating weather indices for three crops viz., wheat, groundnut and cotton with CRIDA, having a network project All India Coordinated Research Project on Agrometeorology (AICRPAM) generating crop and weather data for more than 20 years in important crops at 25 of cooperating centre and having huge inter disciplinary scientific staff strength. Scientists of CRIDA identified critical phenological stages for temperature in wheat and for rainfall in groundnut and cotton. Thresholds of average maximum and minimum temperature in critical phenological stages of wheat were worked out in different varieties of wheat at eight cooperating centres for generating weather indices (Venkateswarlu et al. 2013). Likewise, thresholds of cumulative rainfall in critical stages of groundnut at four centres and cotton at three centres were worked out to serve as indices at the respective centres (Rao et al. 2013). Thresholds of weather parameters in wheat and groundnut are illustrated in Tables 3 and 4. These thresholds serve as triggers and temperature above these limits cause yield reduction in wheat at respective centres. Likewise rainfall below these limits will cause reduction in yield of groundnut at respective centres / districts.

Table 3 Thresholds of temperature at critical stages for obtaining optimum wheat yield at different locations

Centre	Maximum temperature (°C)	Minimum temperature (°C)	Stage
Kanpur	25.6 - 27.5	9.9 - 11.3	Milk
Faizabad	32.0	14.0	Dough
Anand	26.9 - 28.1	9.9 - 11.0	Milk
Ranichauri	13.8 - 16.3	2.9 - 5.3	Jointing to Anthesis
Raipur	29.7 - 31.7	15.1 - 15.8	Milk
Ludhiana	20.0 - 31.3	6.4 - 15.4	Booting to Maturity
Udaipur	28.4	10.8	Dough
Ranchi	25.1 - 27.2	8.7 - 9.8	Milk

Thresholds of Rainfall in critical stages for obtaining optimum yield of groundnut at Anantapur, Anantapur

Table 4 district, Bangalore and Anand

Station/District	Variety	Rainfall (mm)	Critical Stage
Anantapur	TMV-2	191.4	Pod initiation to Maturity
	Robut 33-1	224.3	Pod initiation to Maturity
Anantapur District	-	171.0	Pod initiation to Maturity
Bangalore	DH 3-30	118.7	Pod initiation to pod filling
	Robut 33-1	108.7	Pod initiation to pod filling
	TMV-2	155.7	Pod initiation to pod formation
	JL -24	138.4	Pod initiation to pod formation
	K-134	122.3	Pod initiation to pod formation
Anand	Robut 33-1	318.8	First seed to harvest
	GG-2	469.0	First seed to harvest
	Gaug-10	174.3	First seed to harvest

Other indices like cumulative dry days, water requirement satisfaction indices in groundnut and cotton were worked out. Efforts are on to develop weather indices in some more crops and horticulture systems.

7. Conclusions

Weather risk is assuming importance in agriculture due to climate change. Agriculture insurance has been identified as one of the risk management strategy for adapting to the climate change. In contrast to the traditional crop insurance scheme, weather index based insurance is gaining prominence because of its transparency, low operational costs and fast pay out mechanism. Yet, there are major constraints associated with weather index products that need to be successfully addressed. Foremost among the constraints is high basis risk. There is an urgent need to bring down basis risk arising from insufficient network and spread of weather stations besides improving relationships between the weather triggers and yield loss. Finally, there should be an in-depth research (on a continuous basis) of the associated weather risks for various crops grown in the country.

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Institutional arrangements at Village Level and People's Participation

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"Institutions are the rules, organizations and social norms that facilitate the coordination of human action"
-
World Bank's World Development Report 2003

An *INSTITUTION* is an organized system of social relationships which embodies certain values and procedures and meets certain basic needs of the society(Horton and Hunt, 1976)

Introduction:

Watershed Development programmes objectives and goals could be translated into reality only if the community has the involvement, belongingness, capacity, resources, know-how and ability to execute the programme activities. Hence it is essential to make institutional arrangements with clearly assigned roles and responsibilities in order to mobilize community resources in terms of assessment, needs prioritsation planning , organizing and execution of the tasks. It also facilitates commitment , aids in establishment of strong partnership and collective ownership among various stakeholders at the grass root level . Group building and local institutional development will lead to empowerment. Village institutions need to be nurtured, their functions and funds controlled by local communities, with the emphasis placed by the government on capacity building maintained

Watershed Development through Institutions:

Watershed development refers to the conservation regeneration and the judicious use of all the resources – natural (like land, water plants, animals) and human – within the watershed area. Watershed Management tries to bring about the best possible balance in the environment between natural resources on the one side and man and animals on the other. Since it is the man which is primarily responsible for degradation of environment, regeneration and conservation can only be possible **by promoting awakening and participation among the people who inhabit the watersheds)**

WHY PEOPLE'S PARTICIPATION? (Source: IWDP, Ministry of RD)

There is a close relationship between the environment and the community living within that area as the community derives sustenance from it. Increase in biotic pressure leads to over-exploitation and degradation of natural resources. Paucity of resources also leads to internal conflict giving opportunity to others to exploit the situation. It is thus necessary for people to realize the intrinsic relationship between population, poverty and degraded environment they live in. Still, it is only they who can restore the health to environment thus ruined, outside actors can only facilitate but never substitute for stake holders. Hence, there can be no sustainable natural resources management unless it involves all inhabitants of the affected areas in an active manner and development plans are formulated and executed by them.

It is clear that the watershed development cannot be done in isolation. It is a natural entity and may contain different types of lands namely, forest lands, community lands, government lands or private lands. These lands can be treated on "ridge to valley" approach. A land lying in a valley cannot be improved if the land at upper reaches is not treated. Treatment of land in a scattered manner will not lead to wasteland development. Mere treatment of land is not enough. Land and people cannot and should not be viewed in isolation. So the best possible strategy would be treating the land by empowering the people who live in it. It is watershed plus approach which takes care of holistic development. Therefore, the entire watershed community is to be involved for the integrated development of watershed and the assets created in such an effort are to also be maintained through the people of the watershed community in order to ensure sustainability. People's participation also ensure conservation and development of Common Property Resources. Besides when people decide what they have to do their stake in development become more pronounced leading to their intense involvement. This involvement in decision making is the key to success which brings sustainable development. Hence people's participation is the approach for the purpose.

Need for village level Institutions in watershed programmes:

However people participation is ensured only with the formation of efficient institutions. Local community-based institutions are needed to facilitate and coordinate the activities of NRM at grassroots' level. Local institutions, with the established rules in an informal manner and stakeholders involved to impose them, are essential for sustainable natural resource management of watersheds. Working with community level institutions at ground level helps to identify the real problems / needs and practical issues which affect the implementation of watershed policies and guidelines, and so can feed into the execution of the programme and fine tuning of plan to make sure that it is sensitive and effective

The institutional framework mediates the access of the poor to assets, financial and other services, technologies and markets, and it determines the extent to which poor groups benefit from the production generated by these assets and services. The development of organizations that empower the poor, and the rules and policies that secure sustainable access for the poor to assets such as land and water, to technology, finance and other services and to efficient markets, and allow the poor to participate in decision-making is central to more rapid rural development and poverty reduction.(IFAD, 2003)

CRIDA' s experience in the formation of Rural Institutions:

Our experience in formation and strengthening of rural institutions in the DFID-NRSP livelihoods project clearly demonstrated the tangible benefits of local institutions participation

Sensitization of CBOs and rural institutions

By involving various stakeholders the village in the PRA and focus group discussions, awareness was created regarding the condition and use of the NRs and possible interventions that could be made for better use of NRs. Thus, PRIs and other CBOs were sensitized regarding the need for better NRM. This process of sensitization and awareness was reinforced during the interactions throughout the project duration as well as during the regional workshops that were conducted in the clusters and attended by representatives of the government and non-government agencies. One of the main problem raised during PRA was lack of appropriate village organizations (VO) to support the NR-based livelihood activities

Salaha Samithi (SS)(DFID-NRSP FTR 2006)

Formation of SS

Formation of a *Salaha Samithi* (SS) in the cluster is an important institutional innovation developed by the communities and the project and put in place in all the three clusters. The SS, an advisory group of villagers, is formed considering the need expressed by the villages for an institution that can facilitate the implementation of the project activities in association with the project staff .The SS is formed by members who are voluntarily willing to work for the common good of the villagers and who are acceptable to the community as a whole.

It is an informal and inclusive body in which existing CBOs (PRIs and SHGs) are also represented in order to achieve coherence in the activities and to keep the PRI informed of what is going on in the project. Women and weaker sections (SC, ST) of the society were also included in the SS.

Steps in formation of SS

Arriving at a decision to form an SS. Based on the PRA outcome, both the community and the project staff desired to initiate such an organization.

Identification of individuals willing to participate in SS. Individuals volunteered or were nominated during interactions with the community.

Obtaining the broad consensus of the villagers. The candidature of the individuals for participation in SS was discussed in *gram sabha* and a consensus obtained.

Agreeing upon the roles and responsibilities of the members. Discussions were held with the SS members.

Capacity building of the SS. The members were trained to keep minutes and accounts (to be able to track the cash flow) and on-the-job backup was provided by project field staff (BIRD-K).

Roles of SS

The SS as an informal body and its members played the following roles during project implementation:

The SS helped *elicit and assure* people's participation in all the project interventions. In doing so, it made the implementation of the project activities more transparent. In those interventions which needed large amounts of earth work and financial investment (e.g. check dam construction, farm ponds, trench-cum-bunds in private and common properties) SS was actively involved in implementation by bringing forth peoples' contribution in terms of money and labour. It was also actively involved in selecting sites for soil and water conservation measures such as check dams, farm ponds, etc.

It acted as a *liaison* agency between the project staff and the village community in general and through open meetings it also facilitated communication and interaction among the community as well as between the community and external agencies including the project.

Some members of the **SS assumed the role of *early adopters* of technological interventions, w**hich helped others to accept the technologies.. Thus, SS also helped hasten the technology adoption and diffusion among the village community.

SS **was responsible for the final decisions on *targeting* the technological interventions**. By identifying the needy and appropriate clientele for different interventions, the SS guided the technology testing to those households that could benefit from the technology and hence enhanced the chances of technology acceptance and minimized the conflicts.

Salahasamithi Meeting in Mahabubnagar

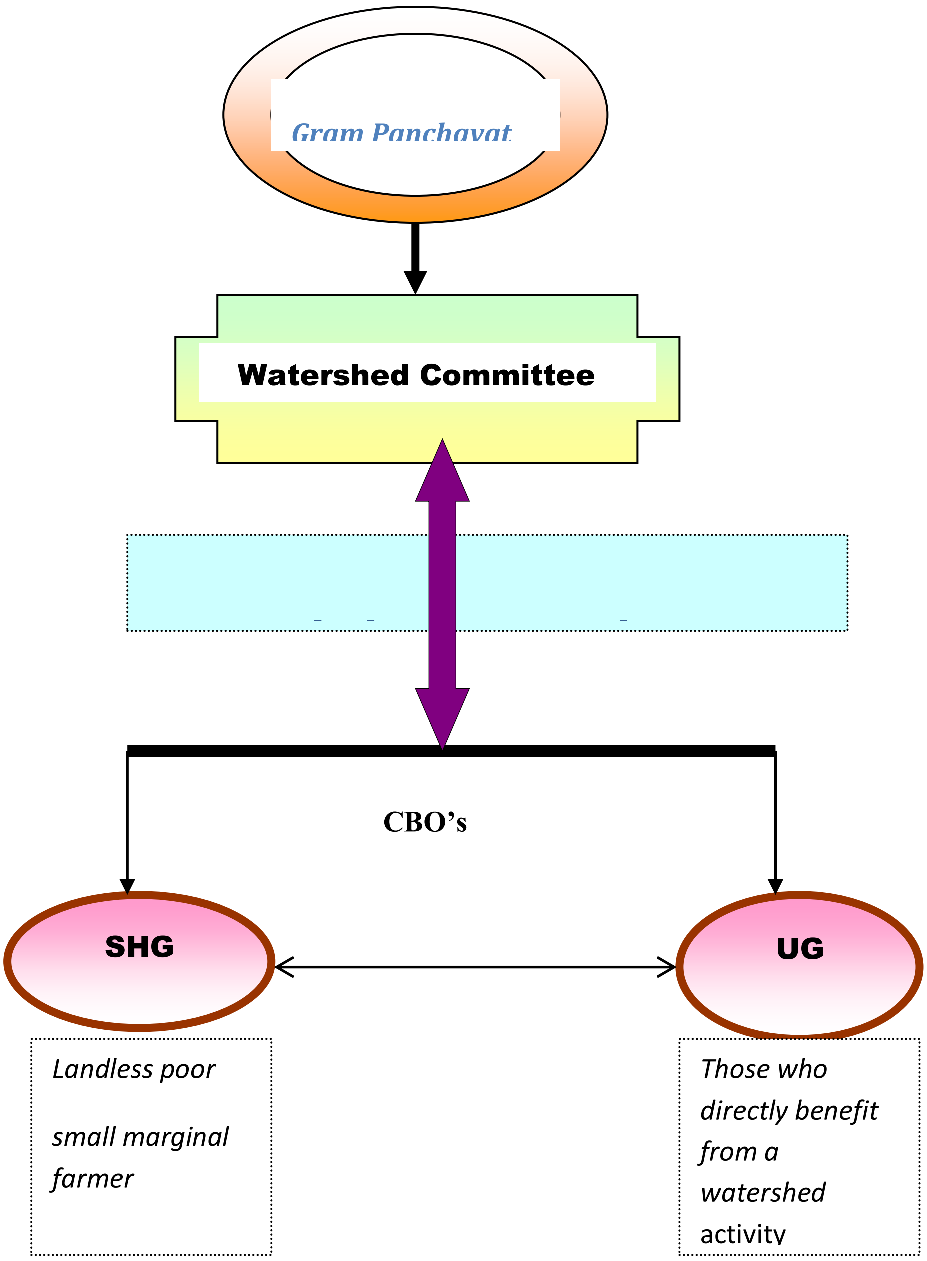
It also identified people for exposure visits and training programs for capacity building. All these activities were done in a transparent and interactive manner in which the rationale for selecting the participating villagers was openly discussed: this minimized the conflicts. The composition of SS, with all socio-economic groups represented also ensured that the decisions were equitable.

SS also took up the responsibility of *maintaining* the assets created in the project.A coincidental but important benefit from the SS is the *time saved* to the project staff. It was felt by the project staff that because of SS they could save 30-50% time in their interactions with the community. The members of SS did have to spend more time in communicating with project staff and the villagers and also in planning for the project activities. However, since most of these activities were carried in an informal manner and within the village, they saw little in terms of transaction costs. Thus, **SS proved to be an effective and efficient mechanism for faster communication and technology diffusion.**

Institutional Arrangements at the Village Level and People's Participation Under Common guidelines 2008 for Watershed development Projects

- Self Help Groups
- User Groups
- Watershed Committee (WC)
- watershed Development Team
- Gram Panchayat

INSTITUTIONAL ARRANGEMENTS AT VILLAGE LEVEL



Institutional Arrangements at community level

It includes identification and organization of the grass root stakeholders rural poor, the women, small and marginal farmers, rural landless in to self help groups inclined to achieve desirable needs of groups

Self Help Groups

The Watershed Committee shall constitute SHGs in the watershed area with the help of WDT from amongst poor, small and marginal farmer households, landless/asset less poor agricultural labourers, women, shepherds and SC/ST persons. These Groups shall be homogenous groups having common identity and interest who are dependent on the watershed area for their livelihood. Each Self Help Group will be provided with a revolving fund of an amount to be decided by the Nodal Ministry.

Case study:

Sujala a community driven Watershed Development Project, is being implemented in five districts i.e. Kolar, Tumkur, Chitradurga, Haveri and Dharwad districts of Karnataka state. The uniquencess of the project lies in the people participation in decision making on the nature of development they perceive to be relevant and their involvement in implementation of activities. The project intends to empower the local people to build a sustainable future with their own hands by SHG members of Sujala Watershed Programmes. Sujala Watershed Project was started in Karnataka from September 2001 covering 1270 villages. Radhakrishna et.al 2008 in their study revealed that maximum number of Self help group (SHG) members (55.00 per cent) had savings level up to Rs. 1000-2000., 20% had savings level upto Rs. 3000 and above. Employment status of majority of the members (79.00 per cent) was improved after joining in the Self help groups of Sujala Watershed Programme.

User Groups

The Watershed Committee (WC) shall also constitute User Groups in the watershed area with the help of WDT(watershed Development Team). These shall be homogenous groups of persons most affected by each work/ activity and shall include those having land holdings within the watershed areas.

Each User Group shall consist of those who are likely to derive direct benefits from a particular watershed work or activity. The Watershed Committee (WC) with the help of the WDT (watershed Development Team). shall facilitate resource-use agreements among the User Groups based on the principles of equity and sustainability. These agreements must be worked out before the concerned work is undertaken. It must be regarded as a pre-condition for that activity. The User Groups will be responsible for the operation and maintenance of all the assets created under the project in close collaboration with the Gram Panchayat and the Gram Sabha.

Watershed Committee (WC)

The Gram Sabha will constitute the Watershed Committee (WC) to implement the Watershed project with the technical support of the WDT in the village. The WatershedCommittee (WC) has to be registered under the Society Registration Act, 1860. The Gram Sabha may elect/appoint any suitable person from the village as the Chairman of Watershed Committee. The secretary of the Watershed Committee (WC) will be a paid functionary of the Watershed Committee (WC). The Watershed Committee (WC) will comprise of at least 10 members, half of the members shall be representatives of SHGs and User Groups, SC/ST community, women and landless persons in the village. One member of the WDT shall also be represented in the Watershed Committee (WC). Where the Panchayat covers more than one village, they would constitute a separate subcommittee for each village to manage the watershed development project in the concerned village. Where a watershed project covers more than one Gram Panchayat, separate committees will be constituted for each Gram Panchayat. The Watershed Committee (WC) would be provided with an independent rented office accommodation. The Watershed Committee will open a separate bank account to receive funds for watershed projects and will utilise the same for undertaking its activities. The expenses towards the salaries of the WDT members and Secretary of Watershed Committee (WC) shall be charged from the administrative expenses under the professional support to the PIA. Secretary, Watershed Committee

The Secretary of the Watershed Committee (WC) will be selected in a meeting of the Gram Sabha. This person would be an independent paid functionary distinct and separate from the Panchayat Secretary. He would be a dedicated functionary with no responsibilities other than the assistance to the Watershed Committee (WC) and would work under the direct supervision of the President of Watershed Committee (WC) and would be selected on the basis of merit and experience. The expenses towards the honorarium to be paid to Secretary of Watershed Committee (WC) will be charged from the administrative support to the PIA.

The Secretary will be responsible for the following tasks:

a. Convening meetings of the Gram Sabha, Gram Panchyat, Watershed Committee for facilitating the decision making processes in the context of Watershed Development Project.
b. Taking follow up action on all decisions.
c. Maintaining all the records of project activities and proceedings of the meetings of Gram Panchayat, Watershed Committee (WC) and other institutions for Watershed Development Project.
d. Ensuring payments and other financial transactions.
e. Signing the cheques jointly with the WDT nominee on behalf of the Watershed Committee.

Role of Gram Panchayat

The Gram Panchayat would perform the following important functions:
a. Supervise, support and advise Watershed Committee from time to time.

b. Authenticate the accounts/ expenditure statements of Watershed Committee and other institutions of watershed project

c. Facilitate the convergence of various projects/ schemes to institutions of watershed development project.

d. Maintain asset registers under watershed development projects with a view to retain it after the watershed development project.

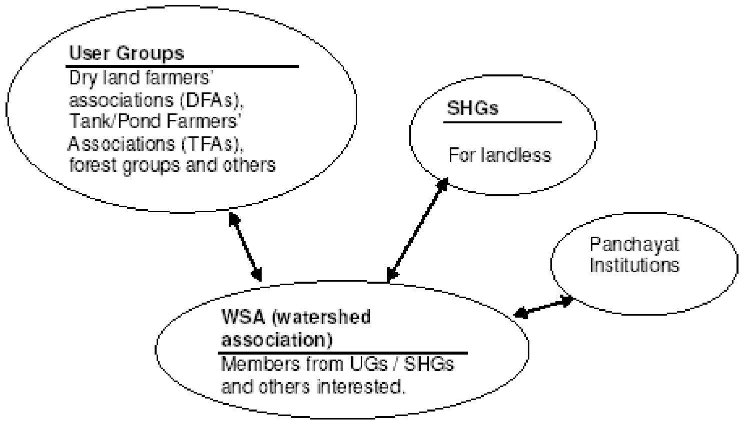
e. Provide office accommodation and other requirements to Watershed Committee.

i. Allocate usufruct rights to deserving user groups/ SHGs over the assets created.

Case study:

NGO, DHAN Foundation, which is a PIA for 40 watersheds in Tamil Nadu and 30 watersheds in Andhra Pradesh, inspired the people to participate and own the watershed programme and used additional innovative approaches in making to build the capacity of the people to ensure systematic planning, implementation and more importantly the sustainability of the assets.

The structure of community organisation is given as



Institution building for community based watershed management in Dhan Foundation

Constraints:

Could not provide diverse range of services due to lack of resources

Leadership development, intrusion of both local and external agencies often result in conflicts

Political interference is another bottleneck in watershed development programmes.

Low level of service delivery standards

Unemployment of sustainable strategies to strengthen CBOs before project withdrawal period

Institutional reforms (Source: Dr.N.K.Sanghi, Adviser, WASSAN)

Delivery mechanism is the main operational constraint under most of the watershed programmes. Under previous guidelines some provisions made at Project level (as PIA) were not enough and the set-up exists at other levels (i.e.district, state or even national level)/ led the need to have an innvative methods. Innovative experiences on institutional reforms have come out during the process of implementation of the programmes by various organizations

Critical functions to be performed by institutions

- Administration
- Project management
- Capacity building
- Democratic decentralization in decision making
- Follow up support

REFORM	Organisation	Purpose
PMU for project period	Bilateral projects in Orissa A.P., Karnataka, etc	Project management
Consortium of resource organization	Bilateral projects in Orissa A.P., Karnataka, etc	Capacity building
Community managed resource centre	CRD – A.P., MYRADA	Follow up support
Autonomous organization under Society Act	State government WS programme in Orissa, T.N	Administration
Empowered review committee	DANWADEP in Orissa, M.P. and Karnataka	Democratic decentraization in decision making

Role of Village Institutions in Sustainability of watershed development Programmes:

Research studies reveal that SHG s are more sustainable than other related CBO's like Ugs, WCs etc,.. As the sustainability of infrastructure , various watershed structures developed under watershed projects depends largely on the upon sustainability of institutions, it is essential to take steps during active phase of the watershed programmes only.

Sustainability is achieved through the establishment of Watershed Development Fund which takes care of past project maintenance and sustenance. This fund is meant to sustain the maintenance of the assets created during the course of project implementation so that the people in the watershed area continue to reap the benefits even after the completion of the project.

Further, the village level institutions such as Watershed Association/Watershed Committee remain in position even after the PIA withdraws from the project after its completion. These institutions have intrinsic strength as they are self constituted and lead by natural leaders in the villages.
The institutional arrangements envisaged in the guidelines ensure sustainability through the following

- Constitution of watershed development fund
- Active people's participation
- Involvement of panchayats
- Involvement of self help groups, user groups, women & weaker sections

Conclusion:

Revised common guidelines are breakthrough in working institutional arrangements at ground level. They connect the primary stakeholders (at village level) with the secondary stakeholders (the district and state level) and the tertiary stakeholders (National level and others) together into a community partnerships ,facilitating the participation of grassroot people through village institutions whom assume responsibility to watershed development activities Hence an element of people participation through SHG's UG's , CBO's at grassroots level in integrated watershed management projects constitute major
developmental thrust to address issues of the natural resource management ,poverty alleviation and to enhance livelihood of rural community.

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Economic Evaluation of Resource Management Technologies

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Introduction

Soil and water are the two basic resources of life. The quality and quantity of these resources has a great bearing on nation's wealth and welfare. The agricultural production in India recorded significant increase due mainly to what is called Green Revolution technology. But, it has by passed the larger tracts of rainfed regions. As a result, the inter-regional and inter-class disparities have widened. This, when considered together with the food and fibre requirements of the country's growing population and the issues of globalization and sustainability, makes it imperative to increase the productivity of rainfed lands.

The rainfed lands are subject to varying degrees of erosion. About 175 m.ha. of land in the country was subject to various forms of erosion out of which 69 m.ha. is experiencing critical degree of erosion. Such large extent of erosion, if not contained, will lead to productivity losses necessating higher costs to produce the same level of output over time and agricultural production cannot be sustainable.

Nature of Soil and Water Conservation Technologies

The principal aim of soil conservation is the control of soil loss and retaining the resources *in situ*. These measures build up the resources over time. The benefits from soil and water conservation measures are, therefore, distributed over time and the beneficial effects may not be as visible in the beginning. Farmers often fail to recognize these benefits, which is why the adoption of these measures is rather slow.

Often there are unavoidable tradeoffs between environmental protection and agricultural growth at given level of technology. It needed to incorporate these trade offs into decision making process both at micro (farm level) and macro (regional level).

Closely related are the technologies for rain water harvesting and management. These technologies help capture rainwater *ex situ* which can then be used productively. Farm ponds is a popular means of rain water harvesting.

Evaluation of Soil and Water Conservation Technologies

Evaluation of any technology is necessary to find out the worthiness of the investment made. As such, it is essential to make better use of available resources. In addition, a clear knowledge of economics of soil and water conservation technologies would help convince farmers for adopting these technologies. Evaluation will also help refine or modify the technologies wherever necessary.

Evaluation can be done at different stages. When the evaluation is done before the implementation of a programme, it is called '*Ex-ante*' evaluation. Here, the stream of costs and benefits as expected from the technology are compared. Some times, evaluation is done at some point of time during the implementation of a programme. This would be helpful to judge whether the programme is progressing in the desired direction. Such an evaluation is referred to as concurrent evaluation. It is also common to carry out the evaluation exercise after the implementation of the programme taking into consideration all the realized (actual) costs and benefits. This is called '*Ex-post*' evaluation. A comparison of these three types of evaluation may throw up some useful lessons for the future.

Evaluation Methodology

When the costs and benefits from a technology are realized in a year, a simple benefit-cost analysis will give the economic viability of the technology. If the benefits associated with the technology outweigh the costs, the technology is considered to be economically viable. Alternatively, the viability can be examined by a partial or complete farm budgeting techniques. Partial budgeting technique is employed when only a part of the enterprise(s) is affected by the introduction of the technology. On the other hand, complete or whole farm budgeting is used when all the enterprises in the farm are influenced.

When the costs and benefits are distributed over time, as is the case with most of the soil and water conservation technologies, various measures employed in project worth measurements have to be computed to assess the economic viability of the project. The principle in these techniques is that all the costs incurred and benefits accrued at different points of time are discounted or compounded so that they can be related to a single point of time. Only then will they be comparable. Pay Back Period (PBP), Net Present Worth (NPW), Benefit-Cost Ratio (BCR), Internal Rate of Returns (IRR) and Annuity Value (AV) are the important measures in this regard.

Both these situations involve comparison of costs and returns attributable to technology. These costs and returns are obtained following a 'with and without' ot 'before and after' approach or a mix of both approaches.

Pay-Back Period

It is the number of years an investment project taken to recover its costs from returns.

Net Present Value

It is the discounted value of all cash inflows net of all cash outflows of the project during its life time.

$$NPV = \Sigma\ (R_t - C_t)/\ (1 + i)^t \quad (t = 1 \text{ to } n \text{ years})$$

Annuity Value

Uniform annual return, which helps in determining the repayment period, is computed by dividing the NPV by the present values of an Annuity Value of Rs.1/- over the life of the project.

$$AV = \Sigma\ (NPV/(1/(1 + i)^t))$$

Benefit-Cost Ratio (BCR)

It is the ratio of discounted value of all cash inflows to the discounted value of all such outflows during the life of the project.

$$BCR = \Sigma\ R_t / (1+i)^t / \Sigma\ C_t / (1+i)^t$$

Internal Rate of Return (IRR)

It is that discount rate at which the NPV is zero.

where,	R_t	=	Returns in the t^{th} year
	C_t	=	Costs in the t^{th} year
	i	=	Interest rate of discounting rate

Data Needs and Quantification Problems

The information on costs incurred and benefits accrued at different points of time is the primary requirement for assessing the economic viability. The benefits from the soil and water conservation technologies include yield and employment gains, asset formation, cost savings, which can be expressed in monetary forms. On the other hands, the quality gains such as improvement in soil quality, off-site benefits, groundwater recharge, etc. are difficult to be quantified. Similarly, the direct costs that go into the soil and water conservation measures include construction costs, maintenance costs, etc. which can be quantified. It is, therefore, useful to consider all the benefits and costs that can be quantified in assessing the economic viability. A statement describing the impact on environment or qualitative change may be appended at the end so that atleast a subjective assessment can be made, for qualitative change may some times be considered more important in view of the future needs of the country.

Evaluation is also determined by the perspective from which it is being done. Identifying and quantifying the costs and returns as well as externalities will change to a great deal when looked from a macro or societal perspective compared to that of a micro-perspective.

Other methods of evaluation include programming (linear/dynamic/goal), simulation modeling etc. The tables that follow provide some examples of the methods mentioned.

BUDGETING

Eg: Improved seed vs local seed

Debit	**Credit**
Increased cost	**Decreased costs**
Seed cost	Plant protection expenditure
Seed treatment	
Other inputs	
Decreased returns	**Increased returns**
	Extra yield
Total: A	**Total: B**
Decision rule: If B>A, then one can adopt the technology	

Economic evaluation of conservation practices in castor, HRF, CRIDA, 2000

Treatment	Yield (kg/ha)	Costs (Rs/ha)	Net returns (Rs/ha)	Addl. costs (Rs/ha)	Addl. Returns (Rs/ha)
Farmers' practice	528	1582	2136		
Glyricidia much	1082	3465	7484	1883	5348
Mung cover	776	3805	9136	2223	6996

Economic evaluation of conservation practices in castor, Nallavelli, 1999

Treatments	Total costs (Rs/ha)	Total returns (Rs/ha)	Additional costs (Rs/ha)		Addl. yield (kg/ha)	Addl. returns (Rs/ha)
			Material	Labour		
T_1 : I.M. + conservation furrows	3981	4593	150	400	92	1245
T_2 : I.M. + vegetal cover with mung bean	3836	4837	206	200	110	1489
T_3 : I.M. + Glyricidia mulch	4131	5335	201	500	147	1987
T_4 + Traditional management (FYM @ 5 t/ha + 10-30-0 kg/ha NPK as basal	3430	3348	-	-	-	-

Profitability measures for a typical farm pond in an Alfisol

Particulars	Measures
Pond size, m^3	500
Pay back period, years	10
Net present value, Rs	29849
Benefit Cost Ratio	1.57
Internal rate of return, %	18.97

Net present values for tobacco producer curers under different soil conservation levels

Conservation method	**NPVs under different discount rates**			
	5%	**8%**	**10%**	**12%**
No soil conservation	51,884.2	46,994.6	43,510.4	40,787.6
Bench terraces	63,680.4	54,495.8	49,156.9	44,999.9
Lock and spill drains	61,511.1	52,419.1	47,463.0	43,117.7
Stoned terraces	64,086.9	54,039.1	48,567.2	43,289.9

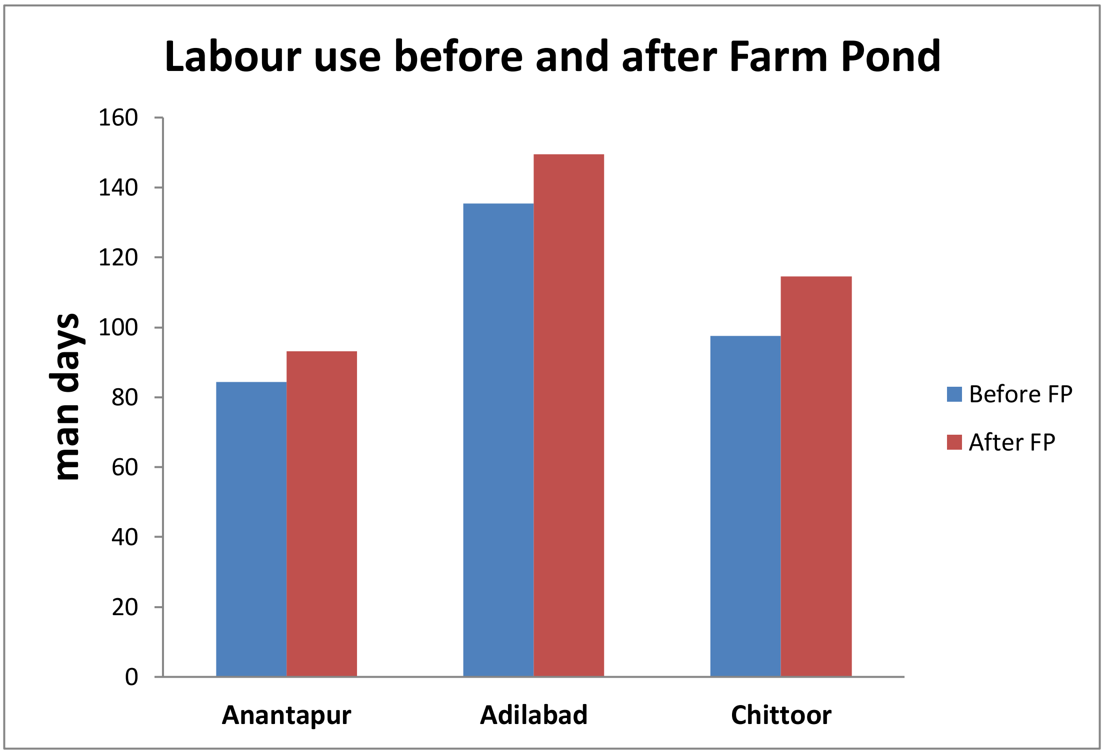
Effects of increased economic goals on environmental variables

Economic goal (at farm level)	Level of environmental variable for Dhading district						
	Soil erosion (Mg/ha)		Cattle grazing (AM)	Forest fodder lopping (000Mg)	N use (kg/ha)	P Use (kg/ha)	Pesticide use (kg/ha)
	Crop land	Pasture					
Food frain production (Mg/ha)							
1.0	4.68	0.28	1.46	22.22	47.30	0.68	59.84
1.4	6.58	0.63	3.29	70.25	34.20	0.90	33.98
1.8	11.22	1.24	6.41	66.51	53.79	8.00	93.98
Milk production (kL/HH)							
0.50	5.62	0.48	2.48	0.00	53.63	10.81	55.61
0.75	6.13	0.56	2.93	174.78	26.88	0.00	30.18
1.00	6.73	0.65	3.38	321.67	19.59	0.00	35.22
1.25	8.39	0.64	3.33	828.21	14.55	0.00	18.85
Cash income (US$/ha)							
410.00	5.91	0.53	2.76	38.81	29.57	0.00	28.33
447.00	6.25	0.53	2.74	62.42	38.80	3.06	49.49
522.00	6.93	0.52	2.69	108.53	56.85	10.10	90.71
597	7.60	0.51	2.64	154.64	74.92	17.24	131.92

AM: Animal months

HH: Household

Source: Pant and Pandey 2001 American Journal of Alternative Agriculture, 16: 114-123



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