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Soil and Water Conservation

BULLETIN

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त्रिलोचन महापात्र, पीएच.डी.
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सचिव एवं महानिदेशक
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Foreword

In the backdrop of the recent Govt. initiatives for improving water availability at farm level, it is highly imperative to extract the most relevant, from the available research outputs, innovations and experiences of various stakeholders across the country on soil and water conservation. The contained land degradation is though a evidence of concentrated efforts of researchers and developmental agencies, a continuous effort is warranted for developing low cost soil and water conservation technologies to outpace the new and dynamic challenges in natural resource management.

The diverse agrarian situation and involvement of large number of stakeholders including researchers across the country, result to large number of technology modifications, farm level innovations and success stories which largly remains unnoticed in absence of a suitable platform. Bringing them in public domain in desired format has potential of motivating different stakeholders in adopting and promoting soil and water conservation technologies. The IASWC has aptly encased the opportunities of bringing rich experiences on planning, implementation, impact evaluation of soil and water conservation interventions in watershed development mode by bringing out this annual publication.

I appreciate the efforts and idea of Indian Association of Soil and Water Conservationists (IASWC) for publishing Soil and Water Conservation bulletin containing information on advancement in SWC technologies, field experiences of various stakeholders and views of the renowned professionals, with objective of sharing farmer's friendly resource conservation technologies with different stakeholders.

I convey my heartiest congratulations to IASWC and editors for their untiring efforts in bringing out the 4th issue of this publication and hope that the IASWC will continue the efforts of bringing future issues to contribute towards natural resource conservation and management in the national interest.

(T. MOHAPATRA)

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Bulletin No. 4 | 2019

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Contents

Soil and Water Conservation Bulletin
No. 4, pp 1-10, 2019

Resource Conservation in Eastern Region of India: Impact Studies on Watersheds

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INTRODUCTION

Rainfed areas currently constitute 55% of the net sown area of the country are home to two-thirds of livestock and 40% of human population in the Eastern Region of India. The region has a predominance of tribal (54 tribal communities) constituting about 30% of the total population (Chauhan, 1998). It's also observed that around 62.5% of the total geographical area of Eastern Region is degraded exclusively by water induced soil erosion which in conjunction with salt-affected and acid soils works out to be 73.9%. Data on soil loss tolerance limits indicate that the tolerance (T) value varies between 7.5 and 12.5 t/ha/yr across the region (Lenka *et al.,* 2013). Indiscriminate deforestation and practice of *Jhum* cultivation lead to accelerated erosion for which proper conservation measures need to be established, especially on very steep slopes. The eastern region as a whole contributes 27, 14 and 8% of area under cereals, pulses and oilseeds, respectively to the country's area under these crops. The production of these crops also follows the similar trend that of area. The average productivity of cereals and oilseeds is lesser by 13 and 36%, respectively over the average national productivity (1950 kg/ha, cereals and 925 kg/ha oilseeds). However, the productivity of pulses is higher (+14%) for the region as compared to the country's average productivity of 593 kg/ha.

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1. Natural Resources and Agriculture in Eastern India

This region is unique and characterized with diverse natural resources (physiographic, soil diversity, bio-diversity, water resources and climatological parameters like rainfall, bright sunshine hours etc.), human resource (majority of tribal population) and socio-economic aspects (low level of literacy, low per capita income etc.). Majority of the population is predominantly tribal and dependent on forest, agriculture and land-based activities. The agricultural production system in the region is predominantly rainfed, mono-cropped at subsistence level. Slash and burn agriculture is still practiced in almost all the states of Eastern India. The region, once richly endowed with rich genetic diversity of plants, has been denuded due to human interference by adoption of unscientific land use practices. With rapid increase in human and livestock population and the rising demand of food, feed, fuel, fodder, fiber, timber and the other developmental activities, the farmers have been forced to exploit forest land and water resources at sub-optimal level in complete defiance of the inherent potential. This has resulted in progressive decrease in forest cover, loss of biodiversity, serious soil erosion leading to depletion of plant nutrients, gradual degradation and decline in land productivity (Sahoo *et al.,* 2018) and its carrying capacity, silting of major river basins causing recurrent floods in the plains, and drying up of perennial steams as well as ecological imbalances. Gradual degradation of these resources is of prime concern and calls for location-specific measure to conserve, utilize and manage these natural resources for optimizing production on sustained basis without adversely affecting its quality.

Agriculture is the main economic activity in the region, and despite major impact of green revolution in the irrigated areas of the country, modernization of agriculture has escaped this region; as evidenced by poor adoption of modern technologies, low consumption of fertilizers and other indicators of growth. One of the most important reasons for this slow growth is the lack of location-specific and system-based technologies. Apart from this, the dwindling resources of soil, water, flora, fauna and increasing concern for environmental safety has drawn the attention of the planners and policy makers at regional as well national level. Historically, the eastern region was the most prosperous agricultural tract of the country (Adhikary *et al.,* 2015). However, with the advent of the input intensive new agricultural technology following the Green Revolution in other states, this region lagged behind in reaping the benefits. Public investments in agriculture in this region during this period were grossly inadequate to be compatible with the requirements of input intensive agriculture, and therefore this region has not benefited by the Green Revolution. Thus, there is an imperative need to improve food grain production from this resource-rich region by formulating multi-pronged strategies to efficiently conserve and utilize natural resources to ensure livelihood security of rural and tribal communities in the region.

2. Watershed Management

Conservation of precious soil, rainwater harvesting and utilization for multiple uses is the foremost priority apart from addressing other issues like supply chain mechanism for increasing availability of inputs and marketing linkages for agricultural produce, increasing input use efficiency, including water etc. in the agricultural systems. The Government of India (GoI) adopted watershed management as a strategy to address in agricultural productivity sustainability in rainfed areas for the last three decades. Further, GoI has adopted watershed management as a national policy since 2003 (Joshi *et al.,* 2004). The prominent national programmes implemented in the Eastern region are NWDPRA, IWDP, RVP/FPRs, WDPSCA, NAP and DPAP. With launch of massive watershed development programmes in the country during 1990's, all the previous programmes were converged to develop different areas by adopting a participatory watershed management approach. The maximum area has been treated under IWDP (43.9 lakh ha) followed by DPAP (25.9 lakh ha), NWDPRA (13.7 lakh ha) and other programmes (13.6 lakhs ha). Similarly, the maximum expenditure has been made under NAP (₹ 708.88 crores) followed by NWDPRA (₹ 547.11 crores) (Sharda *et al.,* 2008, 2010). Different model watersheds in the tribal dominated areas of Odisha were implemented by ICAR-IISWC, Research Centre, Sunabaeda, Koraput under different schemes, sponsored by the Ministry of agriculture, ministry of rural development, GoI, New Delhi. Koraput district (rank 110) is one among the top one-third districts ranked up to 167 based on high Rainfed Areas Prioritization Index (RAPI) by the NRAA (2012).

Integrated watershed development is the strategy adopted in the country for sustainable development of dry land areas. In most of the developed watersheds with intensive interventions to manage rainwater, the groundwater availability improved not only in the watershed, but downstream areas also benefited with increased groundwater recharge. Along with increased surface and groundwater availability, associated activities also substantially increased in the watersheds, resulting in increased incomes as well as improved livelihoods (Dhyani *et al.,* 2001). Increased water availability also had a positive impact in improving socio-economic and environmental impact, in addition to increased productivity in watersheds. Despite increase in agricultural production in many watersheds, productivity per unit of land and water did not increase. There is a need to adopt more water use efficiency (WUE) measures along with integrated management of water resources in watersheds for sustaining the development measures. The results from watershed case studies from different watersheds programme executed by ICAR-IISWC in Semiliguda block of Koraput district, Odisha are discussed here.

3. General Problems and Constraints

- Practice of shifting cultivation in hilly slopes of the region causing severe land degradation leading to loss of top fertile soil, forest cover, biodiversity and environmental pollution.
- Inadequate data base related to availability of various natural resources including soil and water resources in the region which is a hindrance to planning.
- Poor socio-economic status leading to low adoption of modern production-cum-conservation practices resulted in high poverty. Rural population of this region accounts for more than 75% and is characterized by fragility, marginality, inaccessibility, cultural heterogeneity, and ethnicity.
- Soils of this region are acidic to strongly acidic in reaction leading to deficiency and toxicity of essential plant nutrients thereby adversely affecting crop growth and productivity.
- Poor water resource management and inadequate technological backup for harvesting and utilization of surface run off for crop production.
- Large scale deforestation, destruction of native germplasm plants through burning for shifting cultivation leading to loss of biodiversity.
- Deforestation and the resultant loss of soil, especially in the hill areas, are leading to increased siltation of rivers and streams. The deep pools that are the favoured habitats of many species are rapidly becoming shallow and choked with silt, leading to a decline in habitat.
- Very limited information on advanced farming and cropping systems suited to different locations.
- Fragmentation of holdings and right of land ownership issue particularly in NEH region threatening livelihood security due to poor resource conservation.
- Inadequate agricultural mechanization: is due to the hilly terrain, lack of investment and mechanized transfer of technology. Majority of the farmers are below poverty line. This will lead to loss of interest in agriculture especially among the youth with resultant increase in rural-urban migration as well as preference for non-farm sector.
- Inadequate policy frame work for channelization of production-processing-marketing components.
- Large gap between potential and productivity of major crops. This leading to gap between food production and the requirement at the regional basis.
- The region is much vulnerable to recurrent natural disasters like cyclones, flooding, landslides etc.
- Poor co-ordination among different developmental / research agencies working in the region leading to poor implementation of resource conservation programmes resulting in to low impacts.

4. Impact of Watershed Interventions

4.1 Kokriguda watershed

The Kokriguda watershed located in Semiliguda block of Koraput district, Odisha, was implemented on IWDP Watershed guidelines during 1998 to 2003. Its geographical location is 82°52′59" to 82°54′ 03"E longitudes and 18°40′15″ to 18°40′44″ N latitudes with an elevation range of 880 m to 1329 m above mean sea level (amsl). The total area of the watershed is approximately 317.5 ha with undulating to steeply sloping (up to 50%) topography. As per pre-project data the average land holding was 2.15 ha and an average family income was ₹ 1013/- per month. The major crops grown in the watershed were paddy, ragi and niger followed by vegetables. Finger millet (*ragi*) (39%) covers the largest area followed by *jhola* land paddy (31.7%). Cropping intensity in the watershed was 77.9% as no crop is taken up in *rabi* and summer.

Cropping intensity: After implementation of the project, cropping intensity has increased from 78 to 120%. 23 ha more area was brought under cultivation in *rabi* season. Current fallows and cultivable wastelands have reduced by half. 37 ha of unproductive hilly wastelands has been developed under forestry production systems. The Wasteland Development Index (Land put under perennial cover (P) / Available Wastelands (W)) through watershed plantation programmes estimated to be 0.70. More emphasis on vegetables cultivation was given considering market potential and relatively shorter duration of crops. Shannon Weiner Index of crop diversity was estimated to be -1.17194 in 1997 and -1.1176 in the year 1997 and 2001, respectively.

The bio-physical impact was seen in the form of desired positive changes in land use pattern as shown in Table 1, increase in cropping intensity (120%), rise in productivity of different crops (25 to 52%) increased returns (₹ 1.5 lakhs/yr) from vegetable cultivation, soil health almeroration, prevention of soil loss (134 cum in 2002), created fodder potential (120 t/yr), fruit plantation in 11 ha, around 90% more trees on backyards and bunds, availability of fuel wood growing stock of 450 cum and multiplied returns from plantation and protected forest, etc.

Crop diversification index*:* During the pre-project period, crop diversification index (CDI), Sikka *et al.* (2004) was worked out to be 0.62 and 0.06 for *kharif* and *rabi* season, respectively and the overall CDI was 0.98. CDI during the pre-project period increased to 0.74, 0.24 and 0.98 for *kharif*, *rabi* and overall, respectively. The increase in

Table 1: Productivity indicators in Kokriguda watershed

S.No.	Indicators	Unit	Before (1998)	After (2003)	Change (%)
1	Change in land use				
i	Net sown area	ha	127	156	22.83
ii	Area sown more than once	ha	3.5	38.55	1001.4
iii	Gross cropped area	ha	130.7	200.4	53.27
iv	Current fallow	ha	15	4	-73.34
v	Cultural waste land	ha	25	7	-72.0
vi	Area covered under plantation (Non arable land)	ha	0	51	100.00
vii	Area put under agroforestry (Arable Land)	ha	0	5	100.00
2	Area under crops				
i	*Kharif*	ha	127.25	161.9	27.22
ii	*Rabi*	ha	3.5	38.55	1001.4
3	Impact on yield of major crops				
i	Upland paddy	q/ha	7.6	15	97.37
ii	*Jhola* paddy	q/ha	11.2	15.4	37.50
iii	Ragi	q/ha	6.7	9.15	36.56
iv	Niger	q/ha	1.5	2	33.34
v	Groundnut	q/ha	8.5	18	111.76
vi	Suan (Millet)	q/ha	1.3	2.2	69.23
4	Productivity indices				
i	Crop diversification index (CDI)		0.68	0.98	44.11
ii	Crop fertilization index		0.13	0.44	238.4
iii	Index of crop productivity		0.33	0.48	45.45
iv	Cultivated land utilization index (CLUI)		0.14	0.21	50.0
v	Cropping intensity	%	77.9	119.5	53.40

overall CDI over the project period was 44.1%. The cultivated land utilization index (CLUI) of Kokriguda watershed project improved by 50%. During the project implementation phase, a considerable area lying vacant or abanded was brought under cultivation and the double cropping resulted in increase from 0.14 to 0.21. A low CLUI even during the post project period is due to the fact that major portion of the arable land is rainfed and farmers take one crop in a year.

Environmental impact: Considerable decrease in soil erosion rate and surface runoff helped in increased water availability and raise in ground water table in the watershed area (Table 2). Significant conservation of soil nutrients and soil carbon on site helped in increasing soil fertility status.

Participation Index: It was observed that land holding has greatest impact on peoples participation followed by education. Age of the head of the family is also having significant but inverse impact, which means younger the group of the head of the families the greater is the participation in watershed development programme. The cooperative behavior of the farmers also had positive and significant impact on participation (Joshi *et al.,* 2004). Education level and diversification index are other factors having positive though insignificant impact on participation. The impact can be seen in the form of increased cropping intensity (120%), productivity of different crops (15 to 100%), increased return (₹ 1.3 lakhs/yr) from vegetables, cultivation in 8 times more area, soil health amelioration, prevention of soil loss (134 cum this year), created fodder potential (120 t/yr), fruit plantations in 11 ha, around 90% more trees on backyards and bunds, availability of fuel wood growing stock of 4500 cum and multiplied returns from plantations and protected forest etc (Table 3). Social capital have been built by strengthening existing village level institutions, facilitating community organization through interventions, which has resulted in formation of new institutions like formally registered Watershed Association, Watershed Committee, Self Help Groups and User Groups. Social base appreciated over years through self – initiated meetings and renewed reliance on community activities leading to development of leadership.

4.2 Malipungar watershed

The Malipungar micro-watershed located in Semiliguda block of Koraput covers an area of 275 ha area and was implemented during 2001 to 2005 (Table 4). Major problems perceived during PRA exercise were lack of irrigation facility, soil erosion, flooding in *jhola*, shortage of food, fodder and fuel, insect, pest attack, non-availability of good seeds, no electricity, unhygienic conditions, lack of communication and poor extension service. Based on the problems, needs, priorities and preferences of the tribal farmers, technical components of the action plan were modified

Table 2: Environmental impact indicators in Kokariguda watershed

S.No.		Indicators	Unit	Before (1998)	After (2003)	Change (%)
1		Hydrology and water resources				
	i	Surface runoff	%	36.8	12.4	-66.30
	ii	Surface water storage	ha-m	0	1.212	100.00
	iii	Perenniality of stream	%	3.7	4	8.10
	iv	Water table depth in well	m	9.35	9.06	3.10
	v	Increase in ground water contribution	%	17.9	23.6	31.84
	vi	Reduction in soil loss	t/ha/yr	38.2	6.64	-82.61
2		Soil fertility improvement				
	i	Organic carbon	%	0.43	0.48	11.62
	ii	Nitrogen	kg/ha	207.75	229.13	10.29
	iii	Phosphorus	kg/ha	6.31	7.65	21.23
	iv	Potash	kg/ha	262.50	268.88	2.43

Table 3: Socio-economic impact indicators in Kokriguda watershed

S.No.	Indicators	Unit	Before (1998)	After (2003)	Change (%)
1	Women empowerment				
	i Time spent on social activities (festivals/ rituals/marriage, birth/death etc.)	hrs/annum	600	650	8.33
	ii Child care and personal care	hrs/annum	320	440	37.5
	iii Farming activities	hrs/annum	860	1465	70.34
	iv Household activities	hrs/annum	1490	1545	3.69
	v Mushroom cultivation	hrs/annum	0	180	100.00
2	Benefit-Cost ratio				
	i Arable land	Ratio		1.65	
	ii Non arable land			1.89	
	iii Overall			1.7	
3	Family annual income	₹	12155	24981	105.52

Table 4: Details of land-use scenario during the project period

Land use	Area (ha)	
	Pre project (2001)	Post project (2005)
Geographical area	275	275
Forest area	108	108
Miscellaneous tree crops/groves	38	38
Current fallows	10	2
Cultural wastelands	16	4
Barren uncultivable wastelands	2	2
Area under nalas, streams, roads, buildings and other non-agricultural use	8	8
Arable land area put under agro-forestry	0	17.5
Net sown area	93	112
Area sown twice (*jhola* paddy + vegetable crops)	15.5	48.5
Area sown thrice on Beda land (vegetables)	5	15.2
Gross cropped area (ha)	118.5	175.7
Cropping intensity (%)	127	157

based on triangulations. Basic interventions like water resource development, soil and water conservation measures, crop diversification, plantation / ago-forestry, nutrient management options and integrated farming systems activities were identified for overall development of the farmers. Up to completion of the project, total gross area 110.1 ha was treated and farmers themselves covered almost equal area making total treated area to 205 ha.

Water resources development: The hydrology of *jhola kundi* was studied by monitoring water levels, stream flow of *jhola* and recording water pumped by farmers for irrigation. For computation of well yield, it was found that average recuperation time is 22.5 hours and individual farmer can irrigate an area of 0.5 to 1 ha in *rabi* and 0.2 and 0.4 ha in summer. In the command of *jhola kundi,* farmers are presently growing ginger, tomato, maize, cabbage, cauliflower, capsicum, peas, beans, sweet potato, coriander leaves, cucumber etc. and floriculture. Watershed technology has potential and attracting farmers from nearby villages. Fish species like *Catia catia* (30%), *Labeo rohita* (30%) and *Cirrhinus mrigal* (40%) were reared to give an opportunity to improve the nutrition of poor tribal people. Presently, *jhola kundis* irrigates 8 ha area benefiting 24 farmers in Malipungar watershed (Table 5).

Activities under resource conservations are trench cum bund, staggered trench, bunding, V-ditch, vegetative filter strips and hedge planting. Stone bunding, live check dams, brushwood check dams, loose boulders check dams and trenching are the measures implemented for the stabilization of gullies and drainage networks in the watershed.

Bio-physical and socio economic impacts: The soil loss estimated by USLE for the pre-project period (2002) was 40.5 t/ha/yr. This was reduced

Table 5: Crop yield and profit through water resource development

Resources	Yield (q/ha)		% increase	Net Returns (₹)		Increase in net returns	No. of beneficiaries
	Before	After		Before	After		
Dugout pond	115.4	180	55.98	15660	59713	281.3	48
Jhola kundi	68.5	120	75.18	4900	52178	964.9	24
Spring pond	12.8	22.5	75.78	974	5881	503.8	10

to 11.3 t/ha/yr in 2005 as determined through actual measurements on silt deposition behind the conservation measures. Overall increase in crop diversification, land use, fertilizer use and productivity index was by 70.2, 50.0, 107.9 and 75.2%, respectively. Conservation and crop production technologies resulted in increase of organic carbon by about 1.3 times than farmer's field. Similarly in case of phosphorus and potassium, the increase was about 1.4 and 1.17 times, respectively.

4.3 Lachhaputraghati watershed

A model watershed in the tribal dominated areas of Odisha was implemented by ICAR-IISWC, Research Centre, Sunabeda, Koraput during 2007 to 2012 under the MMA, NWDPRA, sponsored by the MoA, GoI, New Delhi. Lachhaputraghati (LPG) watershed is located in Pottangi Tehsil of Koraput district in Odisha state. The watershed is 20 km away from Semiliguda town and 45 km away from Koraput district headquarter. The geographical location is 82°56′ to 82°58′ E longitudes and 19°45′30″ to 19°47′30″ N latitudes with an elevation range of 900 m to 1258 m amsl. The total area of the watershed is about 601.24 ha with undulating to steeply sloping (up to 50%) topography. Out of the total geographical area of 601.24 ha, maximum area is under degraded forest (61%) followed by the net cultivated area (20.15%), current fallow (11.5%), area under non-agricultural use (6.0%) and area under pasture land (1.4%). The average land holding is 0.52 ha and an average family income is ₹ 2500/- per month (Jakhar *et al.,* 2015; Madhu *et al.,* 2015).

Resource conservation and livelihood activities for watershed development: Various interventions were undertaken in the watershed based on the problems, needs, priorities of the watershed community and their technical suitability and economic viability. The watershed development activities under taken in the watershed were soil and water conservation measures in arable lands, water resource development, stream based diversion, productivity enhancement activities, entry point and income generation activities, and community organization, including capacity building (Jakhar *et al.,* 2018). Activities under resource conservations were vegetative filter strips, field bunding, hedge planting, stone bunding and trenching. Live check dams, brushwood check dams, loose boulders check dams, gabions and stream bank stabilization were the measures implemented for the stabilization of gullies and drainage networks in the watershed. Water resources in the watershed area were developed through farm ponds, *jhola kundis*, renovation of water harvesting structures, and providing water convey once systems. To improve productivity of lands, measures like agri-horticulture systems, bamboo plantation, fuel and fodder plantation, silvipasture system and agronomic management practices were taken up in the watershed area (Madhu *et al.,* 2014).

Productivity impact indicators: The different productivity impact indicators (Tuti *et al.,* 2012) were assessed before and after the watershed interventions and are presented in Table 6.

Resource use efficiency impact indicators: The different resource use efficiency impact indicators were assessed before and after the watershed interventions and are presented in Table 7.

Environmental impact indicators: The different environmental impact indicators were assessed

Table 6: Productivity impact indicators and human population carrying capacity in tribal LPG watershed

S.No.	Indicators	Unit	Before (2008)	After (2012-2013)	Change (%)
1	Productivity Indicators				
i.	Productivity of crops	%	9.14		
ii.	Crop diversification index		0.55	0.71	29.10
iii.	Cultivated land utilization index		0.35	0.4	14.0
iv.	Crop productivity index		0.55	0.61	10.9
v.	Crop fertilization index		0.21	0.3	43.0
vi.	Watershed productivity (Ragi Equivalent Yield -REY)	kg/ha	4962	6126	23.46
vii.	Av. survival rate of mango	%	68		
2.	Human Population Carrying Capacity				
i.	Av. energy output	MJ/ha	18296	20006	9.35
ii.	Av. HPCC of land	Adult /ha	4	4.4	10
iii.	*Jhola* land	Adult/ha	6.6	7.2	9.10
iv.	Beda land	Adult /ha	4.2	4.6	9.52
v.	Padda and Donger land	Adult/ha	2.7	3	11.11

Table 7: Resource use efficiency impact indicators in tribal LPG watershed

Indicators	Before (2008)	After (2012-13)	Change (%)
i. RWUE (kg/ha-mm)			
` Av. cereals	2.14	2.35	9.81
Av. pulses	1.47	1.63	10.88
Av. food crops	1.95	2.15	10.25
Av. oil seeds	1.04	1.11	6.73
Av. vegetables	28.92	31.55	9.09
Av. spices	23.44	25.71	9.68
Average for all crops	11.89	12.99	9.25
ii. EERW (MJ/m^3)			
Av. cereals	4.35	4.78	9.88
Av. pulses	3.26	3.63	11.34
Av. food crops	4.04	4.45	10.14
Av. oil seeds	2.49	2.67	7.22
Av. vegetables	7.15	7.78	8.81
Av. spices	4.17	4.57	9.59
Average for all crops	4.71	5.12	

before and after the watershed interventions and are presented in Table 8.

Socio-economic impact indicators: The different socio-economic impact indicators were assessed before and after the watershed interventions and are presented in Table 9.

Technical man days at different phases of watershed: The technical man days at watershed work phase is worked out to be 2.3 and 3.0 man day/ha (71% of the total man days) for the total and the treatable area in the watershed, respectively. The technical man days accounted for only 12 and 17% of total man day/ha during the preparatory and the consolidation phases of the watershed, respectively. Technical man days were slightly higher during the consolidation phase due to completion of pending works.

CONCLUSIONS

The watershed management programme is a very a fitting programme for enhancing productivity, livelihoods, environmental security and for economic efficiency. But due to poor community organization and participation coupled with improper implementation on a large scale, real impact of the programme is not visualized in some of the areas. On the other hand, we have few successful watershed models in different parts of the country representing different agro-ecological regions and socio-economic conditions. Much more focused attention needs to be given for resource conservation, particularly vegetation, soil, water and livestock. Income generating activities initiated under the watershed activities are not found sustainable due to many reasons, including weak marketing linkages. Skill development is one of the major activity that needs attention in rural area through convergence approach to create employment opportunities. Water harvesting and its recycling at each farm

Table 8: Environmental impact indicators in tribal LPG watershed

S.No.	Indicators	Unit	Before (2008)	After (2012-2013)	Change (%)
1	Potential soil erosion rate				
i	Arable	t/ha/yr	17.93	15.61	12.93
ii	Non- arable	t/ha/yr	37.23	30.38	18.40
iii	WS average	t/ha/yr	30.24	25.03	17.22
iv	Soil retention capacity of trenches	t/ha	13.69		
2	Estimated runoff	%	14.68 to 29.92	7.3 to 15.4	
i	Av. runoff	%	24.4	14.6	40.16
3	Water resources development				
i	Storage capacity created	ha-cm	93.91		
ii	Additional area under irrigation	ha	24.2		
iii	Av. water table depth	m	2.97	2.8	5.72
iv	Av. depth of water in well	m	0.99	1.17	18.18
4	Density of trees	Trees/ha	7	14	100
5	Induced watershed eco-index		0.04		4
6	Carbon sequestration potential	Years	10	20	
i	C (t/ha/yr)		2.12	3.40	60.37
ii	C Credit (₹/ha/yr)		2544	4080	60.37

Table 9: Socio-economic impact indicators in tribal LPG watershed

S.No.	Indicators	Unit	Before (2008)	After (2012-2013)	Change (%)
1	Overall People's Participation Index	%	56		
2	Av. family income	(₹/yr)			
i	Large		35700	41000	5300
ii	Medium		21854	31700	9846
iii	Small		13750	18770	5020
3	Av. family expenditure	(₹/yr)			
i	Large		28500	34000	5500
ii	Medium		18600	27500	8900
iii	Small		13500	18300	4800
4	Employment generation	Man days	14052		
5	IGAs (Annual income per SHG)		₹ 14, 000/- to ₹ 40, 000/- (₹ 900 per head)		
6	Amount in WDF account	₹	121252/-		
7	Economic viability of the project				
i	BCR at 10% DR		1.16		
ii	IRR (%)		19.5		

holding needs to be encouraged for mitigating drought and minimizing crop failure. A comprehensive impact assessment of participatory watershed development for resource conservation and increasing livelihoods of poor community revealed a greater success. The result showed positive impacts on productivity, resource use and environmental impact indicators. The community plays a vital role in sustainable use of ecosystem resources and restoring environmental degradation. Technical skilled manpower required for the watershed project on unit area basis must be considered in policy guidelines for effective implementation and greater environmental impacts on larger scale.

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Impact of Rainwater Conservation on Agro-ecosystems in Morena district of Madhya Pradesh

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Rainfed arable systems of India accounts about 55% of the total sown area (Shankar, 2011), while slightly higher parts of the it about 62% is rainfed in Madhya Pradesh state of India. The Madhya Pradesh state has 14.9 M ha cultivated area constitutes almost half of the total geographical area and agriculture is the major source of livelihood for more than 70% human population, production systems should be resilient to risks, be able to ensure food, nutritional security and strengthened livelihood systems with minimum environmental externalities. The Chambal division is consisting of Morena, Sheopur and Bhind district of Madhya Pradesh. Total geographical area (TGA) of Chambal division is 16.054 lakh ha, net crop sown area 7.52 lakh ha and area under ravines is 3.11 lakh ha, which is highly degraded land (Singh *et al*., 2018). Out of total area under ravines in Chambal division have 1.92 lakh ha in undivided Morena (Morena and Sheopur) district (Tomar *et al*., 2015). Ravines owe their origin to rill-erosion on highly erodible soils by run-off rain water. Ravines mean not only a loss of non-renewable land-resource but also destruction of rural economy, loss of public property, creation of socioeconomic problems such as dacoit-infestation and unemployment (Singh *et al*., 2014). Since formation of ravines was a function of uncontrolled run-off, the management of rain-water through storage of rain water in ponds watershed basis was an appropriate approach for control of ravine and increase of irrigated areas (Verma and Singh, 2009). The groundwater table of the area is approximately 122 feet deep. The over exploitation of underground water through well and tube wells in the district the water table goes downwards to 2 to 5 feet every year and ordinary wells and open well become dry and pose problems of domestic use, animal rearing and agriculture activities in remote areas. In general, the quality of under ground water also deteriorated (salinity and alkalinity) with decreasing of water table in some patches are also seen. Rain water collection in ponds and its recycling is very important component of rainfed as well as in irrigated agriculture system. Runoff collection can be done in several ways depending upon the characteristics and suitability site. Runoff will get stored temporarily against submersible check dams, pond, stop dam, anicut, the construction of which will be very essential for stabilization of gully-bed, etc. Also, selection of suitable sites for construction of farm ponds or tanks is necessary to store runoff.

Hon'ble Prime Minister of the country has urged upon doubling farmers' income by 2022. Therefore, it is essential that farm productivity should increase in irrigated as well as rainfed areas. In Morena district the pearlmillet, pigeon-pea, soybean, blackgram, wheat, mustard, chick-pea and vegetables are major existing crops but the productivity of these crops is low from potential yield of crops owing to adoption of local varieties, non-adoption of improved agronomic package, mono-cropping, intensive and repeat tillage, faulty crop establishment method, undulating topography, burning of crop residues and several abiotic and biotic climatic abnormalities.

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Livestock based economy also played important role in the district after crop production. Keeping above points in view, the district administration was planned to increase the number of ponds to conserve rain water on watershed basis under the name of "*Kshir Sagar Abhiyan*". The planning was also made for community mobilization in participatory approach and construction of ponds in remote rural rainfed areas.

Climatic Conditions

The Agro-climatic region of Madhya Pradesh state of India is Central Plateau and Hills Region, state is further divided into 11 sub agro-climatic zone and Morena district comes under Gird Agro-climatic zone. The climate of this area characterized as dry land comes under semi-arid condition, extremely cold during December-January (-1.0°C minimum temperature) and hot during summer months of May-June (49°C maximum temperature). The average annual rainfall of Morena district is 701 mm comes under low rainfall region, mostly concentrated in the months of July and August. Severe droughts are frequently seen in the district. Dry farming cultivation of crops in areas where annual rainfall is less than 750 mm and crop failures due to prolonged dry spells during crop period common is seen. Morena district comes under in tropical zone MP is more vulnerable to climate shocks where more than 70% population still dependent on agriculture. Climate change is being seen as a serious threat to agricultural productivity and farmer livelihood in the district. Several scientific studies indicate probability of 10-40% loss in crop production with increase in temperature by 2050 and reduction of water availability. The mid and late rainy season drought, frost, terminal drought extreme events in the last 10 years were seen in the district. The rainfall will become more erratic and reduced number of rainy days; thus increasing the risk of drought damage to crops.

Methods Adopted for Impact Assessment

Socio-economic data in terms of contribution, change in income, land use and cropping patterns, cropping intensity, productivity, employment generation, income from different sources, annual income of villagers per family, *etc.* of beneficiaries from ponds were collected randomly from 523 beneficiaries (farmers) through pre-tested questionnaires and interviews. The cost of cultivation was calculated based on input costs (expenditure ₹/ha). The data on food crops, dairy and horticultural crops were collected before and after the farmers' irrigated field crops from conserved water. The economics was worked out by calculating the cost of inputs, human labor, tillage, seed, seeding, irrigation, fertilizer, pesticides, weeding, harvesting, etc. Gross returns (GRs) were calculated by multiplying the yields of food crops, dairy and horticultural crops with minimum support price offered by the Government of India for various crops (Economic Survey of India, 2017-18), milk price of *Sanchidugdhasangh* and existing market rates for vegetables and straw, etc. Net returns (NRs) were calculated as the difference between gross returns and total cost of cultivation (NR = GR − TCC). The B:C ratio was computed by dividing the net return by the total cost of cultivation (TCC). Also, calculations were done for employment generations, etc.

Works Executed Under "*Kshir Sagar Abhiyan*"

A total number of 510 ponds on Government land were constructed and renovation of old defunct ponds was undertaken by the Panchayat and Rural Development department under Mahatma Gandhi National Rural Employment Guarantee scheme and PMKSY-Watershed Development, in blocks of Sabalgarh, Joura, Kailarash, Morena, Pahargarh, Porsa and Sabalgarh blocks of Morena, Madhya Pradesh. The details of newly constructed and renovated ponds are given in Table 1. For these works experts from different line departments (Executive Engineer water resource department, Assistant Engineer ground water board, Engineers of MGNREGA and PMKSY-Watershed district Morena and Chief Scientist, AICRP-Irrigation Water Management,

Table 1: Details about ponds/renovated structures constructed during last two years in Morena district of Madhya Pradesh

S.No.	Blocks	No of new pond constructed		No of renovated ponds under
		MGNREGA	PMKSY-WS	MGNREGA
1	Ambah	39	35	8
2	Joura	29	10	20
3	Kailarash	37	2	7
4	Morena	23	0	42
5	Pahargarh	48	13	15
6	Porsa	51	51	26
7	Sabalgarh	53	0	1
	Total	280	111	119

RVSKVV-ZARS, Morena, Madhya Pradesh) were involved for planning and development of integrated ponds in the villages to improve agro based livelihoods though use of stored rain water for irrigation, domestic use and groundwater recharges.

The details of rain water storage are given in Table 2. The average size of ponds is 155 m length x 126 m width x 3.3 m depth (Photo 1). The total cost of construction of these works was 18 crores approximately at Morena district of Madhya Pradesh. After development of ponds, domestic use and irrigation was done by users. Trainings and awareness on improved irrigation practices to increase water use efficiency, and advance technologies on crop production have been undertaken in the village. Soil health cards were also provided to the farmers for optimum and balanced nutrition to crops under crop management.

Changes in Cropping and Land-use Pattern

The gross irrigated area increased from 38 to 100% by adopting the system through pond based lift irrigation (Photo 2). Now farmers are growing pigeonpea, greengram, sesame, pearlmillet, paddy, blackgram and clusterbean in *kharif,* while wheat, mustard, chickpea, berseem fodder crop and vegetable crops in *rabi* and greengram and

Table 2: Details about ponds/water recharging structures constructed during last two years at Morena district of Madhya Pradesh

Characteristics	Values
No of pond constructed during 2016-17 and 2017-18	510
Minimum size of pond	79 m L x 52 m W x 2.8 m H
Maximum size of pond	302 m L x 250 m W x 5.1 m H
Average size of ponds	155 m L x 126 m W x 3.3 m H
Range of depth of water in ponds	2.8 to 5.1 m
Average depth of water in ponds	3.3 m
Range of water holding capacity	0.73-30.9 ha-m
Average water holding capacity/pond	4.49 ha-m
Range of amount of water available for crop production/pond	0.66-27.81 ha-m
Amount of water for crop production/pond	4.04 ha-m
Average irrigated cropped area/pond (Range 3-5 irrigation)	5.1 ha
Estimated total irrigated cropped area in ha	2601 ha
Range of dead water storage	0.07-3.09 ha-m
Average of dead water storage	0.404 ha-m
Range of construction cost of ponds (₹)	3-35 lakh
Total cost (₹)	18 crores
Average cost/ponds (₹)	4.9 lakh

Photo 1. Collection of rainwater in pond constructed under NREGA scheme

Photo 2. Mustard crop irrigated with stored rainwater

vegetables in summer season. Before conservation of rainwater in ponds the area of pigeonpea, greengram, sesame, pearlmillet, paddy, blackgram, cluisterbean was only 8.0, 84.0, 19.0, 708, 3.0, 12.0, 19.0 ha, whereas limited area of wheat, mustard, chickpea, potato and fodder crop *berseem* grown with limited availability of irrigation or as rainfed in 208, 515, 58, 2 and 6.0 ha, respectively. Due to increase in irrigated area, not only cropped area increased but there was a change in cropping patterns. Long duration pigeonpea acreage was reduced, it was replaced by short duration varieties of pigeon pea. In case of increase in area of *kharif* and *rabi* crops by 29 and 40%, respectively due to positive impact of assured irrigation. These findings were confirmed by Singh, 2011. The farmers are also take fodder crop berseem, vegetables and summer season green gram crop. The cropping intensity of the area was also increased from 141 to 215% due to increase in irrigated area.

Impact of irrigation at critical stages of pigeonpea, greengram, sesame, pearlmillet, paddy, blackgram, cluisterbean *kharif* crops on grain yield was increased by 46, 18, 172, 50, 179, 11, 74% and wheat, mustard, chickpea *rabi* season crops by 72, 76, 84%, respectively as compared with crop grown as rainfed or untimely limited availability of irrigation water. Under innovative works the fish culture and water chestnut (Photo 3) are also being taken simultaneously by the farmers groups. Similar findings were also reported by Singh *et al.,* 2005 and Tomar *et al.,* 2015.

Changes in Income

The net income from agricultural crops was only ₹ 67,019/yr/family before intervention of pond irrigation, now it increased ₹ 1,40,623/yr/household with improved cropping intensity, productivity of crops and animal husbandry. Net income of 3307 families was ₹ 741.9 lakhs/yr before intervention which increased after development of pond based irrigation system ₹ 1556.7 lakhs/yr from agricultural crops and animal husbandry component, etc. Similarly to whole B:C ratio of crops also increased from 1.56-2.20 to 2.47-2.63.

Impact on Employment Generation

The increase of availability of water for

Photo 3. Water chestnut crop in pond

domestic use, animal rearing and agriculture activities resulting increased the employment potential in the form of integrated farming operations. It generated employment to the tune of 3,16,012 man-days/yr as compared before development of pond based irrigation system which was 2,58,820 man-days/yr from agricultural crops and animal husbandry practices it resulted into reduction of male out migration to the nearby cities. In other advantages of the pond based irrigation system, increase in water table by 10.0 feet was observed (Photo 4), it resulted in pumping of irrigation with less energy utilization, eco-friendly, work as village waste water storage and less expenditure on fuel, etc. The recharging of groundwater through storage rainwater in ponds that helps in improving both the ground water level and quality. The pond based farming systems are saved energy, time and labour. Thus, the rural community will be able to generate higher income and raise in their living standard by diversified agriculture production. The impact of pond based irrigation system is immense and proved boon for the poor farmers lived in remote areas of the district. This experience of rain water conservation in ponds needs to be extended in rainfed/irrigated areas, poor quality (saline/sodic) ground water for improving quality of water and control of soil erosion.

Ecological and Environmental Impacts

During socioeconomic status survey of rain water harvesting beneficiaries farmers reported several positive, local ecological impacts. Almost 44% of the sampled respondents in study locations responded that the density and availability of wildlife (such as deer, wolves and other similar large animals) have substantially increased in the region following the construction of water harvesting structures. Other ecological changes observed including a return of migratory birds in the region, and a significant increase in the number of resident small birds (e.g., peacocks, ducks and fowl). Now the district is famous for peacocks and migratory birds.

Photo 4. Water table in open well

CONCLUSIONS

The construction / renovation of rainwater harvesting ponds had a great impact on the changes in area of irrigation with storage of water in ponds and recharges of ground water by 10 feet. It resulted increase in irrigated area from 38 to 100%, changes in cropping intensity from 141 to 215% by the adopting system through pond based lift irrigation. The increase in yield was 11 to 179% of rainy season crops, like wise 72 to 84% of winter season crops. Farmers started raising more remunerative crops as well as fodder for milch animals and consequently their annual income increased more than 2 times. Also, there was a significantly higher employment generation, check the migration and overall prosperity. Intangible benefits recharging of ground water had decreased salinity / alkalinity of ground water as well as also checks the formation of ravine land through control the soil erosion, which is serious problem of Chambal division of Madhya Pradesh.

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Restoration of Degraded Land in Coal Mine Areas of Jaintia Hills, Meghalaya through Phytoremediation

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Coal mining in India was started in the year 1774 in the State of West Bengal. At the beginning of 20th century, the total production of coal was just about 6 Mt/yr. In North-East India, coal mining was initiated by Medlicott in 1869 and 1864. Some coal occurrences in Jaintia Hills were examined by shallow drilling by Dias in 1962-63 and Goswami and Dhara in 1963-64 (Bulletin of Geological Survey of India, 1969). Commercial exploitation of coal in Meghalaya started in the Khasi hills during the 19th century. Since most of the coal deposits were small and isolated and it was not amenable for scientific mining to be conducted in the organized sector and mining operations were left to the local miners to take up coal mining as a cottage industry. In due course of time, the tribal miners accepted coal mining as one of their customary rights. From Khasi Hills, these activities proliferated to other parts of the state, *viz.*, Jaintia Hills and Garo Hills in the beginning of the 1970s (Directorate of Mineral Resource, 1992).

Coal deposits of the state occur as thin seams, which range in thickness from 30 cm to 1.5 m in sedimentary rock, sandstone and shale of the Eocene age (Guha Roy, 1991). The coal deposits are found along the southern fringe of the Shillong plateau extending over a length of 400 km. In the hills of Meghalaya, the coal bearing sedimentary formations are sub-horizontal to gently dipping in nature. It is estimated that there is 562.8 Mt of coal reserve in 20 major or minor deposits distributed throughout the state. Some of the areas where extensive coal mining is going on are Laitryngew, Cherrapunjee, Laitduh, Mawbehlarkar, Mawsynram, Lumdidon, Langrin, Pynursla, Lyngkyrdem, Mawlong-Shella-Ishamati in Khasi Hills, Bapung, Lakadong, Sutnga, Jarain, Musiang-Lamare and Ioksi in Jaintia Hills and West Darrangiri, Siju, Pyndengru-Balphakram, Selsela Block in Garo Hills.

The total deposit of coal in Jaintia Hills district of the state is approximately 40 Mt spreading over patches of different sizes. The area where coal mining is prominent are Bapung, Lakadong, Sutnga, Jarain-Shkentalang, Lumshnong, Malwar-Musiang-Lamare, Ioksi, Chyrmang and Mutang (Fig. 1). Bapung has the largest deposit of 34 Mt covering an area of 12 km^2. The main characteristics of the coal found in Jaintia Hills are its low ash content, high volatile matter, high calorific value and comparatively

Fig. 1. Outline map showing coal mining areas in Jaintia hills

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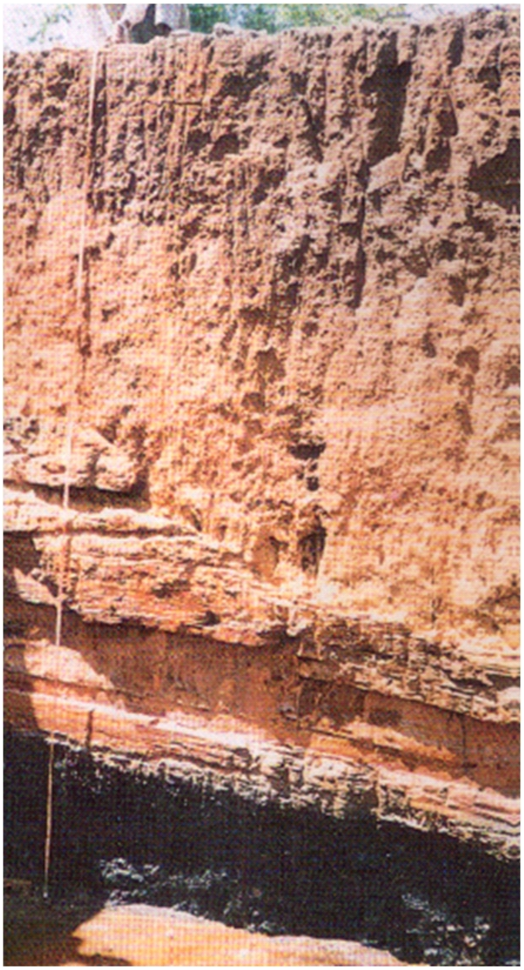
high sulphur content. The coal is mostly sub-bituminous in character. The coal of Jaintia hills district are hard, lumpy, bright and jointed. Composition of the coal revealed by chemical analysis indicates moisture content between 0.4 to 0.9%, ash content between 1.3 to 24.7%, and sulphur content between 2.7 to 5.0%. The calorific value ranges from 5,694 to 8,230 kilo calories/ kilogram (Directorate of Mineral Resources, 1985).

The mining activities in Jaintia hills district are small scale ventures controlled by individual owners of the land. Coal extraction is done by primitive sub-surface mining method commonly known as 'rat-hole' mining. In this method, the land is first cleared by cutting and removing the ground vegetation and then pits ranging from 5 to 50 m^2 are dug into the ground to reach the coal seam. Thereafter, tunnels are made into the seam sideways to extract coal which is first brought into the pit by using a conical basket or a wheel barrow and then taken out and dumped on nearby unmined area (Photo 1). Finally, the coal is carried by trucks to the larger dumping places near highways for its trade and transportation. Entire road sides in and around mining areas are used for piling of coal which is a major source of soil, water and air pollution (Photo 2). Off road movement of trucks and other vehicles in the area causes further damage to the ecology of the area. Hence, a large extent of the land is spoiled and denuded of vegetal cover not only by mining but also by dumping and storage of coal and associated vehicular movement. The district of Jaintia hills has been most extensively extracted in terms of coal among all the district of the state (Das Gupta, 1999). As a result of this, there has been conversion of the original lush green landscape into mine spoils in many parts of the district. The crude and unscientific 'rat-hole' method (Photo 3) of mining adopted by the primitive operators leads to the degradation of the landscape (Sarma, 2002).

In spite of practical success and lower operating cost, there are two major problems associated with 'rat-hole' mining:

(a) Formation of new habitats, called coal mine/colliery spoils which lack structure because of up-side-down change in the position of soil horizons and haphazard mixing of coal particles, and

(b) Deposition of coal particles both in wet and dry season through water seepage and wind, respectively on the land which is not directly hit by mining operation like hilltops, hillslopes, abandoned and cultivated agricultural fields, and coal dumping areas.



Note the proximity of coal seam to the ground surface

Photo 1. Soil profile indicating the position and thickness of coal seam

Photo 2. A view of coal mining in Jaintia hills

Photo 3. Abandoned 'rat-hole' coal mines in Jaintia hills

Coal mine spoils when freshly tipped has a great range of particle size ranging from large pieces of shales to silt and clay. These mine spoils represent extremely rigid substrata for plant growth and development. Among the factors which hinder the growth of plant species on these spoils, acidity merits special attention. Extreme acidity is caused due to the oxidation of iron pyrites (Sailo and Sanjay-Swami, 2019). Besides acids, coal mine spoils contain toxic levels of environmental sensitive organic and mineral bound elements such as Fe, Mg, Bi, Al, V, Cu, Cd, Ni, Pb, and Mn etc. Soils are the major sink for trace elements released into the environment because of their high metal-scavenging potential. This, in turn, degrades the chemical and microbiological quality of soil. All heavy metals released to the soil at high concentrations have strong toxic effects and are regarded as environmental pollutants (Alloway, 1990) which largely effects soil fertility.

Due to extensive coal mining, large areas of Jaintia hills of Meghalaya has been turned into degraded land, creating unfavourable condition for plant growth. In the last 12 years, coal mining area has increased by 1.2% and agricultural land has decreased by 1.5% in Meghalaya due to the deposition of coal particles (Semwal *et al.,* 2004). Owing mostly to acidity-related fertility stress, average crop productivity in acid soil regions like Meghalaya is very low, coupled with increasing concentration of heavy metals; productivity has further dropped (Lyngdoh and Sanjay-Swami, 2018). Continued decline in plant growth reduces yield which eventually leads to food insecurity. Various methods of remediating metal polluted soils exist; these range from physical and chemical methods to biological methods. Most physical and chemical methods such as encapsulation, solidification, stabilization, electrokinetics, vitrification, vapour extraction, and soil washing and flushing are expensive and do not make the soil suitable for plant growth. Biological approach (bio-remediation), on the other hand encourages the establishment / reestablishment of plants on polluted soils. It is an environmentally friendly approach as it is achieved via natural processes. Bio-remediation is also an economical remediation technique compared with other remediation techniques.

Bio-remediation of Heavy Metal Polluted Soils

Bio-remediation is the use of organisms (micro-organisms and/or plants) for the treatment of polluted soils. It is a widely accepted method of soil remediation because it is perceived to occur via natural processes. It is equally a cost effective method of soil remediation. Although bio-remediation is a no disruptive method of soil remediation, it is usually time consuming. Further, heavy metals cannot be degraded during bio-remediation but can only be transformed from one organic complex or oxidation state to another. Due to a change in their oxidation state, heavy metals can be transformed to become either less toxic, easily volatilized, more water soluble (and thus can be removed through leaching), less water soluble (which allows them to precipitate and become easily removed from the environment) or less bio-available. Bio-remediation of heavy metals can be achieved via the use of micro-organisms, plants, or the combination of both organisms.

Phytoremediation is an aspect of bio-remediation that uses plants for the treatment of polluted soils. It is suitable when the pollutants cover a wide area and when they are within the root zone of the plant (Jadia and Fulekar, 2009). Phytoremediation of heavy metal polluted soils can be achieved via different mechanisms. These mechanisms include phytoextraction, phyto-stabilization, and phytovolatilization (Marques *et al.,* 2009).

(a) Phytoextraction: This is the most common form of phytoremediation. It involves accumulation of heavy metals in the roots and shoots of phytoremediation plants. These plants are later harvested and incinerated. Plants used for phytoextraction usually possess the following characteristics: rapid growth rate, high biomass, extensive root system, and ability to tolerate high amounts of heavy metals. This ability to tolerate high concentration of heavy metals by these plants may lead to metal accumulation in the harvestable part; this may be problematic through contamination of the food chain. There are two approaches to phytoextraction depending on the characteristics of the plants involved in the process. The first approach involves the use of natural hyperaccumulators, that is, plants with very high metal-accumulating ability, while the second approach involves the use of high biomass plants whose ability to accumulate metals is induced by the use of chelates, that is, soil amendments with metal mobilizing capacity. Hyperaccumulators accumulate 10 to 500 times more metals than ordinary plant; hence they are very suitable for phytoremediation. An important characteristic which makes hyperaccumulation possible is the tolerance of these plants to increasing concentrations of these metals (hypertolerance). This could be a result of exclusion of these metals from the plants or by compartmentalization of these metal ions; that is, the metals are retained in the vacuolar compartments or cell walls and thus do not have access to cellular sites where vital functions such as respiration and cell division take place.

Generally, a plant can be called a hyper-accumulator if it meets the following criteria: (i) the concentration of metal in the shoot must be higher than 0.1% for Al, As, Co, Cr, Cu, Ni, and Se, higher than 0.01% for Cd, and higher than 1.0% for Zn; (ii) the ratio of shoot to root concentration must be consistently higher than 1; this indicates the capability to transport metals from roots to shoot and the existence of hypertolerance ability; (iii) the ratio of shoot to root concentration must be higher than 1; this indicates the degree of plant metal uptake (Blaylock and Huang, 2000).

Some of these plants include *Haumaniastrum robertii* (Co hyperaccumulator); *Aeollanthus subacaulis* (Cu hyperaccumulator); *Maytenus bureaviana* (Mn hyperaccumulator); *Minuartia verna* and *Agrostis tenuis* (Pb hyperaccumulators); *Dichapetalum gelonioides*, *Thlaspi tatrense*, and *Thlaspi caerulescens* (Zn hyperaccumulators); *Psycotriavan hermanni* and *Streptanthus polygaloides* (Ni hyperaccumulators); *Lecythis ollaria* (Se hyperaccumulator). *Pteris vittata* is an example of a hyperaccumulator that can be used for the remediation of soils polluted with As. Some plants have the ability to accumulate more than one metal. For instance, Zn hyperaccumulator, *Sedum alfredii*, can equally hyperaccumulate Cd. The possibility of contaminating the food chain through the use of hyperaccumulators is a major limitation in phytoextraction. However, many species of the Brassicaceae family which are known to be hyperaccumulators of heavy metals contain high amounts of thiocyanates which make them unpalatable to animals; thus this reduces the availability of these metals in the food chain. Most hyperaccumulators are generally slow growers with low plant biomass; this reduces the efficiency of the remediation process. Thus, in order to increase the efficiency of phyto-extraction, plants with high growth rate as well as high biomass (e.g., maize, sorghum, and alfalfa) are sometimes used together with metal chelating substances for soil remediation exercise.

(b) Phytostabilization: Phytostabilization involves using plants to immobilize metals, thus reducing their bioavailability via erosion and leaching. It is mostly used when phytoextraction is not desirable or even possible. This form of phytoremediation is best applied when the soil is so heavily polluted so that using plants for metal extraction would take a long time to be achieved and thus would not be adequate. The growth of plants (used for phytostabilization) is adversely affected when the concentration of heavy metal in the soil remains high. Phytostabilization of heavy metals takes place as a result of precipitation, sorption, metal valence reduction, or complexation. The efficiency of phytostabilization depends on the plant and soil amendment used. Plants help in stabilizing the soil through their root systems; thus, they prevent erosion. Plant root systems equally prevent leaching via reduction of water percolation through the soil. In addition, plants prevent man's direct contact with pollutants and they equally provide surfaces for metal precipitation and sorption. Based on the above factors, it is important that appropriate plants are selected for phytostabilization of heavy metals. Plants used for phytostabilization should have the following characteristics: dense rooting system, ability to tolerate soil conditions, ease of establishment and maintenance under field conditions, rapid growth to provide adequate ground coverage, and longevity and ability to self-propagate. Soil amendments used in phytostabilization help to inactivate heavy metals; thus, they prevent plant metal uptake and reduce biological activity. Organic materials are mostly used as soil amendments in phyto-stabilization. The best soil amendments are those that are easy to handle, safe to workers who apply them, easy to produce, and inexpensive and most importantly are not toxic to plants. Organic amendments are preferred because of their low cost and the other benefits they provide such as provision of nutrients for plant growth and improvement of soil physical properties. In general, phytostabilization is very useful when rapid immobilization of heavy metals is needed to prevent groundwater pollution. However, because the pollutants remain in the soil, constant monitoring of the environment is required and this may become a problem.

(c) Phytovolatilization: In this form of phytoremediation, plants are used to take up pollutants from the soil; these pollutants are transformed into volatile forms and are subsequently transpired into the atmosphere. Phytovolatilization is mostly used for the remediation of soils polluted with Hg. The toxic form of Hg (mercuric ion) is transformed into the less toxic form (elemental Hg).The problem with this process is that the new product formed, that is, elemental Hg, may be redeposited into lakes and rivers after being recycled by precipitation; this in turn repeats the process of methyl-Hg production by anaerobic bacteria. Examples of transgenic plants which have been used for phytovolatilization of Hg polluted soils are *Nicotiana tabacum*, *Arabidopsis thaliana,* and *Liriodendron tulipifera.*

Phytoremediation is an integrated multi-disciplinary approach that uses the remarkable ability of plants to concentrate elements and compounds from the soil environment and metabolize various molecules in their tissues, making phytoremediation a very promising technique for the removal of pollutants from the environment (Garbisu and Alkorta, 2003). Since most of plant roots are located in the soil, they can play an important role in metal removal via filtration, adsorption and cation exchange, and through plant-induced chemical changes in the rhizosphere. Certain species of higher plants can accumulate very high concentrations of metals in their tissues without-showing toxicity (Bennett *et al.*, 2003). Such plants can be used successfully to clean up heavy metal polluted soils if their biomass and metal content are large enough to complete remediation within a reasonable period. Thus, research on soil contamination around coal mine sites is receiving increasing attention in restoration of soil ecosystems and their sustainable use.

Phytoremediation of Heavy Metals Polluted Soil of Coal Mine Area of Jaintia Hills

In order to assess the phytoremediation effect on the heavy metals polluted soil of coal mine area of Jaintia hills, a pot culture trail was conducted at School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, CAU, Umiam, Meghalaya. The materials used and techniques adopted are discussed in the next section.

MATERIALS AND METHODS

Keeping in view the much higher extraction rate of coal in Sutnga area than in any other part of the state, a bulk surface soil sample (0-15 cm) from Sutnga was collected. Sutnga coalfield is the eastern extension of Bapung coalfield. Coal is found in two seams, the top one being only 0.1 to 0.2 m and the bottom seam varies in thickness from 0.3 to 0.6 m and the vertical interval between the two seams is 3 to 5 m. The total reserve of coal is 0.65 Mt over an area of 0.16 km^2. The collected soil sample was processed and analysed in the laboratory. The physico-chemical analysis of soil sample exhibited pH 3.93, O.C. 0.83%, available N, P and K 259.87, 9.18 and 166.00 kg/ha, respectively. The heavy metals content of the soil with respect to Cr, Cd, Pb, Ni and Co was recorded as 95.39, 25.94, 17.41, 51.13 6.46 mg/kg, respectively.

The pot culture trial was conducted using processed soil with two phytoremediating crops *viz.,* Asparagus *cv.* UPC-287 (PC_2) and Sunflower *cv.* EC-68913 (PC_3) along with control with no phytoremediating crop (PC_1). To find out the variability in the phytoremediation potential of both the crops on the heavy metals, 33 pots for each phytoremediating crop including no crop treatment was considered as 33 replications and the significant means was separated by following one way ANOVA. The crop plants were harvested at 60 days after sowing (DAS).

RESULTS AND DISCUSSION

Plant dry matter yield is an important parameter reflecting the growth of crop. The result revealed that dry matter yield of Asparagus (11.79 g/pot) was higher than the Sunflower crop (5.08 g/pot) (Table 1) due to the vegetative nature of asparagus which is bushy and climbing in nature (Sheahan, 2012) contributing to higher dry matter production (Photo 4) as compared to sunflower (Photo 5) which when grown in heavy metals polluted soil resulted in stunted growth, reduced biomass accumulation and produced low dry matter yield. These results are similar to those

Table 1: Dry matter yield (g/pot) of phytoremediating crops grown in heavy metals polluted soil of coal mine area of Jaintia hills of Meghalaya

Asparagus (Pc_2)	Sunflower (Pc_3)
11.79	5.08

Photo 4. Asparagus at 30 days after sowing

Photo 5. Sunflower at 30 days after sowing

described by other workers in different plant species (Tewari *et al.,* 2002; Zhou and Qiu, 2005; Gajewaska and Sklodowska, 2007). Another factor that contributed to the difference in dry matter yield between Asparagus and Sunflower is the duration of crop growth, since both the crops were harvested 60 DAS, Asparagus reached at physiological maturity stage at 60 DAS due to its early maturing capability (Adeyanju and Ishiyaku, 2007) contributing to a greater biomass in 60 days as compared to Sunflower whose physiological maturity is around 90-120 days for early maturing varieties (Fernández-Luqueño *et al.,* 2014). However, the Sunflower was found to be superior phyto-remediating crop in comparison to Asparagus as it accumulated more heavy metals *viz.,* Cr, Cd, Pb, Ni and Co as 51.83, 15.05, 10.40, 30.88 and 5.68 µg/pot, respectively while Asparagus accumulated 42.98, 14.30, 9.20, 21.43 and 4.06 µg/pot, respectively (Table 2). The analysis of heavy metals in the soil after harvest of phyto-remediating crops indicated that the content of heavy metals reduced significantly in soil phyto-remediated by Asparagus (S_2) and Sunflower (S_3) compared to non-phytoremediated soil (S_1) as presented in Table 3. However, the soil phyto-remediated by Sunflower recorded least heavy metals content in soil indicating its superiority over Asparagus.

CONCLUSION

Extensive coal mining in the hill state of Meghalaya, has resulted in ecological upheaval of thousands of hectares of land. The land which is directly hit by mining operations like excavation and dumping of overburden and coal is converted into new habitats, called coal mine/colliery spoils, which lack completely the soil structure and whose elemental concentrations are greatly altered. The areas like hilltops, hillslopes and cultivated and abandoned agricultural fields, which are not directly hit by mining operations, though retaining their structure, are affected by deposition of coal particles through wind and seepage water. The coal mine spoils contain toxic levels of environmental sensitive organic and mineral bound elements such as Fe, Mg, Bi, Al, V, Cu, Cd, Ni, Pb, and Mn etc. The heavy metals released to the soil at high concentrations have strong toxic effects and are regarded as environmental pollutants which largely effects soil fertility. Due to extensive coal mining, large areas of Jaintia hills of Meghalaya has been turned into degraded land, creating unfavourable condition for plant growth.

Most physical and chemical methods of remediating metal polluted soils such as encapsulation, solidification, stabilization, electro-kinetics, vitrification, vapour extraction, and soil washing and flushing

Table 2: Heavy metals concentration (mg/kg) and uptake (µg/pot) by phytoremediating crops grown in heavy metals polluted soil of coal mine area of Jaintia hills of Meghalaya

	Chromium (Cr)		Cadmium (Cd)		Lead (Pb)		Nickel (Ni)		Cobalt (Co)	
	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
Asparagus (PC_2)	3.67	42.98	1.22	14.30	0.78	9.20	1.83	21.43	0.35	4.06
SD	±0.36	±2.37	±0.16	±1.60	±0.08	±1.07	±0.18	±1.25	±0.08	±0.85
Sunflower (PC_3)	10.22	51.83	2.99	15.05	2.07	10.40	6.15	30.88	1.13	5.68
SD	±0.34	±1.50	±1.06	±4.08	±0.21	±0.88	±0.68	±1.20	±0.15	±0.40

Table 3: Heavy metals content (mg/kg) in soil after harvest of phytoremediating crops grown in heavy metals polluted soil of coal mine area of Jaintia Hills of Meghalaya

Non-phytoremediated soil (S_1)					Asparagus remediated soil (S_2)					Sunflower remediated soil (S_3)				
Cr	Cd	Pb	Ni	Co	Cr	Cd	Pb	Ni	Co	Cr	Cd	Pb	Ni	Co
95.05	25.20	17.07	50.59	6.65	51.70	11.25	8.80	30.30	2.44	41.63	9.32	7.10	20.02	0.79

are expensive and do not make the soil suitable for plant growth. Biological approach (bio-remediation), on the other hand encourages the establishment / reestablishment of plants on polluted soils. Phyto-remediation is an aspect of bio-remediation that uses plants for the treatment of polluted soils. Therefore, in order to assess the phyto-remediation effect on the heavy metals polluted soil of coal mine area of Jaintia Hills, a pot culture trail was conducted using two phyto-remediating crops *viz.,* Asparagus *cv.* UPC-287 (PC_2) and Sunflower cv. EC-68913 (PC_3) alongwith control with no phyto-remediating crop (PC_1). On the basis of present investigation, the farmers of coal mine areas of Jaintia hills of Meghalaya may be advised to phyto-remediate their soil with Sunflower crop before planting the main crop to reduce the adverse effects of heavy metals.

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Water Harvesting and its Management through Farm Pond and Utilization of Conserved Water for Vegetable Crops for Sustainable Production in Upland Areas

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The light textured well-drained upland soils in North Eastern Ghat Zone provide scope for cultivation of vegetables during rainy season. Harvesting of this runoff water in farm pond with proper lining can conserve the runoff water and recycling of this water for life-saving irrigation can protect the crop from drought/dry spell grown in 90% of land area. The ponds can be very helpful for sustainable production of dry land crops. A trial was therefore conducted during 2005 to 2007 in All India Coordinated Research Project (AICRP) for Dryland Agriculture Phulbani, Odisha with an objective to obtain the water loss and economics of the lined ponds. There were three treatments T1-Lined pond with soil cement plaster (6:1) 8 cm thickness, T2-Unlined pond, T3-No pond. 10% of the cropped area was dug for construction of the pond in Lined and Unlined pond treatments. The size of the pond was 7 m top width, 1m-bottom width, 3 m height, and 1:1 side slope. The water harvested in pond was reutilized for the pumpkin and radish crop, which was sown only in lined pond treatment during *rabi*, as there was no water available in unlined pond so the crop was not sown there. The water loss was 4.21 litre/day/m^2 in lined pond and 1089 litre/day/m^2 in unlined pond. Provision of dugout pond in 10% area of the plot at the downstream side with 8 cm thickness soil cement plaster (6:1) gave 14.5% higher cauliflower equivalent yield compared to no pond. The B:C ratio was found to be 2.25 in lined pond. The payback period for lined pond (soil cement plaster 6:1 of 8 cm thickness) is 5 years and unlined pond was estimated at 2 years.

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INTRODUCTION

The light textured well-drained upland soils in North Eastern Ghat Zone provide scope for cultivation of vegetables during rainy season. The intermittent dry spells and terminal drought affect the performance of those high value crops in most of the years. About 25% of the rainfall is lost as runoff. Harvesting of this runoff water in farm pond with proper lining can conserve the runoff water and recycling of this water for life-saving irrigation can protect the crop from drought / dryspell grown in 90% of land area. The ponds will be helpful for sustainability in productivity of dryland crops. Soil structure and organic matter status decide the water holding capacity of the soil. Keeping those points in view, the present experiment involving two water management systems (no pond and pond) has been designed. *Ex-situ* water management is one type of management of land and conservation of excess rainfall which not only helps the havoc at the lower side but also provides life saving irrigation for a second crop. Many authors have focused on on farm reservoir (OFR) with lined and unlined system for increasing the yield and economic condition of the farmers. Panigrahi and Panda (2003) found the average increase in yield of rice and mustard yield due to supplemental irrigation from the OFR to be 29.2% and 22.3% more over the average yield of corresponding crops under rainfed condition The side slope of the harvesting pond was maintained as 1:1 (Panigrahi and Panda

2003). The optimum size of OFR was found to be 12% of the land area which gave B:C ratio internal rate of return and payback period of 1.22, 16.1% and 13 years, respectively with the cropping system of rice mustard. The B:C ratio of lined and unlined OFRs occupying 10% of the farm area becomes 1.65 and 2.70, respectively (Sethy *et al.,* 2005). Suraj Bhan (2009), Jindal *et al.* (2009), Sharma *et al.* (2004) and Kumar *et al.* (2006) found that the effect of rainwater harvesting and ponds in different parts of the countries were suitable for soil and water conservation and increasing crop yield and economics of the farming communities. The present study was therefore conducted to quantify the increase in land productivity and land use efficiency through on-farm water harvesting and water/seepage loss in different ponds.

MATERIALS AND METHODS

The present study was conducted in AICRP, OUAT, Phulbani, Odisha during the year 2005-2007. 10% of the cropped area was dug for construction of the pond in lined and unlined pond treatments (Photo 1). Size of the pond was 7 m top width, 1 m bottom width, 3 m height, and 1:1side slope. The water harvested in pond was re-utilized for the pumpkin crop, which was sown only in Lined pond treatment, as there was no water available in unlined pond so the crop was not sown there. The treatments tried were T1-Lined pond with soil cement plaster in 6:1 ratio (8 cm thickness), T2- Unlined pond, T_3- No pond (control). The water harvested in pond was re-utilized for the pumpkin and radish crop, which was sown only in lined pond treatment during *rabi*, as there was no water available in unlined pond so the crop was not sown there. Cauliflower was sown at 45 x 45 cm and radish at 45 x 5 cm spacing in gross plot size of 30 x 15 m and net plot size of 28.2 x 12.3 m. Recommended package and practices were given to the both the vegetable crops.

RESULTS AND DISCUSSION

The mean cauliflower equivalent yield was highest (5.015 t/ha) (Table 1) in lined pond and water loss was lowest (147.3 litre/day) (4.21 litre/day/m^2) (Table 2) in lined pond.

The mean *rabi* pumpkin equivalent yield in lined pond was 33.583 t/ha. The mean yield in last

Photo 1. Lined pond

Table 1: *Kharif* crop yield during 2005-06 to 2007-08

Treatment	Yield of *kharif* produce (t/ha)				Yield of *rabi* produce t/ha			
	2005-06 Tomato (C.E.Y.)	2006-07 Tomato (C.E.Y.)	2007-08 Cauliflower	Mean C.E.Y	2005-06 Pumpkin	2006-07 Pumpkin	2007-08 Radish (PEY)	Mean (PEY)
T1-Lined pond with soil cement (6:1) plaster 8 cm thickness	22.83 (9.132)	3.78 (1.512)	4.4	5.015	32.5	34.5	22.5 (33.75)	33.583
T2-Unlined pond	21.33 (8.532)	3.55 (1.42)	3.82	4.591				
T3-No pond	19.83 (7.932)	3.52 (1.408)	3.53	4.29				
Mean	21.33 (8.532)	3.62 (1.448)	3.92	4.633				

Table 2: Water loss in different treatments in different years

Treatment	Water loss litre/day			
	2005-06	2006-07	2007-08	Mean
T1 - Lined pond with soil cement (6:1) plaster 8 cm thickness	86	131	225	147.3
T2 - Unlined pond	37,000	33,000	28,000	32,667
T3 - No pond	-	-	-	-

three years shows that the cauliflower equivalent yield in lined pond was highest (5.015 t/ha) which is 8.5% higher than the unlined pond due to more number of irrigation was given to unlined pond (4.591 t/ha) and 14.5% higher than the no pond (4.29 t/ha) as no irrigation was given in no pond. The seepage loss in unlined pond was highest (32.667 m^3/day) (1089 litre/day/m^2). The cost of lined pond was ₹ 9.967/- and that of unlined pond was ₹ 2,993/- (Table 3).

Biometric observation during *kharif* and *rabi* shows the lined pond got highest plant height and spread compared to others due to more number of irrigation was applied to them (Tables 4 and 5).

Table 6 revealed that the WUE was highest in lined pond (3.165 kg/ha/mm).The cost of lining per square meter was ₹ 88.5/-. Water loss in lined pond is in increasing trend where as the water loss in unlined pond is decreasing trend which may be attributed to siltation. It is observed that tomato yield was better than the cauliflower yield. The

Table 3: Water loss in different treatments

Treatment	Total cost of the pond (₹)	Cost of lining (₹)	Water loss from the pond lit/day	Time taken to dry up the pond (Days)	Cost of storage (₹/m^3)	Economics loss due to seepage loss (₹/day)	Water loss (lit/day/m^2)
	1	2	3	4	5	6=(7/4)X1000	7=2/58
T1-Lined pond with soil cement (6:1) plaster 8 cm thickness	9,967	88.5	147.3	509	133	19.58	4.21
T2-Unlined pond	2,993	0	32,667	2.3	40	1301.3	1089
T3-No pond							

Table 4: Biometric observations of *kharif* (2007-08) and *rabi* (radish)

Treatment	Plant Height (cm)	Spread (cm)	No of leaves
kharif			
T1	39	51.6	17.6
T2	37.5	43.8	16.4
T3	31.2	36.8	13.2
rabi			
T1	20.8	44.4	20.8

Table 5: Number of irrigation applied in different years

Treatment	Irrigation numbers			Quantity of water applied, litre (mm)		
	2007-08	2006-07	2005-06	2007-08	2006-07	2005-09
T1-Lined pond with soil cement (6:1) plaster 8 cm thickness	18	10	13	600 x 18 = 10,800(24)	600 x 10 = 6,000 (13.4)	600 x 13 = 7,800 (17.33)
T2-Unlined pond	1	8	6	300x1=300(0.7)	2,400(5.6)	300X6=1,800(4)

rich farmers or farmers can dug pond can go for this technology as higher B:C ratio (2.25) is obtained in lined pond compared to 2.12 in unlined pond and 1.97 in no pond treatment plots. Water balance revealed that 74.5% were lost through seepage and only 3.9% can be irrigated (Table 7).

Techno Economic Analysis

The net present worth of investment made on lined pond where lined pond was made is ₹ 40,487/-, whereas it was ₹ 15,279/- for unlined pond and ₹ 8,935/- for no pond system against an investment (Total PW Cash inflow) of ₹ 72,877; ₹ 28,873/- and ₹ 18,136/-, respectively. Based on the NPW and B:C ratio it was concluded that the lined pond is economical and there is substantial increase in income of farmer by making lined pond and using the water of lined pond for raising a second crop.

Table 6: Water use efficiency in different treatments during 2007-08

Treatments	Water use efficiency (litre/day/mm)
T1 - Lined pond with soil cement (6:1) plaster 8 cm thickness	3.165
T2 - Unlined pond	2.748
T3 - No pond	2.539
Mean	2.820
Rainfall, mm	1390

Table 7: Water balance in the lined pond

Item	Quantity (litre)	%
Water in the tank on 1.04.2009	Nil	
Water from runoff and rainfall	2,01,753	100
Water loss during 2009-10	1,50,338	74.5
Irrigation	7,800	3.9
Over flow	43,615	21.6
Water on 31.03.2010	Nil	
Rainfall volume	7,60,140	100
Runoff volume	1,17,293	15.4

The B:C ratio for lined pond was 2.25 where as it is 2.12 in case of unlined pond. It indicates that the B:C ratio is high in lined pond in comparison with unlined pond and no pond has lowest B:C ratio (1.97). Hence it is worth constructing the lined pond. The interim rate of return is 66% in lined pond. Internal rate of return is more than the present interest rate *i.e.* 12%. Payback period for both lined and unlined pond were found to be two years.

CONCLUSIONS

Provision of dugout pond in 10% area of the plot at the downstream side with 8 cm thickness soil cement plaster (6:1) gave 41% higher cauliflower equivalent yield compared to no pond. The B:C ratio was found to be 2.25 in lined pond. The payback period for lined pond (soil cement plaster 6:1 of 8 cm thickness) is 5 years and unlined pond was estimated as 2 years.

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Soil Health Management: An Overview

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Soil health is an integrative ecosystem property that represents the ability of soil to respond to agricultural intervention, so that it continues to support agricultural production and soil function. The major challenge for sustainable soil management is uninterrupted ecosystem services with optimum nutrient supply for crop production. Soil health is dependent on the maintenance of four major functions: carbon transformations; nutrient cycles; soil aggregation; and the regulation of soil pathogens. Each of these functions is manifested as an integration of a variety of processes driven by interacting soil organisms under the influence of the abiotic soil environment. Soil microbial community under the impact of agricultural interventions shows integrative pattern of interactions within each of these functions and leads to the conclusion that measurement of individual groups of organisms, soil processes does not suffice to attain the state of the healthy soil. In this paper we have comprehensively reviewed on different factors directly or indirectly related to various functions soil health, impact of long-term cropping system on major soil health indicators (soil organic carbon, soil microbial biomass, SMBC etc.) and further proposed minimum dataset which is more feasible, reproducible and accessible for inclusion in rapid soil health data analysis related to productivity.

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INTRODUCTION

Soil health is widely used in sustainable agriculture to describe the general condition or quality of the soil. On the other hand, soil management is fundamental for all agricultural systems, still there are proofs for widespread degradation of agricultural soils in the form of erosion, loss of organic matter, soil pollution, compaction, increased salinity and other harms (Bhattacharyya *et al.,* 2015). The soil degradation sometimes occurs rapidly because of poor soil management. For this reason, research has been directed for devising measures of the healthy soil, which could be used to monitor its condition and inform its management input so that degradation is avoided. This has led to debate around the question 'What is soil health?' There are two ways in which the concept of soil health has been studied a) 'reductionist' b) 'integrated'. The former is based on estimation of soil condition using a set of independent indicators of specific soil properties like physical, chemical and biological. This approach has been much discussed and well-reviewed (Doran and Jones, 1996). This reductionist approach has much in common with conventional quality assessments in other fields, such as materials science. The alternative, integrated, approach makes the assumption that the health of a soil is more than simply the sum of the contributions from a set of specific components. It recognizes the possibility that there are emergent properties resulting from the interaction between different processes and properties. These aspects do not seem to have been explored to the same extent in recent literature (Harris *et al.,* 1996). A working definition is that 'a healthy agricultural soil is one that is capable of supporting the production of food and fibre, to a level and with a quality sufficient to meet human needs, together with continued delivery of other ecosystem services that are essential for maintenance of the quality of life for humans and the conservation of biodiversity'.

The sustenance of soil health depends on an understanding of how soils respond to agricultural practices over time. In order to develop best management practices, it is necessary to improve method to assess the soil heath over timescale. There is a great need to determine the status and to enhance the quality of our soil resources. Assessment and monitoring the soil health must also provide opportunity to evaluate and redesign soil and land management systems for sustainability. Standards of soil health are needed to determine whether it is sustainable or not and also to determine any soil management system is functioning at acceptable levels of performance or not. The aim of sustainable agriculture is to develop farming systems that are productive and profitable, conserve the natural base, protect environment and enhance health and safety in natural resource environment in long-term perspective. In this article we have discussed the impacts of land use and management practices on soil health, considering soil organic matter as EPI centre of soil health.

An Integrated Concept of Soil Health

Considering soil as a system: Soil is undeniably a multi-component, multi-functional and very complex system with definable operating limits and a characteristic spatial configuration. Within a continuum of possibilities, there are recognizable soil types that originate depending on variations in factors, such as parent material, climate and topography, which largely determine the dominant physical and chemical properties (Manna *et al.,* 2017). These have often been altered, however, by agricultural interventions, such as drainage, irrigation, use of lime to alter soil reaction and additions of plant nutrients. The agricultural soil system is a subsystem of the agro-ecosystem, and the majority of its internal functions interact in a variety of ways across a range of spatial and temporal scales.

Considering soil as an ecosystem service provider: Humans depend on both natural and managed (including agricultural) ecosystems for a range of what have been called 'ecosystem goods and services' (De Groot *et al.,* 2002). These include the natural processes that support the production of food and fibre, such as nutrient cycles and the biological control of pests and diseases together with the regulation of water flow and quality, and influence on the gaseous composition of the atmosphere with its implications for the control of the global climate. In reality, these goods and services are functional outputs of biological processes. Soil is a living system and as such is distinguished from weathered rock mainly by its biology. Nonetheless, it should be emphasized that these functions operate by complex interaction with the abiotic physical and chemical environment of soil. Both natural and agricultural soils are the habitat for many different organisms which collectively contribute to a variety of soil-based goods and services. Fig's. 1 and 2 shows the relationships between these and the soil-based biological processes that deliver them. We propose collectively the major services provided by soil, *viz.,* (i) Transformation of carbon through the decomposition of plant residues and other organic matter, including soil organic matter, together with the synthetic activities of the soil biota, including, and particularly, soil organic matter synthesis. Decomposition in itself is not only an essential ecosystem function and driver of nutrient cycles but also supports a detoxification and waste disposal service. Soil organic matter contributes to nutrient cycling and soil structure maintenance. Sequestration of C in soil also plays some role in regulating the emission of greenhouse gases such as methane and carbon dioxide (ii) Cycling of nutrients, for example nitrogen, phosphorus and sulphur, including regulation of nitrous oxide emissions (iii) Maintenance of the structure and fabric of the soil by aggregation and particle transport, and formation of bio-structures and pore networks across many spatial scales. This function underpins the maintenance of the soil

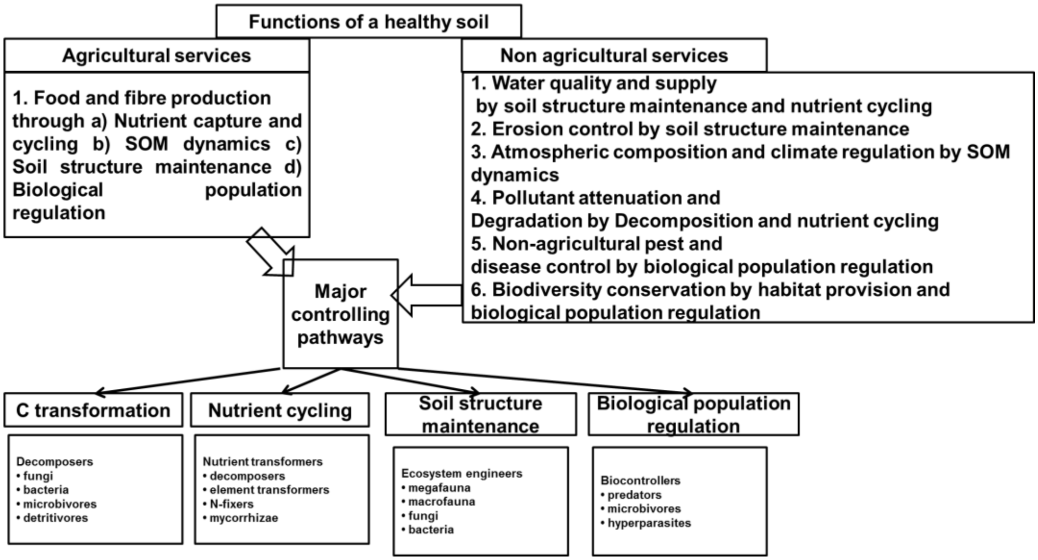
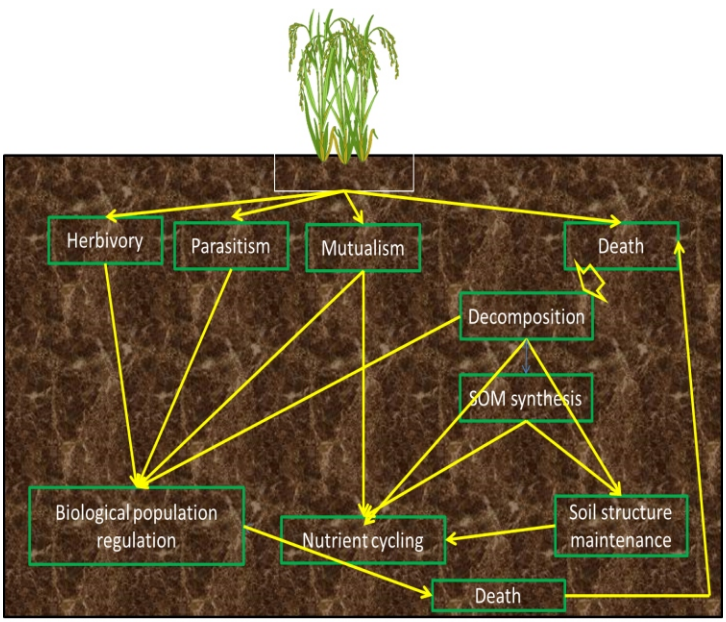


Fig. 1. Relationship between the functions and pathways of healthy agricultural soils



The arrows hypothesize two flows of energy from the plant to the major functions of the soil biota; either directly through the actions of herbivory, parasitism and mutualistic symbiosis, or indirectly via heterotrophic carbon-transforming processes in the soil. Soil organic matter (SOM) synthesis is pictured as supported by energy flowing from the decomposition of plant residues and contributing energy in its turn directly (i.e. by virtue of its properties) to soil structure maintenance and indirectly, through its own decomposition, to nutrient cycling and biological population regulation.

Fig. 2. Inter-connectedness between the major ecosystem functions of soil

habitat and regulation of the soil-water cycle and sustains a favourable rooting medium for plants (iv) Biological regulation of soil populations including organisms recognized as pests and diseases of agriculturally important plants and animals as well as humans.

Factors Controlling Soil Health

Soil type: Particular soil types form in response to the nature of parent material, topography and environmental factors, such as climate and natural vegetation. Past land management by humans can alter natural soils considerably, for example by loss of surface horizons due to erosion, alteration of soil water regime via artificial drainage, salinization due to poor irrigation practices, loss of natural soil organic matter caused by arable production or contamination. Thus, land use and management are the controlling factors for soil health. A set of fixed characteristics such as texture, sand content, etc. combine with climate to set an envelope of possible soil habitat conditions, especially those relating to the soil water regime. Variable factors such as pH, bulk density and soil organic matter content, which are influenced by land-use and management, then determine the prevailing condition of the habitat within the range for a particular soil. These fixed and variable abiotic factors interact with biotic ones to determine the overall condition of the soil system and its associated health. Primary biological factors will include the presence or absence of specific assemblages and types of organisms, the availability of carbon substrate and nutrients, and the concentrations of toxic materials.

Organisms and functions: The relationships between community structure and function are inevitably complex and a prevalent theme in contemporary soil ecology. Relationships between diversity and function of organisms have been postulated to follow a number of forms but rigorous experimental demonstration of these issues is relatively scarce, not least owing to the difficulty in manipulating soil biodiversity as the sole factor. It can be argued that high biodiversity within trophic groups is advantageous since the group is likely to function more efficiently under a variety of environmental circumstances, due to an inherently wider potential. More diverse systems may be more resilient to perturbation since if a proportion of components are removed or compromised in some way, others that prevail will be able to compensate. However, more diverse systems may be less efficient since a greater proportion of available energy is used in generating and countering competitive interactions between components, a situation which may be exacerbated by the similarity in functional properties and hence potential niche competition. All these factors are likely to influence the patterns of interaction between the soil-based functions (Fig. 3), and thence the status of soil health.

Carbon and energy: The energy that drives soil systems is derived from reduced carbon that is ultimately derived from net primary productivity (Fig. 3). Carbon is the common currency of the soil system, and its transfer with associated energy flow is the main integrating factor. This suggests that the quantities and quality of different organic matter pools may be indicative of the state ofthe soil system, while the flows and allocations of carbon between assemblages of organisms may provide information about their relationships to ecosystem functions. However, Existing models of soil carbon dynamics assume the presence of pools of carbon that turn over at different rates. Rapid and medium turnover fractions provide immediate and short-term sources of carbon substrate for the soil biota. More recalcitrant forms that turn over slowly represent long-term reservoirs of energy that serve to sustain the system in the longer term, as well as provide some structural stability.

Nutrients: Nutrients are a controlling input to the soil system and the processes within it. Their

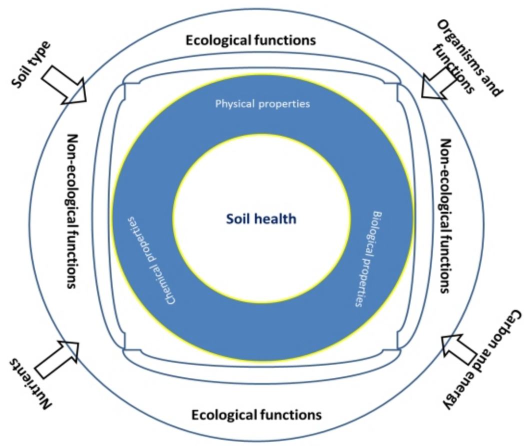


Fig. 3. An integrated concept of soil health along with the factors influencing it

levels and transformations are critical to soil health. After carbon, the cycling of nitrogen and phosphorus to, from and within the soil system most affects its dynamics and the delivery of ecosystem services, including agricultural production. Manipulation of nutrient supplies to increase productive outputs from the soil system by the addition of fertilizers has been one of the key stones of agriculture for centuries. Nonetheless, knowledge is limited about the impacts of nutrient additions on the condition of different assemblages of soil organisms and thence on their functions. Generally, while it is considered that the availability of carbon substrate is normally the primary limiting factor on microbial activity in soils, this is not necessarily the case, and there is accumulating evidence that soil microbes may frequently be N limited (Schimel *et al.,* 2005). Agricultural strategies based on additions of animal manures and the use of mineral fertilizers counter losses of nitrogen, phosphorus and other nutrients with the aim of restoring and sustaining soil health. In well-managed systems employing high levels of manufactured, processed or mechanized inputs, where these strategies are implemented effectively, and productivity is maintained, but it may be compromised in subsistence agriculture where nutrient additions are inadequate or absent. In commercial agriculture, on the other hand, additions of nutrients beyond that which can be used by the soil–plant system lead to their damaging leakage from the soil system into other environmental compartments via leaching and gaseous emissions. In this case the soil system is polluted and unhealthy.

Measuring Soil Health

Soil health is measured mainly for two purposes: i) monitoring for building an inventory as to its status (health); and ii) assessing the impacts of human perturbations onto it. Truly, such assessment should be done against undisturbed virgin sites. But, it is very difficult to find such sites (as reference level) for comparison for a possible degradation or aggradation caused by human disturbances. Under such situations, we can make at least a relative assessment of health of soils with varying anthropogenic stresses for screening and subsequent adoption of less / non-damaging types for upgrading the health. Accordingly, a sequential framework for assessment of soil health is given hereunder (Table 1) wherein a number of interrogations are made as to the purpose, functions, processes that support the functions, critical soil function, and surrogate indicators for a logical interpretation of the whole process. Such assessment of soil health should be done keeping in mind the management goals with associated soil functions and screening of relevant indicators. But the indicators vary according to soil type, microbial diversity, carbon and energy input and nutrient supply (Table 2). Selection of an indicator constitutes an important part of soil health measurement. It is of two types

Table 1: A framework for assessment of soil health

Ecosystem goal	Soil function	Indicators
Food-feed-energy supply	Nutrient cycling including SOC	Microbial biomass C, potentially mineralizable N, dehydrogenase activity, soil respiration, available N, P, K, micro-nutrients, cation exchange capacity, β-glucosidase
Water supply	Water relation	Hydraulic conductivity, maximum water holding capacity, porosity, SOC
Waste recycling	Physical, chemical, biological and cultural environment	Soil aggregate stability, bulk density, sesquioxides, microbial diversity, SOC
Biodiversity protection and conservation	Filtering and buffering	Bulk density, hydraulic conductivity, SOC, cation exchange capacity
Environmental protection and climate change mitigation	Resistance and resilience	SOC, bulk density, potentially mineralizable N, dehydrogenase activity

Table 2: Soil health indicators for diverse agro-ecosystems

Soil type	Cropping system	Indicators identified
Clay loam	Rice-rice	Available K, Zn, OC, %BS and dehydrogenase activity
Sandy loam	Groundnut-redgram	MBC, pH, available P and K, WHC and Zn
Sandy loam	Rice-lentil	OC, available P, Ca and Mg
Sandy	Sorghum-castor	HC, available N, P, K and S, and MBC
Sandy loam	Jute-rice-wheat	Available P and K, MBC, MWD and OC
Sandy clay loam	Rice-rice	Dehydrogenase activity, available K and OC
Silty clay loam	Rice-field pea	MBC, OC, available S and P
Sandy loam	Rice-wheat	MBC, OC, mineralizable N and alkaline phosphatase activity
Loam	Maize-wheat	Available N, OC, MBC, alkaline phosphatise activity, BD and available Zn
Sandy loam	Sorghum-mung bean	Available N, Available Zn, available Cu, MBC, MWD and HC

Source: Mandal et al., 2005 ; Masto et al., 2007 ; Sharma et al., 2008

– one, inherent indicators – these are native and quasi-permanent in nature, undergo little changes; and the other, dynamic indicators – these reflect / capture the signatures of perturbations soils are subjected with. Now-a-days, attempts are being made to find alternative to costly laboratory analysis-based indicators with those having methods involving visual, morphological and spectroscopic. Subsequently, many researchers in India have screened out major indicators for different soil types and cropping systems for assessment of soil health as a function of biological productivity / sustainable yield only; although a few of them have assessed soil quality using two goals *viz.,* i) productivity and ii) environmental protection, and also identified two distinguishing minimum datasets of indicators for those goals (Batra and Manna, 1997; Bhaduri *et al.,* 2014; Bhaduri and Purakayastha, 2014).

Causes for Poor Soil Health

The major reason for poor soil health are: (1) wide gap between nutrient demand and supply; (2) high nutrient turnover in soil plant system coupled with low and imbalanced fertilizer use; (3) emerging deficiency of secondary and micronutrients due to improper use of inputs such as water, fertilizers, pesticides ; (4) insufficient use of organic inputs; (5) acidification and Al toxicity; (6) development of salinity and alkalinity in soils; (7) development of adverse soil condition such as heavy metal toxicity; (8) disproportionate growth of microbial population responsible for soil sickness, and (9) natural and man-made calamities such as erosion, deforestation occurring due to rapid industrialization, urbanization.

Small Farmer Oriented Soil Health Management Planning Framework

Each farmer is generally faced with a unique situation in the choice of management options to address soil health constraints and each system affords its own set of opportunities or limitations to soil management. A more comprehensive understanding of soil health status can better guide farmers' soil management decisions. However, until recently, there has not been a formalized decision making process for implementing a soil health management system. So, we propose a framework to alleviate field-specific constraints, identified through standard measurements, and then maintain and monitor the measurement unit for improved soil health status. The framework includes (Fig. 4):

Determine farm background and management history: Compile background info: history by management unit, farm operation type, equipment, access to resources, situational opportunities or limitations.

Set goals and sample for soil health: Determine goals and decide on the number and distribution of soil health samples, according to operation's background and objectives.

For each management unit: identify and explain constraints, prioritize: The Soil Health

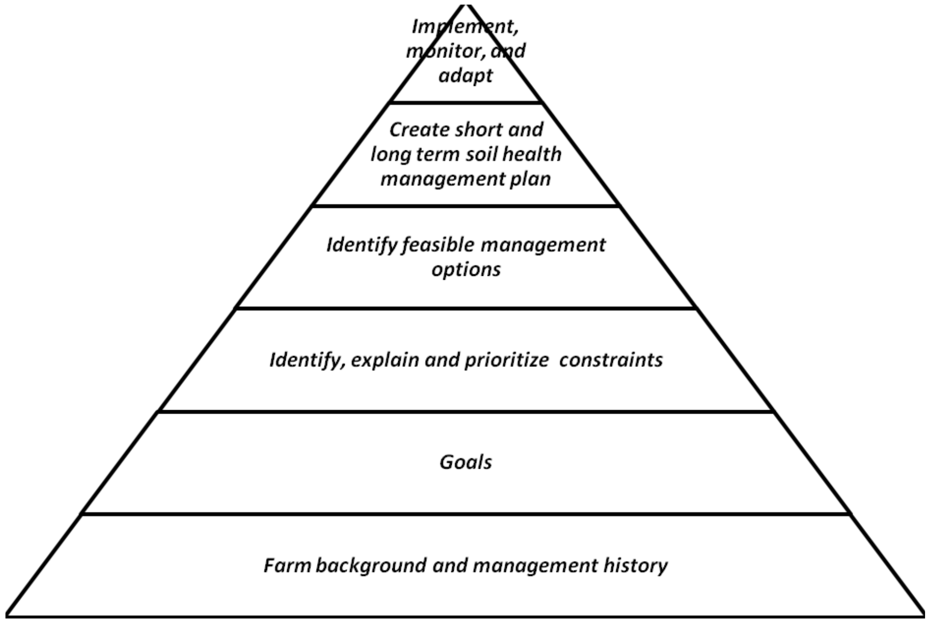


Fig. 4. Small farmer oriented soil health management planning framework

Assessment Report identifies constraints and guides prioritization. Explain results based on background where feasible, and adjust priorities.

Identify feasible management options: Identify which of the suggestions from Step 3 may be feasible for the operation. For guidance, use the management suggestions table available as part of the Soil Health Assessment Report, or online with NRCS practice linkages.

Create short and long term soil health management plan: Integrate agronomic science of Steps 3 and 4 with grower realities and goals of Steps 1 and 2 to create a specific short-term schedule of management practices for each management unit and an overall long-term strategy.

Implement, monitor and adapt: Implement and document management practices. Monitor progress, repeat testing, and evaluate outcomes. Adapt the plan based on experience and data over time. Remember that soil health changes slowly.

Soil Health Management Strategy

Tillage management: As new technologies have been developed, the reliance on full width tillage to kill weeds, incorporate crop debris and amendments, and prepare seedbeds has been diminished. At the same time, we now have a better understanding of how critical decreasing soil disturbance is for diverse and active biological activity that is critical for well-functioning, healthy soil. Extensive tillage temporarily stimulates certain species making up the microbial community to 'burn off', or decompose, organic matter quickly. This reduces soil aggregation, resulting in crusting and soil compaction, in addition to decreased beneficial microbial activity. It is now well understood that reducing tillage intensity, and mechanical soil disturbance in general, can improve soil health and, over time, maintain or even increase yields, while reducing production costs due to saved labour, equipment wear, and fuel. The reducing tillage intensity helped in increasing soil organic carbon and microbial biomass carbon. Reduced tillage and SOM build-up stabilise soil structure, the undisturbed structure is known to produce macropores and preferential flow channels that can direct nutrients (including P) downward into deeper parts of the soil profile. Reduced tillage can reduce overall N loss by reducing ammonium and organic N losses with sediment; however, it may not reduce N leaching in the nitrate form.

Crop rotation: Initially, crop rotation was practiced as a way to avoid depleting the soil of various nutrients and to manage pathogens and pests. Today, crop rotation is also an important component of soil health management in many agricultural production systems. Crop rotations can be as simple as rotating between two crops and planting sequences in alternate years or they can be more complex and involve numerous crops over several years or even at the same time for improved soil health. Proper crop rotations generally increase species diversity, and reduce insect pressure, disease causing pathogens, and weed pressure by breaking life cycles through removal of a suitable host or habitat. Additionally, crop rotation can improve nutrient management and improve soil resiliency (to drought, extreme rainfall and disease) especially after root crops such a carrot or potato that usually involve intensive tillage. Generally yield increases when crops in different families are grown in rotation versus in monoculture (referred to as the "rotation effect"). One basic rule of crop rotation is that a crop should not follow itself. Continuous mono-cropping generally results in the build-up of disease causing pathogens, nematodes, insects and weeds that can lead to yield reductions and the need for increased inputs such as herbicides, insecticides and other pesticides. A cropping sequence for soil health management should include the use of cover crops and / or season-long soil building crops. Rotating with a diversity of root structures and make-ups, from taproots to fibrous rooted crops from a variety of plant families, will also improve the soil organic carbon storage and hence physical, chemical and biological health and functioning.

Cover cropping: Cover crops are usually grown for less than one year. They provide a canopy, organic matter inputs, increased species diversity, and living root activity for soil protection and improvement between the production of main cash crops. They can also be inter-seeded between some main crops. They can be grown as monocultures, or as mixes of two or many more species. When specifically used for improved soil fertility (often by incorporating), cover crops are also referred to as green manures. However it should be noted that often the greatest benefits are derived from cover crops that are terminated in place as this prevents damaging soil disturbance, and allows roots to decompose in the field and create continuous pores. Roots are also generally more effective at contributing to soil organic matter than above ground biomass. Cover crops with shallow fibrous root systems, such as many grasses, build soil aggregation and alleviate compaction in the surface layer. Cover crops with deep tap roots can help break-up compacted layers, bring up nutrients from the subsoil to make them available for the following crop, and provide access to the subsoil for the following crop via root channels left behind. Cover crops can thus recycle nutrients that would otherwise be lost through leaching during off-season periods. Leguminous cover crops can also fix atmospheric nitrogen that then becomes available to the following crop. Other benefits from cover crops include protection of the soil from water and wind erosion, improved soil aggregation and water storage, suppressing soil-borne pathogens, supporting beneficial microbial activity, increasing active and total organic matter, and sequestering carbon. Dead cover crop material left on the soil surface can become effective mulch that reduces evaporation of soil moisture, increases infiltration of rainfall, minimizes temperature extremes, increases soil organic matter, and aids in the control of annual weeds.

Integrated nutrient management: Organic matter is critical for maintaining balanced soil biological communities, as these are largely responsible for maintaining soil structure, increasing water infiltration and building the soil's ability to store and release water and nutrients for crop use. Organic matter can be maintained better by reducing tillage and other soil disturbances, and increased by improving rotations and growing cover crops as previously discussed. Organic materials can also be added by amending the soil with composts, animal manures, and crop or cover crop residues imported to the field from elsewhere for enhancing SOC storage. The addition of organic amendments is particularly important in vegetable production where minimal crop residue is returned to the soil, more intensive tillage is generally used, and land is more often a limiting factor making the use of cover crops more challenging. Various organic amendments can affect soil physical, chemical and biological properties quite differently, so decisions should be based on identified constraints and soil health management goals. Organic amendments derived from organic wastes should not only be tested for nutrients, but also for contaminants such as heavy metals.

Soil erosion control for improving soil health: The global problem of accelerated soil erosion is a major environmental threat to sustainability and productive capacity of agricultural soils. The reduced productivity of eroded lands further decreases their functionality and degrades ecosystem services (Kumar *et al.,* 2018). Crop lands are the most vulnerable to erosion because of the scanty vegetation cover and seasonal disturbance of the surface soil. The vulnerability of croplands to erosion is determined by management practices and by a range of physical conditions; including climate, lithology, topography and soil texture. The main risky periods for runoff and soil erosion occur when the vegetation cover is minimal and rainfall intensities are relatively high. The increase in carbon dioxide as a result of erosion is based on the fact that a larger part of released carbon from eroded soils is easily mineralized. From long-term experiments the annual net flux of carbon to the atmosphere from water erosion was calculated to be 0.37 Pg CO_2 (Jacinthe and Lal, 2001). Erosion leads to soil carbon loss and subsequently to increasing concentrations of carbon in sediments (enrichment ratio). But the input of organic matter into the soil (especially farmyard manure and green manure) significantly contributes to a decrease in surface runoff and soil loss and also to a reduction of carbon leaching into sediments; so it contributes to carbon sequestration into the soil and enables soil to perform function consistently (Poonia *et al.,* 2019).

CONCLUSIONS

Continuous monoculture cropping systems and excessive cultivation have led to unacceptable erosion loss of our limited topsoil. Agricultural input alternatives that reduce reliance on non-renewable fossil fuels and petrochemicals, ensure productivity, and maintain the quality of our air, water, and soil resources are badly needed. Soil health indicators, and the changes in those indicators, can be a major link between the strategies for conservation management practices and achievement of the major goals of sustainable agriculture. Confirmation of the effectiveness of systems for residue management, organic matter formation, nitrogen and carbon cycling, soil structure maintenance, and biological control of pests and diseases will assist in discovering system approaches that are both profitable and environmentally friendly. The challenge ahead is to make better use of the diversity and resiliency of the biological community in soil to maintain a quality ecosystem, thus fostering sustainability. Strategies will then need to be fine-tuned using such practices as crop rotation for greater crop diversity and tighter cycling of nutrients, reduction of soil disturbance to maintain soil organic matter and reduce erosion, and development of systems which make greater use of renewable biological resources. Crop rotation, legume companion crops, and animal manuring practices can reduce reliance on non-renewable fossil fuels and petrochemicals. The minimum data set includes SMBC, labile pool of C, SOC, potential mineralisable C and activity of dehydrogenase, which are more feasible, accessible and reproducible for analysis. Ultimately these indicators of soil health and strategies for sustainable management must be linked to the development of management systems that foster reduction in the inputs of non-renewable resources, maintain acceptable levels of productivity, minimize impact on the environment and enable small farmers to care for soil health.

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Fresh Water : The Concern and Steps Essential to Combat Water Crisis

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The very basic and primary resources Land, Water and Air constitute the Globe or Earth. On the Globe or Earth, two kingdoms originated, advanced, spread and thrive are the Plant and Animal . Water is essential constituent of the plant and animal lives, since maximum constituent of living cell is water and no plant and animal cell division and multiplication can take place without water, be the water visible or invisible forms. As such, it is commonly told the "Other name of water is life". There is enough water in the Earth or Globe on Bay, Sea and ocean which is hard saline. But for every purpose and existence of non-marine members of the Plant and Animal Kingdoms, only fresh water is essential. Its availability has become a great concern World wide. The UNs, FAO, WMO, WHO, UNEP etc. International organisations repeatedly alerted the countries to take appropriate steps to conserve/ store fresh water received from rainfall and use it without wasting.

Not withstanding the good ongoing schemes, without derogation of the steps taken, appreciating the laudable achievements gained, a discussion may be done on this issue and how to resolve and avoid the apprehended crisis/scarcity for the present and for future .

1. What United Nations Tells About the Fresh Water

Fresh water is at the core of sustainable development and is critical for socio-economic development, energy and food production, healthy eco-systems and for survival of the non-marine members of the Plant and Animal Kingdoms, one of which is the human itself.

As the global population grows, there is an increasing need of fresh water to balance all of the competing commercial, non-commercial, industrial and agricultural demands, so that communities get enough of it. In particular, women and girls must have access to clean, private sanitation facilities to manage menstruation and maternity in dignity and safety.

At the human level, water cannot be seen in isolation from drinking water and sanitation. Together, they are vital for reducing the global burden of disease and improving the health, education and economic productivity of populations (United Nations). Without food no living beings can exist. For deriving food, water is the pivotal input of Agriculture. The main source of this fresh water is the rainfall.

2. The World Land Resource

Land is the solid state of the Earth, that holds the different forms of water. Earth's total surface area is 510.072 billion hectares, out of this, total water area is 361.132 billion hectares, which is 71%; Earth's total land surface area is about 14.894 billion hectares which is 29%. Of this surface area about 33% is desert and about 24% is mountainous. Subtracting this uninhabitable 57% (8.46045024 billion hectares) from the total land area, remaining 6.38189258 billion hectares is habitable land" (Feb 12, 2016).

***Water Spread on Earth*:** Average yearly total rainfall on earth is 505,000 cubic kilometres of which 398, 000 cubic kilometres is over ocean (Guide to planet earth 2005).

***Quantified Holdwise World Water Resource*:** (In cubic kilometre and % constituent):- (1) Bay, Sea

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and Ocean (Saline) - 1,338,000,000 (96.5%), (2) Ice cap, Glacier, Permanent snow (Fresh) -24,064,000 (1.74%), (3) Ground water- (i) Fresh -23,400,000 (0.76%) + (ii) Saline - 12,870,000 (0.94%) = 36,270,000 (1.70%), (4) Soil moisture (Fresh) - 16,500 (0.0010%), (5) Ground ice and Permanent frost - (Fresh) 300,000 (0.022%), (6) Lake - (I) Fresh - 91,000 (0.007%) + (ii) Saline-85,400 (0.006%) = 176,400, (0.013%), (7) Atmosphere (Fresh) - 12,900 (0.001%), (8) Swamp water (Fresh) -11,470 (0.0008%), (9) River (downward flow) (Fresh) - 2,120 (0.0002%), (10) Biological water (Fresh) - 1,120 (0.0001 %) ; Total = 1,386,000,000 (100%). [*Source: Gleick, P.H., 1996: Water resources. In Encyclopedia of Climate and Weather, ed. by S.H. Schneider, Oxford University Press, New York, Vol. 2, pp. 817-823*].

Saline water in oceans, seas and saline groundwater is about 97% of all the water on Earth. Only 2.5–2.75% is fresh water, including 1.75–2% frozen in glaciers, ice and snow, 0.5–0.75% as fresh groundwater and soil moisture, and less than 0.01% of it as surface water in lakes, swamps and rivers.

3. Aggravated Problems

Present time, concern for fresh water scarcity / crisis in different countries including India is being aired. Weather aberration, reduced storage in surface water bodies, reduced recharge of the ground water, increased use in industries and factories, increased use in urban areas, misuse/ wastage of the fresh water, increased run-off, increased evaporation are some of the causal factors of water scarcity / crisis. Over draft of the ground water for industries, factories, urban areas, not only bankrupting the aquifer storage, but also causing depletion / drawdown of the Ground Water Table (GWT) , some where nearly full exhaust of groundwater in aquifer evident leading to more worsen, unless stepped up recharge. These increased usage are encroaching in to the share of water use in agriculture with threat on production of agricultural commodities. Use of water irrespective of surface and ground is increasing leaps and bound. Urbanization, sky scraping buildings are coming up as another sophisticated menace. Within the limited concentrated high density populated urban/town ship areas, groundwater continuously lifted due to dependence, added with use in Industry on this source, fresh water of the aquifer is lifted. Urban dwellers are the happy consumers of the fresh water resource with little or no care. Concern is of others to provide them water. Under such situation, if no water scarcity occurs, that is wonder.

4. United Nations WATER : Water Scarcity

Let us have a look on what the United Nations made us aware of about world wide status.

Status and forecast*:* (1) Over 2 billion people live in countries experiencing high water stress. (UN, 2018); (2) 700 million people worldwide could be displaced by intense water scarcity by 2030. (Global Water Institute, 2013); (3) About 4 billion people, representing nearly two-thirds of the world population experience severe water scarcity during at least one month of the year (Mekonnen and Hoekstra, 2016); (4) With the existing climate change scenario, by 2030, water scarcity in some arid and semi-arid places will displace between 24 million and 700 million people. (UNESCO, 2009); (5) A third of the world's biggest groundwater systems are already in distress (Richey *et al.,* 2015); (6) Nearly half the global population are already living in potential water scarce areas at least one month per year and this could increase to some 4.8–5.7 billion in 2050. About 73% of the affected people live in Asia (69% by 2050) (Burek *et al.,* 2016); (7) Fast facts: Global water crisis enfaced ; 844 million people lack basic drinking water access, more than 1 of every 10 people on the planet. Women and girls spend an estimated 200 million hours hauling water every day. Every day, more than 800 children under age 5 die from diarrhea attributed to poor water and sanitation. Mar 1, 2019 (UN).

Level of water stress: Water stress starts when the water available in a country drops below 1700 m^3/yr or 4600 liters/day/person. When the 1000 m^3/yr or 2700 litres/day/person threshold is crossed, water scarcity is experienced. Absolute water scarcity is considered for countries with less 500 m^3/yr or roughly 1400 litres/day/per/ person. By this definition, 49 countries are water stressed, 9 of which experience water scarcity and 21 absolute water scarcity.

Challenge: Water scarcity will be exacerbated as rapidly growing urban areas place heavy pressure on neighbouring water resources. Climate change and bio-energy demands are also expected to amplify the already complex relationship between world development and water demand.

Opportunity: There is not a global water shortage as such, but individual countries and regions need to urgently tackle the critical problems cropped by water stress. Water has to be treated as a scarce resource, with a far stronger focus on managing demand. Integrated water resources management provides a broad framework for governments to align water use patterns with the needs and demands of different users, including the environment.

Situation of India: Annually 400+ M ha meters of fresh water is received through precipitation spread over India from hill to sea shore. This quantity / volume of downpour is not evenly distributed in all the months on all the geographical territory. Downpour is subject to variation, during South-west monsoon (June to September) is 75%, North-east monsoon (October -December) is 13% , January-February is 2% and March-May is 10% (pre-monsoon). Where does this huge volume of fresh water goes ?

India's rampant urban water issues and challanges: In India, the demand of water for domestic use is increasing with the increase of population concurrently. The rate of increase of population with its density is more in urban area than rural areas. Because of this, demand of domestic water is much more in urban areas. The urban population in 2001 was 285 million for which the demand of domestic water was 38,475 million litres/day. In 2011, the urban population became 377 million for which the demand of domestic water became 50,895 million litres/day. Thus, demand enhanced to 12,420 million litres/day. Currently average water supply in urban areas is 69.25 litres/head per day as against the service level bench mark of 135 litres/head/ day (Central Public Health and Environmental Engineering Organization). Thus there is huge gap between demand and supply. If this disastrous trend continues, half of the India's population will dwell in urban areas by 2050. It is apprehended that, Urban areas will face acute shortage of water supply. However, 84% of the rural population, which is 72% of the total population, has access to safe water. (Energy Resource Institute, 28/12/2018) Industrial water use in 1999 was 67 billion cubic metre, is expected to rise up to 228 billion cubic metres by 2025 (World Bank) .

5. Advice of the Food and Agricultural Organization (FAO) of the United Nation's (UN) to the Countries

FAO of UNs many times circulated the degrading status of natural resources of countries, advised and suggested to take active measures and actions on Soil and Water Conservation in many of the times, are very much relevant and may be recalled. It is applicable for all the countries mutatis mutandis including India. The Global Symposium on Soil Erosion 2019 (GSER 2019) on Stop Soil Erosion, Save Our Future, held during 15-17 May, 2019 at the United Nation (UN) Food and Agriculture Organization (FAO) headquarters in Rome, Italy was, perhaps one, that was exclusively exercised for soil erosion and its conservation, where expressed great concern in Global sphere. Hope the persons attended on behalf of the GoI, after return from Rome, has/have apprised the concerned authorities, The concerned authorities may have informed and issued advices to the State Governments. FAO suggests for betterment, but it is left for the pleasure of the National and State Govt's to obey and implement. FAO continuously releasing messages world wide about the status of land degradation, soil erosion, surface and groundwater status. It is continuously asking to take active steps and actions to combat and prevent. I am also a declared top fan of it, sharing these in social media for awareness of the people. But either no or few of these have been cared for and implemented.

6. Accelerated Soil Erosion and Its Impact

It is the accelerated soil erosion, caused by rainfall and wind force that detach and displace soil. Most likely range of Global soil erosion by water is 20-30 giga t/yr, while faulty tillage erosion may amount 5 giga t/yr. Dust mobilization by wind erosion may amount to 2 giga t/yr (FAO). This exposes sub-soil in one place and buries top soil in other place. Eroded soils deposit in the surface water bodies and river bed. Depth of these decrease, decrease storage capacity and decrease discharge capacity of drainage network. Over the land runoff, of rain water, accumulated un-interrupted rush down to the drainage courses, leaving little scope of recharge of ground water, in addition already shallow depth surface water bodies that hold/ store less volume of water. Thus ultimately goes to Bay, Sea and Ocean.

Accelerated soil erosion, its consequences in India: It is the accelerated Soil Erosion by rain and Wind that detach and displace soil. Water erosion alone is estimated to cause loss of 5,334 Mt of top soil annually (Dharuvanarayana and Rambabu, 1983). It is to the extent of 12000 Mt/yr (WDB) that deposits in the surface water bodies, river bed undesired places and moves to bay and sea. These eroded soils decrease depth, decrease storage capacity and decrease discharge capacity of drainage network. The accumulated run-off rush down to the drainage courses within limited span of times, leaves little scope of recharge of ground water by vertical movement through the soil horizons and layers, in addition already shallow depth surface water bodies that can hold less volume of water. Thus ultimately goes to Bay of Bengal, Arabian Sea and Indian Ocean.

7. Prioritisation of the Rainwater Conservation / storage

Under the circumstances / and situations mentioned hereinbefore, if adequate quantum / volume of the surplus / runoff water of rainy season is not stored / conserved in the surface water bodies and ensure recharge to the aquifer for ground water storage during monsoon, then certainly during no-rainfall and less rainfall period, water scarcity can not be avoided. To combat, prevent and over come, only task/work that should be priorities, is the Integrated soil conservation. If soil is conserved, then automatically, water will be conserved/stored. This is the prime action need now.

UN and FAO have already repeatedly alerted, it is left for the Countries and States to take steps and measures. So the central and State Govt's. of countries may like to think over this .

8. Water Conservation *vs* Irrigation and Its Other Use

Often these independent two groups are miss-mixed and confused. Irrigation and its other uses are solely dependent on water conservation / storage *i.e.* store both in sub-surface aquifer and surface water bodies. If there is stored water out of precipitation, then irrigation and its other uses are possible from other source. If not, no scope. Therefore, these two terminologies should be used to mean and indicate appropriately.

9. Water Conservation *vs* Water Savings

Often, meaning and implication of water conservation and water savings are miss mixed, confused and applied wrongly. Water conservation is the retention and storing of water after receipt through precipitation in land in the soil horizons, surface water bodies and underground aquifer. Water savings is the balance of that conserved/ stored water after its various uses. It is the prudent use, which is retained as balance after its optimum use avoiding wastage. Whatever use may be, all are solely dependent on the water conservation.

10. Scarcity of Water for Irrigation and Its Other Uses

Irrigation is the artificial application of water in to the crop field. During no-rainfall period it is necessary. When inadequate availability of water from the stock to meet up the demand in the event of necessity happens, that is the Scarcity, surely due to inadequate conservation/storage of natural fresh water in both ground aquifer and surface water bodies. Similar is in other uses.

11. Global Natural Receipt of Fresh Water through Precipitation but Failure and Negligence to Conserve / Store in Land

Annually 107,000+ cubic kilometre rainfall / fresh water is received through precipitation spread over land area of the Earth. Its distribution has been mentioned herein before. If that volume is retained in the various holds, in all elevations then, the scarcity can be avoided, provided its wastage is avoided. If adequate volume of that water is stored in the surface water bodies and aquifer, then certainly during no-rainfall and less rainfall period water scarcity can be avoided. This action through various measures is the prime importance now.

12. Runoff, Inadequate Storage Conservation of Water in Under Ground Aquifer and Surface Water Bodies

Due to accelerated soil erosion, dereliction of surface water bodies for sedimentation and uninterrupted increased run-off, the storage capacity of water bodies is decreased , percolation of field water for recharge of aquifer also decrease, ultimately decreased storage of natural water. Rainwater touching the ground *i.e.* received through precipitation, if not halted in each elevation *i.e.* topographical situation for prolonged time, but moves downwards rapidly, then accumulated downward rush happens in lower reach, that causes devastating flood and departs rapidly, decrease recharge to aquifer. Thus, maximum of such water flows over land un-interrupted in the form of run-off through the river system, that ultimately ends to Bay, Sea and Ocean leaving decreased storage/ conservation in the in-land aquifer. That is to some extent happening now where either no or inadequate soil conservation measures taken up. So, it is obvious that, added with over draft to met the demand of various uses during no-rainfall period, scarcity will crop up; now that is the consequence.

13. Futile Excavation and Re-excavation of Derelict Surface Water Bodies

Often derelict water bodies are re-excavated and new water bodies are excavated / bundhs / dams are constructed for storage of natural fresh water. But its projected performance, longevity / life period do not long last, if soil conservation is not done in the catchment areas. Eroded soils transported with the run-off water, deposit in to these and soon decrease depth, thereby decrease storage capacity. If calculated surplussing structure, either in both sides or in down side not constructed or provided, then the water holding embankment will easily breach. Hence wherever surface water body either be re-excavated or be newly constructed should have soil conservation in the catchment area together with surplusing structure.

14. Integrated Soil and Water Conservation

Soil Conservation is the pre-cursor of the Water Conservation. If soil is conserved by various measures, then automatically natural water will be conserved or stored in situ and enhance recharge of the aquifer. For real water conservation, 3 group of soil conservation measures are adopted to disintegrate raindrop biting energy on land surface, to decrease sediment yield, to halt rain water in each elevation for prolonged time, to interrupt the direct flow of run-off water, to arrest the eroded soil *in-situ*, to enforce recharge of surface water in to ground aquifer through the soil horizons / layers, to store surface water in surface water bodies, to surplus transparent water, to increase the time of concentration of runoff water in the drainage net work, to non-erosive safe disposal of surplus water, for prolongation of stream flow in the natural drainage system, to resist degradation and restoration of degraded land and development of micro climate suitable for habitation. This is also the preventive measure to flood and drought. This is the conservation of the soil *in-situ* together with conservation /

storing rainwater within the village. This is the *khet ka mitti khet mein, gaon ka pani gaon mein* (Soil of plot of land to be conserved within the plot, rainwater received with the village to be stored within the Village). Thus in India 5,334-12000 Mt of soil can be conserved / retained within 329 Mt, together with maximum of 400+ M ha meters of natural water can be conserved / stored within the 329 M ha of land. Over the Globe, 22-32 giga tonnes of soil can be retained / conserved together with maximum of water 107,000+ cubic kilometre rainfall can be conserved/ stored spread over total surface 14.894 billion hectares of the Earth. Integrated soil and water conservation not only conserve soil and rainwater, but also resist environmental warming and pollution, increase crop production, and employment potentiality. The great achievement that can make possible by integrated Soil is that, it can convert a water scarcely or dry area in to water saturated/surplus area. The great achievement that can make possible by integrated Soil is that, it can convert a water scarcely area in to water surplus area, that is *sukhanchal* to *neeranchal*.

Group-wise Soil Conservation Measures

Mechanical measures: Erection of barriers by works on the field, water courses, drainage lines to arrest and hurdle the run-off and for safe disposal of surplus water. New works and maintenance of Contour bunding, Field bunding, Compartmental bunding, Bench Terracing, Gully plunging, Graded terracing (inward and out ward), Conservation Bench Terrace, Stager Contour trench cum ridge, Small Dam, De-siltation basin, Silt detention dam, Waste wire, Inlet drops, Chute, Diversion channel, Land shaping, Land levelling, field bunding, plot to plot drainage, sluice gate, percolation tank, impoundment ditch, Dug out, Farm pond, Cause-way, Vented cause-way, Course training (spur), river course deflecting brush wood structure, surface reservoirs, torrent control structures , land slip and land slide resisting structures, culverts with weir or without weir, wire net binded loose boulder / stone gabion etc.

Vegetative measures*:* Raising non-weed grasses and legumes like carpet cover (Agrostological) on the lands. Contour vegetative hedge (vetivar, lemon grass and vitex etc.). Eye-brew of erect, bushy grasses on riser of contour bund and terrace risers. Grassed water ways. Turf on embankment flank. Raising trees like umbrellas on the land. Association of trees and crops / grasses and legumes on the land, such as Agro-forestry, Farm forestry, Shelter belt (two storied) etc.

Farming practices (Agronomic): Farming operations like contour ploughing across the slope, contour cropping (row) across the slope, strip cropping with erosion resisting and erosion permitting crops at appropriate ratio of the cover of the strip along the contour, Inter-cropping at appropriate ratio of rows of erosion resisting and erosion permitting crops. Detailed soil survey report based replenishment of macro and micro-nutrients through green manuring, organic and inorganic manures and fertilizers combination, etc.

15. Stopping / Discontinuation of Useful Soil Conservation Schemes

In India, the soil and water conservation schemes under the Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, have been discontinued, *viz.,* (1) Soil Conservation in the catchments of River Valley Project (RVP), (2) Soil Conservation in the catchments of Flood Prone Rivers (FPR), (3) Reclamation of Alkali Soil, (4) Watershed Development Project in Shifting Cultivation Areas, (5) Soil Conservation Training Centre at Hazaribagh managed by DVC and National Watershed Development Programme for Rainfed Areas (NWDPRA) of the Rainfed Farming System Division. In fact, stopping / discontinuing these schemes appears welcome of disaster. It is direly felt to restart more vigorously all the discontinued soil conservation schemes to confront the serious degradation of land and to resist run-off of fresh water, ultimately to conserve/store enough fresh water to overcome the menace of water scarcity.

16. Importance on Soil Conservation

In the National level conference, India on Agriculture, for doubling farmers income by 2022, held during 19-20th February, 2018 in New Delhi, organised by the National Rainfed area Authority (NRAA) of the Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Co-operation and Farmers Welfare, the NRAA invited famous specialists except soil conservation experts (having field level working experience) where and when deliberated, discussed many items / subject except soil conservation. Later it was pointed out through memorandum to the NRAA, that without soil conservation, farmers income hardly can be doubled. But no reply, no action. This is an example, how much importance is given on soil conservation in India.

While this is an example of want of importance on soil conservation of the GoI, also the State Govt's. are not exception. It is told of many items, including irrigation, flood and drought, diversified crop production, but either no or least of soil conservation, there are many schemes, but either no or perfunctory schemes for soil conservation, subject to exception.

17. Immediate Actions Need

In India all the discontinued / stopped soil conservation schemes should be restarted more vigorously and new scheme should be launched in the title of scheme of soil conservation on plot to plot from Hill to Sea shore. Both the Central and State Govt's. need to prioritise on soil conservation through Centrally sponsored and Sate sector schemes. Other countries of the globe may like to consider similarly.

18. Establishment of New Research and Training Centre Exclusively for Soil and Water Conservation for North Eastern States

North Eastern States comprising of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, a large tract, has no Soil and Water Conservation Research and Training Centre, though these states are most vulnerable to accelerated soil erosion. While its necessity was voiced, it was told that, the SWC activities are done in other ICAR Centres/ Stations in this reason. It is a forced denial reason, because, there are many ICAR Research and Training Stations, centres concentrated in Hyderabad. People have sentiment, out of sight out of mind for further from Delhi. Hence, new Soil and Water Conservation, Research Training Centre under the ICAR-IISWC, Dehradun need be established soon.

19. Allotment of Fund and the Official Functionary Need

Extent of problem enfaced and realised, need for effective steps felt and actions, actions to be taken are known, there is enough specialised human resource, there is enough stock of proven and validated technologies. Govt's should invest adequate fund for prophylactic and preventive measure, instead of curative. But no desired and fruitful result can be achieved unless the technologies are rightly and appropriately applied and materialised through the experts.

Strong official organization should be established with the specialized enough number of technical personnel who will transform and transmit the established practices to the land owners and users and will plan, design, formulate and implement the Govt. schemes. Once resources will be build up, then, industry, agriculture, non-agriculture etc. can be accommodated thereon. Governments should established such functionary at National, State / Provincial, District, Sub-Division / Taluka, Block and Ground level maintaining a line of hierarchy on the principle of responsibility and authority should be co-terminus. If strong setup of functionary is built up then only both quality and quantity achievement will be possible. While more new posts should be created, existing created many posts are remaining vacant month after month. Hence, it is left for the Governments and the people what to do.

20. National Water Policy

Each country should frame National Water policy under the superintendence of the constituted National Water Resources Council. The policy should envisage the formulation of a State water policy and preparation of an operational action plan in a time bound manner to achieve the desired objectives. The developmental strategy includes many effective water conservation and management plans as a component of the long term perspective planning of water resources.

21. Our Clarion Call

Let the forthcoming year be the year of Integrated Soil Conservation. May it be voiced clarion call "*Agriculture is the super culture of all the cultures in the World. Conserve land, Soil, fresh water for nourishing people, Plants and animals and for survival of the Civilization*". Unless enough fresh water is conserved / stored, the water scarcity can hardly be overcome. Therefore, to launch a development programme exclusively for "*Natural Resources Conservation (Soil Conservation) Mission*" .This emphasis and augmentation on integrated soil conservation, thereby water conservation, will comply with the advice of the FAO of the United Nations too. It is very much relevant that, the entire soil conservation operation is protection–cum–production, environment friendly, rather environment refreshing, many-fold benefits and for all he positive gains for the present and future.

[Note : Gigaton = 1000,000,000 tones; Megatons = 1,000,000 tons; Teragram = 1000000 tons; Billion = 1000 thousand million or 1,000,000,000; Million = 10 lakhs].

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Rainwater Management Techniques in Porous and Gravelly Soils of Arunachal Pradesh

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Water is the vital resource available to mankind. This natural resource is the scarcest commodity for hill farmers, though Arunachal Pradesh receives huge amount of rainfall (about 3000 mm, annually), still there is extreme scarcity of water during post and pre-monsoon season (Mid-October to March) even for drinking. The soil of the state is porous and sandy and impregnated with gravels, having less water holding capacity. The horticultural crops planted in slopes remain water stressed for about five months. This is one of the major factors responsible for low productivity of the state. Under such situation, rain water harvesting holds promise for multiple livelihood opportunities for the hill farmers of the state. Over the years, the need for preserving and maintaining water resources has been made at various levels and the subject got importance. One of the major advantages of rain water harvesting is that no catchment area is needed for the storage of water. The rainwater can be harvested *in-situ* in water harvesting pond. This reduces the cost of the rainwater harvesting system. Techniques have been developed at College of Horticulture and Forestry, Central Agricultural University, Pasighat, East Siang district of Arunachal Pradesh.

Rainfall and Climate

The East Siang district has cold mountainous climate in the north while tropical climate exists in the south where winter temperature drops upto 7°C and summer temperature goes up to 36°C. December and January are generally the coldest months and July-August are the hottest months. Copious rainfalls during monsoon and wind circulation during the winter are important feature of the climate. Rainfall occurs mostly throughout the year but maximum from April to September. The average rainfall in the district is 2910.18 mm. The rainfall is erratically distributed throughout the year. The period from Mid-October to March is dry and evaporation exceeds the rainfall. The winter in the region experiences high velocity wind. The wind helps in higher evaporation rate.as shown in Fig. 1.

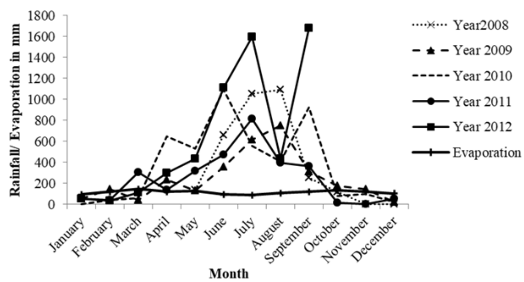

Fig. 1. Monthly variation of rainfall vs. evaporation showing the dry months at Pasighat, Arunanchal Pradesh

Gravely-sandy soils

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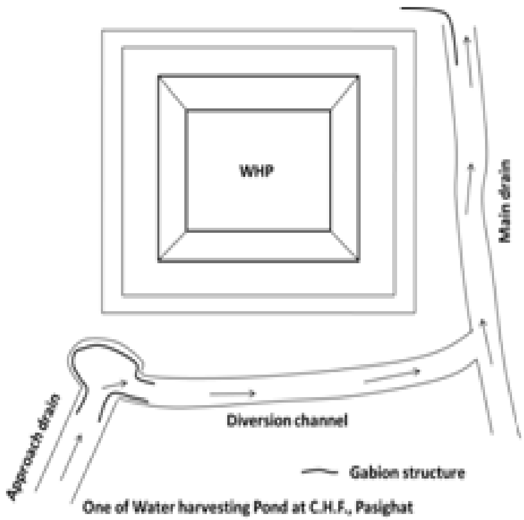
Soil

Soil of East Siang district is porous and has sandy loam texture. Bulk density, soil porosity and available Phosphorous are higher in lower altitude. Water holding capacity is lower in upper portion of soil profile. Soil is strongly to moderately acidic in nature (pH 4.5 to 7.2), rich in organic matter content (0.8 to 5.2% OC) which declines sharply with depth.

Rainwater Management Technique - A Case Study

Gravely and sandy soil is characterized by low water-holding capacity and excessive drainage of rain and irrigation water below the root zone, leading to poor water and fertilizer use efficiency by the crops. The soil of Arunachal



Sketch of layout of WHP

Unfolding of Silpaulin film

Spreading of Silpaulin film

Harvesting of *in-situ* rainwater in the water harvesting pond

Harvesting of *in-situ* rainwater in the water harvesting pond

Pradesh is highly porous, gravely and sandy in nature. The soils have very less clay content (<20%), and are unable to hold water. This causes the water scarcity in winter and summer seasons causing low productivity of the horticultural crops. The crops are subjected to acute water stress during five months from November to March. Further the people of North Eastern region is having non-veg food habit and their liking towards fish is very much. The pisciculture in these soils is difficult as storage of water is not possible in such soils. The high rainfall of the state

SPV Module

Submersible Pump in Floating Platform

Solar based low cost drip irrigation Cowpea

Solar operated Sprinkler Irrigation in Potato

Solar operated Low cost drip irrigated cabbage

French bean cultivation near WHP

can be managed well through harvesting of rain water by polyethylene lined water harvesting pond. Location specific design of the rainwater harvesting system plays an important role in managing such problem. An experience on the rainwater management technology implemented at the College of Horticulture and forestry, Pasighat, East Siang, Arunachal Pradesh is shared. The construction of RCC made water harvesting pond is costly and needs skill in its design and its construction takes a long time. Utilization of unused naturally depressed areas can be converted into low cost polythene lined water harvesting ponds. The hydrologic, hydraulic and structural design of the water harvesting pond is made first. Then based on the design the construction of the pond is completed within a month. The excavated gravely/ stony soil is kept as an embankment surrounding the pond. A trench of at least 1′ × 1′ is made surrounding the

Practicing composite fish farming in WHP with mean yield 19.6 q/ha

Micro-irrigation system in oil palm crop (6yr old-25.8 t/ha)

Micro-irrigation system in Litchi crop (7 yrs old - 30 kg/plant)

upper surface of the pond. The surface of the pond is then laid by 10-15 cm soil cushioning with subsequent laying of 250 GSM finish size silpaulin films. It is found that the pond can be made full of water by *in-situ* rainwater harvesting as the a.a.r is 3000 mm. The construction work should be completed before the onset of monsoon (prior to March – April). The harvested water can be used for life saving irrigation as well as pisciculture activities successfully. Micro-irrigation system can be effectively used for life saving irrigation. It found that the horticultural crops can be irrigated very well during the water scarce months. It is observed that Oil palm (*Elaesisguineensis*) variety Tenera has shown good growth in the porous and gravelly soils due to the fact that the crop are well irrigated and fertigated. The micro-jet irrigation is successfully provided to the oil palm crop by utilizing the harvested water from the water harvesting pond. The six year old irrigated oil palm crop has productivity of 10 t/ha in comparison to the without irrigated productivity of 2 t/ha. The litchi (*Litchi chinensis*) crop is irrigated by the trickle irrigation system using the harvested water from the WHP. The yield obtained from four years litchi plant was 12 kg/ha. Similarly mean yield of fishes from the silpaulin lined pond is 19.6 q/ha by practicing composite fish farming system. Average total cost of production per ha is found to be ₹ 1,44,066/- and B:C ratio is 2.21. Fish species Silver carp, Catla and Grass carp shows better growth in the polythene lined pond in comparison to Common carp, Rohu and Mrigala.

CONCLUSIONS

Specific rainwater management techniques are needed for the porous and gravelly soil of East Siang district of Arunachal Pradesh. The horticultural crops are usually water stressed during the period from mid-October to March. This is one of the major causes of low productivity of horticultural produce in the state. If the rainwater of the state can be managed efficiently the problem of water scarcity during winter can be managed well. Techniques have been developed at CHF, CAU, Pasighat. The high rainfall during rainy season can be harvested in silpaulin lined WHP and the harvested water can be applied as irrigation to various horticultural crops through micro-mode. Solar energy can be tapped to pump water from the WHP well. Pisciculture has been found to be a feasible enterprise.

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Novel Ways to Use Water for "Per Drop More Pomegranates (*Punicca granatum* L.)"

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Pomegranate is an important fruit crop of the Deccan plateau Region of India and its cultivation is now expanding to non-traditional region of Gujarat, Madhya Pradesh, Andhra Pradesh, Rajasthan and Tamil Nadu. The huge popularity of the crop is mainly due to its less resource demanding nature, great adaptability and high returns on investment. Water is a major scarce resource in most of the Pomegranate dominating areas which necessitates judicious are of water for irrigation. Efficient utilization of irrigation water to maximize yield and quality is of paramount importance for pomegranate researchers in India. By employing scientific methodologies, the water requirements of 1st to 5th year's old age pomegranate trees were found to be in the ranged 1900 to 13,580 litre/yr/tree. In this study weekly water requirement of 1st to 5th years old pomegranate tree had been calculated for economizing water use and enhancing crop productivity. Water use efficiency (WUE) for three to five years old pomegranate has been increased by almost 31% after implementing this method of water requirement estimation. In addition, introduce various water conservation technologies for optimization of pomegranate production (*i.e.* water harvesting structure, micro-irrigation system, organic and inorganic mulches, deficit and partial root zone drying irrigation techniques).

In pomegranate growing regions of India, water is a scarce resource and its efficient use has to be prioritized. Regular water supply through irrigation system is of paramount importance for sustainable production of pomegranate. In Maharashtra pomegranate is predominately grown in the regions of Solapur, Ahmednagar, Pune, Nasik, Sangli, Satara and Osmanabad. In these parts of Maharashtra water is scarce commodity and hence there is need to apply water judiciously as per the water requirement of the crop. The water requirement of pomegranate crop depends on age, season, location and management strategies.

The following parameters will be required for estimation of water requirements in liters / day / tree for optimum pomegranate production.

Pan Evaporation (mm) / Reference crop evapotranspiration (mm); Pan Coefficient (Fraction); Crop Coefficient (Fraction); Wetted Area (Fraction); Pomegranate Tree Area (m^2); Irrigation Efficiency (Fraction).

Pan Evaporation (E_{pan})

Pan evaporation was measured every day by pan evaporimeter (Photo 1). Evaporation rate is measured in mm/day at 8.30 AM. Suppose

Photo 1. Pan Evaporimeter

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rainfall occurs before irrigation then evaporation loss will be estimated and thus accordingly irrigation should also be reduced. If evaporation occurs more than rainfall, then the irrigation will be delivered depending upon the soil type. Average weekly evaporation rate (mm) of past 35 years for Solapur region is presented in Fig.1. This average weekly evaporation rate will be useful for daily or alternate day irrigation scheduling during *Hasta, Ambia and Mrig bahars* in pomegranate orchards.

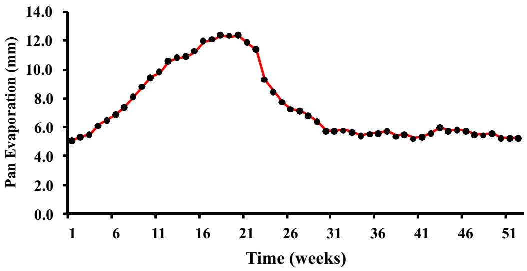

Fig. 1. Average weekly pan evaporation (mm) for Solapur region during 1983-2018

Pan Coefficient (k_{pan})

Pan coefficient (k_{pan}) is an important factor for computation of reference crop evapotranspiration from pan evaporation. One common method to estimate ET_r is converting the pan evaporation (E_{pan}) into ET_r by using a pan coefficient (k_{pan}), which varies depending on the site and climatic conditions. For Solapur, pan coefficient is 0.70.

Reference Crop Evapotranspiration (ET_r, mm)

The Penman-Monteith method has a strong likelihood of correctly predicting ET_r in a wide range of location and climates (Allen *et al.,* 1998). The monthly values of reference ET_r were estimated by eq. 1 and presented in Fig. 2.

$$\mathbf{ET_r} = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_{2(e_s-e_a)}}{\Delta + \gamma(1 + 0.34u_2)} \quad ...(1)$$

Where, ET_r = Reference crop evapotranspiration, (mm/day); G = Soil heat flux density, ($MJ/m^2/day$); R_n = Net radiation, ($MJ/m^2/day$); T = Mean daily air temperature, (^0C); γ = Psychometric constant, (kPa^0/C); Δ = Slope of saturation vapour

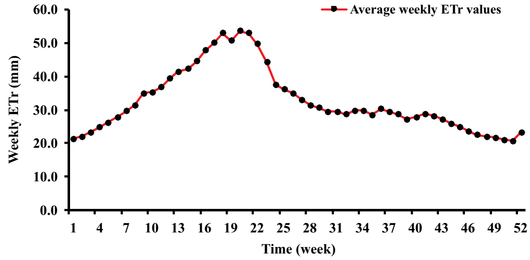

Fig. 2. Average weekly reference crop evapotranspiration (ET_r, mm) values of the study area

pressure function, (kPa^0/C); e_s = Saturation vapour pressure at air température T, (kPa); e_a= Actual vapour pressure at dew point température, (kPa); u_2= Average daily wind speed at 2 m height, (m/sec).

Crop Coefficient (k_c)

The crop coefficient can be calculated by using eq. 2, which is developed for deciduous fruit crops.

$$k_c = 0.014x + 0.08 \quad ...(2)$$

Where, k_c = Crop coefficient, x = Percentage of shaded area, (%).

By using the above stated equation, the week wise crop coefficient values can be developed for different phenological stages *i.e.* new leaf initiation, crop development, crop maturity and crop harvesting for the orchards of one to five years old (Fig. 3 and Table 2). The procedure of shaded area measurement at solar noon hour is shown in Photo 2.

Wetted Area (WA)

Wetted area is the proportion of the effective

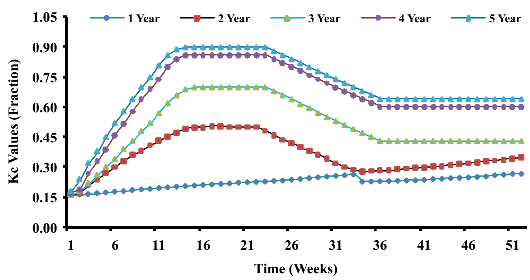

Fig. 3. Average weekly crop coefficient (kc) values of 1st to 5th year pomegranate trees

Photo 2. Shaded area measured at solar noon hour

wetted root zone with respect to the total area. Wetted Area can be calculated by eq. 3.

$$WA = \frac{SA}{A} \quad ...(3)$$

Where, WA = Wetted area, (Fraction); SA = Shaded area, (m^2); A = Area occupied by a tree, (m^2).

The average wetted area can be calculated for the pomegranate trees of one to five years old (Table 1).

Pomegranate Tree Area (m^2)

One pomegranate tree area can be calculated by eq. 4.

$$PTA = PPD \times RRD \quad ...(4)$$

Where, PTA- Pomegranate tree area (m^2); PPD - Plant to plant distance (m); RRD - Row to row distance (m).

Table 1: Year wise wetted area of pomegranate tree

Parameters	Age of tree (Years)				
	1	2	3	4	5
Shaded area (m^2)	2.65	4.05	5.40	6.75	8.10
Area per plant (m^2)	13.5	13.5	13.5	13.5	13.5
Wetted area (Fraction)	0.20	0.30	0.40	0.50	0.60

Irrigation Efficiency (%)

The effectiveness of the irrigation system in delivering all the water beneficially used to produce crop. The growers are using drip irrigation system, which have drippers calibrated in liters/hour and that operate at a level of 90% irrigation efficiency.

Water Requirement (liters/day/tree)

The farmers need the information on water to be applied in liters/day/tree to each pomegranate tree (Meshram *et al.,* 2011). Water to be applied was estimated on daily basis for the pomegranate trees up to the age of 5 years by using the eq. 5.

$$WR = \frac{(E_{pan} \times K_{pan} \times k_c \times A \times WA}{IE} \quad ...(5)$$

Where, WR= Water requirement, (liters/day/tree); E_{pan} = Evaporation rate, (mm); k_{pan} = Pan Coefficient, (Fraction); k_c = Crop Coefficient, (Fraction); WA = Wetted Area, (Fraction); A = Area occupied by each tree, (m^2); IE = Irrigation efficiency, (Fraction).

Irrigation Time (hr)

$$IT = \frac{WR}{DC} \quad ...(6)$$

Where, IT - Irrigation time (hr); WR - Water requirement (liters/day/tree); DC - Dripper discharge capacity (liters/hours).

The values in the Tables (1 & 2) and Figs. (2 & 3) of evaporation or reference crop evapo-transpiration, pan coefficient, crop coefficient, wetted area, tree area and water to be applied in liter/day/tree on weekly basis are presented in Tables 3, 4 and 5 for *Mrig, Hasta* and *Ambia bahars* would be useful for water management in pomegranate orchards.

Table 2: Phenological stages of pomegranate *cv.* Bhagawa

Stages	Indicators	Days
New leaf initiation stage	Start of new leaves to 10% ground cover	0-21(28)
Crop Development	10% ground cover to effective full cover, about 60-70% coverage for tree crops	22-99(77)
Crop maturity	Effective full cover to maturity and increasing size of fruit	100-156(56)
Harvesting	Maturity to harvest	157-217(60)

Example for Determination of Water Requirement of Pomegranate

Daily evaporation -9.8 mm; or reference crop evapotranspiration -6.86 mm, Pan Coefficient (K_{pan}) -0.70; Crop Coefficient (k_c) -0.16

Wetted Area (WA) - 0.20; Area occupied by each tree (A) - 13.5 m^2; Dripper/tree -1 No.; Dripper discharge - 4 lph; Irrigation Efficiency (IE) - 0.90.

According to formula No. 5

$$\text{WR (Liters/day/tree)} = \frac{9.8 \times 0.70 \times 0.16 \times 0.20 \times 13.5}{0.90}$$

= 3 liters/day/tree

According to formula No. 6

$$\text{Irrigation time} = \frac{3}{1 \times 4} = 0.75 \text{ hrs, 45 min}$$

Table 3: Water to be applied (litre/day) for 1st to 5th years old pomegranate tree during *Mrig bahar*

MW	Age of the plant					MW	Age of the plant				
	1st	2nd	3rd	4th	5th		1st	2nd	3rd	4th	5th
23	3	5	6	8	11	39	2	9	16	25	31
24	3	5	6	8	13	40	2	8	15	24	30
25	3	5	7	11	16	41	2	8	16	24	30
26	3	5	8	13	17	42	3	9	16	25	32
27	3	6	9	15	20	43	3	9	18	27	34
28	3	6	10	16	22	44	3	9	17	26	33
29	2	7	11	18	23	45	3	9	17	26	33
30	2	7	10	17	23	46	3	8	16	25	32
31	2	7	12	19	25	47	3	8	15	24	30
32	2	8	13	21	27	48	3	7	15	23	29
33	2	8	14	22	29	49	3	7	14	23	29
34	2	8	14	23	29	50	3	6	13	21	27
35	2	8	15	25	31	51	3	6	13	21	26
36	2	9	16	25	32	52	3	6	12	20	25
37	3	9	17	26	33	01	3	5	12	19	24
38	2	8	16	24	31	02	3	6	12	20	26

Note: MW-Meteorological week

Table 4: Water to be applied (litre/day) for 1st to 5th years old pomegranate tree during *Hasta bahar*

MW	Age of the plant					MW	Age of the plant				
	1st	2nd	3rd	4th	5th		1st	2nd	3rd	4th	5th
36	2	3	4	5	6	52	2	8	16	24	30
37	2	3	4	6	9	01	2	8	15	23	29
38	2	4	5	8	11	02	2	8	16	24	30
39	2	4	6	10	13	03	3	9	16	25	31
40	2	4	7	11	15	04	3	10	18	28	35
41	2	5	8	13	18	05	3	10	19	29	37
42	2	6	9	15	20	06	3	10	20	31	39
43	2	7	11	18	24	07	4	11	21	33	41
44	2	7	12	19	25	08	4	11	23	35	44
45	2	8	13	21	28	09	4	12	24	37	47
46	2	8	14	22	29	10	5	12	24	39	49
47	2	8	14	23	30	11	5	12	25	39	49
48	2	8	15	24	31	12	6	12	25	41	52
49	2	9	16	25	32	13	6	12	25	41	52
50	2	8	16	24	30	14	6	12	25	41	52
51	2	8	16	24	30	15	6	12	26	43	54

Note: MW-Meteorological week

Table 5: Water to be applied (litre/day) for 1st to 5th years old pomegranate tree during *Ambia bahar*

MW	Age of the plant					MW	Age of the plant				
	1st	2nd	3rd	4th	5th		1st	2nd	3rd	4th	5th
1	2	3	3	5	6	17	5	19	35	54	68
2	2	3	4	5	8	18	6	20	36	56	70
3	2	4	5	8	11	19	6	19	36	56	70
4	2	5	7	11	15	20	6	19	36	56	70
5	2	6	8	13	18	21	6	19	35	54	67
6	3	7	10	17	23	22	5	18	33	51	65
7	3	8	12	20	27	23	4	14	27	42	53
8	3	9	15	25	33	24	4	12	24	37	47
9	4	11	18	30	39	25	4	11	22	33	42
10	4	12	21	34	45	26	4	10	19	30	38
11	4	13	24	38	50	27	4	9	18	29	37
12	4	15	28	44	57	28	4	8	17	27	34
13	5	16	30	48	60	29	3	7	15	25	32
14	5	17	32	49	62	30	3	6	13	22	27
15	5	18	33	51	64	31	3	6	13	21	27
16	5	19	35	54	68	32	3	6	13	21	27

Note: MW-Meteorological week

Water Conservation Technologies for Optimization of Pomegranate Production

The objectives is to achieve convergence of investments in irrigation at the field level expand cultivable area under assured irrigation, improve on farm water use efficiency to reduce wastage water, enhance the adoption of precision–irrigation and other water saving technologies (*More Crop Per Drop*).

Water Harvesting Structure (WHS)

Solapur district (*i.e.* North latitude $17^0 10''$E longitudes by $74^0 42''$and 483.5 m amsl) is facing the problem of water scarcity throughout the year. Unavailability of adequate amount of water during the dry season is a serious problem for successful pomegranate production in drought prone areas. Pomegranate cultivation in these regions is predominantly rainfed, but rainfall during *hasta* and *Ambia bahar* (*i.e.* September–October and May-June) is an insufficient and is always uncertain with bimodal situation for optimum production of pomegranate.

WHS was excavated of size 80 x 60 x 3.5 m depth in the year 2008 and due to shortage of water for irrigation in the year of 2007, the WHS was again deepening 2.0 m depth of same size and inside WHS small pond was constructed having capacity 30 x 30 x 4 m depth for recharging of groundwater during shortage of water. The excavated farm pond size and its capacity were 80 x 60 x 5.5 m and 30 x 30 x 4 m, 26,400 m^3 and 3, 600 m^3 of water equivalent to the storage capacity. WHS (Photo 3) in ICAR-NRCP area is constructed for multi-purpose which provides additional income and sustainability to experimental plots in additional to reducing the crop loss due to unforeseen uncertainties like water shortages. Therefore, farmers may be

Photo 3. Water Harvesting Structure excavated at ICAR-NRCP, Solapur

encouraged to construct different sizes of farm ponds across different locations of command areas as micro-balancing reservoirs by providing financial assistance of incentives to the farmers. Similarly, there is need to awareness among farm pond holding farmers about judicious use of farm pond water for different purpose like aquaculture, growing of horticulture crops on embankments so that higher sustainable income made available to the farm family (Kumar, 2016). In order to compare the costs of water use for pomegranate versus various terrestrial agricultural activities could be considered. It can be concluded that, water harvesting techniques are successful in rainfed areas for enhancing crop production and increasing irrigation potential.

Organic Mulches

A field experiment was carried out during 2014-2017 in *hasta bahar* at Solapur to quantified yield, quality and WUE of pomegranate Bhagawa *cv.* at 4.5 x 4.0 m spacing. Three different types of organic mulches (*i.e.* wheat, sugarcane baggas, safflower) at different irrigation levels were evaluated for their effects under split plot design. The actual water requirement (WR) varied from 10-40 litre/day/ tree during different phenological stages and irrigation level is the best for Sugarcane baggas old age of pomegranate tree. Also, study revealed that Sugarcane baggas (Photo 4a) enhanced vegetative growth and yield contributing characteristics. However, 40, 50 and 60% irrigation levels for 3^{rd}, 4^{th} and 5^{th} year's pomegranate plants, respectively produced results at par with respect to yield attributing traits, quality, nos. of fruit, LAI and water use efficiency. Based on statistical analysis of vegetative and yield characteristics, it was inferred that the treatment combination comprising of sugarcane baggas and irrigation levels at 30, 40 and 50% with alternate day irrigation resulted into higher yield with good quality fruits as compared to other treatments. Henceforth, water management ensure increased crop yield, high WUE, high water saving, energy consumption and minimal weed problems. Maximum WUE was 3.5, 4.3 and 3.7 kg/m^3 for 3, 4 and 5 year pomegranate tree with sugarcane baggas at 0.40, 0.50 and 0.60*ET_r irrigation level. All organic mulches significantly decreased soil temperature and temperature differences -0.65 to -2.10^{0}C were observed between control and organic mulches. WUE does not depend only on the total amount of water consumed by the crop but also on its distribution during the various growth stages of the crop. It is concluded from the present study that, organic mulch (*i.e.* sugarcane baggas) and irrigation levels (*i.e.* 0.40, 0.50 and 0.60* ET_r) is the better technological option for improving crop production as well as water productivity in pomegranate cultivation (Meshram *et al.,* 2018).

Photo 4. Organic and Inorganic mulches

Inorganic Mulches

A field experiment was carried out during 2014-2017 in late *hasta bahar* at Solapur to quantified yield, quality and water use efficiency of pomegranate Bhagawa cultivars at 4.5 x 4.0 m spacing. Three different types of inorganic mulches (*i.e.* black and white, black and pervious) at different irrigation levels were evaluated for their effects. The amount of water applied was minimum $0.30*ET_r$ and maximum $0.70*ET_r$ through drip irrigation for black and white, black and pervious under split-plot design. Maximum plant height, flowers, branches, stem diameter and fruits was recorded in inorganic (*i.e.* pervious) mulches. The actual water applied in different inorganic mulches treatments 30-70% is less than the actual water demand due to the reduced wet evaporative surface. The actual water requirement (WR) varied from 10-40 litres/day/tree during different phenological stages and 0.40, 0.50 and $0.60*ET_r$ irrigation level is the best for inorganic mulches (*i.e.* pervious) for 3rd, 4th and 5th year-old age of pomegranate tree. Also, study revealed that inorganic mulches (*i.e.* pervious) enhanced vegetative growth and yield contributing characteristics. However, 0.40, 0.50 and 0.60% irrigation levels for 3rd, 4th and 5th year's pomegranate plants, respectively produced results at par with respect to yield attributing traits, quality, juice content and TSS. Henceforth, water management ensures increased crop yield, high WUE, high water saving, energy consumption and minimal weed problems. It is concluded from the present study that, inorganic mulch (Photo 4b) is the better technological option for improving crop productivity (Shirgure *et al.,* 2003).

Subsurface Drip Irrigation System (SSDI)

The effects of various subsurface drip irrigation (SSDI) systems on some parameters of Pomegranate (*Punica granatum* L. *cv.* Bhagwa) *i.e.* physiological, yield, fruit qualities, root density, water use and WUE parameters studied in the field experiments. Under SSDI (Photo 5), six types of micro-irrigation treatments with four replications were applied: 4-subsurface and 2-surface micro-irrigation were presented along with the 1-inline lateral at dripper spacing 30 cm, 2-inline laterals at drippers spacing 30 x 30 cm, 2-inline laterals at drippers spacing 40 x 40 cm; 2-inline laterals at drippers spacing 50 x 50 cm; 1-online lateral with 2-drippers (2D) and 2-online laterals with 4-drippers (4D), respectively. Maximum plant height, steam diameter, leaf area index, flowers, nutrient status and yield was recorded in subsurface drip irrigation system (SSDI) with 2-inline laterals (30 x 30 cm) followed by (40 x 40 cm), (50 x 50 cm), surface drip irrigation (SDI) with 2-laterals and 4-drippers, 1-inline lateral at dripper spacing 30 cm and 1-online lateral with 2 drippers. Soil moisture withholding was also higher in the SSDI with double inline laterals (30 x 30 cm). The total average quantities of water used ranged from 2520.20 to 8340.60 L/bahar/t and WUE was

Photo 5. Two laterals with six inline drippers (2 LPH) per tree by SSDI

found to be ranged from 1.98 to 4.01 kg/m^3 in micro-irrigation systems. The biophysical advantages are low canopy humidity and fewer diseases and weeds. The results showed that 30 x 30 cm inline double lateral enhanced the flowering intensity, yield, root density and water use efficiency of pomegranate (Meshram *et al.,* 2019).

Surface Drip Irrigation System (SDI)

The drip irrigation system with lateral lines laid on the soil surface is the most popular application method in our country. It has advantage of ease of installing, inspecting and changing emitters and possibility of checking soil surface wetting pattern and measuring individual emitter discharge rates. In surface drip irrigation (Photo 6) can be made more applicable for a wide range of horticultural fruit crops using above the soil surface placement of laterals. The main components consists of a pump, main pipe line, sub-main pipe, laterals with resistant emitters/ drippers, pressure gauges, water meter, control valves, filtration unit, fertigation unit, flush valve, flush line and other accessories required for connections and installation. Conventional surface drip facilitates optimal moisture conditions in the upper soil layers. Studies indicated that, SDI (Photo 6) was beneficial in increasing crop yield and saving of water at two laterals with four drippers/emitters per tree of pomegranate. Water is most essential thing to sustain life for plants, human and animals. Irrigation is the lifeline for any crop production and based on the elementary concept on irrigating root zone rather than entire land surface, which results in higher water use efficiency and improved crop yield. This technique is now being used to mitigate water scare situation in the pomegranate growing areas of the country in enormous way.

Deficit Irrigation System

A field experiment was carried out during 2014-2018 in late *hasta bahar* at Solapur to evaluate the effect of deficit irrigation (Photo 7a) strategies on growth, yield and WUE. Five treatments (30 to 70% * ET_c) at different age of the plant were undertaken. The results showed that, less water produce good performance of vegetative growth, no water shoot and luxur. Reduced moisture content and maximum plant height, branches, flowers and yield is recorded at 30 to 60%* ET_c for 3rd to 6th old age pomegranate tree. The moisture content and relative leaf water content in percentage varies between 17.29 to 32.59 and 62.9 to 79.3%, respectively. The root geometry results showed that, the higher and lower root length, weight and density (69.44 cm, 89.91 gm and 1.48 kg/m^3) and (40.66 cm, 40.80 gm and 0.67 kg/m^3) was observed in giving more irrigation. The yield and WUE under deficit irrigation were 7, 12, 14 and 18 t/ha and 2.2, 2.8, 3.2, 3.5 kg/m^3 at 30% to 60%*ET_c for 3rd to 6th old age pomegranate trees. In conclusion, 30% to 60%*ET_c for 3rd to 6th old age pomegranate tree is

Photo 6. Two laterals with four online drippers (4 LPH) per tree by SDI

Photo 7. Deficit and partial root zone drying irrigation system

recommended, applicable water saving strategy and good alternative with respect to other techniques of water managements when water resources are limited in order to increase WUE while other physiological growth, roots, soil moisture, relative leaf water and water use parameters are maintained at an acceptable level.

Partial Root Zone Drying Irrigation System (PRZDI)

A field experiment was carried out during 2015-2018 in *hasta bahar* at Solapur to evaluate the effect of PRZDI (Photo 7b) strategies on physiological growth, yield and WUE in light texture soils under semi-arid condition of Maharashtra. Four treatments (40, 60, 80 and 100%*ET_c) and three sub-treatments of shifting of irrigation at 20, 40 and 60% available soil water deficit (ASWD) at drying side were undertaken. The results showed that, less water produce good performance of vegetative growth, no water shoot and luxur. Reduced moisture content and maximum plant height, branches, flowers and yield is recorded at 40, 60 and 80% *ET_c shifting of irrigation with 20% ASWD at drying side. The moisture and relative leaf water content varies between 17.29 to 36.12% and 60.24 to 83.15%, respectively. The root geometry results showed that, the higher and lower root length, weight and density (69.44 cm, 89.91 gm and 1.48 kg/m^3) and (40.66 cm, 40.80 grams and 0.67 kg/m^3) was observed in 100%*ET_c shifting of irrigation with 20% ASWD at drying side. The yield and WUE under PRZDI were 14.5, 21.10, 28.0 t/ha and 2.91, 2.64, 2.55 kg/m^3 at 40, 60 and 80%*ET_c with 20% ASWD for 3rd, 4th and 5th old age pomegranate trees. In conclusion, 40, 60 and 80%*ET_c with 20% ASWD is recommended, applicable water saving strategy and good alternative with respect to other techniques of water managements when water resources are limited in order to increase WUE while other physiological growth, roots, soil moisture, relative leaf water and water use parameters are maintained at an acceptable level.

CONCLUSIONS

Water harvesting structure is constructed for multi-purpose which provides additional income and sustainability to experimental plots in additional to reducing the crop loss due to unforeseen uncertainties like water shortages. The water requirement of pomegranate plants had been estimated to improve WUE. The utilization of various parameters and their scientific estimation enable the researchers to come up with more precise water requirement estimation for pomegranate plants of different age. Phenological stage wise daily, weekly and yearly water requirement of pomegranate trees had been calculated for young plants as well as trees under production.

Mulching and irrigation technologies are beneficial to the farmers for higher production and quality of fruits. The water to be applied through micro-irrigation system ranged from 7 to 40 litre/day/tree at different phenological stages and water saved 30-60% due to mulches (*i.e. organic* and *inorganic*) and micro-irrigation techniques. Micro-irrigation including mulching, deficit and partial root zone drying irrigation techniques ensure increased crop yield, high WUE, reduced water and energy consumption and minimal weed problems. It is concluded from the present study that, water harvesting structure, micro-irrigation, mulches, deficit and partial root zone drying irrigation is the better technological option for improving crop as well water productivity.

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Soil Compaction: Agro-ecosystem Impacts and Alleviation Strategies

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INTRODUCTION

Soil compaction is a paramount factor of the land degradation syndrome which is a major constraint for managing soil globally. It is a long lasting phenomenon not only linked with agriculture but with land use, forest harvesting pipeline installation and land renovation. Soil compression is defined as the change in volume of a soil under an applied stress, whereas soil compaction refers to an increase in the density of a soil as a result of applied pressure or load. The degree of compaction depends upon the soil type, energy applied, moisture content and extent of manipulation of soil. Compaction is also associated with the rearrangement of the soil solid particles so that soil water and soil air are compressed within the pore spaces. The predominant reason behind compaction is the compressive forces of wheels of trailers and harvesters, passage of powered rotary equipment and other tillage implements and due to the trampling of animals (Milne and Haynes, 2004). Moreover, it is exacerbated by presence of low soil organic matter content and practising tillage practices or grazing at higher soil moisture content. Reduction in pore space occurs within the macropores and the tortuosity of pore conductivity is enhanced by the rearrangement of soil aggregates. Consequently, there is alteration in soil properties (Defossez and Richard, 2002), restriction in growth of plant root either by increased mechanical resistance (Unger and Kaspar, 1994) or by reduced oxygen supply and air permeability (Czyz, 2004) which impedes plant growth and development (Cook *et al*., 1996) and lowers crop yield (Ishaq *et al*., 2001). Hence, the EU Soil Framework Directive has regarded soil compaction as one of the five threats to sustained soil quality (Commission of the European Communities, 2006). Soil aeration and strength are the dynamic parameters which are mainly affected by compaction. Besides, it is the most troublesome type of degradation to recognise and rationalize, as it may not show any visible marks on the soil surface.

Identification of Compaction

The complex nature of soil compaction on crops and soil properties needs to be assessed and the parameters for its characterization include visual assessments based on descriptions of soil profiles by soil surveying (Hodgson, 1976); visually assessing the porosity and soil strength (Peerlkamp, 1967) in semi-quantitative methods (Ball and Douglas, 2003; Shepherd, 2000; McKenzie, 2001) and examination of the root system of an established crop (Spoor *et al*., 2006). Additionally, predictive methods through computer modelling (Tranter *et al*., 2007), measurements of bulk density (Hatley *et al*., 2005), soil strength (Hamza and Anderson, 2005), cone penetration resistance and sensor based studies are in vogue. Soil water infiltration rate of the top soil can also be used in monitoring soil compaction status. Examining a soil face exposed in a trench provides an effective means of identifying soil compaction. Under certain circumstances, it may be beneficial to set up an inspection trench at right-angles across suspected compacted land which will help in comparing a compacted and less compacted land. Once

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offending layers have been identified in the field, further measurements or tests may be done at specific locations to quantify the compaction which may be particularly useful where experimental treatments have been applied.

Factors Affecting Soil Compaction

In modern agriculture, the prevalent reasons for soil compaction are farm animals and heavy machines which is exacerbated by working the soil at the wrong soil water content.

Soil Water Content

Soil water content is the potent factor having direct influence on soil compaction processes during field traffic (Hamza and Anderson, 2005). When the same stress is applied, compaction of soil is more when it is moist. Penetration resistance rises with a decrease in soil water potential, at almost all compaction levels (Lipiec *et al*., 2002). Accordingly, it is important to till the soil at the right moisture if compaction needs to be minimised. 'Simplified' tillage had no influence on soil density to 30 cm depth, in soils with low moisture (Weber *et al*., 2000). Comparison of soil compaction and soil moisture should be done at the same depth because considerable variation between inter and intra depths makes it problematic to conclude. It becomes necessary to define the moisture content of the soil corresponding to the liquid, plastic and solid limits in soils with low moisture. Soil moisture lower than (plastic limit) PL (appropriate 0.95 PL) is the most optimum and desirable condition for tilling the soil (Spoor and Godwin, 1978). It is noteworthy that increase of soil compaction with increasing soil moisture is valid up to the optimum moisture content, above which increasing soil moisture results in decrease in compaction under a given load as the soil becomes increasingly plastic and incompressible.

Mechanized Farm Operations and Soil Compaction

Trafficking by wheeled farm machines is prevailing in most of the agricultural operations, even in zero tillage systems (30% of ground area is trafficked) (Tullberg, 1990). Mostly all the agricultural operations like tilling, harvesting, bailing and spreading of chemicals or fertilisers are performed by heavy, wheeled machines. Characteristic feature due to compaction is reduction in soil porosity beneath the wheel and rut formation at the soil surface. The extent of compaction depends on mechanical strength of soil, structure of the tilled layer at wheeling point and its water status; on axle load, dimensions of tyre and velocity, number of passes as well as soil-tyre interaction. Mosaddeghi *et al*., 2000 found that tillage and traffic using heavy machines induces subsoil compaction in cropped systems to a depth of 10 to 60 cm. However, structural degradation of the subsoil in both conventional and reduced tillage systems was noted due to higher wheel loads. Some researchers favour minimum or conventional tillage against zero tillage, as the former maintains a more favorable soil physical conditions for the crop growth and development as compared to no-tillage (Tormena *et al*., 2002). If farm operations are performed when soil is dry to very dry, soil compaction could be minimised significantly. Random traffic can severely compact the soil, reduce infiltration and increase energy consumption.

Trampling and Soil Compaction

Grazing animals significantly affect the soil properties and plant growth under wet soil conditions. Penetration resistance is most vulnerable to animal trampling. There has been large scale intensification of farm animals whose trampling deleteriously affect soil quality, in terms of compaction by trampling which results in production losses and decreased hydraulic conductivity (Mitchell and Berry, 2001). Soil compaction due to trampling depends on trampling intensity (Donkor *et al*., 2002), cover of soil by plants, slope, soil moisture and land use type.

Effects of Soil Compaction on Soil, Crop Growth and Environment

Mostly all physical, chemical and biological soil properties and processes are affected to varying degrees by soil compaction. The manifestation of soil compaction varies according to crop species, variety and stage of growth, the depth at which the compaction occurs, seasonal soil moisture stress and to rainfall intensity and distribution. In forestry, root damage during compaction may facilitate the entry of pathogenic fungi. Legumes are known to be particularly sensitive to compaction, possibly because of the need for adequate aeration on N fixation in nodules. Mostly, soil compaction has often been found to have harmful effects on soil workability, macroporosity and crop growth. Moreover, field trafficking increases the dry bulk density, shear strength and penetrometer resistance of different soils, limiting root growth and increasing the draft requirement. Reduction in water infiltration, air exchange and saturated hydraulic conductivity (Alakukku *et al*., 2003) have been reported due to compaction. There are problems of drainage due to reduction of permeability in the subsoil and may lead to water-logging problems in rainy years. This increases the number of days for field operations and hinders crop growth. Reduction in drainage eventually leads to enhanced emissions of greenhouse gases from soil (Ball *et al*., 1999), for instance by increasing denitrification. Further-more, compaction may result in increased surface runoff and topsoil erosion by impeding water infiltration. Harmful soil compaction leads to reduced yield, crop water use efficiency (Radford *et al*., 2001) and nutrient uptake (Alakukku, 2003). Where roots in compact soil are confined to macropores, the rate at which they can extract water and nutrients from the soil between the macropores may be considerably slowed. However, soil compaction can have positive impacts, for instance by increasing the plant-available water capacity of sandy soils or by reducing nitrate leaching (Kirkham and Horton, 1990).

Persistence of Soil Compaction

Short-term (1–5 years) effects on soil are mainly associated with topsoil (0–30 cm) compaction, which is largely controlled by tillage operations, field traffic and the way in which these operations are adapted to soil conditions. Topsoil compaction can be alleviated by freezing, thawing, wetting, drying, microbial activities of ant and earthworm. It is noteworthy that normal tillage does not loosen the subsoil (30 cm below the surface). The effects of heavy machine traffic have been detected in soils more than 10 years after application of the load (Wu *et al*., 1997). Grain yield reduction (Hakansson and Lipiec, 1994) and reduced nitrogen uptake (Alakukku, 2003) have been attribute to sub soil compaction for several years.

The long-term effect on crop growth and yield has been found to be most evident in rainy growing seasons. Hakansson and Petelkau (1994) suggested high persistence level of subsoil compaction in non-swelling sandy soils and it may be permanent phenomenon in tropical soils. Hence, subsoil compaction is recognized as a severe invisible and accruing problem which is difficult to alleviate.

Alleviation of Compaction

Although avoiding soil compaction through proper soil management (Hatley *et al*., 2005) is the chief principle, its assessment and alleviation is also an important aspect. In case, the compaction is found on the surface, cross-tillage soon after its creation can be an effective method of control. Whereas, when it is within the topsoil, the next tillage operation may be sufficient to loosen the compacted area as discussed by Birkas (2008). To loosen compaction that is severe and deep, special equipment and techniques is required (Spoor, 2006). Birkas (2008) recommended 'Avoidance of wet soil ploughing and abstinence from drive cart or livestock on a rain-soaked field'. Modern agriculture involves the use of larger and heavier machines for tillage and other farm related operations. Therefore, it seems prudent to make use of techniques which will assess the degree of compaction, minimise compaction and prevent its formation.

Controlled Traffic

Controlled traffic helps to restrict soil compaction in the traffic lanes and maintain a zone more favourable for plant growth by providing a loose rooting zone and firmed traffic lane. It helps in long-term management of soil compaction induced by traffic, avoids machinery-induced soil compaction and provides optimum soil tilth for both crop and tyres (Taylor, 1989). However, the soil must be loosened to remove any compacted layers before implementation of controlled traffic. It has been found that soil water infiltration is similar between zero-till system and virgin soil under controlled condition (Li *et al*., 2001). As the soil is worked by a tractor, rate of infiltration could be reduced to that of long-term cropped soil. This indicates that the major factor governing infiltration is wheel traffic rather than tillage and cropping. Adoption of conservation tillage may be a potent and sustainable practice to reduce compaction, thereby enhancing the plant water availability and reducing soil erosion caused by runoff. Thus, controlled traffic together with conservation tillage has been found to slow down the effect of recompaction on tilled soil (Busscher *et al*., 2002), significantly increase soil water infiltration (Li *et al*., 2001), improve soil structure, reduce run-off, make field operations more timely and precise (Li *et al*., 2000), reduce energy requirement and minimise losses of nitrogen by reducing the emission of N_2O (Ball *et al*., 1999). Nikolic *et al*., 2001 estimated the saving in energy upto 20–25%. The second best tillage for energy conservation is reduced (minimum) tillage, which has proven to offer significant energy savings over conventional systems. Investigation done by Van den Akker (1998) showed that low tyre pressures, use of dual wheels, rubber tracks and flotation tyres can be of immense importance with respect to reduce compaction. To avoid compaction deeper than 40 cm, axle loads should be restricted, with a limit of 6 t on a single axle or 8–10 ton a tandem axle (Hakansson *et al*., 1988). Bed sowing (wheel tracks are excluded) is suitable for high-value crops which respond unfavourably to compaction.

Use of Soil Organic Matter

Organic matter helps in: (a) binding soil mineral particles (Zhang, 1994); (b) reduction of aggregate wettability (Zhang and Hartge, 1992); and (c)influencing the mechanical strength of soil aggregates (Quirk and Panabokke, 1962). Maintaining sufficient quantity of organic matter in the soil stabilizes structure, makes it degradation resistant and decreases bulk density and soil strength. Since organic materials possess greater porosity besides, lower bulk density than mineral soils (Martin and Stephens, 2001), they should be mixed and incorporated within the top soil to better soil bulk density and porosity (Hamza and Anderson, 2003). Increasing animal population has resulted in abundant supply of dung which can be used as manure to prevent the stress transmission towards the subsoil in the lower depths thus acting as a buffer to reduce farm machinery impact on subsoil. Mosaddeghi *et al*., 2000 showed that incorporating 50 and 100 t/ha of cattle manure significantly counteracted the effects of load and wetness on B.D and soil strength of a silty clay loam topsoil. Green or brown manuring as a source of organic matter is a beneficial practice in improving soil physical properties in compacted soils. Reddy (1991) observed that application of 10 t/ha of green leaf manure led to a decrease of 0.02 Mg/m^3 in bulk density and 11.8 kPa in soil strength of a sandy loam soil, while infiltration rate was elevated by 0.4 cm/h^1. Incorporating organic matter into the subsoil may be a better alternative to stubble retention in countering the soil compaction problem in dry ecologies where surface applied materials may be partially lost due to the adverse environment.

Deep Ripping or Ploughing

Deep ripping or deep cultivation is one of the foremost practice for eliminating soil compaction, destroying hard pans, shatter dense subsurface soil horizons and ameliorate hard setting soils (Hamza and Anderson, 2003) that limit water percolation and penetration of roots

(Bateman and Chanasyk, 2001). However, ripping can become a valuable soil management practice the availability of highly powerful tractors and better sub-soilers. Hamza and Anderson (2003) reported that deep ripping of soil to 40 cm along with gypsum application (2.5 t/ha) increased the legumes and wheat yield significantly on loamy sand and sandy clay loam soils. Reduction in soil strength and increased soil water permeability helped in achieving the expected yield (Bateman and Chanasyk, 2001). Laker, 2001 reported that ripping significantly increased the tobacco (*Nicotiana* spp.) quality and consequently the income per hectare, compared with conventional tillage. Shen *et al*. 2016 from China used three field tillage experiments in peanut producing areas, mainly no tillage, shallow (20 cm) ploughing, deep (30 cm) ploughing and deep (30 cm) loosening on changes in soil bulk density at 0–10 cm, 10–20 cm and 20–30 cm depths, growth of pods and root, and nutrient accumulation. It was concluded that tillage management (deep ploughing) effectively mitigated compaction stress for peanut production. Greater improvement of underground roots and pod growth and N accumulation ranked as deep ploughing > shallow ploughing and deep loosening. Increase of 7.5% and 4.6% in root biomass and peanut yields were obtained when soil bulk density was decreased by 0.1 g/cm^3, respectively. One major setback however, is that the open soil condition is prone to recompaction by subsequent machinery traffic and grazing animals, through repeated precipitation of fine clay and colloids, (Busscher *et al*., 2002). Thus, prevention of recompaction and reformation of the structure of ripped soil is possible with the help of a binding or flocculating agent (gypsum or organic matter).

Plant Roots and Soil Compaction

Hydrostatic or turgor pressure within the root elongating region provides the force required to push the root cap and meristematic region through the resisting soil. Elongation ceases due to insufficiency of hydrostatic pressure to overcome soil impedance. Plant roots when decomposed are capable of stabilizing useful structural features of the soil. Research reports indicate that plants grown in compacted soil have less number of lateral roots and dry matter than grown under both low and high soil water contents (Panayiotopoulos *et al*., 1994). Besides, compacted soil roots had smaller ratios of fresh to dry mass. Plant species with deep root system (pigeon pea) have the ability to penetrate soils with high strength. Incorporation of such plants in the rotation is desirable to minimize the risks (Ishaq *et al*., 2001). For example, in Vertisols with high shrink-swell potential, deep rooted crops such as safflower (*Carthamus* spp.) can be utilized for biological soil loosening and profile drying of subsoil (Jayawardane and Chan, 1994). Chen *et al*., 2014 reported that in loamy soil, the effect of cover crops on air permeability in compaction treatments was in the order: forage radish= rapeseed > rye = no cover crop. However, cover crops had no effect on air permeability in sandy soil probably due to coarse soil texture.

Minimising the Effect of Trampling

Gifford and Dadkhah (1980) showed that 50% cover was sufficient for maximizing infiltration rates and preventing sediment loss whereas, 30% grass cover had the lowest infiltration rates at all levels of trampling. Animal trampling had little effect on soil physical properties when pasture biomass of oats (*Avena* spp.) and Italian ryegrass (*Lolium* spp.) were about 1.0 t/ha dry matter (Silva *et al*., 2000). Furthermore, the harmful impact of livestock trampling has been found to increase as the soil moisture at the time of trampling increases and grazing should be strictly prevented on wet soils.

Use of Biochar

Biochar, a recalcitrant aromatic carbon product derived from pyrolysis of agricultural waste under no or limited oxygen, may help in alleviation of soil compaction problems due to its porous structure and large surface area (Lee *et al*., 2013). Reduced penetration resistance and increased soil water holding capacity with biochar application could improve plant root elongation (Vaccari *et al*., 2015; Andrenelli *et al*., 2016). Due to compaction, anaerobic condition prevails and there is increased emission of N_2O. Biochar enhances soil aeration which hinders the microbial denitrification pathway, thereby cutting off soil N_2O emissions (Yanai *et al*., 2007). Harter *et al*. 2014 observed that biochar application enhances N_2O reducing bacteria, thereby converting N_2O to N_2 under denitrification. However, Case *et al*., 2012 illustrated that soil physical changes caused by biochar contributed no significant effects to soil N_2O emissions. It is also reported that soil compaction favors the colonization of denitrifiers while inhibiting the growth of nitrifiers (Beylich *et al*., 2010). In wheat, Liu *et al*., 2017 observed that biochar has the potential to alleviate soil compaction stress and mitigate soil N_2O emissions.

CONCLUSIONS

In order to feed the ever-increasing global population, there has been a large scale intensification of farm machineries and cropping systems. This has eventually resulted in soil compaction and deterioration of soil physical properties. The detrimental effects are reduction in storage and supply of water and nutrients through increased soil bulk density, decrease in porosity, threat to soil quality, gaseous exchange reduction between soil and root, increased soil strength, reduced soil water infiltration and water holding capacity. Furthermore, these aids to reduced fertilizer efficiency, water use efficiency and crop yield, increased water-logging, runoff and soil erosion with undesirable environmental pollution problems. On sloping land, compaction may induce both surface and subsurface water flow which can lead to erosion with both in-field and off-field consequences.

Thus, to mitigate or delay the problem of soil compaction, a combination of practices should be followed. These practices include minimum (and zero) tillage, controlled traffic (machinery should be confined to tracks), using the same machine to minimize number of passes, combining more than one farm operation simultaneously, minimizing traffic, minimizing intensity and number of animals per grazing, maintaining vegetative soil cover, use of biochar, loosening compacted soil by deep ripping and using aggregating agent such as gypsum to slow down the recompaction process and using a rotation which includes deep and strong rooting plants able to penetrate relatively compacted soils. Farm operations must be carried out at the minimal acceptable soil moisture necessary for farm operations. To prevent soil compaction, the machines used on fields should be adjusted to the actual strength of the soil by using low tyre inflation pressure and controlling wheel / track loads. Furthermore, for sustainable soil compaction reduction, there should be addition of organic matter through inclusion of legume, green and brown manure, animal manure addition, stubble retention, which will aid in decreasing bulk density and act as a buffer for preventing further compaction in the subsoil layers.

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Soil Erosion: Hidden Threat to Human Nutrition

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Soils sustain life and serve as a foundation for the plant and human nutrition, especially acting as a medium for producing 95% of human food. Healthy soils are not only critical for sustainable agriculture but also vital for food security due to their influence on quantity, quality and safety of food produced. The burgeoning human population of the world presently had crossed 7 billion and likely to reach 9.3 billion by 2050, poses serious challenges in ensuring food security for all. Also, in most of the countries the priority is not only set for enhancing food production but also improving its nutritional quality as wide spread prevalence of micro-nutrient malnutrition, which is known as a hidden hunger, is afflicting more than 2 billion people worldwide. Deficiencies of iodine, iron, vitamin A, and zinc found to be very critical which led to important health ramifications (WHO, 2000). Dysfunctional agriculture system is major contributing factor for this micro-nutrient malnutrition (Welch, 2002). Studies reveal that the vitamins and mineral content of fruits, vegetable and other crops have declined significantly in the past 70 years (Davis *et al.,* 2004 ; White, 2005). In general, edible portion of crops raised in healthy soils has high nutritional content compared to unhealthy soils. Soil degradation deteriorates soil health and has been considered as one of the major causes of human malnutrition (Lal, 2009). In combating malnutrition, presently adopted approaches like food fortification, mineral supplementation, food diversification and bio-fortification are not sufficient and call for additional and simultaneous soil based sustainable measures. Since soil erosion is a major soil degradation process, this opinion article looks to develop comprehension about nexus between soil erosion and nutritional quality of produce and human nutrition.

Plants acquire mineral elements from soil in specific chemical forms under favourable conditions. The uptake of these elements by plants depends upon several factors *i.e.* climate, edaphic, cultural practices, genotype, etc. and interactions between them. Among edaphic factors, soil properties like pH, cation exchange capacity, soil structure, soil organic carbon, soil water content, and microbial activities and interaction among them play a crucial role in plant nutrition (Frossard *et al.,* 2000). Although certain minerals are abundant in soil their phyto-availability also depends upon interaction and antagonism between different nutrients. Further accumulation of these mineral elements in edible portion of plants depends upon their mobility and partitioning within plants (White, 2009). At present direct linkages between iodine, selenium and zinc content in soil and their status in plant and human is well established (Pimentel, 2006).

Soil erosion involves three steps *viz.,* detachment, transport and deposition of soil particles by different agents. Soil erosion causes loss of fertile top soils and alone water induced soil erosion poses serious degradation challenge to soils of Asia and Africa. Worldwide, about 24 billion tonnes of productive top soil lost annually because of water erosion (Dubois, 2011). In India, out of 328 Million hectares (M ha) total geographical area (TGA), 120.7 M ha is suffering from different soil degradation processes, 68.4% (83 M

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ha) of which is affected by water erosion (ICAR and NAAS, 2010). According to latest estimate, India's average soil loss is 15.4 t/ha/yr and nutrient loss from soil is 5.4 to 8.4 M t/yr (ICAR-IISWC, 2015). The loss of nutrients from soil reduces the nutrient density in crop produce and it was estimated that approximately INR 8893/ha would be required to replace the lost macro-nutrients through inorganic fertilizers alone. Soil erosion processes alters soil physical, chemical and biological properties. It diminishes soil quality by inflicting adverse changes on different soil properties e.g. structure, water holding capacity, water infiltration SOC (Pimentel *et al.,* 1995; Quinton *et al.,* 2010), macro and micro nutrients status, soil biota (Wall *et al.,* 2015) and soil depth within landscape as well as offsite and thus possibly influence nutritional quality of food produced. Eroded soil materials selectively carry away soil organic matter in which most of the potentially available micro-nutrient held, while leaving behind coarser fraction and cause nutrient imbalance within and outside landscape. Subsoil's exposed by erosion processes are generally higher in pH than topsoil's, that may cause deficiency of some micronutrients (Brady and Weil, 2010). Soil erosion washed away vital nutrients from soil, eroded material contains three times more nutrients compared to eroded locations. Furthermore, soil erosion causes spatial variability of soil nutrients resulting in eroded locations deficit, deposited region enriched and non-eroded position neutral condition (Mariappan, 2016). This erosion induced spatial variability in soil quality (nutrients) leads to unevenness in crop yield / productivity. In deposited area heavy accumulation of macro and micro nutrients can leads to nutritional imbalances in plants due to luxury consumption of certain elements and hyper-accumulation of some trace elements in plant edible portion. To date soil erosion impact was primarily focussed on soil quality and crop productivity losses nevertheless its impact on nutritional quality and quantity of crop edible produce was largely overlooked (Lal, 2009). Looking at complex interaction among these factors, distinguishing impact of particular factor on food nutritional quality is strenuous. Therefore, it is necessary to understand that how different processes of soil erosion alter soil properties within and outside landscape and that in turn affects nutritional quality of crop produce. Considering this, a comprehensive and meticulous study is required to know the aggregate impact of different erosion processes by moderating certain controllable factors in field condition. Multi-disciplinary approach (soil scientist, agronomist, plant physiologist, and human nutritionist) is to be adopted for better understanding of linkages between soil erosion processes, nutrient density in plant edible portion and human nutrition which in turn can help in framing alternative soil based policies to restore eroded soils, improve nutritional quality of food crops and human wellness.

Future Prospect

1) How removal and deposition of soil particles influence soil organic carbon and nutrient cycling and thus nutritional quality of edible portion of crops.
2) How secondary metabolites (antioxidants, phenols) content of crop edible portion get altered with soil erosion processes.
3) Whether restoration of eroded soils through conservation practices enhance the nutrient density of produce.
4) How different fertilization strategy (Integrated Nutrient Management, Site Specific Nutrient Management) influence crop nutritional quality on eroded and accreted area.
5) What are the impacts of erosion processes on nutritional quality and quantity of perennial fruits and vegetable crops (nutrient dense crops).

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Dissemination of Farmers' Friendly Technologies Improves Farm Income

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Dissemination of improved horticultural technologies to farmers' fields is very important for enhancing farm income and making them self-sufficient. The per capita income of small and marginal farmers of our country involved in fruit production is low as compared to other countries. Horticultural technologies like high density plantation, rejuvenation and canopy management, micronutrient management, proper harvesting, ripening protocols and pest management in subtropical fruits etc. were disseminated at farmers' orchards in nearby villages of Mall, Malihabad and Kakori blocks of Lucknow district of Uttar Pradesh during 2012-18. Apart from local areas, quality planting materials were also supplied and performed well in different parts of the country. Based on feedback from the farmers, guava cultivation in high density enhanced farmer's income by about ₹ 1.5 to 2.0 lakh/ha during 5th year and onwards. Field demonstration were also conducted on nutrient management *i.e.* soil and leaf tissue sampling procedures, distribution of soil health cards, and nutrient management adoption for quality fruit production. Field demonstrations for adoption of technologies and providing benefit to the farmers were carried out wherein farmers' income was low at initial stage; study revealed that farmers income improved, and it was recorded more than ₹ 50,000/ha after the technology demonstration and adoption. Proper harvesting protocol, ripening and packing were advocated to farmers for better marketing. Pest control measures were also disseminated for reducing the cost of cultivation.

Proper dissemination of farmers friendly technologies is the key to success for improving farm income, particularly of small and marginal farmers. Technologies, such as nutrient management, canopy architecture, pest and disease control measures, and value addition of products must be transferred to farmers in real time (Photo 1 and 2). Field demonstration of nutrient management *i.e.* soil and leaf tissue sampling procedures, preparation of soil health cards, nutrient adoption as per recommendation are required for quality fruit production.

Farmers from different states of the country were apprised of soil sampling procedures and laboratory analysis for determining the exact quantity of nutrients needed to apply at fields. Site specific nutrient recommendations are needed in order to reduce the cost of cultivation as well as increase nutrient use efficiency. Guava requires specific nutrients for its quality fruit production. Farmers from Nasik, Maharashtra were demonstrated soil sampling procedures and precision farming technologies in guava field for enhancement of income. Guava growers across countries adopted the precision farming technologies, particularly water and nutrient management strategies apart from canopy management and pest control, which improved their income. Ideal canopy management during the month of May is required for fruiting in November-December. For getting March-April fruiting, canopy management is required in the

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month of October. January-February months are best suited for profitable fruiting in July-Aug. A minimum of 27 t/ha yield and profit of ₹ 1.5 to 2.0 lakhs from 5th year onwards in high density guava cultivation is success story of many farmer's fields (Photo 3).

A field demonstration on adoption of technologies and benefit earned by farmers was studied wherein farmers' initial income ranged between ₹ 9000 to 30,000 (52.4%), ₹ 30,000 to 50,000 (19%) and ₹ >50,000 (28.6%) before adoption. The improvement in income was recorded more than ₹ 50,000 after the technology demonstration and adoption. Productivity level

Photo 1. Interaction and *in-situ* demonstration of soil sampling in mango orchard at farmer's field

Photo 3. Discussion with farmers of Nasik (Maharashtra) on precision farming in guava (fertigation, soil sampling techniques and yield improvement)

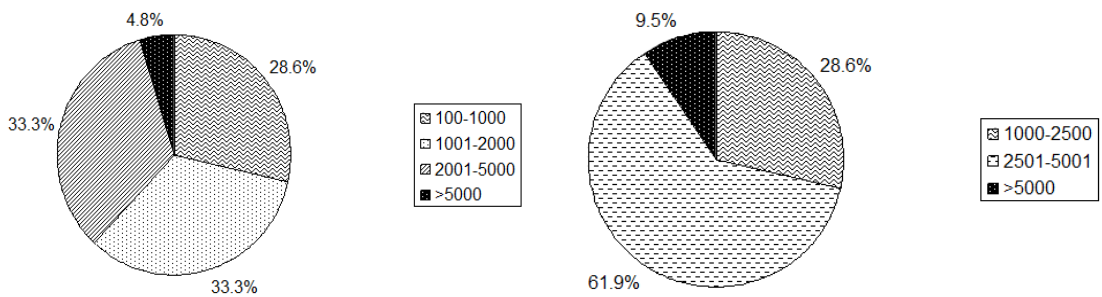
Photo 2. Rejuvenation and canopy management in mango

also improved by 4.8% to 9.5% (>5 t/ha) and 33.3% to 61.9% (2-5 t/ha) before and after transfer of technology. Thus, technological dissemination, demonstrations at farmers' field as well as its adaptations by the farmers are very crucial for the improvement in earning of the small and marginal farmers (Photo 4 and Fig. 1).

Photo 4. Distribution of fertilizers (free of cost) to farmers for on-field demonstration of nutrient management technologies

Rejuvenation of old unproductive mango orchards is required to make them economically sustainable *i.e.* giving quality fruit production for longer periods. Severe pest menace in mango orchards during the life cycle of mango was noticed during the last couple of years. Recent changes in weather parameters are responsible for such variations in insect attack and its menace on fruit growing areas (Photo 5). Farmers were puzzled about thrips attack on mango, and the

Photo 5. Mealy bug control was demonstrated to farmers



Dashehari mango production level (kg) before and after technology adoption by the farmers

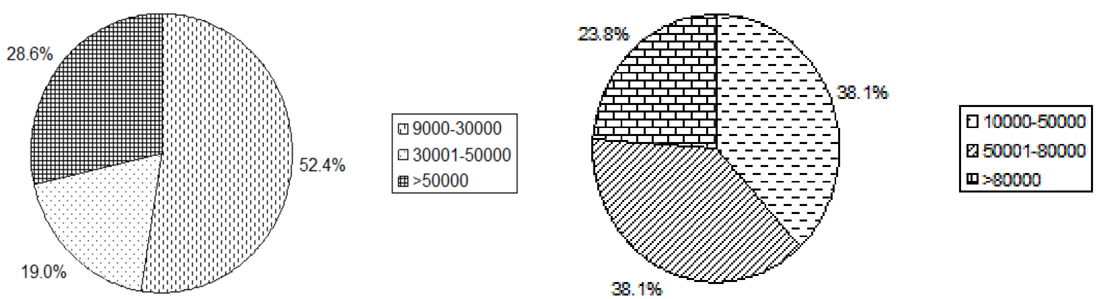


Fig. 1. Gross income (₹) of the farmers before and after technology adoption

Photo 6. Demonstration of harvesting protocol and ripening at farmer's door step

Photo 7. Frontline demonstration of bagging technology

hopper has devastated some mango orchards. Thus, mango growers encountered heavy loss. Technology on control of thrips and hopper were disseminated to farmers and feedback on saving the crop was recorded from time to time. Several farmers' trainings, sensitization workshops and awareness programmes in this direction were conducted in and around Malihabad region in order to reduce the pest load, and thereby save the input cost of pesticides. Further, technologies for mango mealy bug, inflorescence midge, fruit fly etc. were also transferred to growers. Progressive farmers easily adopted these technologies for enhancing their income. Benefit was also accrued to small and marginal farmers who were devoid of such technologies. By adoption of fruit fly trap during April to July, growers saved maximum of ₹ 10,000 on per ha basis. Frontline demonstration on safe harvesting and ripening protocol along with bagging technology was disseminated for growers benefit (Photo's 6 and 7).

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Moisture Conservation and Productivity in Mango *cv.* Langra using Drip Fertigation

Tarun Adak*, V.K. Singh, Kailash Kumar and G. Pandey

Moisture conservation *in-situ* in the orchard soils is important for maintaining better root zone soil moisture and increasing the productivity. This is particularly needed during dry period and absence of rain spells at the time of fruit setting to developmental stages. The reference evapo-tranpiration was varied from 1.25 to 7.63 mm/day during the flower bud differentiation, flowering, fruit setting and fruit developmental stages while pan evaporation during the same periods ranged between 0.50 to 9.8 mm/day. Drip fertigation is useful in maintaining wet root zone in mango fruit; it also regulates the soil thermal activity in Langra crop under subtropical climatic condition.

Conservation of soil moisture is important for maintaining the root zone wetness and to make sufficient soil moisture available to the trees. Trees need considerable amount of moisture for maintaining its turgidity; metabolic activity, transpiration and other physiological activity. The moisture retained in soil however depends on the types of soil and distribution of pore size; conductivity etc. Different soils like sandy loam, clayey, sandy soils / alluvial soils, red and lateritic soils, black soil and forest soils etc differs in their water holding capacities. Pore water conductivity also plays crucial role in moisture movement either through mass flow or diffusion to the root zone (Adak *et al*., 2014). Moisture conservation during dry spells of dry hot summer with absence of rains by adopting practices like mulching and drip fertigation is crucial for fruit set to fruit developmental stage. Many a times, in absence of over saving irrigation, fruit drop along with fruit cracking is a common visible phenomenon observed across fruit orchards. Sometimes in sloppy lands, half moon terracing and other micro-catchment area moisture conservation through water harvesting improves the survivability of fruit trees as well as productivity (Farmahan and Sharma, 2005; Laishram and Ghosh, 2017).

In order to conserve the soil moisture, irrigation was applied through drip and fertilizers were also incorporated for better water use efficiency (WUE) of the Langra fruit (Photo 1 and 2). The recommended fertilizer doses were applied in the basin as practiced by farmers (T-1), followed by fertigation applied from the beginning of Sept. to the end of October (T-2), fertigation at time of flowering (T-3), at the time of fruit setting (T-4) and beginning of Sept. to second week of May (T-5), respectively (Table 1). All these time periods coincides with the critical tree phenological stages. Since Langra crop is sensitive and responsive to soil water content; retention of moisture in the root zone applied during critical phenological stages through drip fertigation improves the productivity to 43.40 kg Langra fruit per tree as compared to farmer's practice of basin irrigation application (28.54 kg Langra fruit per tree). Quality parameters influenced by way of improvement in applied nutrients through fertigation. The moisture dynamics also contributes towards prevailing soil thermal activities. In fact, both soil moisture and temperature undergoes simultaneous flow and are inter-dependent; influenced by the conductivities and existing weather situations determines the rate at which such dynamisms occur (Singha *et al*., 2016). The moisture and temperature within the root zone in mango tree showed variations

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Photo 1. Productivity of Langra mango at Lucknow experimental site


Photo 2. Drip irrigation system installed for maintaining different fertigation regimes

Table 1: Effect of soil moisture and nutrient regimes on productivity and quality of mango *cv* Langra

Treatment	Fruit yield (kg/plant)	TSS (^{0}Brix)	Acidity (%)	Ascorbic acid (mg/100g)
T-1	28.54	19.33	0.227	33.25
T-2	33.0	19.13	0.262	35.55
T-3	34.42	18.93	0.237	33.25
T-4	42.0	19.63	0.237	32.11
T-5	43.40	19.23	0.212	33.25

between 13.85 to 15.28% and 19.52 to 20.61°C, respectively. Ambient weather conditions particularly the pan evaporation and reference evapotranspiration impacts on the WUE and productivity of the fruit crops. The estimated Ref ET_0 ranged between 1.25 to 4.03 mm/day during the flowering stage while at fruit set to developmental stages; it ranged from 3.41 to 7.63 mm/day (Fig. 1). Pan evaporation in the said stage was 0.5 to 5.2 mm/day and thereafter remained mostly between 6 to 9.8 mm/day (Fig. 2). Higher pan evaporation and ET_0 indicated drier condition and to meet out the situation, drip irrigation was applied for better root zone soil moisture maintenance (Photo 3).

The perception and awareness on soil and water conservation is important for fruit crop like mango (Adak *et al*., 2017b). Actually the way we communicate and farmers adoption rate determines the success on water conservation

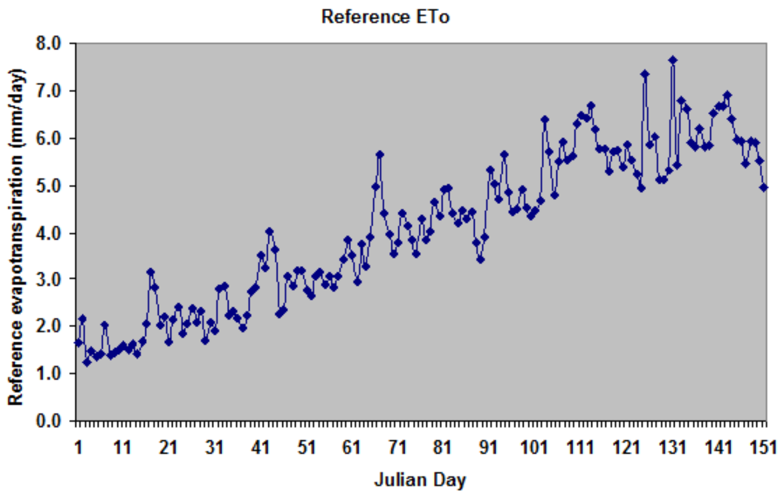

Fig. 1. Reference evapotranspiration (ET_0) during the flowering, fruit set and fruit developmental stages

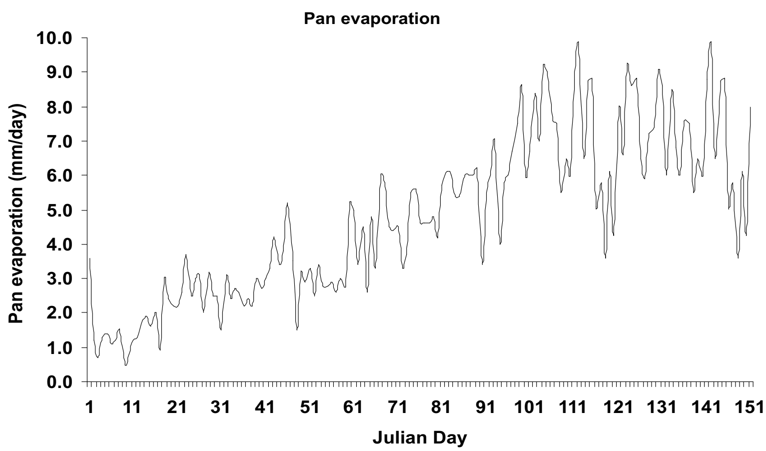

Fig. 2. Pan evaporation at the time from flowering to Fruit setting and its developmental stage

Photo 3. Response of Langra tree at different drip fertigation scheduling

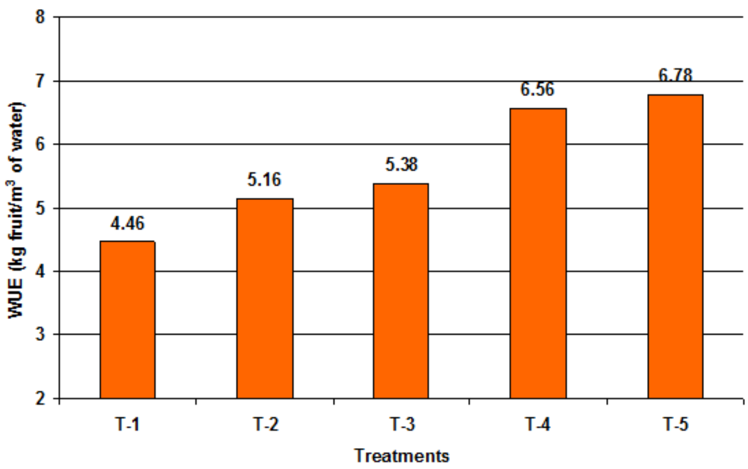

Fig. 3. Water use efficiency in Langra mango under fertigation at Lucknow condition

measures. Drip irrigation not only saves water; major source of which mostly ground water; but also improves the WUE (Adak *et al*., 2017a). It was recorded that WUE in Langra varied between 4.46 to 6.78 kg fruit/m^3 of water applied (Fig. 3). The response of fertigation and mulching for moisture conservation and thermal regulation in different fruit orchard was also evidenced (Raina *et al.,* 2013; Shimazaki and Nesumi, 2016; Poonia *et al.,* 2019 and Namaghi *et al.,* 2018). Therefore the positive response of moisture conservation measures should be disseminated for better adoption, improving WUE and reducing the load on grounding water for future use.

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अपउर्वर जमीन के लिए निराला वृक्षः सहजन

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सारांशः

सहजन या ड्रमस्टिक (मोरिंगा ओलिफेरा) का मूल निवास स्थान हिमालय की दक्षिणी प्रतिबंधित तलहटी क्षेत्र है जहाँ पर यह वनस्पति बहुतायत में पाया जाता है। यह सभी उष्णकटिबंधीय देशध्क्षेत्रों में भी पाया जाता है। मोरिंगा ओलीफेरा एक अति महत्वपूर्ण और गुणकारी औषधीय पौधा है, जो की भारत और इसके पड़ोसी देशों में व उप–हिमालयी क्षेत्रों में स्थित है। मोरिंगा ओलीफेरा एक छोटा, सुशोभित और तेजी से बढ़ने वाला, पर्णपाती वृक्ष है। इनकी पत्तियां, फूल और बीजों में प्रचुर मात्रा में ऑक्सीकरणरोधी (एन्टीआक्सीडेण्ट्स) विधमान होते हैं जिनसे यह ऑक्सीकरणरोधी (एन्टीआक्सीडेण्ट्स) शरीर में रेडियोधर्मीता को कम कर कैंसर और गठिया (आर्थराइटिस) जैसी गम्भीर बीमारियों से बचाव या रोकथाम करते हैं। औषधीय गुण विद्यमान होने के कारण इसे ''मिरेकल ट्री'' के नाम से भी जाता है। सहजन अपने औषधीय गुणों के साथ साथ मृदा सरक्षण में भी काफी उपयोगी है। इस पौधे को बंड (ठनदक) पर लगाने से किसान फसल के अलावा अतरिक्त लाभ ले सकते हैं।

परिचयः

सहजन का वैज्ञानिक नाम मोरिंगा ओलीफेरा है। मोरिंगा ओलीफेरा ''हॉर्सरैडिश पेड़'' या ''ड्रमस्टिक पेड़'' के रूप में भी जाना जाता है। यह मोनोजेनिक परिवार मोरिंगेसिया से संबंधित पंद्रह प्रजातियों में से एक प्रजाति है, जो भारत का मूल निवासी प्रजाति है। इसे सीजना, सुरजना, शोभाजन, मरूगई, मरूनागाई, इण्डियन हार्सरैडिश आदि नामों से भी सम्बोधित किया जाता है। अन्य नाम अर्थात् अंग्रेजी– ड्रमस्टिक ट्री, हॉर्सरैडिश पेड़, वेस्ट इंडियन बेन, मदर्स बेस्ट फ्रेंडय मोरिंगा से भी जाना जाता है।

मूल और आवासः

मोरिंगा ओलीफेरा एक बहुत महत्वपूर्ण और गुणकारी औषधीय पौधा है और मोरसिंगा परिवार की सबसे व्यापक रूप से खेती की जाने वाली प्रजाति भी है, जो भारत, अफगानिस्तान, पाकिस्तान और बांग्लादेश के उप–हिमालयी क्षेत्रों में स्थित है। सहजन के पेड़ का उपयोग मिस्र, यूनानियों और प्राचीन रोमन द्वारा किया जा चुका है। इसके अत्यधिक औषधीय गुणों के कारण यह प्राचीन समय से हीं बहुत मूल्यवान और प्रचलित है।

वनस्पतिक विवरणः

मोरिंगा ओलीफेरा एक छोटा, सुशोभित और तेजी से बढ़ने वाला पर्णपाती वृक्ष है जो 10–12 मीटर (32–40 फीट) की ऊंचाई और तना का व्यास 45 सेमी (1.5 फीट) तक होता है। इस वृक्ष में कम घने पत्ते होते हैं, जो अक्सर एक फलीदार प्रजाति से मिलते–जुलते होते हैं, खासकर जब फूल होते हैं, यद्यपि फल होने पर तुरंत पहचान में आ जाते हैं। छाल में एक सफेद–धूसर रंग होता है और यह मोटे काग (कॉर्क) से घिरा होता है। नयी टहनी में बैंगनी या हरे–सफेद, रोयेंदार छाल होती है। ठूंठ कुटेढा मुड़ा हुआ, अक्सर नींव के पास से दो नोकवाला होता है। छाल चिकनी, गहरे भूरे रंग की, पतला परोक्ष या तिर्यक, पीलापन लिए हुए होता है। टहनियाँ और अंकुर छोटे लेकिन घने रोयेंदार होती हैं। पेड़ में नाजुक शाखाओं का एक खुला शीर्ष होता है और पत्तियां ट्रिपेरिनेट पत्तियों के एक पंखदार पत्ते का निर्माण करती हैं। शीर्ष चौड़ा, खुला, साधारणतः छतरी के आकार का और आमतौर पर एक ही तना होता है जिनकी जड़ें अक्सर गहरी होती हैं। इसकी लकड़ी मुलायम होती है। साधारण प्रजाति में एक वर्ष में एक बार फूल लगते हैं जबकि कुछ चुनिंदा प्रजातिओं में फूलों को पूरे वर्ष में उत्पादित किया जाता है। रोपण के

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बाद पहले छह महीनों के भीतर फूल आना शुरू हो जाता है। मौसमी रूप से ठंडे क्षेत्रों में, अप्रैल और जून के बीच केवल एक बार फूल आते हैं। अधिक निरंतर मौसमी तापमानों में और निरंतर वर्षा के साथ, वर्ष में दो बार या यहां तक कि वर्ष भर फूल आ सकते हैं।फल 20 से 45 सेंटीमीटर आकार की लम्बाई का एक लटकता हुआ, तीन तरफा भूरे रंग का सम्पुटिका (कैप्सूल) होता है, जो लगभग 5 सेंटीमीटर परिधि के साथ गहरे भूरे, गोलाकार बीज रखता है। बीज में तीन सफेद कागजी पंख होते हैं जो हवा और पानी से फैल जाते हैं। खेती में, इसे प्रायः नीचे से १–२ मीटर (३–६ फीट) तक आंशिक रूप से काटा जाता है और फली को छोड़ दिया जाता है, ताकि फलियाँ और पत्तियाँ हाथ की पहुँच से दूर रहे।

सहजन या ड्रमस्टिक (मोरिंगा ओलिफेरा) एक अत्यन्त गुणकारी और पोषक तत्वों से भरपूर होने के कारण सुपर फूड के नाम से भी जाना जाता है। इनकी पत्तियां, फूल और बीजों में प्रचुर मात्रा में ऑक्सीकरणरोधी (एन्टीआक्सीडेण्ट्स) विधमान होते हैं जिससे यह ऑक्सीकरणरोधी (एन्टीआक्सीडेण्ट्स) शरीर में रेडियोधर्मीता को कम कर कैंसर और गठिया (आर्थराइटिस) जैसी गम्भीर बीमारियों से बचाव या रोकथाम करते हैं। मोरिंगा ओलिफेरा की पत्तियों में वसा (कार्बोहाइड्रेट्स), प्रोटीन, कैल्शियम, पोटैशियम, आयरन, मैग्नीशियम, विटामिन्स आदि की उपस्थति भी प्रचुर मात्रा में पायी गयी है।मोरिंगा ओलीफेरा पहले से ही कटिबंधों और उप–उष्णकटिबंधीय क्षेत्र में लोगों के बीच काफी प्रचलित है और कई मायनों में इसका उपयोग स्थानीय वैद्यों द्वारा औषधीय रूप से किया जाता है। इन पारंपरिक उपयोगों में से कुछ पेड़ के विभिन्न भागों की पोषण क्षमता को दर्शाते हैं। हाल के वर्षों में, प्रयोगशाला जांच में इनमें से कुछ अनुप्रयोगों की प्रभावकारिता की पुष्टि भी की है। भारत, ईस्ट इंडीज, फिलीपींस और उष्णकटिबंधीय अफ्रीका के सभी भागों में मोरिंगा और अर्क, काढ़े और उनसे बने अर्क विभिन्न प्रकार से देशी चिकित्सा में प्रयोग किया जाता है।

मोरिंगा ओलीफेरा के औषधीय गुणः

अपने उच्च पोषक मूल्यों के साथ हीं पेड़ का हर हिस्सा पोषण या व्यावसायिक उद्देश्यों के लिए उपयुक्त है। पत्ते खनिज, विटामिन और अन्य आवश्यक फाइटोकेमिकल्स से परिपूर्ण होते हैं। स्तनपान कराने वाली माताओं में पत्तियों के अर्क का उपयोग कुपोषण, स्तन के दूध को बढ़ाने के लिए उपयुक्त है। यह एक संभावित एंटीऑक्सिडेंट, एक एंटीकैंसर, सूजन–निरोधक, एंटीडायबिटिक और एंटीमाइक्रोबियल घटक के रूप में भी उपयोग किया जाता है। एम.ओलीफेरा का बीज, एक प्राकृतिक रूप से स्कंदनकारी (बवंहनसंदज) है जो एक बड़े पैमाने पर जल शोधन के कार्यों में उपयोगी साबित हुआ है। वैज्ञानिक शोध परीक्षण में मधुमेह और कैंसर के इलाज के रूप में भी मोरिंगा का चलन है और वाणिज्यिक उत्पादों में भी मोरिंगा के प्रयोग पर बल दिया जाता है। औषधीय गुण विद्यमान होने के कारण इसे ''मिरेकल ट्री'' भी कहा जाता है।मोरिंगा के प्रत्येक भाग का उपयोग, पोषण तथा औषधीय गुणों को प्रस्तावित करता है। प्रोटीन, विटामिन, तेल, असंतृप्त अम्ल (फैटी एसिड), माइक्रो–मैक्रो खनिज तत्व, और विभिन्न फेनोलिक्स का अच्छा स्रोत होने के अलावा यह एंटी–इंफ्लेमेटरी, एंटीमाइक्रोबियल, एंटी–ऑक्सिडेंट, एंटीकैंसर, कार्डियोवस्कुलर, हेपेट्रो–प्रोटेक्टिव, एंटी–अल्सर, मूत्रवर्धक के रूप में भी प्रख्यात है। इस अलौकिक उपचारक वृक्ष पर भविष्य में शोध से विभिन्न रोगों के लिए नवघटकों का विकास किया जा सकता है। इस अध्ययन का विषय मोरिंगा की औषधीय क्षमता और आधुनिक औषधीय प्रणाली के एक घटक के रूप में इसके भविष्य का संक्षिप्त विवरण व्यक्त करना है।

मोरिंगा ओलीफेरा के उपयोगः

विकासशील देशों में, मोरिंगा ओलीफेरा का पोषण में सुधार करने, खाद्य सुरक्षा को बढ़ावा देने, ग्रामीण विकास को बढ़ावा देने और स्थायी भूमि की देख–रेख को प्रोत्साहित करने में किया जा सकता है। इसका उपयोग पशुधन के लिए चारे के रूप में, एक सूक्ष्म पोषक तरल के माध्यम से, एक प्राकृतिक कृमिनाशक की भूमिका में और संभावित सह–औषध के रूप में भी किया जा सकता है।

मोरिंगा ओलीफेरा की पत्तियों का चूर्ण हाथ धोने के लिए साबुन के रूप में भी प्रभावी रहा है, पत्तियों में फाइटोकेमिकल्स से रोगाणुरोधक (एंटी–सेप्टिक) और शोधक (डिटर्जेंट) के गुण विद्यमान हैं। इनके बीज और इनसे बने प्रेस केक को अपशिष्ट जल अवस्था सुधारक के रूप में भी उपयोग किया गया है जो कि जल अवशोषण और मल (फेकल) युक्त कीचड़ को सोखने के लिए उपयोगी है।

मोरिंगा सीड केक, जो कि बीजों द्वारा तेल प्राप्त करने के बाद प्रतिफल (बायप्रोडक्ट) के रूप में प्राप्त होता है। यह पशु या मानव के उपभोग के लिए, फ्लोकुलेशन का उपयोग करके पानी को निस्पंदन (फिल्टर) करने के लिए भी उपयोग किया जाता है।

तालिका १ : मोरिंगा ओलिफेरा के प्रति १०० ग्राम हरी फली का पौष्टिक मूल्य

क्रम संख्या	पोषाहार	मात्रा प्रति 100 ग्राम फली
1	श्वेतसार (कार्बोहाइड्रेट)	9.1 ग्राम
2	तन्तु (फाइबर)	2.1 ग्राम
3	वसा (फैट)	1.7 ग्राम
4	प्रोटीन	8.1 ग्राम

तालिका २: मोरिंगा ओलिफेरा का विटामिन प्रकरण प्रति १० ग्राम हरी फली

क्रम संख्या	सभी विटामिन	मात्रा
1	विटामिन ए(समकक्ष)	80 मइक्रोग्राम
2	थिआमिन (बी 1)	0.103 मिलीग्राम
3	राइबोफ्लेविन (बी 2)	0.112 मिलीग्राम
4	नियासीन (बी 3)	1.5 मिलीग्राम
5	पैंटोथैनिक अम्ल (एसिड) बी 5	0.48 मिलीग्राम
6	विटामिन (बी 6)	0.129 मिलीग्राम
7	फोलेट (बी 9)	41 माइक्रोग्राम
8	विटामिन सी	8.6 मिलीग्राम

मोरिंगा के बीजों में डिमेरिक धनायनित (बंजपवदपब) प्रोटीन होते हैं जो गंदले पानी में श्लैष के कणों को अवशोषित और बेअसर करते हैं, जिसके कारण श्लैष के कण आपस में टकराते हैं, जिससे निलंबित कणों को या तो निस्तारण या निस्पंदन की प्रक्रिया द्वारा अलग–अलग करने में सुलभता प्रदान करता है। मोरिंगा सीड केक पानी से अशुद्धियों को दूर करने में प्रभावी पाया गया है।

मोरिंगा के बीज का उपयोग तेल को निकालने के लिए किया जाता है। यह तेल ओलिक एसिड, टोकोफेरोल और स्टेरोल्स में समृद्ध होता है। इस तेल का उपयोग खाना पकाने के लिए जैतून के तेल के विकल्प के रूप में और साथ हीं साथ इत्र के रूप में और चिकनाई के लिए भी किया जा सकता है। मोरिंगा के बीज सौंदर्य प्रसाधनों के उत्पादन में भी उपयोग किए जा सकते हैं और जैविक ईंधन (बायोडीजल) के स्रोत तो हैं हीं साथ हीं साथ बीजक, हरी खाद या उर्वरक के विकल्प के रूप में इस्तेमाल किए जा सकते हैं।

अन्य महत्वपूर्ण जानकारीः

मोरिंगा ओलीफेरा एल (मोरिंगा) एक प्राकृतिक रूप से जैव कीटनाशक (बायोपेस्टीसाइड) और कई पादप रोगजनकों के अवरोधक में प्रभावी रूप से उपयोग में लाया जा सकता है। इसी प्रकार, इसे एकीकृत कीट प्रबंधन रणनीतियों में कार्यान्वित किया जा सकता है। मोरिंगा और इससे बने उत्पादों की कई कृषि प्रणालियों में अलग–अलग अनूठा उपयोग है। फसल बढ़ाने के रूप में मोरिंगा का उपयोग न्यूनतम संभव लागत पर फसल की पैदावार में सुधार लाने का एक पर्यावरण–अनुकूल तरीका है। उत्पादकता में यह कम

तालिका ३: मोरिंगा ओलिफेरा में अल्प मात्रा वाली धातु खनिज सामग्री प्रति १०० ग्राम हरी फली

क्रम संख्या	खनिज सामग्री	मात्रा (मिलीग्राम में)
1	कैल्शियम	99.1
2	लोहा	1.3
3	मैग्नीशियम	35.1
4	मैंगनीज	0.119
5	फॉस्फोरस	70.8
6	पोटैशियम	471
7	सोडियम	70
8	जस्ता (जिंक)	0.85

तालिका ४: मोरिंगा ओलिफेरा की फली में मूलभूत एमिनो अम्ल (एसिड) प्रति १०० ग्राम हरी फली

क्रम संख्या	खनिज सामग्री	मात्रा (मिलीग्राम में)
1	कैल्शियम	99.1
2	लोहा	1.3
3	मैग्नीशियम	35.1
4	मैंगनीज	0.119
5	फॉस्फोरस	70.8
6	पोटैशियम	471
7	सोडियम	70
8	जस्ता (जिंक)	0.85

लागत में वृद्धि कर दुनिया के कुछ हिस्सों में खाद्य जरूरतों को पूरा करने में इसका योगदान सराहनीय है क्योंकि जिस प्रकार वैश्विक जनसंख्या बढ़ती है उसी गति से गरीबी दर बढ़ती है।

सहजन की खेती कम उपजाऊ जमीन अथवा बंजर जमीन में करने तथा इसकी पत्तियों को मिट्टी में मिलाने से जमीन की उत्पादकता में वृद्धि देखि गयी है। यह बंजर जमीन सुधार के लिए एक उपयोगी पादप है जिसमें से आर्थिक आमदनी भी प्राप्त की जा सकती है। कोरापुट के क्षेत्र में सहजन एवं सहजन आधारित कृषि–बागवानी पद्धति पर किये गए अनुसंधान में, अपप्रवाह एवं मिट्टी के कटाव में कमी के साथ–साथ मिट्टी की गुणवत्ता में वृद्धि पायी गयी है। हाल के अनुशंधान से प्राप्त जानकारी से ज्ञात होता है कि सहजन के सूखी पत्ति जिसमें प्रचुर मात्रा में प्रोटीन पाया जाता है, इन का उपयोग मछली(ग्रास कार्प) के फीड में मिलावट के तौर पर भी किया जा सकता है। सहजन की घनी खेती से 50 से 100 टन प्रति हेक्टेयर फ्रेश पत्ति प्राप्त की जा सकती है जो कि दूध देने वाले पशु के चारे में 20 प्रतिशत तक उपयोग किया जा सकता है। सहजन की पत्ती को पशु चारे में उपयोग कर, पशु स्वास्थय एवं दुग्ध उत्पादन वृद्धि के लिए भारत सरकार के नवनिर्मीत मंत्रालय (पशुपालन एवं मतस्य विभाग) द्वारा भी सम्बन्धी परियोजनाओं पर विचार हो रहा है।

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"Save Soil Campaign"

"Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it"

From Atharvavedas (Sanskrit Scripture) – 1500 BC

"I pledge to intensify our endeavours to protect and improve soil resources that surround us in order to restore and maintain a sound ecological balance in land, air, and water. I commit myself to promoting public awareness and education on the "*Save Soil Campaign*" as well as the public reporting of the environmental impact of various activities being taking place on the thin layer of SOIL. I believe it is our responsibility to take care of soil and land resources so that it remains available in good condition to my children and grand children (for generations). I also pledge to continue promoting the benefits of soil conservation for the sake of human's well being".

Facts and Popular quotes about the importance of soil resources

- It can take more than 1,000 years to form a centimeter of topsoil
- In a handful of fertile soil, there are more individual organisms than the total number of human beings that have ever existed
- There are over 100,000 different types of soil in the world
- Five tonnes of animal life can live on one hectare of soil
- SOIL is "*Soul of infinite life*"
- Listen to soil, if you have ears - *Jesus*
- Take good care of me or else, when I get hold of you, I shall never let your soul go - *Kipsigis proverb cites soil as saying to man*
- We know more about the movement of celestial bodies than about the soil underfoot - *Leonardo da Vinci*
- Soil is a storehouse of Carbon to mitigate Climate change
- A land without a Farmer becomes barren
- Agriculture connects Farmer, Land and Nature
- Soil sustains all life on the Earth
- Farmers are the Human factors in soil Management
- Farmers first in soil and water conservation: Beginning the Journey towards a new vision
- Farmers heal the land

Indian Association of Soil and Water Conservationists

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