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Natural resource management to improve rural livelihoods in a natural protected area in Central Mexico: Exploring communities´ attitudes on conservation

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ABSTRACT

This investigation examines the attitudes of 150 inhabitants of 6 different communities located in the Sierra de Huautla Biosphere Reserve, in Morelos, Mexico, regarding environmental degradation, conservation of natural resources and the biosphere reserve. The interviewees value the forest mainly because of the natural resources and the environmental services it provides, and in general, they have a positive attitude towards conservation initiatives and the establishment of the biosphere reserve, even when they do not see any benefits derived from the conservation of natural resources. Despite the existence of favorable attitudes towards conservation, this research also highlights the absence of knowledge and information within the communities regarding the objectives, projects and activities performed by the reserve, indicating a scarce intervention of the rural population in the management of the area. It is necessary to consider that the environmental attitudes are dynamics and non favorable changes can occur if some central aspects of the management of the protected area are not changed, among them, the existence of effective spaces of social participation where rural inhabitants can present their opinions, interests, demands and priorities, have access to decision making or receive compensations for the conservation costs.

Key words: Conservation, Natural resources, Social participation

INTRODUCTION

The establishment of natural protected areas (PA) as been one of the most used strategies to protect biodiversity and sustain ecosystem health worldwide (Hockings, 2003). Initially, these areas were only conceived to protect natural ecosystems and therefore their actions were directed to strict conservation and non human activity was allowed. However, many areas with high biodiversity, particularly in development countries, are inhabited by human communities that rely on harvesting the resources of the natural environment. For this reason, the figure of the PA has been changing to include objectives of social and economic development. Therefore, PA have become entities that require multidisciplinary efforts and focus to achieve their objectives of biodiversity conservation and sustainable harvesting of natural resources, enhancing the livelihood of local communities (Naughton-Treves *et al*., 2005, Durand, 2010).

The University of the State of Morelos (UAEM) and the Commission for Natural Protected Areas (CONANP) signed a collaborative agreement in 1999 to create and co-administer almost 60 thousand hectares called Sierra de Huautla Biosphere Reserve (REBIOSH). The current objectives of this PA are directed to preserve natural habitats and fragile ecosystems; promote the rational and sustained harvest of natural resources; and promote social and economic development of the area through productive sustainable projects (CONAN P-SEMARNAT 2005).

To co administrate a PA between the federal government and an academic institution such as UAEM, represent formidable challenges for both institutions. They not only have to work closely together to integrate strategies that help fulfill the objectives of conservation and environmental management, but also to interact with the local communities to conceive, coordinate and apply actions to achieve their objectives.

To date, this interaction has resulted in diverse workshops to obtain the first zoning of the REBIOSH, to recover traditional knowledge on the use of medicinal plants, to implement the use of wood saving stoves, an tot promote the construction of greenhouses to reproduce native

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plants (Durand and Vázquez, 2011). However, on occasions this relation has not been so cordial: five years after the REBIOSH was created, inhabitants of the

Huautla community started to have doubts about the legitimacy of the administration of the newly created biological station Cruz Pintada, in particular regarding the distribution of resources obtained. The conflict grew in proportion until it finished with the expulsion of the PA personal from the biological station, which currently remains out of operation (Durand and Vázquez, 2011).

Less than a year from the mentioned conflict, Dr. Leticia Durand from UNAM, interviewed the population of the REBIOSH in order to evaluate the attitudes of the local population regarding the deterioration, conservation and the approaches of the PA to the local inhabitants (Durand, 2010a). The results of her study indicate a lack of knowledge and information regarding the purposes, projects and activities of the PA, as well as an scarce intervention of the local population in the management of the area (Durand, 2010a).

During the last decade, the situation of the REBIOSH has changed: in 2007 a new biological station was created in the community of El Limon. Also since 2001 there is another biological station in the community of Quilamula. In 2012, the objectives of the PA changed in order to contribute to the biological conservation of the country, with emphasis on the dry tropic, through frontier research, high quality teaching, work in rural communities and the diffusion and application of the generated knowledge (CONANP-SEMARNAT, 2005, Durand, 2010).

These changes represent an excellent opportunity to evaluate the efficiency of the REBIOSH in the fulfillment of its conservation, management and economic development objectives. The present project contributes with the environmental attitudes of the population of six local communities located within the REBIOSH, regarding the conservation and sustainable harvesting of the environment, as well as the role of the REBIOSH in the social and economic development of the population through the last 10 years.

Justification

To evaluate the efficiency of environmental management practices and the social development of the REBIOSH, will provide the authorities with useful information to develop coordinated strategies that will adequately distribute the environmental, social, cultural and institutional resources (Timko y Satterfield 2008). The present study is conceived as a tool to strengthen communication and decision making that will help managers to evaluate the efficiency of the applied programs and strategies that are being used in the environmental management of the REBIOSH.

The importance of this project relies not only on its multidisciplinary spirit, because it involves social and biological scientists; it will also use quantitative and qualitative research techniques that will allow to perform different types of analyses and obtain better results. The students involved on this project will also know about the importance of integrating efforts of different disciplines to resolve environmental, social and economic problems, this will form integrated professionals compromised with the environment and the population. This study will also contribute to conceive new project and research lines to researchers and students interested in these type of projects. Finally, this study aims to provide an evaluation tool to allow REBIOSH personnel to identify the main challenges of their administration and allow the development of new actions and programs to improve their task.

General Objective

To register and evaluate the perceptions of the population in six communities located within the Natural Protected Area Sierra de Huautla in relation to the fulfillment of the conservation, environmental management, and social development objectives of the REBIOSH.

Particular objectives

1. Identify the priorities and needs of information from the local population regarding environmental management and the development of new economic alternatives.
2. Analyze the influence of the REBIOHS in the social and economic development of the local inhabitants.
3. Identify communication issues between authorities, researchers and inhabitants that can interfere with the generation and execution of environmental management and social development programs and finally contribute with strategies of participative planning.

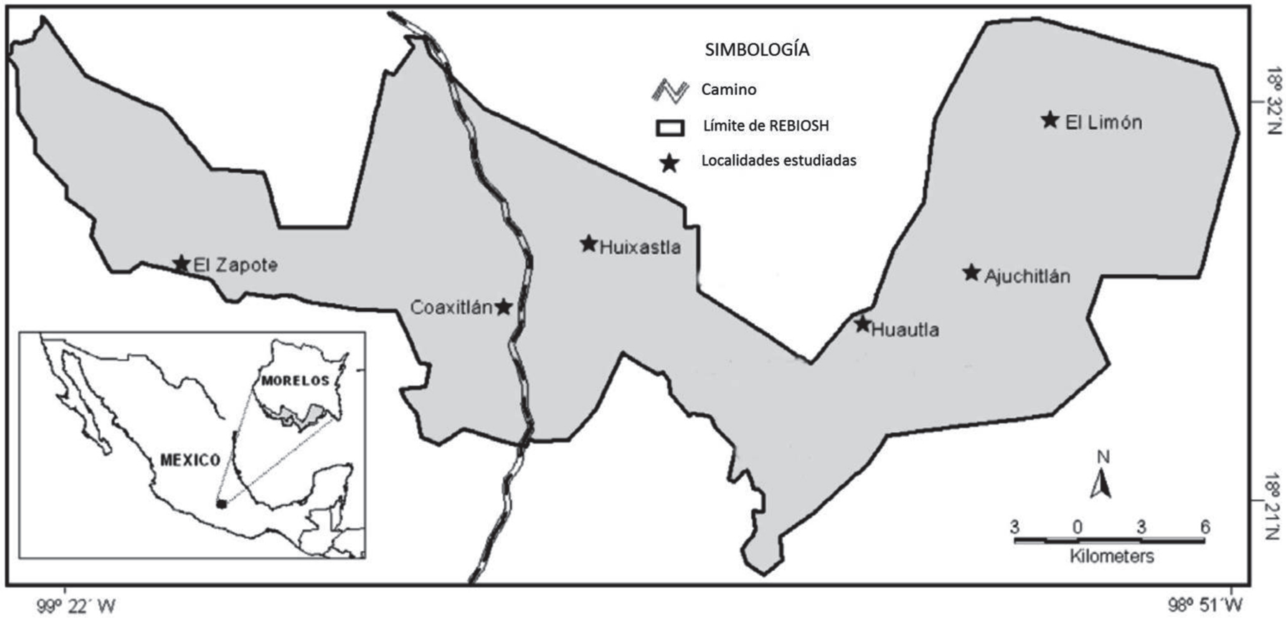

Fig. 1. Studied communities within the REBIOSH

4. Contribute with communication and environmental education strategies to strengthen and promote the interaction between the different actors involved in the environmental management of the REBIOSH.

METHODS

During the first phase of this research project, periodic visits to the *El Limón*, *Ajuchitlán*, *Huautla*, *Coaxitlán*, *El Zapote* and *Huxastla* communities were performed (Fig. 1). During these first visits we presented the study we intended to do to the local authorities, we interacted with the population and identified those key actors relevant in the management and conservation of natural resources that could provide the best information useful for this research. These first informal meetings were crucial to create an environment of mutual trust and cooperation between researchers, PA authorities and local population, which latter allowed a better communication, information flux and experience exchange.

In order to know the needs, priorities and demands regarding environmental management and social development from the local population within the REBIOSH, we applied qualitative techniques such as participative observation and questionnaires that were applied to rural inhabitants from these six communities located within the REBIOSH. The objective of these questionnaires was knowing local perceptions regarding the deciduous forest; the conservation of natural resources and environmental deterioration; functioning of the REBIOSH, its authorities and the influence on the inhabitants lives; and finally, about conservation projects and those projects perceived as priorities by the communities. This information in turn will be very useful to those in charge of decision making so they can do it more informed and thus improve their tasks.

These questionnaires were captured in a word processor and then imported to Atlas.ti, a software specialized in the management, synthesis and analysis of qualitative information. Transcripts were coded and analyzed with a through a line by line revision of the texts, which allowed us to create categories as they were mentioned in the questionnaires. This allowed us to reduce information into more manageable formats to facilitate its interpretation. Each of the studied localities was analyzed separately to know the particular realities perceived by each community.

RESULTS

Communities of the REBIOSH

A total of 150 questionnaires were applied to local inhabitants, with an average age of 58.3 years.

Tropical Decidous Forest Perceptions

The interviewees consider the forest as something important for the life of their communities due to the resources they obtain from it for their sustenance, as well as the ecosystem services it provides (Fig. 2).

Table 1. Interviews performed in the six studied communities within the REBIOSH

Community	Interviews
Huixastla	20
El Zapote	15
Ajuchitlán	20
Huautla	58
Coaxitlán	20
El Limón de Cuauchichinola	17
Total	150

The grand majority mentioned that the presence of vegetation provides pure air and without pollution. They also mentioned the importance of the vegetation to attract rains in their communities, providing the vital liquid both for human and animal consumption through their recollection in special containers, and for the harvesting, which is the principal sustaining activity performed by all communities within the REBIOSH.

They also mentioned that the forest is important to sustain the biodiversity that lives in it, because animal species like white tailed deer, iguanas, and doves complement the diet of the local inhabitants. They also mentioned the presence of a great variety of medicinal plants in the forest, mentioning that these plants are used by the population to treat many diseases, therefore avoiding traveling to clinics or health centers.

Wood availability from the surrounding vegetation was also among the principal reasons involved in the positive valorization of the forest. This wood is used both domestically and to be sold and obtain economic profit from it (Fig. 2).

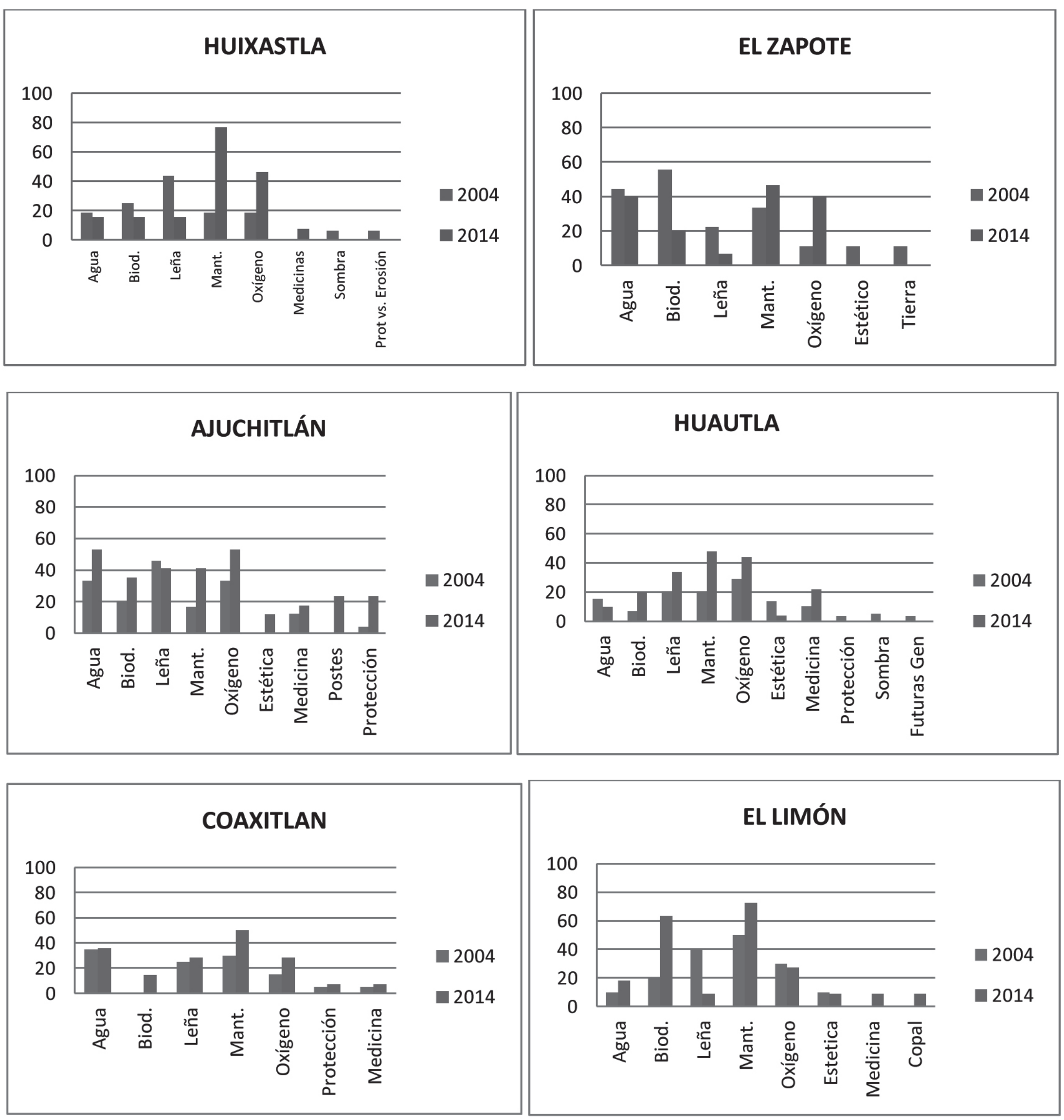

Fig. 2. Perceptions on the importance of the tropical decidous forest to the analyzed communites within the REBIOSH in 2004 and 2014

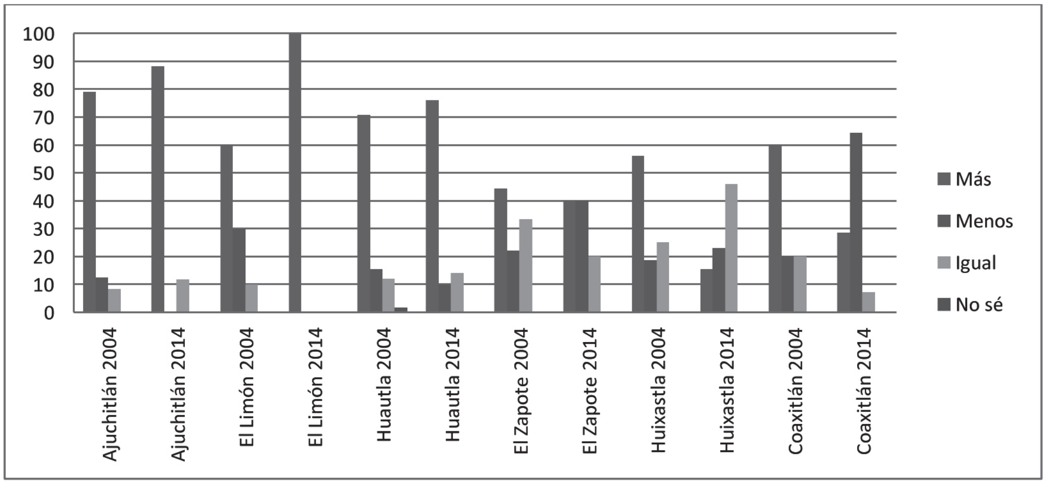

Fig. 3. Comparision of the perception between forest surface change according to the analyzed communities within the REBIOSH in 2004 and 2014.

Most of the interviewees pointed out that the forest has increased in surface in relation to 10 years before, which is probably resulting from the change of productive practices in the region. The main exception is the community of Coaxitlan, in which the inhabitants perceived a lesser surface of vegetation. According to the population, such reduction is derived principally from the mining activities in the area and the construction of roads to transport the extracted mineral. They also mentioned that in the vicinity of the community, much wood was extracted to make coal, but such activity completely ceased once the PA was decreed (Fig. 3).

In the other communities, the perceived environmental damages are derived from illegal lumbers and hunters that enter their lands without permission to extract resources illegally.

Regarding the population of animal species in the tropical deciduous forest in relation to 10 years before, the general perception was that there are more animals (Fig. 4). Among the animals that have been observed to increase is the white tailed deer, which is harvested by the inhabitants through various Wildlife Management Units (UMAS), that have been established in the REBIOSH; but the increase of species like iguanas, doves, coati, raccoons, foxes, coyotes, rabbits, quails, snakes, etc. was also noted.

In the communities of El Zapote, Huixastla and Coaxitlán a general reduction of wildlife animals was perceived. This is mainly due to illegal hunting, which is performed by outsiders as mentioned by locals, and therefore they request to strengthen surveillance actions.

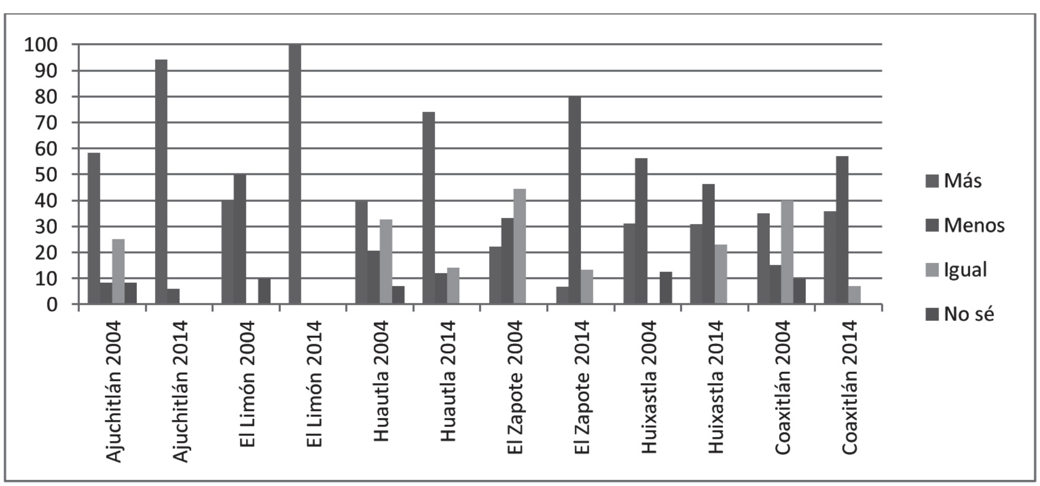

Fig. 4. Comparision of the perceptions about wildlife animals according to the analyzed communities within the REBIOSH in 2004 and 2014

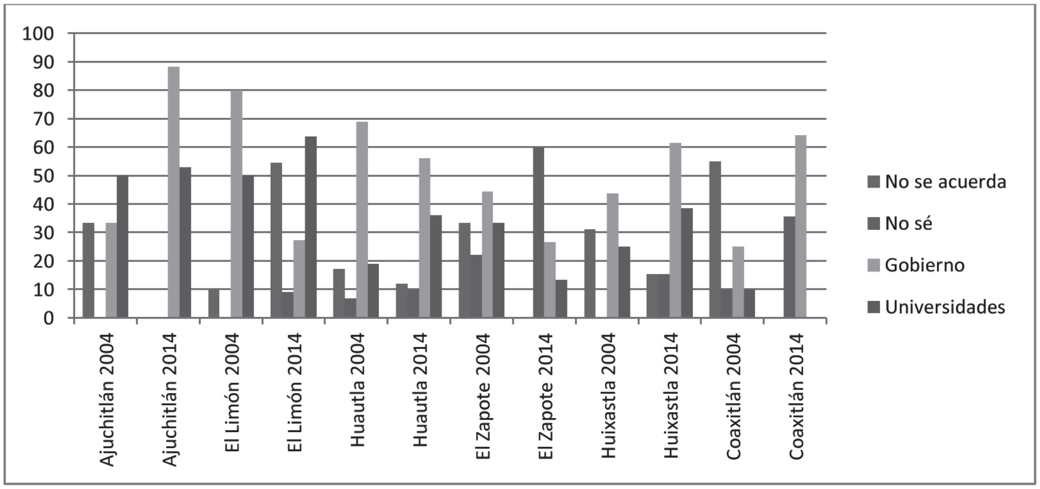

Fig. 5. Comparison of the perceptions about the presence of institutions or persons that visit the community to talk about the importance of maintaining the forest and its resources, according to the analyzed communities in 2004 and 2014

Conservation Perceptions

We questioned the interviewees about the presence of institutions or persons visiting their community to speak about the importance of preserving the forest and their resources. The general perception is about the presence of certain government environmental institutions, particularly the National Forest Commission (CONAFOR) and the technicians in charge of the management of the UMAS, which assist regularly to the communities to offer day payments to make reforestation actions and other activities, and to promote, establish and monitor UMAS. The following more cited institutions were universities, among which is the University of Morelos, Chapingo and the National University of Mexico. El Zapote is an out layer because according to the interviewees, the presence of any institution is very rare in their community (Fig. 5).

They mentioned the idea that it is necessary that the government implement conservation actions, as long as the inhabitants are allowed to work, because most of them are farmers. However, many expressed that the imposed restrictions by the REBIOSH do not let them use natural resources as freely as they did, particularly in the communities of Huautla and Coaxitlan.

When asked about if they agree in not to open new forested areas to transform them in spaces for agriculture and/or cattle ranching, the local perceptions varied among the analyzed communities (Fig. 7). El Limón and El Zapote showed agreement about not opening new forested areas, mentioning that their communities have already zoned the areas for such activities and that they did not need new ones. However, in the majority of the communities the inhabitants

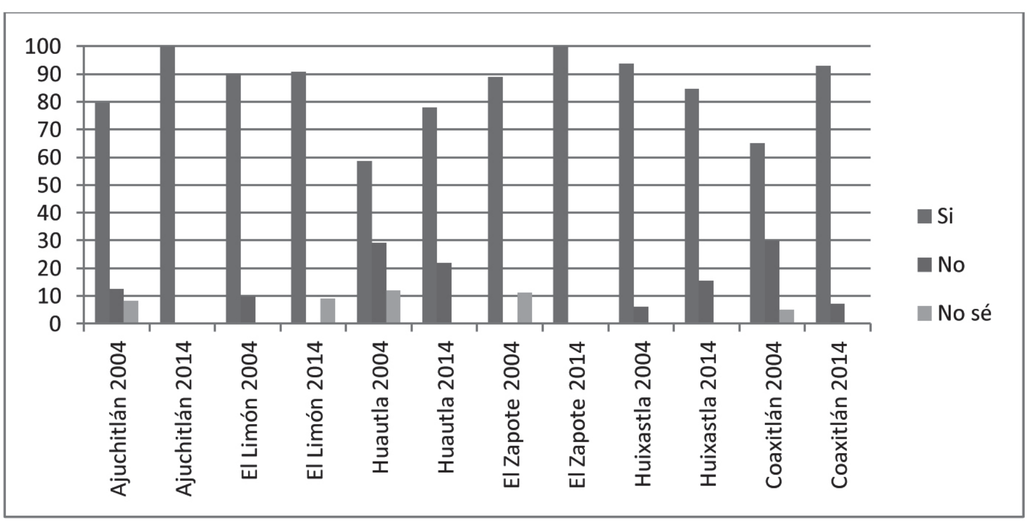

Fig. 6. Comparison of the perceptions about the government implement actions to protect the forest, according to the analyzed communities in 2004 and 2014

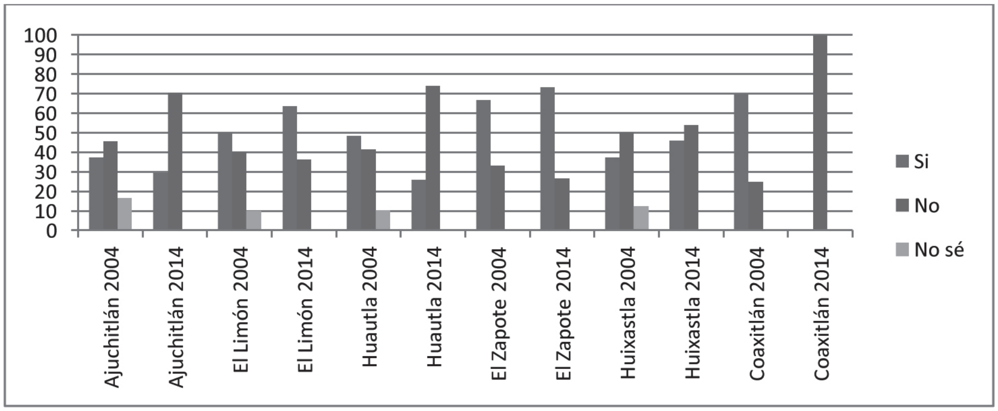

Fig. 7. Comparison of the perception on opening new vegetation areas for agriculture and cattle raising, according to the analyzed communities in 2004 and 2014

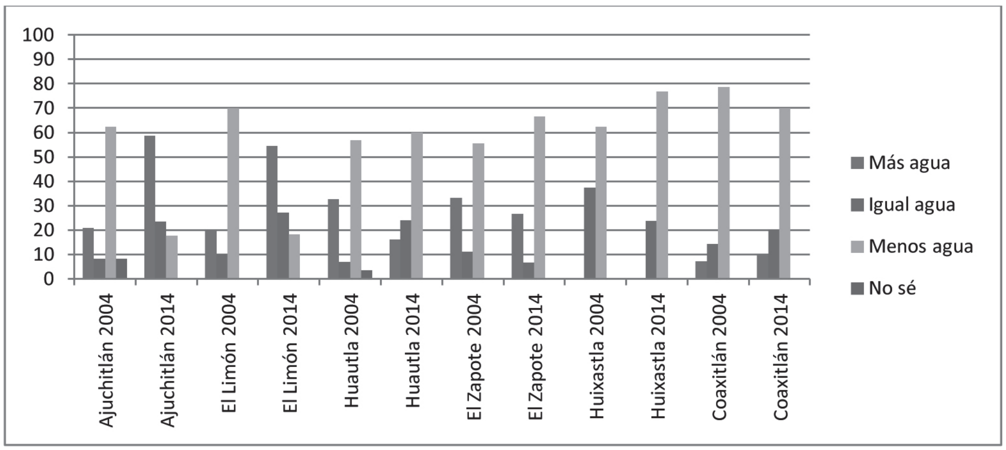

Fig. 8. Comparison of the perceptions on current water availability according to the analyzed communities in 2004 and 2014

disagree with this, mentioning that their primary economic activity is done by farmers and/or cattle ranchers, so they need to continue opening new lands for their activities. They also mentioned that the population in their communities is growing, so they need new spaces for the new settlers, as well as for the future generation of the current farmers.

In relation with the availability of water for the communities within the REBIOSH, the general perception is that water is more scarce. With the exception of Ajuchitlan and El Limon, where there are dams that where long wished for, or that are currently under construction, these dams provide water for these communities. However, the rest of the analyzed communities mentioned that the rains are more and more scarce, and for this reasons the natural water from where the population obtained water have dried. Another important thing is that in Coaxitlan, the population mentioned that the dam that was constructed there needs urgent repairs, and its capacity has been affected due to lack of maintenance and it is not enough to provide water for all the community (Fig. 8).

Perception on the Rebiosh

In relation to the presence of the REBIOSH, the interviewees in general knew that their communities are located inside the PA. The exception was Coaxitlan, that in the interviews conducted in 2004 were not aware that they were part of the PA, and even in those performed ten years later, half of the interviewees did not know they were part of the REBIOSH (Fig. 8). Even though in general the perception on this subject was raised in the interviews performed in 2014, the awareness and communication tasks with the local population has to be a constant activity by the REBIOSH.

Regarding the perception about the objectives of a natural protected area such as the REBIOSH, we observed that during the study period, the knowledge of the local population about the objectives of the PA raised. However, in the community of El Zapote we identified an inverse tendency, which strengthens our last comment on the need of more awareness tasks among the communities to let their inhabitants know about the importance and objectives of the REBIOSH (Fig. 10).

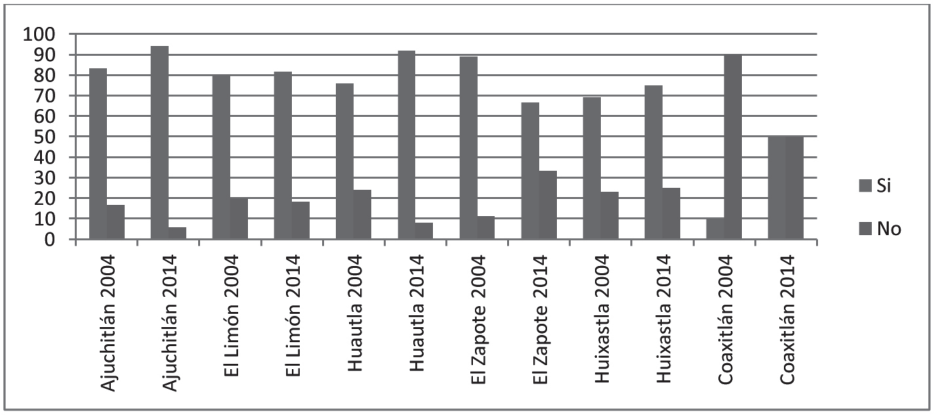

Fig. 9. Comparison of the perception about their community being inside the REBIOSH, according to the analyzed communities in 2004 and 2014

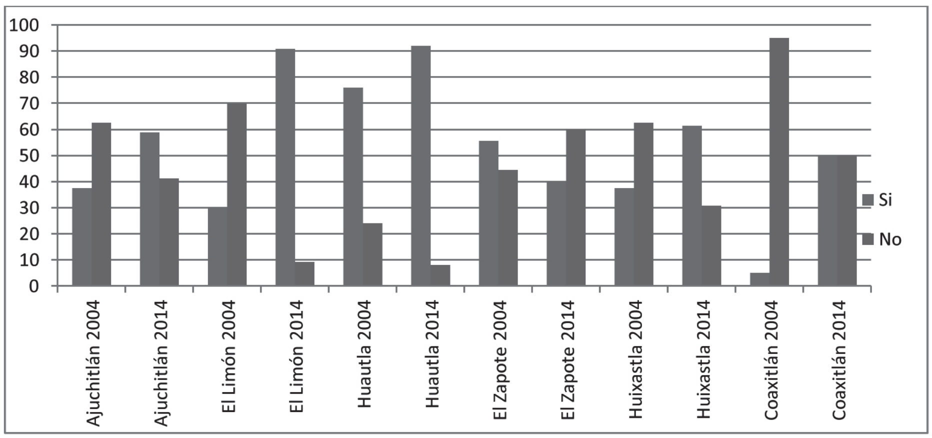

Fig. 10. Comparison of the percpetions about the objectives of an PA such as the REBIOSH, according to the interviewed communities in 2004 and 2014

In relation with the benefits obtained by living within the REBIOSH limits, the local population showed a negative perception, which is contrasted by the communities of Ajuchitlan and El Limon, in which the population mentioned support from salaries directed to maintain the functioning of the UMAS of white tailed deer. It is worth mentioning here that in these latter communities, is where for a long time most of the economic resources where exerted, which is probably why their inhabitants mentioned more favorable opinions on this matter. However, during these past years, the REBIOSH administration have diversified the number of communities that received such support, and that is perhaps the reason why the perception on these benefits increased in 2014. It is to be expected that this tendency of a positive perception will continue to raise as long as more support is distributed in more communities (Fig. 11).

We also inquired about if living within the REBIOSH has caused any problems to the population. The majority of the interviewees responded not to have problems, however the community of El Limon showed more perceptions about having problems with the PA. In the interviews performed in 2004, such problems were originated by the prohibition to cut wood, a common activity practiced by the inhabitants. Ten years later, the manifested problems, although in less frequency, derived from the same issue, but they alsomentioned that due to the presence of the UMAS the population of the white tailed deer has increased and these animals are now eating their crops, causing economic impacts to the communities (Fig. 12).

We asked if in relation to 10 years before, the life in their community had improved, remained the same or was worst. The general tendency was that life had improved thanks to the different supports from the various government institutions, either for house improvements, streets pavement, lightning, public transportation, dam construction, material and days labor payments, etc. The community that did not show this tendency was Huautla, this because the activity that contributed with more jobs and income was the mining

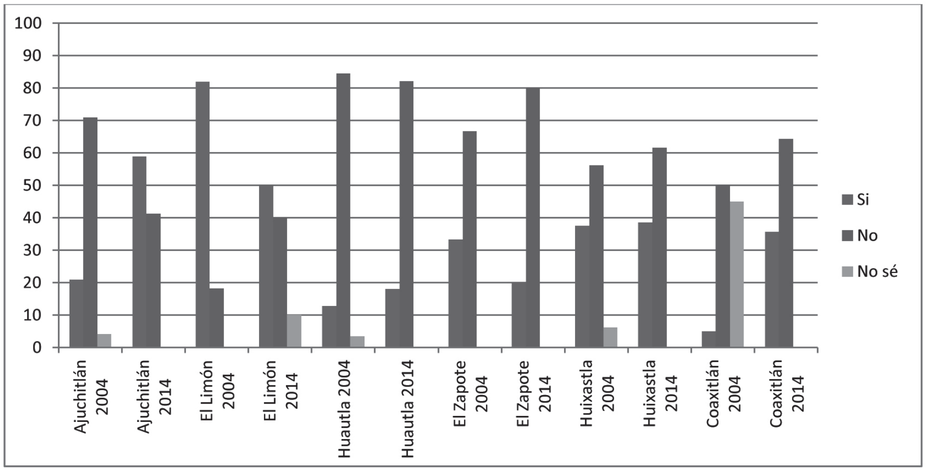

Fig. 11. Comparison of the perception about the benefits obtained by being located within the reserve by the analyzed communities in 2004 and 2014

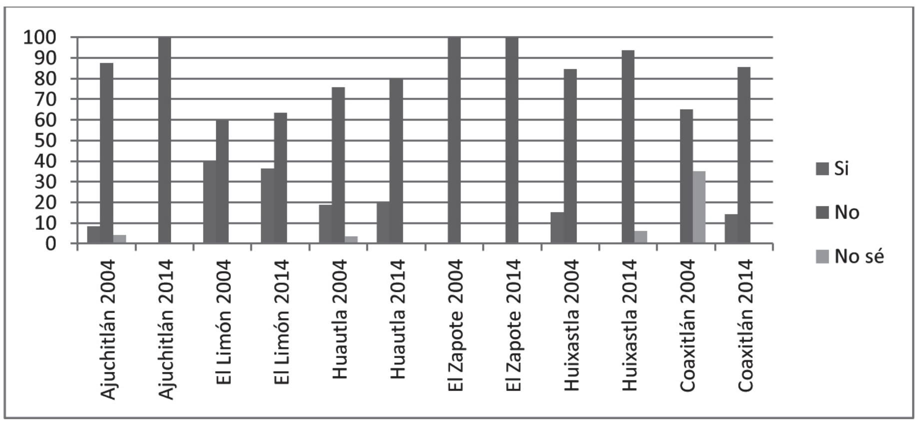

Fig. 12. Comparison of the perception about problems living inside the REBIOSH, according to the analyzed communities in 2004 and 2014.

extraction in the area. Such industry broke and closed down in 1991, and this caused a lot of people to run out of jobs and without being paid. For this reason, the population mentioned the lack of work in the community has caused the life to get worst, and demand permanent jobs and even ask that the mining industry is re activated, even though, as we will latter show, studies performed by UAEM researchers have evidenced the presence of heavy metals and other contaminants in the residues left by this activity, which have contaminated soil and water. However, this information seem not to be known or even believed among the inhabitants and therefore they request that mining activities are re activated (Fig. 13).

Perception on the Authorities of Rebiosh

In relation the REBIOSH authorities, we asked if the population knew them. The general tendency found was that they do not, even in those communities where most work has been done by REBIOSH personnel, and even in El Limon, where the Biological Station is located. This perception might be due because since it is a co administration, the personnel from the University is not considered as CONANP personnel and are not permitted to wear the official uniform. The population however knew other officials from different government institutions because they wear their official uniforms. Therefore is fundamental that the personnel has some sort of distinctive, if not the CONANP uniform, at least some new uniform that identifies such authorities when they assist to the communities to communicate programs or deliver economic support. This will help the population to identify the REBIOSH personnel (Fig. 14).

We latter asked if the population knew what the REBIOSH authorities were supposed to do for their communities. Again the general tendency was the lack of knowledge on their work, excepting the communities of El Limon and Huaxtla, where more positive answers were registered. This is due mainly because of the presence of the Biological Station and that in Huaxtla the authorities have actively

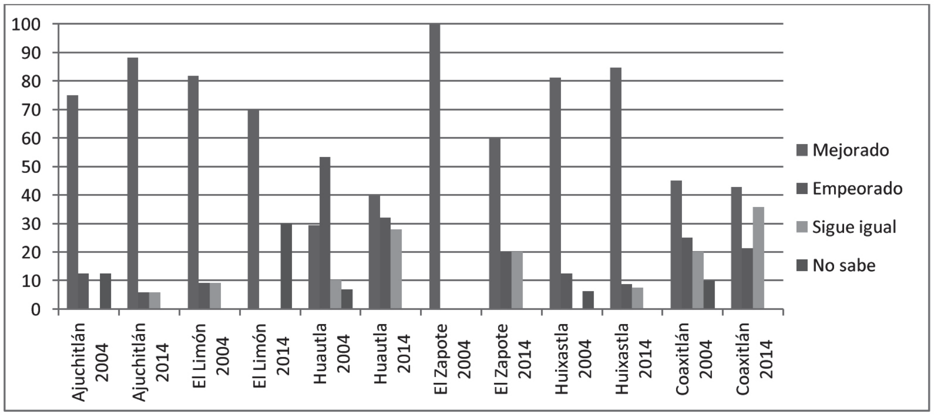

Fig. 13. Comparison of the perception on the change of quality of life in the analyzed communities in 2004 and 2014

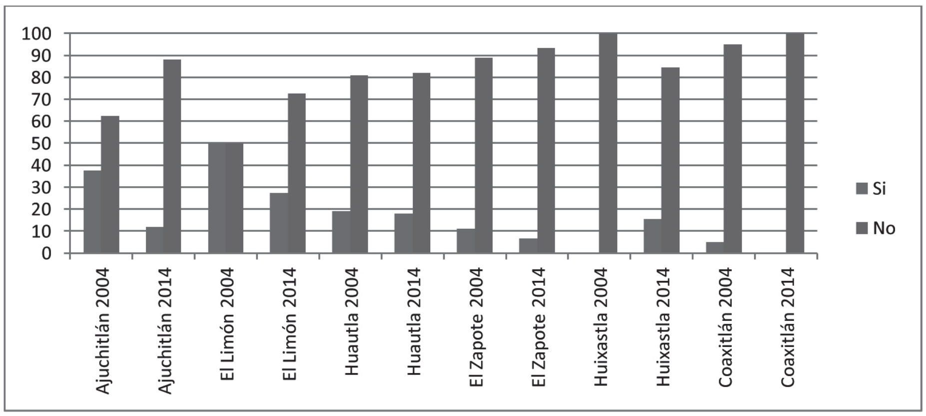

Fig. 14. Comparison of the answer to the question if the population know the REBIOSH authorities according to the analyzed communities in 2004 and 2014

contributed to the construction of two water parks that have created employments that directly or indirectly benefit many families. This task is the reasons perceptions changes from 2004, because in this period most answers were negative. The communities of El Zapote and Coaxitlan are to be noted because there is scarce knowledge on the labor of the authorities for their community, which evidences urgent need of approaches from the authorities to these communities (Fig. 15).

The last question on this section was if there had been a conflict between their community and the REBIOSH authorities. Even though in general the answers showed there has not been a conflict, in the communities of El Limon and Huautla, the answer was positive. In El Limon, such conflicts derive because the Biological Station, because some interviewees mentioned that the University has not complied with the agreements reached when they first build the Station. They also mentioned that no

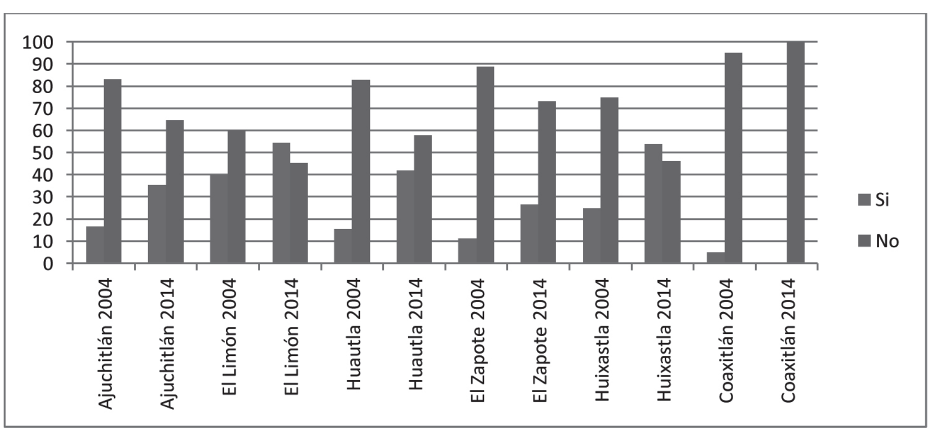

Fig. 15. Comparison of the answer to the question if whether or not the population knew what the REBIOSH authorities did for their communities, according to the analyzed communities in 2004 and 2014

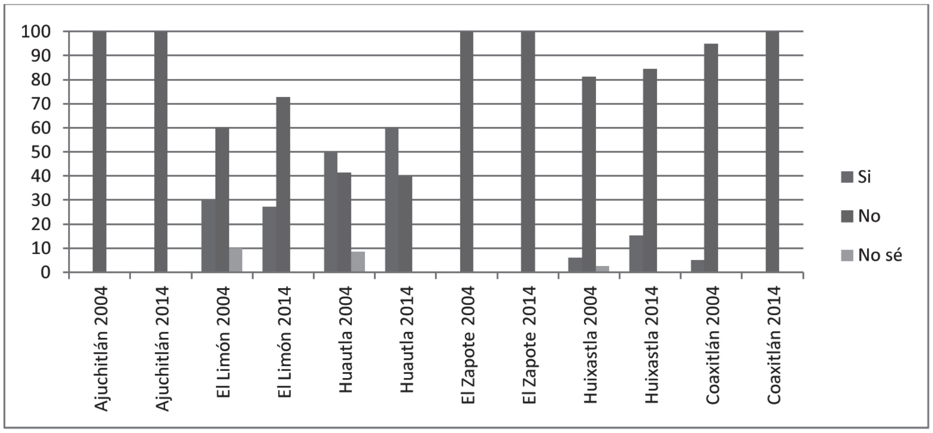

Fig. 16. Comparison of the answers if the communities have had conflicts with REBIOSH authorities, according to the communities analyzed in 2004 and 2014

contract has ever been signed, in this contract clear roles should be given as who will help in the kitchen, or as guides, or assistance in the researcher's work. In the case of Huautla, the main conflict was created when the University was expelled from the community because they did not comply with the agreements reached when they constructued the Biological Station of Cruz Pintada in 2002. To date this station is still abandoned (Fig. 16).

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Soil quality and its assessment: A review

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ABSTRACT

The competitive demand from different sectors and deteriorating resource base necessitated to deliberate soil quality and its functionality and way to improve it for higher productivity of produce without deteriorating the ecosystem and in this context, the historical perspective of soil quality and its indicators and methods of quality evaluation have been reviewed and presented here for the benefit of larger readership.

Key words: Soil quality indices, Minimum datasets, Indicators, Assessment

INTRODUCTION

India is endowed with vast water resources, and a wide variety of soil, climatic and physiographic conditions, and thus, has environment for the growth of diverse agricultural, horticultural, medicinal crops and forest species. Nevertheless, scientific conservation and management of the natural resources are of utmost significance to maintain the much needed tempo of growth in agricultural production and to meet the increasing and multiple demands against the fast mounting pressure on the limited soil resource base.

Agricultural production has witnessed dramatic rise in the last three decades or so in the countries world over. In India, Green Revolution brought about technological breakthrough, which led to the use of short duration high yielding varieties helping intensive use of land in a year, increasing area brought under irrigation and prolific use of chemicals such as fertilizers and pesticides. India, being vastly agriculture oriented, historically has had policies in various phases for the development of agriculture with the expectation that development of agriculture would lead to overall development of the nation and help in eradication of poverty. It has been of lately recognized that the increasing efforts to raise agricultural growth has cost us dearly in the form of land (Table 1) and its degradation.

Large scale ecological losses were reported in crop land, pasture land and forest land, such as soil erosion, soil alkalinity and salinity, micronutrient deficiency, water-logging and fast depletion and contamination of ground water. These factors limit future gains from the land and water resources. The specific crops grown and the cropping practices employed also determine the residuals generated by the erosion and run-off. Intensive farming practices, particularly with wheat and rice in India, have virtually mined nutrients from the soil. Due to heavy use of fertilizers, excess nitrates have leached into groundwater and contamination of groundwater with nitrates has increased dramatically. As such, the cultivable lands have become sick by excess application of chemicals. Apart from over use of chemicals, equally important issue is imbalance in the application of fertilizers and pesticides (Tables 2 & 3).

History tells about several periods characterized by severe degradation of the soil resource. Present-day soil management is often to be based on lessons learned from history. However, the mechanized agricultural systems are manipulating the soil in a way that has never seen before. The increased awareness of the problems has led to increased attention to the term 'soil quality'.

Soil quality is important for two reasons. First, using a soil improperly can damage it and the ecosystem; therefore we need to match our use and management of the land to the soil's capability. Second, we need to establish a baseline understanding about soil quality so that we can recognize temporal changes as they develop. By using baselines to determine if soil quality is

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Table 1. Extent of land degradation in India

Degradation type	Area affected (mha)	Percent (%)
Water Erosion	148.9	45.3
Wind Erosion	13.5	4.1
Chemical Deterioration (loss of nutrients, salinization)	13.8	4.2
Physical Deterioration (Water logging)	11.6	3.5
Total affected area	187.7	57.0
Land not fit for Agriculture	18.2	5.5
Total Geographical Area	**328.7**	**100.0**

Source: NAAS, 2010

Table 2. Nutrient-wise consumption of fertilizers materials in India (Lakh M.T.)

Year	Consumption			Total
	N	P	K	
1981-82	40.69	13.22	6.73	60.64
1991-92	80.46	33.21	13.61	127.28
2001-02	114.16	44.16	17.07	175.39
2011-12	173.00	79.14	25.76	277.90

Source: Ministry of Chemical & Fertilizer, Govt. of India, 2013

Table 3. Consumption of pesticide(Technical Grade) in India

Year	Consumption ('000 tone)
1981-82	84.00
1991-92	72.13
2001-02	47.02
2011-12	53.00
2012-13	45.00

Source: Ministry of Agril.GOI, 2013

deteriorating, stable, or improving, we have a good indicator of the health of an ecosystem. The ultimate purpose of researching and assessing soil quality is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including people.

SOIL QUALITY EVALUATION

Soil quality is the integrated effect of management on most soil properties that determine crop productivity and sustainability (Fig. 1). Unfortunately, with the advancement of agriculture, soils are being degraded at an alarming rate by wind and water erosion, desertiûcation, and salinization because of misuse and improper farming practices. Further, side effects, such as soil compaction, reduced structural stability, surface runoff and water erosion, wind erosion and general reduction in soil fertility, are often reported in literature. Growing of crops one after another without giving due consideration to nutrient requirement has resulted in decline in soil fertility. Soil quality assessment has been suggested as a tool for evaluating sustainability of soil and crop management practices. Hence, there is a need to develop criteria to evaluate soil quality and to take corrective actions to improve it. Assessing soil quality is difficult, because unlike water and air quality for which standards have been established primarily by legislation, soil quality assessments are purpose oriented and site-speciûc. However, a quantitative assessment of soil quality could provide much needed information on the adequacy of the world's soil resource base in relation to the food and ûber needs of a growing world population.

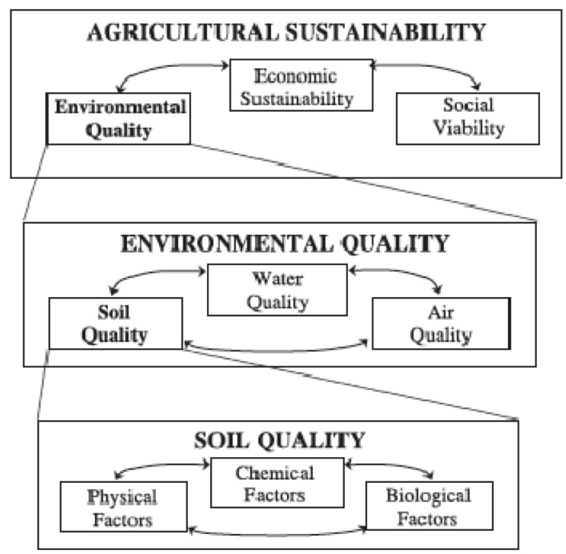

Fig. 1. Hierarchical relationship of soil quality to agricultural sustainability (Andrews, 1998)

The idea for developing soil quality criteria and using them to facilitate better management was introduced more than 30 years ago, but has undergone its most rapid evolution and adoption during the past decade (Karlen *et al.*, 1997, 2001, 2003, 2004). Soil quality is defined as the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil quality assessment is a tool focus on dynamic soil properties and processes which are useful for assessing the sustainability of soil management practices

Suitable evaluation methods and appropriate indicators of soil quality are among the most

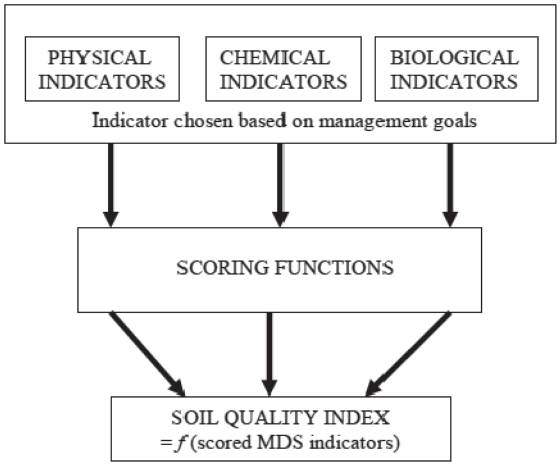

Fig. 2. Conceptual model for converging data set indicators to index values (Karlen *et al.*2003)

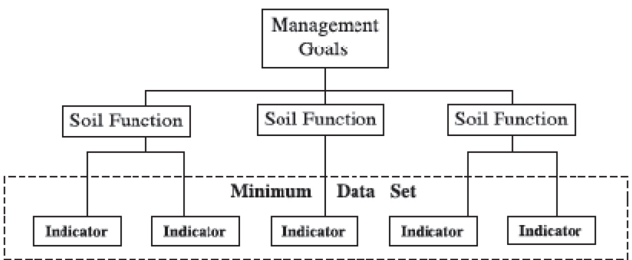

Fig. 3. A framework for selecting indicators for a minimum dataset (Karlen *et al.*2003)

important considerations due to their significant influence on soil quality results (Ditzler and Tugel, 2002). The assessment of soil quality starts from the definition of soil quality indicators *i.e.* processes and properties of the soil that are sensitive to changes caused by both natural and anthropogenic factors (Doran and Jones, 1996). Choice of a standard set of specific properties as indicators of soil quality can be complex and will vary among management objectives. Many soil quality evaluation methods (such as comparative evaluation, dynamic evaluation, and soil quality index methods) have been proposed (Doran and Jones, 1996; Larson and Pierce, 1994), among these; soil quality index is perhaps the most commonly employed method today due to its easy usability and quantitative flexibility.

SOIL QUALITY INDICATORS

Specific functions and subsequent values provided by ecosystems are variable and rely on numerous soil physical, chemical, and biological properties and processes, which can differ across spatial and temporal scales. An indicator of soil quality is a measurable surrogate of a soil attribute that determines how well a soil functions (Burger and Kelting, 1999). Many soil quality indicators have been rationalized and proposed, and a few have been tested and validated. To be useful as an indicator of the sustainability of land management practices, a soil parameter must respond to changes in management sensitively (Doran and Parkin, 1996). Indicators should be easily measurable and measurement should be reproducible (Gregorich *et al.* 1994). Arshad and Coen (1992) also suggested that indicator should be sensitive enough to detect changes in soil as a result of anthropogenic degradation. Many basic soil properties like percent sand, per cent clay, BD, organic carbon content etc. are useful in estimating other soil properties or attributes like infiltration rate, hydraulic conductivity, aggregate stability, CEC, that are difficult or too expensive to measure directly (Doran and Parkin, 1996).

In particular, soil quality indicators are physical, chemical and biological soil properties, able to readily change in response to variations in soil conditions (Brejda *et al.* 2000; Marzaioli *et al.* 2010a). Numerous studies are being conducted worldwide to examine the accuracy, sensitivity, and usefulness of various soil properties and processes at scales ranging from single points to entire land resource areas (Karlen *et al.* 1998; Brejda *et al.* 2000; Elmholt *et al.* 2000). A first step in this respect is the identification of soil parameters that are comparable across several soil types.

USDA (2014) selected seven physical, three chemical, and two biological indicators, which represent a minimal dataset to characterize soil quality (Table 4). Gomez *et al.* (1999) define six indicators and threshold values for measuring sustainability of agricultural production systems at farm level. Other examples of soil-quality studies are reported by Doran and Jones (1996) who list soil characteristics as indicators of soil quality. Critical limits of the soil-quality indicators are the threshold values which must be maintained for normal functioning of the soil system. Within this critical range, the soil performs its specific functions in natural ecosystems. Schoenholtz *et al.* 2000 have listed many chemical and physical soil quality indicators recommended or used by soil researchers.

METHODS OF SOIL QUALITY ASSESSMENT

Several methods of soil quality evaluation have been developed, such as soil card design and test kits (Ditzler and Tugel, 2002), visual soil assessment (Peerlkamp 1967; Mueller *et al.* 2009; Shepherd,

Table 4. Soil attributes which may be used as indicators ofsoil quality

Grouping type	Soil indicators
Physical attributes	Soil texture[a]
	Stoniness
	Soil structure[a]
	Bulk density[a]
	Porosity
	Aggregate strength and stability[a]
	Soil crusting
	Soil compaction[a]
	Drainage
	Water retention
	Infiltration[a]
	Hydraulic conductivity
	Topsoil depth[a]
Chemical attributes	Color
	Reaction (pH)[a]
	Carbonate content
	Salinity[a]
	Sodium saturation
	Cation exchange capacity
	Plant nutrients[a]
	Toxic elements
Biological attributes	Organic matter content
	Populations of organisms[a]
	Fractions of organic matter
	Microbial biomass
	Respiration rate[a]
	Mycorrhizal associations
	Nematode communities
	Enzyme activities
	Fatty acid profiles
	Bioavailability of contaminants

[a] Key indicators selected by the USDA (2006)

2000, 2009; Ball *et al.* 2007), soil quality index methods (Doran and Jones, 1996; Marzaioli *et al.* 2010a; Qi *et al.* 2009), and geostatistical methods (Sun *et al.* 2003). Among these methods, soil quality indices are the most commonly used today (Andrews *et al.* 2002), because they are easy to use and quantitatively flexible (Qi *et al.* 2009).

Soil health card

A soil health card is used to assess the current status of soil health and, when used over time, to determine changes in soil health that are affected by land management. A soil health card displays soil health indicators and associated descriptive terms. The indicators are typically based on farmers' practical experience and knowledge of local natural resources. The card lists soil health indicators that can be assessed without the aid of technical or laboratory equipment.

Visual assessment of soil quality

Many physical, biological and, to a lesser degree, chemical soil properties show up as visual characteristics. Visual-tactile recognizable soil features like colour, structure, aggregation, texture, moisture conditions, earthworm casts may serve to evaluate and classify the quality of soil (Shaxson, 2006). As indigenous people have done before, soil science and soil advisory services utilize the same common field diagnostic criteria within defined frameworks and check their validity over larger scales. Methods of visual soil structure examination enable semi- quantitative information for use in extension and monitoring (Shepherd, 2000) or even modeling (Roger-Estrade *et al.* 2004). One of their advantages is a quick, reliable assessment of good, acceptable or poor states of soil structure. Soil structural features meet the farmer's perception on soil quality (Shepherd, 2000; Batey and McKenzie, 2006) and are correlated with measured data of physical soil quality (Lin *et al.* 2005) and crop yield (Mueller *et al.* 2009). However, clearly defined rules and scoring methods are necessary to minimize subjective errors. Visual methods based on, or supplemented by illustrations, have clear advantages for the reliable assignment of a rating score based on visual diagnostic criteria.

Several methods have been developed over the past five decades. One of the oldest but most accepted methods is that of Peerlkamp (1967). The traditional French method "Le profil cultural" (Roger-Estrade *et al.* 2004) belongs to a group of more sophisticated methods providing detailed information on the total soil profile. A quantitative comparison of some methods and their correlations with measured physical parameters after standardizing data revealed that most methods provided similar results (Mueller *et al.* 2009). Types and sizes of aggregates and abundance of biological macropores were the most reliable criteria as related to measurement data and crop yields. Differences in soil management could be recognized by visual structure criteria (Mueller *et al.* 2009). Unfavorable visual structure was associated with increased dry bulk density, higher soil strength and lower infiltration rate but correlations were site-specific. Effects of compaction may be detected by visual examination of the soil (Batey and McKenzie, 2006).

Also, the New Zealand Visual Soil Assessment (VSA, Shepherd, 2000, 2009) as an illustrated multi-criteria method enables reliable assessments of the soil structure status. These are feasible tools for structure monitoring and management recommendations. However, they may explain only part of crop yield variability, as the influence of inherent soil properties and climate on crop yield is dominant, particularly over larger regions. In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called ''profil cultural'' or soil profile in English, the soil structure of the tilled layer is observed on a vertical face of a pit.

The use of techniques of visual evaluation is now well established and proving valuable in explaining differences in crop performance and yield due to soil management and type. The tests are particularly helpful in conveying the importance of soil structure to farmers and in fostering the exchange of soil knowledge. Visual evaluation has also moved beyond soil structure to include other soil properties and crop and topographic conditions.

SOIL QUALITY INDICES

Evaluation of individual physical, chemical and biological parameters of soil is one way to study the impact of soil management on soil quality. Soil quality assessment might be enhanced if individual parameters were combined in a meaningful way. Thus, integrated soil quality indicators based on a combination of soil properties could better reflect the status of soil quality, than individual parameters (Dick, 1994; Elliot, 1994). One way to integrate information from soil indicators into the management decision process is to develop a soil quality index (Mohanty *et al.* 2007). Soil quality indices have been used to evaluate impacts of agricultural practices (Wander and Bollero, 1999), crop production (Andrews *et al.* 2002) and litter management practices (Andrews and Carroll, 2001: Sharma et.al., 2009) on soil as well as the influence of soil management at regional scale (Brejda *et al.* 2000). The development of a soil quality index should follow three steps: (1) selection of indicators best representing the soil function associated with management goal, (2) transformation/ normalization of indicators into score and (2) integration of transformed score into SQI.

Selection of indicators (Minimum dataset)

Considering basic soil functions *i.e.,* provision of sufficient amounts of water and nutrients, provision of resistance and resilience to physical degradation, and sustaining plant growth under appropriate management, numerous soil analyses might be required to fully characterize the soil/plant system. Using a minimum data set (MDS) reduces the need for determining a large number of indicators to assess soil quality. To identify the smallest number of measurable soil properties that define the major processes functioning in soil, several MDS have been proposed by Larson and Pierce, 1991: Doran and Parkin, 1996; Andrews and Carroll, 2001).

MDS is a collection of selected indicators chosen according to correlation among indicators and their ease of measurement (Andrews *et al.*2002; Gómez *et al.* 2009).In order to obtain an MDS and soil quality index, many statistical techniques (*e.g.* grey system theory, fuzzy theory, artificial neural network, and Principal Component Analysis [PCA]) have been widely used for soil quality evaluation (Li *et al.* 2007a, b). In PCA, soil properties are grouped into several factors, and these factors, although statistically constructed, can be assessed with respect to specific soil functions (Brejda *et al.* 2000). Therefore, the number of independent soil parameters can be reduced and multi-co-linearity can be solved to some extent.

MDS of Soil Quality through NIRS (Near Infra-Red Reflectance Spectroscopy)

This technique is a rapid, non-destructive, reproducible and cost-effective analytical method involving diffuse reflectance measurement in the near infrared region (NIR; 780-2500 nm; Sheppard *et al*., 1985). Reflectance signals result from vibrations in C–H, O–H, N–H chemical bonds, and provide information about the proportion of each element in the analysed sample (Ciurczack, 2001).

Regarding soil chemical properties, accurate NIRS predictions have been reported with respect to soil total C and N (Chang *et al*., 2001; Brunet *et al*., 2007) and pH (Chang *et al*., 2001; Reeves and McCarty, 2001; Shepherd and Walsh, 2002).The prediction for soil physical properties using NIRS, which have yielded good results for soil particle size distribution (especially for clay content; Al-Abbas *et al*., 1972; Ben-Dor and Banin, 1995; Chang *et al*., 2001; Morón and Cozzolino, 2003), soil moisture (Bowers and Hanks, 1965; Ben-Dor and Banin, 1995; Chang *et al*., 2001), water holding capacity (Sudduth and Hummel, 1993; Zornoza *et al*., 2008), NIRS prediction of soil biological properties has often yielded good results, as reported for microbial biomass (Reeves *et al*., 1999; Chang *et al*., 2001;), soil respiration (Palmborg and Nordgren, 1993; Chang *et al*., 2001;), potentially mineralizable N (Chang *et al*., 2001; Shepherd and Walsh, 2002), and even for the ratio of microbial to total organic C (Cécillon*et al*., 2008) and for the density of soil microorganisms (Zornoza *et al*., 2008). Good predictions have been attributed to the similarity between spectral responses of most biological properties and that of soil organic C (Chang *et al*., 2001).

Transformation/normalization of indicators into score

The complexity of co-evaluating the status of many chemical, physical, and biological parameters has prompted investigators to integrate multiple indicators into a soil quality index (Smith *et al.,* 1993). In order to solve the bias caused by the use of different indicators expressed by different numerical scales, scoring functions (linear and nonlinear scoring) are used to normalize data. The integration of dimensionless indicators (obtained by normalization) into quality indices is possible through many procedures based on additive, multiplicative or weighed mean techniques (Andrews *et al.,* 2002).

Integration of transformed score into SQI

The most commonly used approach to develop an integrated soil quality index was suggested by Karlen and Stott (1994). They selected soil functions associated with soil quality, such as accommodating water entry, accommodating water transfer and absorption, resisting surface degradation, and supporting plant growth, to evaluate the effects of different types of soil management on soil quality. These functions were weighted and integrated according to the following expression:

$$\text{Soil quality index} = qwe(wt) + qwt(wt) + qrd(wt) + qspg\,(wt)$$

where, qwe is the rating for the soil's ability to accommodate water entry, qwt is the rating for the soil's ability to facilitate water transfer, qrd is the rating for the soil's ability to resist degradation, qspg is the rating for the soil's ability to sustain plant growth and wt is the numerical weight for each soil function.

Soil quality indicators should be selected according to the soil functions of interest (Nortcliff, 2002) and threshold values have to be identified based on local conditions to generate a meaningful soil quality index. Indicator selection can be done using expert opinion, based purely on statistical procedures, or some combination of both to obtain a minimum data set (MDS).Furthermore, with regard to agricultural production, a high quality rating should equate to high productivity with some soil improvement or little possible environmental degradation (Govaerts *et al.,* 2006: Arora *et al.,* 2006). Soil quality is simply related to the quantity of crops produced. Unfortunately, many researchers have neglected the crop yield factor during soil quality evaluation. In those studies that did consider the correlation between soil quality and crop yield, only one year of crop-yield data were used (Shukla *et al.,* 2006; Zhang *et al.,* 2009). We do not believe that one year of data can sufficiently explain the soil factors that limit crop yield. When soil quality indices have had no significant correlation with crop yield, the soil quality indicator system would have no biological significance. Therefore, further investigation on crop yield is necessary to improve the evaluation of soil quality. Soil health using soil quality index is a tedious and cumbersome method because it involves identification of soil health indicators based on Principal Component Analysis and rational judgment of screening of indicators. Therefore, it may not be easy for large scale adoption.

EMERGING ISSUES

Sensing soil health: Assessments of soil chemical properties normally rely on laboratory data with large numbers of samples required to adequately characterize spatial variability at farm scales. Spectral techniques (non-destructive) allow large numbers of samples to be rapidly analyzed, resources can be directed towards thorough characterization of the soil and its spatial variability within a target region.

Soil and human/animal health: Currently, the concept of soil quality is in the process of evolution and progressively moving from a concept focused on yield potential and nutrient levels to one of environmental quality, food safety and human health. Soil is a crucial component of rural and urban environments, and in both places land management is the key to soil quality maintenance. Due to increased anthropogenic activities, soil is the recipient of several pollutants like pesticides, herbicides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, heavy metals and many inorganic salts. These pollutants have adverse impacts on soil physico-chemical environment, nutrient cycling/transformation processes, soil biodiversity, plant growth, food quality through contamination etc. Large quantity of urban wastes is produced in different cities causing water, air and soil pollution. Mining, manufacturing and the use of synthetic products (*e.g.* Pesticides, paints, batteries, industrial wastes, and land application of city and industrial sludge) can result in heavy metal contamination of urban and agricultural soils.

Soil and climate change: Global climate change is dramatically increasing the variability of weather conditions worldwide and soil is a critical buffer medium for hydrologic and biogeochemical processes and therefore can mitigate the effects of extreme weather conditions and uncertainty in the availability of water resources. The present threats of global climate change and ozone depletion, through elevated levels of certain atmospheric gases and altered hydrological cycles, necessitate abetter understanding of the influence of land management on soil quality. Management systems need to be further fine-tuned in order to balance the need and priorities for food production with those for a safe and clean environment.

Soil health resources: Educational materials are being developed because most smallholder farmers still lack the basis on which to evaluate the complexity of soil health and soil quality changes. Again, most smallholders may not be aware of how soil literally provides the foundation for sustainability through processes such as nutrient and hydrological cycles, filtering and buffering of soil pollutants, decomposition of crop residues and organic matter inputs. The availability of internet based soil health resources continues to significantly bridge the gap between these sources and users. Presently, there exists a wealth of soil health and soil quality related information from educational institutions, private corporations, foundations and networks, agricultural commodity companies as well as national, regional and international research and development bodies. The soil health portal serves as a key entry point to access soil health information on-line.

CONCLUSION

The term 'soil quality' has been widely discussed among scientists and conservationists, to integrate the concepts of soil quality into conservation planning and resource inventory activities. The soil quality concept is a valuable tool in getting scientists involved with managed soil systems, giving a mutual focus to their research efforts. Studies into soil productivity, biological diversity and impacts on the surrounding environment of agricultural systems should be combined to give a more complete description of the soil resource as a dynamic living system. The 'new' concept of soil quality may be regarded as a means of differentiating and quantifying our understanding of soil behavior, especially in relation to soil conservation.

With inadequate inputs in agriculture, developing countries are degrading their lands rapidly and destroying ecosystems. Therefore, soil quality or soil health was concluded to be an appropriate concept for the poly-function approach necessary for soil assessment. Currently, soil resource assessment and monitoring is entering a new era, in terms of quality of information produced by new information technologies through the innovative use of Geographic Information Systems and remote sensing and will significantly improving the acceptance and use soil health information. The use of electronic technology will significantly increase the demand for and ability to process more data. Further innovation will result in model approaches in soil genetic studies that will demonstrate the integral role of soils in ecosystems. At the more fundamental level, basic research will be needed in order to select and develop proper indicators, applicable at different farmer scales. Innovation will be required in setting up effective study programs, which would guarantee the accumulation of the necessary baseline soil data in order to develop appropriate minimum datasets.

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Runoff and sediment yield prediction for Chambal basin using artificial neural network and regression analysis

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ABSTRACT

Assessment and inventory on soil erosion hazard are essential for formulation of effective soil conservation plans of a watershed for sustainable development. The modern information technology tools like artificial neural network (ANN) and traditional methods like multiple linear regression analysis with easily available hydrologic parameters can provide a more accurate and practical prediction of runoff and sediment yield. In the first ANN model the neural network was trained with catchment area and annual rainfall as input and estimated runoff as the desired output. The best ANN architecture was selected on the basis of mean absolute error, mean square error and maximum correlation coefficient. The ANN architecture 3-4-1 (three four and one neurons in the input, hidden and output layers respectively) was found best in training and testing. In the second ANN model network were trained with catchment area and annual rainfall as input and estimated sediment yield as the desired output. The ANN architecture 3-6-1 was found as best in this case. Same data set, which was used in ANN, was used for developing multiple regression (MREG) models and also for validation. The results compare the prediction of runoff and sediment yield through multiple regression equations and ANN method. Performance evaluation analysis indicated that prediction ability of artificial neural network model is better than multiple non linear regression model.

Key words: Regression, Neural network, Runoff, Sediment yield

INTRODUCTION

Sediment delivered from water erosion causes substantial waterway damages, depletion in water storage capacity and water quality degradation. Problems caused by soil erosion and sedimentation include losses of soil productivity, water quality degradation, and less capacity to prevent natural disasters such as floods. Sediments may carry pollutants into water systems and cause significant water quality problems. Sediment yield is defined as the total sediment outflow from a watershed measurable at a point of reference during a specified period of time. Sediment outflow from the watershed is induced by processes of detachment, transportation, and deposition of soil materials by rainfall and runoff (Cigizoglu, 2002).

Sediment yield is a critical factor in designing of the constructions such as dams and reservoirs. The hydrological processes are dynamic in nature, therefore, modelling is more appropriate approach for sediment yield estimation. Modelling watershed sediment yield based on input-output concept is one of the approach which transfers rainfall, runoff and other related information into sediment yield information. This prediction of sediment yield is very much important in order to adopt the suitable soil conservation measures in the watershed area for minimising the sediment load in the reservoir or river to increase the life of structure. Over the last 20 years, there has been remarkable progress in development of erosion and sediment transport models, still a number of important issues remain unsolved. Still we don't have suitable empirical methods for sediment yield estimation for small watershed. Therefore, it is necessary to develop simple models using easily measurable soil, land use and topographic characteristics to estimate sediment yield from small watersheds.

Sediment yield, usually expressed as tonnes per unit area of the basin per year, is the amount of sediment measured at the runoff exit point in the basin area. Water erosion and sedimentation processes are influenced by a multitude of factors and occur at different intensities across the landscape which makes the monitoring and assessment a complex and cumbersome task with considerable uncertainty.

The sediment load process is a highly nonlinear and complex system. However, the empirical regressions, despite of their inability to represent

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successfully, the nonlinear complex system have been widely used (Wang *et al.* 2006).

Therefore, there is a need to improve the understanding of erosion and deposition processes at field, catchment and regional scales from quantitative perspective, in order to analyse their on-site impact on soil productivity as well as off-site impact on streams *(e.g.,* sedimentation and water quality). It seems necessary that nonlinear methods such as artificial neural networks (ANNs), which are suited to complex nonlinear models, be used for the analysis of real world temporal data (Cigizoglu, 2004). The ANN is capable to model any arbitrarily complex nonlinear process that relates sediment load to continuous hydro-meteorological data (Wang and Traore, 2009). In engineering practice, simple methods are important for predicting runoff from watersheds. Raina *et al.* (2011) predicted run off in Shivalik microwatersheds and found that SCS – CN equation in its elementary form fitted data well.

To estimate sediment yield, there are generally categories of procedures such as predictive equations, gross erosion and sediment delivery ratio computations and suspended sediment load or reservoir sediment deposition measurements. The small spatial and time scales of runoff or erosion events makes observation and measurement of erosion processes difficult and necessitates the use of erosion models for the estimation of erosion and sedimentation in catchments. Commonly used process based equations are complicated which requires too many parameters as input. The USLE based research is generally applicable to field sized data and its modification to estimate the erosion/ sediment yield on watershed scale has not given good results. The aim of this research is to meet the is an urgent need to develop simple empirical methods/ models which can be conveniently used for small watersheds and even for ungauged watersheds / catchments.

In recent years, the research efforts have been directed to develop the new ways of estimation of rainfall, runoff and sediment yield relationships with greater precision and accuracy using modern information technology tools and procedures. The artificial neural networks have been successfully adopted for a number of different hydrological and meteorological aspects such as rainfall runoff modelling (Sudheer, 2002), evapotranspiration (Bhatt, 2007a), rainfall erosivity estimation (Bhatt *et al*., 2007b). It has been found to produce more accurate than conventional methods in the field of hydrological monitoring and modeling (Zealand, 1999).

Artificial Neural Network

An ANN is a parallel - distributed information processing system that has certain characteristics resembling biological neural network of human brain (Haykin, 1994). The development is based on the following rules (ASCE, 2000a).

1. Information processing occurs at many single elements called nodes, also referred as unit cells or neurons.
2. Signals are passed between nodes through connection links.
3. Each connection link has an associated weight that represents its connection strength.
4. Each node typically applies a nonlinear transformation called as activation function to its net input to determine its output signal.

The distinct advantage of ANN over traditional methods is that they are distribution free; are less susceptible to outliers and do not require prior knowledge about the error structure. In addition, ANN models have the intrinsic ability to generalize and are capable of forming highly nonlinear functional relationships from observed data (Islam and Kothari, 2000). Configuration of a typical three-layer ANN is shown in Fig.1.

Generalized feed forward networks are a generalization of the MLP such that connections can jump over one or more layers. In theory, a MLP can

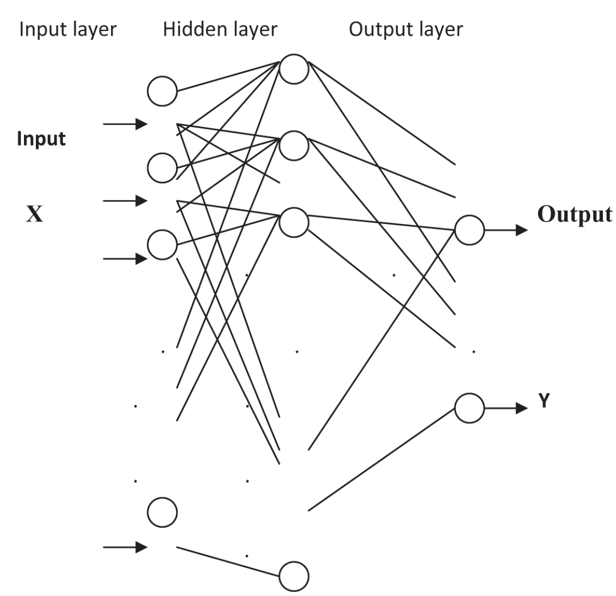

Fig.1. Configuration of a typical three layer ANN

solve any problem that a generalized feed forward network can solve. In practice, however, generalized feed forward networks often solve the problem much more efficiently. A classic example of this is the two spiral problem. Without describing the problem, it suffices to say that a standard MLP requires hundreds of times more training epochs than the generalized feed forward network containing the same number of processing elements.

The hyperbolic tangent activation function (TanhAxon) is popular with neural networks because of the shape of its graph. The hyperbolic tangent activation function has a range from -1 to 1. Because of this greater numeric range the hyperbolic activation function is often used in place of the sigmoid activation function.

The mathematical formula for the hyperbolic tangent activation function is shown here:

$$f(x) = \frac{\sin x}{\cosh x} = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}} = \frac{e^{2x} - 1}{e^{2x} + 1} \qquad \ldots(1)$$

The problem of neural network learning can be seen as a function optimization problem, where we are trying to determine the best network parameters (weights and biases) in order to minimize network error. This said, several function optimization techniques from numerical linear algebra can be directly applied to network learning, one of these techniques being the Levenberg-Marquardt algorithm.

The Levenberg-Marquardt algorithm is a very simple, but robust, method for approximating a function. Basically, it consists in solving the equation:

$$(J^{t}J + \lambda I)\delta = J^{t}E \qquad \text{Eq. 2}$$

Where **J** is the Jacobian matrix for the system, $\boldsymbol{\lambda}$ is the Levenberg's damping factor, $\boldsymbol{\delta}$ is the weight update vector that we want to find and **E** is the error vector containing the output errors for each input vector used on training the network. The $\boldsymbol{\delta}$ tells us by how much we should change our network weights to achieve a (possibly) better solution. The $\mathbf{J^{t}J}$ matrix can also be known as the approximated Hessian.

The $\boldsymbol{\lambda}$ damping factor is adjusted at each iteration, and guides the optimization process. If reduction of **E** is rapid, a smaller value can be used, bringing the algorithm closer to the Gauss–Newton algorithm, whereas if an iteration gives insufficient reduction in the residual, λ can be increased, giving a step closer to the gradient descent direction.

MATERIALS AND METHODS

The selected study area is Chambal basin located in Madhya Pradesh state of India. Catchment area and mean annual rainfall of basin were taken for modeling. Total 40 stations were taken for study. Sandy soil is dominantly found in that area. The mean annual rainfall in different experimental stations varies from 600 to 900 mm. In the present study, attempt have been made to examine the possibility of using ANN for predicting runoff and sediment yield using other easily available hydrological parameters and compared the performance of ANN with conventional techniques as MREG.

Table 1. The stations of Chambal Basin

Sl No	Station name	Area (km^2)
1	Amba Nala No 1	15.4
2	Amba Nala No 2	16
3	Andheria Nala	25.4
4	Balsakhiya Nala	29.2
5	Bhamni River	883.2
6	Bhotiya Khai (Dhanora)	47.5
7	Borkui ka Nala	11
8	Borkui ka Khal	7
9	Dhakarmau ka Nala	16.5
10	Eru river	345.65
11	Ganghobi - A	15.3
12	Ganghobi- B	20
13	Gangdhar ka nala (Jamunia)	32.1
14	Garrari Mahadev ka Nala	7.7
15	Kajli kehra ka Nala	57.75
16	Karab ka khal	49.5
17	Kota dam ka nala	28.45
18	Mandawara ka nala	19.8
19	Nagdara ka nala	53.1
20	Padajar	87
21	Parapipli	29.2
22	Rai ka khal	46
23	Tamlav ka khal	24.5
24	Tawara	43.4
25	Gandhar	56.62
26	Sukhpura	11.49
27	Jamunia	29.64
28	Ramnagar	29.68
29	Karab ka khal	71.68
30	Parapipli	24.40
31	Parajhar	70.20
32	Baisakiya	31.93
33	Mandawara	39.66
34	Nagdra	24.48
35	Gangobhi-B	13.31
36	Barkha-B	8.21
37	Gangobhi-A	22.05
38	Padmakheri	8.85
39	Basar	27.97
40	Rajpuriya	7.18

Training of Network

Training is a process by which the connection weights of ANN are adapted through a continuous process of simulation by the environment in which the network is embedded. There are primarily two types of training – supervised and un-supervised. A supervised training algorithm requires an external teacher to guide the process. In order for an ANN to generate an output vector $Y = (y_1, y_2, ..., y_p)$ that is as close as possible to the target vector vector $T = (t_1, t_2, ..., t_p)$, a training process, also called learning, is employed to find optimal weight matrices w and bias vectors v, that minimize global error E is defined as follows:

$$E = \sum_{P}\sum_{p}(y_i - t_i)^2 \qquad \ldots(3)$$

where t_i is a component of desired output (target vector) T; y_i = corresponding ANN output; p = number of output nodes and P = number of training patterns.

The process of adjusting the weights is referred to as 'training the network' and the set of weights then encapsulate the desired input output relationship. To ensure good approximation number of data pairs used for training should be equal to or greater than the number of data parameters (weights) in network (Carpenter and Bartheleny, 1994 and ASCE, 2000a). In the present study, conjugate gradient algorithm has been used as the training algorithm. The details are explained in the following section.

Evaluation of Network

In order to train and test ANN networks, it is necessary to have two sets of data- a calibration set and a validation set. The commonly used evaluation criteria include root mean square error (RMSE), correlation coefficient (r) and coefficient of efficiency (C.E.):

$$RMSE = \left(\sum_{1}^{n}(T_p - O_p)^2 / n\right)^{1/2} \qquad \ldots(4)$$

$$r = \left[\sum_{1}^{n}((T_p - T_m)(O_p - O_m)) / \left(\sum_{1}^{n}(T_p - T_m)^2 \sum_{1}^{n}(O_p - O_m)^2\right)^{1/2}\right] \qquad \ldots(5)$$

$$CE = 1 - \left(\sum_{1}^{n}(T_p - O_p)^2 / \sum_{1}^{n}(T_p - T_m)^2\right) \qquad \ldots(6)$$

where, T_p is the target value for the p^{th} pattern; O_p is the estimated value for the p^{th} pattern, T_m and O_m are the mean target and estimated values respectively and n is total number of patterns.

Root mean square error (RMSE) shows the measure of mean residual variance, Correlation coefficient (r) defines the degree of correlation between two variables. Coefficient of efficiency (CE) criterion has the basis of standardization of the residual variance with initial variance (Nash and Sutcliffe, 1970). In this criterion, a perfect agreement between the observed and estimated output yields an efficiency of 1.0. For a zero agreement, all the estimated value must be equal to the observed mean and a negative efficiency represents a lack of agreement.

To start with modeling work the entire dataset was first divided in two parts as calibration sett and validation set. Then both the parameters (catchment area and rainfall) were taken as input and runoff and sediment yield as desired output in separate models. Then three parameters catchment area, average basin slope and annual rainfall were taken as independent variables and runoff and sediment yield as dependent variable in separate calibration sets. Each individual parameter has its own contribution towards runoff and sediment yield. Several trials were carried out in order to determine the best configuration of hidden layers and nodes. The ANN models with different configurations were trained several times for different iterations / epochs (a complete cycle of presentation of entire set of input data is known as iteration / epoch). Average basin slope could not show any impact on runoff and sediment yield in combination as well as in isolation as such this parameter was removed from study. After this test only two parameters catchment area and rainfall were taken as input both for ANN and MREG. Again several trials were carried out in order to determine the best configuration of hidden layers and nodes. The ANN models with different configurations were trained several times for different iterations / epochs. In order to ensure good approximation number of data pairs used for training were always taken more than total weights. All the developed models were validated. The neural network software 'NeuroSolutions' was used for ANN. The conjugate gradient algorithm was chosen to train the feed forward ANN algorithms.

Similar to ANN, entire dataset was divided in two parts in MREG i.e.,calibration set and validation set. Then three parameters catchment area, average basin slope and annual rainfall were taken as independent variables and runoff and sediment yield as dependent variable in separate calibration sets. Average basin slope could not show any impact on runoff and sediment yield in MREG

Table 2. Brief description of developed ANN models

Particulars	Network configuration	Type of network	Iterations	Learning
Runoff	3 - 4 - 1	Feed Forward	10011	Levenberg Marque
Sediment yield	3 – 6 - 1	Feed Forward	595	Levenberg Marque

also as such this parameter was removed from study. After this test only two parameters catchment area and rainfall were taken as input (independent variables) and runoff and soil loss as dependent variables in separate models of multiple regression analysis.

RESULTS AND DISCUSSION

After several trials a three layer ANN architecture consisting of input layer, hidden layer and output layer was found best for the data set and for runoff estimation. This resulted 3-4-1 as best model configuration and indicated that 4 nodes in hidden layer fitted best on test data and showed a high degree of accuracy with training data set. ANN with above configuration was trained with several iterations and best results were obtained with 10011 iterations on the basis of minimum MSE. In the same way a 3-6-1 was found to be best configuration for sediment yield which resulted at 595 iterations. Details of network type, configuration and number of iterations used in minimizing error, are given in Table 2.

MREG Models

Attempts were made to develop multiple linear regression models with both input parameters (as independent variable) but linear model did not generate good validation results. Therefore, attempts were made to develop non-linear regression models. Developed non-linear regression models were found satisfactory with respect to validation result. The non-linear regression models one for runoff and another for estimation of sediment yield developed in the studyare shown by equations below.

Runoff: $Q = 0.561*P+0.157*S-0.007*A - 147.88$ …(7)

Soil loss = $9.39x10^{-8}\ A^{0.144}\ S^{-0.11}\ P^{2.608}$ …(8)

where, A = Catchment area, S= Slope and P = Annual rainfall

Calibration for ANN and multiple regression model is shown in Fig. 2 for runoff and sediment yield. Both the figures indicated that ANN is very closely fitted with observed data than non linear

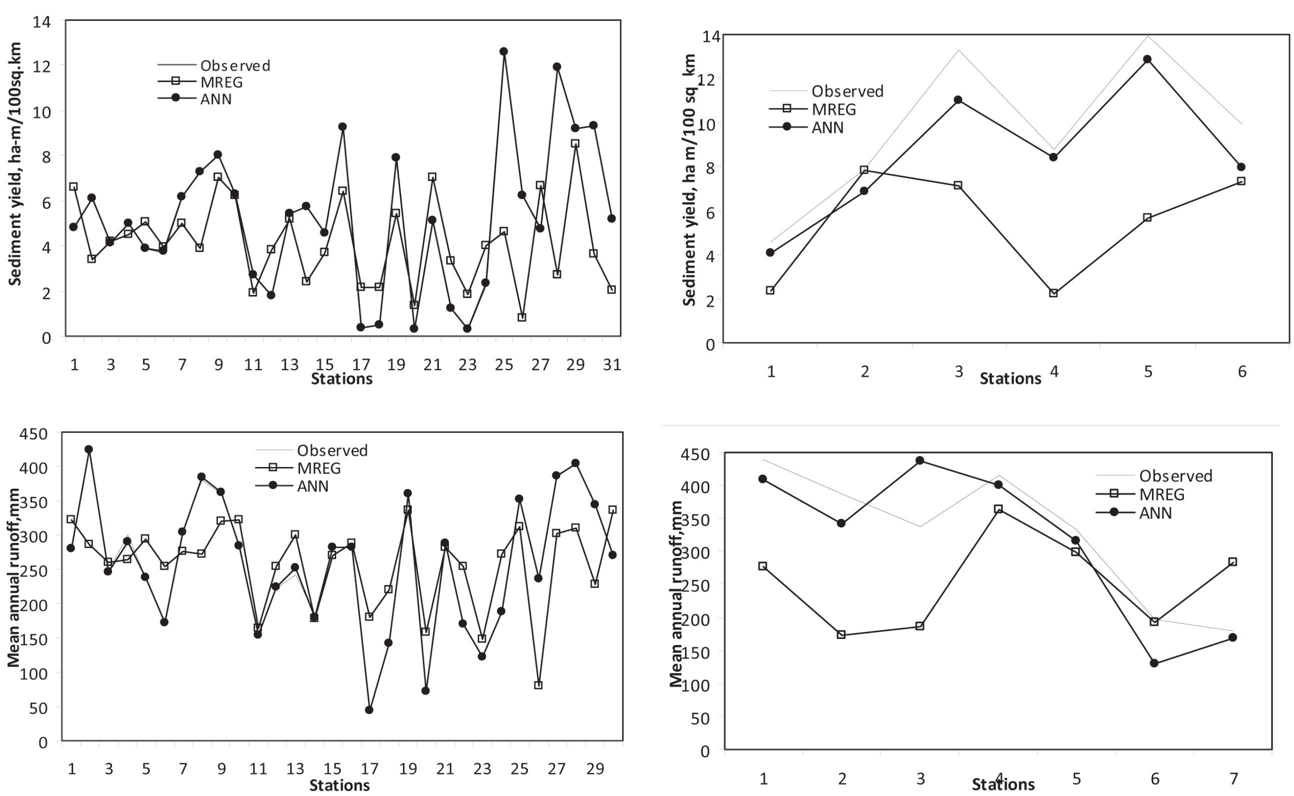

Fig. 2. Calibration and validation of runoff and sediment yield prediction models

Table 3. Model performance of training /calibration by ANN

Evaluation parameters	Runoff	Sediment yield
Correlation coeff., r	0.999	1
RMSE	0.522	0.0017
CE	0.99	0.999

Table 4. Model performance table for estimation of runoff and sediment yield for test set (validation)

Evaluation parameters	Runoff		Sediment yield	
	ANN	MREG	ANN	MREG
r	0.89	0.24	1	0.5
RMSE	19.21	47.51	0.565	2.11
CE	0.71	-0.75	0.81	-1.63

of 't' as worked out through paired t-test. All the values of correlation coefficient were significantly different than zero pointing out a definite correlation between the observed and estimated runoff and sediment yield by both models. Lower value of 't' for ANN models further confirm the superiority of ANN over MREG. Thus paired t-test showed that values of runoff obtained by ANN was better than MREG.

RMSE was lowest in case of ANN and model efficiency were highest for ANN. It is therefore inferred that runoff estimated by the ANN model is more rational and realistic as studied for Chambal basin. However sediment yield may be estimated either by ANN or by MREG.

Table 5. Values of coefficient of correlation (r) and calculated 't' between observed runoff and sediment yield with ANN and MREG

Pairs of observed and estimated runoff /Sediment yield	r	t_{cal}	t_{tab}
Obs runoff ~ runoff by MREG	0.65	1.765	2.447; at 5% level of significance for 6 degree of freedom
Obs runoff ~ runoff by ANN	0.90	0.640	
Obs sediment yield ~ sediment yield by MREG	0.51	3.374	2.015; at 5% level of significance for 5 degree of freedom
Obs sediment yield ~ sediment yield by ANN	0.98	3.922	

*Significant at 5% level of significance

regression model, for runoff as well as sediment yield.

Model performance of training set (calibration data) is very good both for runoff and sediment yield (Table 3). On comparing values of evaluation parameters for test set (validation) it is evident that runoff estimated by ANN is better than regression models (Table 4). Root mean square error (RMSE) and Nash-Sutcliffe model efficiency were worked out for the estimated values obtained through MREG and ANN for the test stations. For runoff predicted by ANN Coefficient of efficiency is 18.75% higher than MREG and RMSE is lower by 50.66 %. According to criteria of Nash-sutcliffe efficiency neither ANN nor MREG is robust for estimation of soil loss from catchment area and annual rainfall. However both models are comparable for prediction of sediment yield.

Paired t-test was conducted to study the difference between the annual runoff and sediment yield estimated by each of the model and the observed runoff and sediment yield for test stations. Table 5 shows the 'r' value and the calculated values

CONCLUSIONS

The ANN models performed better than MREG, as RMSE value was found to be lower for ANN with higher model efficiency and correlation coefficient compared to MREG in case of runoff prediction. Therefore, the study concludes that If catchment information like area and average annual rainfall are available, ANN can be used as an alternate and more efficient tool for estimation of runoff for ungauged catchments in Chambal basin of India.

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Soil characterization as influenced by cropping sequences under different Agro climatic zones of Jammu Region

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ABSTRACT

Studies on soil characteristics under different cropping sequences as influenced by agro climatic zones revealed that soils were acidic to moderate in reaction and EC values were observed in a safe limit (< 1 ds m^{-1}) in soils of all the zones. Organic carbon and Cation Exchange Capacity showed wide variation from low to high and medium to high respectively. The available N, P and K were also in low to medium range. The overall values of available N, P, and K were higher in soils of intermediate zone followed by temperate zone whereas low values of these nutrients were observed in soils of subtropical zone. The OC, CEC and available N, P, and K were higher in surface soils in comparison to sub surface soils.

Key words: Cropping sequence, Agro-climatic zone, Soil characteristics, Available nutrients

INTRODUCTION

The cropping sequences have great influence on the organic carbon content of the soil which plays an important role in governing physico-chemical, biological properties and availability of nutrient in soils. Number of cropping sequence *viz*. vegetables- vegetables, maize-mustard, rice-wheat, maize-wheat and fruit crops are being practiced in different part of Jammu region. Each cropping sequence has its own effect on soil characteristics (Gupta *et al*., 2001). The total geographic area of the Jammu region is 26293 km^2. There are three agro climatic zones *viz.* sub-tropical, intermediate and temperate zone covering 2.53, 3.56 and 4.04 lakhs ha area respectively. The area under different cropping sequence *viz.* vegetables (7.24 thousand ha), maize-mustard (221.94 thousand ha), rice-wheat (273.0 thousand ha) maize-wheat(305 ha) and fruit crops (2.92 thousand ha). All the zones vary in weather parameters. Moreover, climate and soils of regions have great bearing on sources, availability and degree of decomposition of organic material of soils as climatic factors such as, temperature, rainfall, wind velocity, humidity, sun shine hours and intensity decide the growth and development as well as overall biomass of the crop plants and their decomposition and mineralization process. Sharma and Gupta (2010) studied the soil characteristics of rainfed maize-mustard cropping sequence under different agro climatic zones of Jammu region and found that soils of intermediate zone were better in available nutrient followed by temperate and subtropical zone. Another study conducted by Sharma *et al.* (2002) indicated that higher content of available sulphur in Haplaquent great group and minimum in Eutochrept group whereas other forms of sulphur decreased with depth in subtropical zone of Jammu region. However, the information with regards to monitoring of soil characteristics under different cropping sequences and agro climatic conditions is scanty. Therefore, present investigation was undertaken.

MATERIALS AND METHODS

One hundred sixty surface and sub-surface soil samples from different cropping sequence and agro-climatic zones *viz*. sub-tropical, intermediate and temperate zone of Jammu region were collected, processed and analyzed for various physico-chemical properties and available N, P, and K by following standard methods(Jackson, 1973).The soils of the region belong to orders inceptisols oxisols and entisol with ochric and cambic surface horizons are classified at great group lavels into Ustifluvents and Ustiorthents. Quartz is found as the most dominant mineral in the light sand fractions followed by mica and muscovite, sericite and feldspars (Gupta *et al*., 2001). The clay mineralogy consists of illite, chlorite, smectite, vermiculite and kaolinite (Gupta and Verma, 1992). The area is slightly sloppy having

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mean annual rainfall ranging from 900-1200 mm. The salient characteristics of the area includes accumulation of $CaCO_3$ in the upper 150 cm of soils which results in moderate profile development and low biological activities, low organic matter content and nutrient poor materials on which they are formed. These soils not only suffer from the severe problem of the erosion but also remain dry during most part of the year due to uncertain and erratic rainfall which results in poor water and nutrient retention.

RESULTS AND DISCUSSION

The pH value showed wide variation and were acidic to moderately alkaline in reaction in different agro climatic zones and cropping sequences (Table 1). On an average high pH value ranging from 7.67 to 8.36 with mean value of 8.10 was recorded in soils of fruit cultivation under subtropical zone followed by soils of maize-mustard cropping sequence ranging from 7.48-8.10 with average value of 7.79 under intermediate zone while lowest value of pH was found in soils of maize-wheat cropping sequence varying from 6.24 to 6.28 with average of 6.26 under temperate zone. The higher value of pH in soils of fruit cultivation under subtropical zone might be due to deposition of OH ions on the surface soil under the influence of more transpiration pull from subsurface soils. The pH values of surface soils were higher as compared to subsurface soil in almost all the cropping sequences and agro-climatic zones. This might be due to poor water retention and clay content of these soils. These findings corroborate with the observation of Sharma and Bali (2000). The data pertaining to EC value did not show any marked difference and found under the safe limit (less than 1.0 dS m^{-1}) in all the agro climatic zones and cropping sequences (Table 2). However, higher value of EC with average of 0.99 dS m^{-1} was recorded in soils of rice-wheat cropping sequence under intermediates zone whereas rest of the cropping sequences and climatic zones showed erratic trend. The surface soils showed higher value of EC in comparisons to subsurface soils under majority of the cropping sequences and agroclimatic zones. The higher value of EC under rice-wheat cropping sequence may be due to less precipitation and higher transpiration of water resulted upward movement of salts and their more accumulation of on the soil surface. The wide variation in organic carbon ranging from 0.67-1.20% with average value of 0.89% was obtained in vegetable sequence followed by soils of fruit growing areas ranging from 0.82-0.90% with mean value of 0.86% under intermediate zone where as lower values of OC ranging from 0.3 to 0.6% with mean value of 0.45% was observed in maize-wheat cropping sequence under soils of subtropical zone (Table 3). The values of organic carbon in soils of rest of the cropping sequences were observed in between these. Overall OC was found to be higher in surface soils as compared to subsurface .The higher values of organic carbon under intermediate zone might to be due to favourable weather conditions and less disturbances to soils by tillage practices. These results are in conformity with the findings of Kern (1994). Among the different cropping sequences, the surface soils showed highest average value of organic carbon (0.89%) in vegetable field followed by soils of fruit crop (0.86%), maize-mustard (0.82%), rice-wheat (0.75%) whereas lowest average value of OC was recorded in surface soils of maize-wheat sequence (0.69%). The higher value of OC under the soils of vegetable crops may be due to more addition of organic manure and incorporation of crop residue thereby

Table 1. Effect of cropping sequences on Soil pH under different climatic zone of Jammu region

Cropping sequences	Soil depth	Sub-Tropical		Intermediate		Temperate	
	(cm)	Range	Average	Range	Average	Range	Average
Vegetable	0-15	6.88-8.25	7.76	6.70-7.36	7.03	6.25-6.70	6.45
	15-30	7.02-8.29	7.7	6.65-7.30	6.97	4.55-7.14	6.07
Maize-Mustard	0-15	7.19-8.08	7.74	7.48-8.10	7.79	7.0 -7.68	7.18
	15-30	7.16-8.13	7.72	6.34-7.80	7.14	6.03 - 7.70	6.86
Rice-Wheat	0-15	6.14-7.68	6.99	6,60-7.64	6.97	5.45-7.45	6.51
	15-30	6.20-7.32	6.87	5.98-7.70	6.62	5.61-7.11	6.35
Maize-Wheat	0-15	6.84-7.1	6.97	5.6-8.14	6.77	6.24-6.28	6.26
	15-30	6.24-7.2	6.72	5.78-7.68	6.78	6.20-6.84	6.52
Fruits	0-15	7.67-8.36	8.10	6.13-7.64	7.20	6.65 -7.25	6.99
	15-30	7.32-8.37	7.84	5.48-7.49	6.70	6.40 - 6.85	6.61

Table 2. Effect of cropping sequences on Soil EC (dS m^{-1}) under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-Tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	0.12-0.40	0.44	0.13-0.30	0.22	0.12-0.34	0.21
	15-30	0.10-0.25	0.15	0.11-0.37	0.21	0.12 -0.24	0.16
Maize-Mustard	0-15	0.13-0.14	0.13	0.12-0.25	0.19	0.21 -0.33	0.27
	15-30	0.05-0.11	0.08	0.01-0.94	0.39	0.42 -0.45	0.28
Rice-Wheat	0-15	0.08-0.21	0.14	0.02-0.68	0.99	0.21-0.30	0.25
	15-30	0.06-0.22	0.11	0.03-0.63	0.21	0.22-0.27	0.23
Maize-Wheat	0-15	0.09-0.14	0.115	0.02-0.15	0.08	0.03-0.12	0.075
	15-30	0.07-0.12	0.095	0.02-0.13	0.08	0.05-0.06	0.06
Fruits	0-15	0.3-0.13	0.09	0.12-0.13	0.12	0.03 -0.28	0.14
	15-30	0.2-0.14	0.14	0.11-0.13	0.12	0.04 -0.27	0.17

Table 3. Effect of cropping sequences on Soil Organic carbon (%) under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	0.46-0.75	0.57	0.67 -1.20	0.89	0.62-0.90	0.70
	15-30	0.42-0.48	0.45	0.3 -0.9	0.60	0.50-0.67	0.63
Maize-Mustard	0-15	0.46 -0.49	0.47	0.67-1.05	0.82	0.58-0.60	0.59
	15-30	0.44-0.45	0.45	0.6-.67	0.63	0.45-0.64	0.54
Rice-Wheat	0-15	0.42-0.68	0.53	0.45-1.75	0.75	0.60-0.67	0.63
	15-30	0.48-0.65	0.53	0.45-0.75	0.64	0.5-0.75	0.63
Maize-Wheat	0-15	0.45-0.75	0.61	0.45-0.85	0.69	0.50-0.75	0.625
	15-30	0.30-0.60	0.45	0.43 -0.75	0.65	0.42-0.45	0.435
Fruits	0-15	0.45-0.75	0.54	0.82 - 0.90	0.86	0.52 - 0.75	0.58
	15-30	0.30-0.67	0.45	0.60 -0.87	0.63	0.45 -0.58	0.56

enhanced the organic carbon content. The present findings support the study made by Pal at el (2006).The CEC of surface soils of intermediate zone was higher and ranged from 13.5 to 15.6 (cmol(p$^+$)kg^{-1}) with mean value of 14.2 (cmol(p$^+$) kg-^{1}) followed by soils of temperate zone ranged from 12.0-13.5 cmol(p$^+$)kg^{-1}) with average of 13.2 cmol(p$^+$)kg^{-1}) under vegetable cropping sequence where as lower values of CEC ranged from 8.5 to 10.5 cmol(p$^+$)kg^{-1}) with mean value of 9.3 cmol(p$^+$)kg^{-1}) was obtained in soils of subtropical zone under maize-mustard cropping sequence (Table 4). The CEC content of subsurface soils was lower in comparison of surface soils. The highest average value (14.2 cmol(p$^+$)kg^{-1}) of CEC was recorded in surface soil of vegetable sequence followed by soils of fruits crops 13.5 cmol(p$^+$)kg^{-1}, rice-wheat (12.8 cmol(p$^+$)kg^{-1}), maize-wheat (11.8 cmol(p$^+$)kg^{-1}) whereas lowest average value of CEC (11.5 cmol(p$^+$)kg^{-1}) was found in surface soils of maize-mustard sequence. The higher value of CEC in soils of vegetable sequence under intermediate zone could be attributed to higher organic carbon content and less losses of cations by different process of soil degradation viz. volatilization, leaching *etc*. These results are in line with the findings of Rudramurthy *et al*. (2007).

The available N content in respect of the cropping sequences and climatic zones was found in low to medium range (Table 5). The highest average value of available N (318 kg ha^1) was observed in surface soils of vegetable sequence under intermediate zone followed by soils of temperate zone (220 kg ha^{-1}) (Table 2). The surface soils of subtropical zone had average value of 217.0 kg N ha^{-1}. Among cropping sequences, the surface soils of vegetable sequence had on an average higher value of available N content (318.0 kg ha^{-1}) followed by soils of maize-mustard(316.0 kg ha^{-1}), rice-wheat (307.0 kg ha^{-1}) and maize-wheat (281.0 kg ha^{-1}). Lowest value of average available N (271.0 kg ha^{-1}) was obtained in surface soils of fruit cultivation. The over all values of available N were higher in surface soils as compared to subsurface soils. The higher content of available N in vegetable crops might be due to more addition of organic

Table 4. Effect of cropping sequences on Soil CEC [cmol(p+)kg-1] under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	10.8-11.20	11.0	11.2-12.8	11.8	11.0-12.3	11.4
	15-30	9.5-10.8	10.2	10-11.5	11.0	10-11.6	11.0
Maize-Mustard	0-15	8.5-10.5	9.3	9.8-12	11.5	10-11.5	10.5
	15-30	8.0-9.8	9.2	9.0-11	10.2	9.2-10.8	9.5
Rice-Wheat	0-15	11.6-11.8	11.2	11.5-13.5	12.8	11.0-12.0	11.5
	15-30	10.5-11	10.6	11.0-11.5	11.2	10.2-11.8	11.3
Maize-Wheat	0-15	11.5-12.8	12.6	13.5-15.6	14.2	12-13.5	13.2
	15-30	10.5-11.5	11.5	12.7-14.0	13.4	11.2-12.5	11.0
Fruits	0-15	10.2-12.5	11.3	11.5-14.2	13.5	11.0-12.2	11.8
	15-30	11.6-11.8	11.2	11.5-13.5	12.8	11.0-12.5	11.5

Table 5. Effect of cropping sequences on Soil N (kg ha^{-1}) under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	214-220	217	288-400	318	218-220	220
	15-30	192-220	206	271-355	291	180-210	195
Maize-Mustard	0-15	214-220	217	288-400	316	218-220	220
	15-30	192-220	206	271-355	291	180-210	195
Rice-Wheat	0-15	69-180	135	254-364	307	202-280	230
	15-30	89-164	131	280-392	305	192-236	211
Maize-Wheat	0-15	114-159	137	240-323	281	130-280	204
	15-30	101-111	106	210-397	272	180-210	197
Fruits	0-15	89-116	135	187-355	271	198-270	226
	15-30	114-146	116	188-291	240	168-280	219

Table 6. Effect of cropping sequences on Soil P (kg ha^{-1}) under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	4.5 - 9.0	6.7	9.1 -9.2	9.1.0	7.9 -10.2	9.1
	15-30	4.1 - 9.8	5.9	8.1 -9.1	8.6	8.1 -8.2	8.2
Maize-Mustard	0-15	3.3 -8.3	6.2	14.8 -37.7	26.2	8.6 -10.1	9.2
	15-30	4.5 -8.8	6.0	17.8 -19.3	18.6	7.9 - 10.2	8.9
Rice-Wheat	0-15	3.4 -8.8	5.6	8.0-41.0	26.3	7.9 -10.1	9.0
	15-30	3.5 -6.6	5.0	7.9-36.6	24	8.2-10.3	9.2
Maize-Wheat	0-15	4.5 - 9.0	6.7	9.1 -9.2	9.1	7.9 -10.2	9.1
	15-30	4.1 - 9.8	5.9	8.1 -9.1	8.6	8.1 -8.2	8.2
Fruits	0-15	6.0 - 9.3	7.6	12.0 -19.0	14.7	9.0 -9.8	9.2
	15-30	4.1 - 9.3	6.7	9.8-15.5	12.2	7.9 -10.1	8.8

manures and crop residues which enhance the available N content in long run. The available P content in soils of different cropping sequences and climatic zones falls in low to high range with maximum average value of 26.3 kg ha^{-1} under the surface soils of rice-wheat cropping sequence followed by maize-mustard soils (26.2 kg ha^{-1}), fruit cultivated soils (14.7 kg ha^{-1}) and a minimum of 9.1 kg ha^{-1} under the soils of vegetable sequence (Table 6). The on an average, intermediate soils had high content of available P followed by soils of temperate zone while minimum average value of available P was recorded under the soils of subtropical zone. The higher available P content in rice-wheat soils may be due to more application of phosphotic fertilizer for rice-wheat cultivation and relatively

Table 7. Effect of cropping sequences on Soil K (kg ha^{-1}) under different climatic zone of Jammu region

Cropping sequences	Soil depth (cm)	Sub-tropical		Intermediate		Temperate	
		Range	Average	Range	Average	Range	Average
Vegetable	0-15	110 - 120	121.0	107 - 229	168.0	82-102	92.0
	15-30	98 - 120	109.0	186 -232	204.0	63 -82	73.0
Maize-Mustard	0-15	100 - 172	127.0	236 - 272	254.0	163-173	168.0
	15-30	96 - 215	124.0	229 -308	269.0	157 -265	203.0
Rice-Wheat	0-15	93-104	99.0	157-265	202.0	63-165	103.0
	15-30	82-112	95.0	143-244	161.0	68-117	102.0
Maize-Wheat	0-15	110 - 120	121.0	186 -232	204.0	82-102	92.0
	15-30	98 - 120	109.0	107 - 229	168.0	63 -82	73.0
Fruits	0-15	102 -104	103.0	210 -229	219.0	33 -229	143.0
	15-30	80 -103	90.0	122 -210	166.0	27-224	139.0

lower fixation of nutrient. These results corroborate the findings of Sharma *et al*. (2000). Available K status varied between 63.0 and 308 kg ha^{-1} under all the soils of different cropping sequences (Table 7). The maximum available K content was recorded in subsurface soils of maize-mustard sequence (269 kg ha^{-1}) followed by surface soils of fruit cultivation (219 kg ha^{-1}), maize-wheat sequence (204 kg ha^{-1}) and subsurface soils of vegetable sequence (204 kg ha^{-1}) whereas lowest value of available K (202 kg ha^{-1}) was observed in rice-wheat soils. The average value of available K was higher in soils of intermediate zone followed by temperate zone where as lowest value of available K was noted in soils of subtropical zone. The lower value of available K in subtropical zone may due to intensive cropping with less addition of K fertilizer nutrient in comparison of removal. Similar findings have also been reported by Hegde (1996).

CONCLUSION

It may be concluded from the findings that soils of intermediate zone are found better in soil characteristics followed by temperate and subtropical zone. Vegetable cropping sequence had marked impact on soil health and brought better improvement in soil characteristics followed by fruit crops, maize-mustard, rice-wheat and maize-wheat cropping sequence. On the basis this study it can be advised to the farmers to include vegetable crops in their cropping sequence to improve and sustain the soil health in long run.

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Effect of various soil amendments and moisture regimes on nutrient availability in a light textured soil in rice-wheat cropping system in eastern Bihar

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ABSTRACT

A field experiment was conducted on a calcareous soil to find out the effect of flyash (FA) and sulphitation press mud (SPM) on soil nutrient availability at different irrigation regime under rice-wheat cropping system. Light textured soils suffer from poor soil conditions like poor nutrient retention capacity and nutrient release characteristics which ultimately result in poor crop yields. Application of flyash and sulphitation press mud alone or in combination and pond soil resulted in an increase in organic carbon content and available nitrogen, phosphorus and potash content of soil as compared to control. The trend for this increase followed the SPM+FA > SPM > FA > pond soil for organic carbon and available nitrogen and phosphorus whereas for available potash the trend was SPM+FA > FA > SPM > pond soil. Changing the soil moisture regime with irrigation did not significantly influence the soil chemical characteristics.

Additional Key words: Calcareous soil, Pond soil, Irrigation

INTRODUCTION

The light textured soils are characterized by high bulk density, low to moderate total porosity, dominance of macro pores, high infiltration rate and high hydraulic conductivity which leads to high percolation rates and in turn resulting in excessive leaching of water and water soluble nutrients from the crop root zone soil. This can be reduced by addition of materials like Sulphitation Press Mud (SPM), finer particles of Flyash (FA), pond or *chaur* land soils or other organic materials. Flyash, which predominantly contains silica, alumina and iron, constitutes about seventy per cent of the total residues generated in coal fired power plants. It also contains sulphur, calcium, potassium etc besides heavy metals like cadmium and their content depends upon the type of coal used. The problem of disposal of huge quantities of flyash produced daily by coal based power stations, industries and railways are of great concern to the producers and environmental protection agencies. In India, over 200 million tonnes of flyash is produced every year. Upon addition to soil at optimum dose, flyash can help in maintenance of soil quality and also contribute to ecosystem protection and environment conservation (Jala and Goyal, 2014).

Reports have indicated its possible use as a source of plant nutrients and as an ameliorant for counteracting soil acidity (Adriano *et al.*, 1980; Lal *et al*., 1996). From a plant nutrition point of view, flyash contains considerable amount of ammonium acetate extractable potassium (Maiti *et al*., 1990; Sikka and Kansal, 1994; Lal *et al*., 1996; Oswal *et al*., 1997). The available sulphur, iron and zinc content of a soil was increased with flyash application (Ramesh and Chhonkar, 2001). There may also be an increase in pH of the soil with flyash application due to its comparatively higher pH and presence of Ca, Mg, Na and K in flyash which is responsible for increase in pH of the acid soil (Srivastava and Chhonkar, 2000). The concentrations of B, S, Se, Mo and Al in plants may increase with flyash application in soils (Schwab *et al*., 1991; Tolle *et al*., 1983). Similarly, press mud, a sugar industry by-product contains fairly high quantities of plant nutrients (Yaduvanshi & Yadav, 1990). India is the second largest sugar producing country in the world and about 5 million tonnes of press mud is produced annually in India. Pressmud application has been reported to increase the available content of nitrogen in the soil (Tiwari *et al*., 1992).

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MATERIALS AND METHODS

The experiments were conduced in *kharif* and *rabi* season in the experimental area of Rajendra Agricultural University, Pusa (Bihar) situated on the bank of river Burhi Gandak at 25°98′ N latitude, 85°67′ E longitude and an altitude of about 52.0 meter above the mean sea level. The climate of the area is humid subtropical. It receives fairly good amount of rainfall during the south west monsoon season with an average annual rainfall of 1270 mm out of which nearly 1026 mm occurs in the monsoon months. The maximum temperature is around 45°C during the months of May-June and the minimum is about 6°C during December January. The maximum relative humidity ranges from 85 to 95 per cent during July- September and the minimum relative humidity is in the range of 40 to 60 per cent during March-April. The soil of the experimental area was calcareous having free calcium carbonates of about 28.2 per cent. The soil of the experimental field was Entisol and sandy loam in texture with low available nitrogen, medium available phosphorus and low available potassium. Surface soil samples were taken randomly at different places from 0-30 cm depth to determine the physico- chemical properties and fertility status of the experimental plots whose values are given in table 1.

The pH of the soil water suspension with a soil: water ratio of 1: 2.5 was determined with a pH meter and the electrical conductivity in the clear extract of the same suspension after sedimentation was determined with the help of a conductivity bridge (Jackson, 1978). Organic carbon was determined by rapid titration method (Walkely and Black, 1934). The available nitrogen of the soil was measured by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by the ascorbic acid procedure using red filter (660mm) (Watanabe and Olsens, 1965) and available potassium by flame photometer in neutral normal ammonium acetate extract (Jackson, 1978).

Field experiments were conducted to find out the effect of amendments on soil chemical propreties under rice-wheat cropping system in a light textured soil with five treatments viz. control, sulphitation press mud @10 t/ha, fly ash @ 10 t/ha, sulphitation press mud @10 t/ha+fly ash @ 10 t/ha, and clay @ 50 t/ha with un-irrigated and irrigated (recommended) plots in a split plot design with three replications. The data obtained were analysed by statistical procedure as outline by Fisher (1950). The size of each plot was 5m × 4.5m. Rice *c.v.* Prabhat and wheat *c.v.* UP-262 were sown during the two years with recommended basal doses of fertilizers.

Treatment details

Main plot treatments (irrigation regimes)

I_1 - Unirrigated

I_2 - Irrigated (recommended)

Sub plot treatments (amendments)

A_1 - No amendment

A_2 - Sulphitation pressmud (SPM) @ 10 t ha^{-1}

A_3 - Flyash @ 10 t ha^{-1}

A_4 - SPM 10 t ha^{-1} + flyash 10 t ha^{-1}

A_5 - Clay soil @ 50 t ha^{-1}

RESULTS AND DISCUSSION

Light textured soils suffer from poor soil conditions like poor nutrient retention capacity and nutrient release characteristics which ultimately results in poor crop yield. Amendments are likely to improve the soil chemical properties resulting in improvement in nutrient retention and release capacity, which ultimately improve the soil chemical properties and crop yields.

Soil pH and electrical conductivity

The light texture soil was calcareous in nature having a pH of 8.8 (Table 1). Irrigation regimes had

Table 1. Initial properties of the experimental materials

Property	Soil	SPM	Fly Ash	Pond soil
pH (1:2.5)	8.8	6.4	7.8	8.0
Electrical conductivity (dS m^{-1})	0.78	0.22	0.82	0.18
Organic Carbon (%)	0.40	32.4	2.2	0.42
Available P_2O_5 (ppm)	7.23	730	97	9.5
Available K_2O (ppm)	40.3	880	128	42
Available Nitrogen (ppm)	71.4	1520	32	81

Table 2. Effect of amendments on soil pH and electrical conductivity (1:2.5 soil-water suspension) under two moisture regimes after crop harvest

Treatment	pH								Electrical Conductivity							
	Year I				Year II				Year I				Year II			
	Rice		Wheat		Rice		Wheat		Rice		Wheat		Rice		Wheat	
	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2
Control	8.8	8.7	8.8	8.7	8.7	8.7	8.8	8.7	0.75	0.72	0.74	0.79	0.77	0.78	0.75	0.70
SPM	8.3	8.3	8.5	8.3	8.3	8.2	8.3	8.3	0.63	0.61	0.62	0.68	0.65	0.67	0.64	0.62
FA	8.5	8.4	8.5	8.4	8.3	8.2	8.3	8.2	0.78	0.75	0.77	0.82	0.80	0.81	0.80	0.77
SPM + FA	8.3	8.2	8.4	8.3	8.2	8.2	8.2	8.2	0.69	0.67	0.68	0.71	0.68	0.70	0.70	0.67
Pond Soil	8.6	8.6	8.6	8.6	8.5	8.5	8.5	8.5	0.71	0.69	0.70	0.74	0.72	0.73	0.72	0.70
SEm+ (irrigation)	0.04		0.00		0.01		0.01		0.04		0.05		0.07		0.03	
SEm+ (amendments)	0.04		0.04		0.04		0.04		0.05		0.05		0.05		0.05	

little influence on pH of the soils. However, all the applied amendments contributed to reduction in the pH of the soil (Table 2). The maximum reduction in soil pH was observed with the combined application of both pressmud and flyash, followed by pressmud, flyash and pond soil alone respectively. An appreciable decrease in pH from 8.8 to 8.1 due to application of amendments like pressmud and pyrites in calcareous soils of north Bihar has also been reported by Singh *et al.* (1986). This reduction in soil pH due to application of amendments has created slightly favorable environments for availability of nutrients for the rice and wheat crops. Reduction in soil pH due to the application of pressmud and organic amendments to a sodic soil were also reported by Kumar and Mishra (1991) and More (1994) respectively. Soluble salts play an important role in soil water relations and availability to the plants. The soil of the experimental plot had an EC of 0.78 dS m^{-1} at the time of initiation of the experiment which is considered normal. No significant changes in the electrical conductivity of the soil were observed with irrigation (Table 2). Further, from the critical perusal of the data, it can be inferred that application of pressmud significantly decreased the electrical conductivity of the soil. The application of flyash increased the electrical conductivity of the soil which was significantly higher than the control during the second rice crop. The electrical conductivity of the soil amended with both flyash and pressmud was significantly lower than the electrical conductivity of the control and that of the solely flyash amended soil but significantly greater than that of the soil amended with pressmud alone. Amendment of the soil with pond soil did not result in any significant decrease in electrical conductivity. Further, the changes in electrical conductivity resulting from the application of these amendments did not create any effect that may be considered detrimental for plant growth. Similar observations were made by Dahiya *et al.* (2003) when they reported that the amendments (sugarcane trash @ 6 t/ha + industrial glue waste @ 4 t/ha) significantly decreased electrical conductivity over control. Singh *et al.* (1986) also reported an appreciable decrease in electrical conductivity from 5.4 to 2.9 dS m^{-1} due to the application of pyrites and SPM in calcareous saline sodic soils of north Bihar.

Organic carbon

From the critical perusal of the table 3, it can be seen that the application of amendments significantly increased the organic carbon content of soil as compared to control. The maximum increase in mean value of organic carbon per cent were found in order SPM + FA (0.57) > SPM (0.53) > FA (0.47) whereas pond soil (0.45) showed non-significant value as compared to control after harvest of first rice crop. Irrigation had no significant effect on organic carbon content. Similar trends were found in after harvest of first wheat, second rice and second wheat crop. The increase in organic carbon content in different treatments were due to addition of organic constituents in the form of amendments in light texture soil, whereas slight increase in organic carbon content in pond soil added treatments was due to higher organic carbon content of pond soil. Similarly Dang and Verma (1996) also observed that the application of pressmud cake brought about increase in soil organic carbon in wheat after rice, however, Somani *et al.* (1996) reported that using pressmud and flyash significantly enhances soil organic carbon.

Table 3. Effect of amendments on organic carbon (%) of soil under two moisture regimes after crop harvest

Treatment	Year I						Year II					
	Rice			Wheat			Rice			Wheat		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
Control	0.43	0.45	0.44	0.44	0.44	0.44	0.43	0.44	0.43	0.45	0.46	0.45
SPM	0.53	0.55	0.54	0.54	0.55	0.54	0.52	0.54	0.53	0.52	0.53	0.52
FA	0.45	0.49	0.47	0.5	0.51	0.5	0.47	0.49	0.48	0.49	0.51	0.5
SPM + FA	0.57	0.58	0.57	0.59	0.6	0.59	0.55	0.57	0.56	0.58	0.58	0.58
Pond Soil	0.44	0.45	0.45	0.45	0.46	0.45	0.43	0.46	0.45	0.46	0.47	0.46
Mean	0.48	0.5	0.49	0.5	0.51	0.5	0.48	0.5	0.49	0.5	0.51	0.5
CD (5%) (irrigation)		0.03			0.03			0.01			0.03	
CD (5%) (amendments)		0.03			0.02			0.02			0.05	

Table 4. Effect of amendments on available nitrogen (kg ha^{-1}) of soil under two moisture regimes after harvest crop

Treatment	Year I						Year II					
	Rice			Wheat			Rice			Wheat		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
Control	160.3	162.4	161.4	162.4	165.6	164	162.5	166	164.2	168.7	171.8	170.31
SPM	178.7	185	181.8	188.1	191.2	189.6	185.1	193	189	194.4	197.5	195.9
FA	169.3	178.7	174	178.1	181.8	180	182.1	183	182.5	188.8	191.2	190
SPM + FA	191.2	191.2	191.2	194.4	197.5	195.9	196	198	197	197.4	200.7	199
Pond Soil	172.4	172.4	172.4	175.6	175.6	175.6	175	176	175.5	175.6	178.7	177.1
Mean	174.4	178	176.2	179.7	182.3	181	180.1	183.2	181.6	184.8	188.2	186.5
CD (5%) (irrigation)		20.13			5.78			1.88			6.79	
CD (5%) (amendments)		9.02			7.03			7.56			6.12	

Amendments on available nutrients of soil

The crops grown on a light textured soil is not only affected by physical property of soil but it is also affected by the chemical fertility of the soil. Thus crops grown under light textured soil suffers on one hand by moisture stress and simultaneously on the other hand by water induced nutrient stress. Apart from this, the light textured soil is known to have higher leaching losses, lower available water storage in the form of soil water solution and it is also blessed with lower soil surface area for ions alongwith low cation exchange capacity due to lower content of finer soil particles alongwith poor organic matter content. Amendments were added in form of SPM, FA, SPM + FA, and pond soil, apart from addition of macro and micro nutrients.

Available nitrogen

The application of amendments significantly improved the nutrient status of the soil under both unirrigated and irrigated conditions. From the critical perusal of the table 4, the maximum increase in mean value of available nitrogen has been found in SPM + FA (191.2) followed by SPM (181.8), FA (174.0), and pond soil (172.4) and control (161.4). Irrigation did not increase the available nitrogen content of the soil significantly. Similar trends were found after harvest of first wheat, second rice and second wheat crop. It has clearly indicated that amended treatments have maintained better nutrient status as compared to control. As the amendments were also having available nitrogen, it has improved the status of light texture soil. The availability of higher available nitrogen content after each crop harvest indicated the better availability of nitrogen, for the growing crops which has been able to grow better, yield and water use efficiency. Sriramachandrashekharan (2001) reported that the application of flyash and pressmud significantly enhanced available nitrogen compared to control.

Available phosphorus

In general the availability of phosphorus has been found below the normal in light textured calcareous soil due to low nutrient retention capacity and fixation at high pH. The application of amendments under irrigated and unirrigated condition has improved the available phosphorus status of the soil. From the table 5, the significantly

Table 5. Effect of amendments on available phosphorus (kg ha^{-1}) of soil under two moisture regimes after harvest crop

Treatment	Year I						Year II					
	Rice			Wheat			Rice			Wheat		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
Control	16.24	16.7	16.47	17.06	17.78	17.42	17.04	18.32	17.68	17.23	18.3	17.77
SPM	28.17	30.01	29.09	29.93	31.24	29.08	24.24	28.55	26.39	24.24	28.55	26.39
FA	26.93	27.47	27.2	25.55	28.32	26.93	28.01	28.01	28.01	28.01	28.91	28.46
SPM + FA	32.86	38.79	35.82	33.94	36.63	35.28	35.35	38.25	36.9	35.55	38.78	37.16
Pond Soil	19.24	19.78	19.51	18.32	18.32	18.32	18.78	18.32	18.55	18.77	18.31	18.54
Mean	24.68	26.55	25.61	24.36	26.45	25.4	24.72	26.29	25.5	24.76	26.57	25.66
CD (5%) (irrigation)		4.58			2.88			3.50			2.42	
CD (5%) (amendments)		1.91			2.82			3.24			2.49	

Table 6. Effect of amendments on available potash (kg ha^{-1}) of soil under two moisture regimes after harvest crop

Treatment	Year I						Year II					
	Rice			Wheat			Rice			Wheat		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
Control	89.1	90	89.5	94.6	97.7	96.1	92.2	92.8	92.5	92.5	93.2	92.8
SPM	139.1	140.6	139.8	141.2	142.3	141.7	130.3	135.3	132.8	135.2	140.6	137.9
FA	151.9	162.7	157.3	159.4	162.1	160.8	138.5	152.5	145.5	150	161.2	155.6
SPM + FA	170.2	175.5	172.9	177.7	179.8	178.8	141.7	159.4	150.6	165.4	165	165.2
Pond Soil	94.8	97.7	96.2	97.1	97.7	97.4	94.2	95.1	94.7	94.3	96.5	95.4
Mean	128.9	133.3	131.1	134	135.9	135	119.4	127	123.2	127.4	131.3	129.3
CD (5%) (irrigation)		14.51			8.12			3.61			5.60	
CD (5%) (amendments)		6.53			6.94			8.13			8.85	

higher mean value of available phosphorus has been found in SPM + FA (35.82) followed by SPM (29.09), FA (27.2), pond soil (19.51) and control (16.47) kg ha^{-1}. Irrigation did not result in any significant increase in the mean value of available phosphorus after harvest of first rice crop. Similar trends were found in after harvest of first wheat, second rice and second wheat crop. This favourable situation created by use of amendments has favorably affected the growing crops for better nutrient status in the amended treatments as compared to control. Higher available phosphorus status of the soil has been found due to reduction in soil pH. This result is supported by Selvakumari *et al.* (2000) who indicated that the addition of flyash results in significant increase in available phosphorus for the rice crop. The available phosphorus content in soil increased from 3.58 to 4.55 after application of 10 t/ha sulphitation pressmud. Adriano *et al.* (1980) and Mittra *et al.* (2000) reported beneficial effect of FA as soil amendments in terms of increased available phosphorus in FA treated soil. Similarly Yadav and Yaduvanshi (1993) showed that SPM application (10t/ha) significantly increased availability of phosphorus in soil. Gaind *et al.* (2002) also indicated that FA improved available phosphorus in FA treated soil.

Available potash

The role of available potash is well known for higher crop yield and higher water use efficiency. In light texture soil many times available potash becomes a limiting factor for crop growth due to poor retention capacity of the soil. For improving available potash status of light texture soil amendments were found to be beneficial. From table 6, the maximum value of available potash has been found in SPM + FA (172.9) followed by FA (157.3), SPM (139.8), and pond soil (96.2) and control (89.5). The level of irrigation has not been found to affect markedly and it was not significant after harvest of first rice crop. Similar trends were found in first wheat, second rice and second wheat crops with slight change in magnitude. The treatments having FA application have been able to increase potash status of the soil as compared to other treatments seems to be the contribution of more potash content in the FA as compared to other amendments. The better available potash status was maintained in the amended treatment which favorably supported the growing plants for better plant growth and yield. Apart from this the amendments applied were also having some amount of secondary and micro nutrients which have also affected the plant growth and yield favorably. Mulla *et al.* (2000) showed that the beneficial effect of flyash application on increase in available potassium. Similarly the available potassium increased significantly with the application of farm yard manure. Adriano *et al.* (1980) and Mittra *et al.* (2000) have also reported that FA application improves available potash.

CONCLUSIONS

The application of various amendments significantly increased the organic carbon and available nitrogen, phosphorus and potash content of soil as compared to control after the harvest of crops. The trend for this increase followed the SPM+FA > SPM > FA > pond soil for organic carbon and available nitrogen and phosphorus whereas for available potash the trend was SPM+FA > FA > SPM > pond soil. Irrigation did not affect the level of availability of N, P and K in the soil.

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Effect of mulches on soil temperature and soil moisture level under capsicum *(Capsicum annuum)* crop

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ABSTRACT

Field experiment was carried out in winter season at research field of Precision Farming Development Centre (PFDC), Department of Horticulture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). The soil temperature was taken at 7:30 am and 2:00 pm. It was observed that at 7:30 am the average soil temperature under black plastic mulch (BPM) is 1.29 and 1.93°C higher as compared to the Paddy straw mulch (PSM) and without mulch (WM) respectively. At 2:00 pm under BPM the average soil temperature increases by 4.6 and 1.62 °C compared to under PSM and WM condition respectively. The average soil temperature under WM is 3.0°C more than PSM condition. It was also found that the soil temperature under PSM was higher than the WM condition. It was found that BPM saves significantly higher soil moisture (49%) as compared to paddy straw mulch at 15 cm soil depth, similarly BPM saves 44% more soil moisture as compared to paddy straw mulch at 30 cm soil depth. BPM with 80% irrigation level gives maximum yield 20802.40 kg/ha, followed by BPM+100% irrigation level which gives 20000.00 kg/ha. Minimum yield was found in without mulch with control irrigation condition.

Key words: Drip irrigation, Capsicum, Black plastic mulch, Paddy straw mulch, Level of irrigation

INTRODUCTION

Drip irrigation system alongwith mulching is most suitable approach for cultivation of capsicum (*Capsicum annuum*). Mulching, a surface covered cultivation is a recommended practice of moisture conservation for arid and semi arid regions. Mulches of various kinds have been used to modify hydrothermal regime in the crop root zone. Mulching reduces the water evaporation by interfering the radiation falling on the soil surface. Thus mulching delays the drying of the soil and reduces the soil thermal regime during the day time (Mane and Umrani, 1981). Continuous use of mulches is helpful in improving the organic matter content of soil which in turn improves the water holding capacity of the soil. Plastic mulch on the surface of the soil causes a change in the microclimate in its vicinity. This results in moisture conservation, less soil compaction, and higher CO_2 levels around plants. Plastic mulch maintains higher soil temperature in the night which favours the root activity. It also reduces the weed population and improves the microbial activities of the soil by improving the environment around the root zone.

The use of wastewater for irrigation purposes is being established as a future alternative in water scarce areas and in those areas where there is heavy competition for water. Since efficient use of irrigation water is of major importance for sustainable agriculture development, different measures have been introduced to conserve water (Taylor *et al.,* 1995). Drip irrigation is an efficient method of water application for vegetables and horticultural crops. This method is widely used because it allows efficient management of both water and fertilizer (Rajurkar *et al.,* 2012). The cost depends upon the crop, spacing, water requirements, source of water supply etc. The payback period of drip irrigation system was worked out about one to two years for most of the crops and the benefit cost ratio varies from 2 to 5 (Sivannapan, 2009).

MATERIALS AND METHODS

Description of study area

Experimental site

Field experiment was carried out in winter season at research field of Precision Farming Development Centre (PFDC), Department of Horticulture, Indira Gandhi Krishi Vishwavidyalaya, and Raipur (C.G.). Raipur is situated in the central part of Chhattisgarh at latitude 21.16° N and longitude 81.36° E at

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an altitude of 289.56 meters above the mean sea level.

Experimental details

Crop: Capsicum *(Capsicum Annuum)*

Variety: Indira Hybrid

Mulch: Black Pastic Mulch (BPM), Paddy Straw Mulch (PSM) and Without Mulch (WM)

Experimental area: 1375m-2 (55m×25m)

Row to row spacing: 1m

Plant spacing: 0.45m

Design: Split Plot Design (SPD)

Level of Irrigation: 60, 80, 100% and control

Replicated planting of capsicum was planted utilizing four irrigation level by drip irrigation (0.6VEpan, 0.8VEpan and 1.0VEpan) and control by furrow irrigation. A split plot design, with irrigation as main plot treatment and mulching as the subplots treatments was utilized. The drip irrigation system consists of drip tubing placed in each row of plants. During irrigation, water pressure in the system was maintained at 1.2 kg/cm^2. The furrow irrigation system consisted of the typical furrow method of irrigation with plants on the top of the bed.

Mulching

The black LDPE film of 25µ was laid on the surface of strip of 0.6m width and 3.5 m length on 1st of November using black plastic mulch of 25 micron and paddy straw mulch as per the layout. The LDPE film of 25µ was laid in such a way that it would not touch the rows of capsicum. A cut of 10 cm diameter was provided around each seedling on polyethylene mulch and mulch was laid carefully. To avoid the nuisance of prevailing wind the film was covered by soil from all the sides. Drip laterals were laid under the mulching film and irrigation was applies daily on climatologically approach through the drip system.

Measurement of soil temperature

Soil thermometer was used for the measurement of soil temperature. Soil thermometer was inserted below the soil surface up to the depth of 10cm. Three different thermometers were individually used in black plastic mulch (25µ), paddy straw mulch, and without mulch on the field (Fig. 1). The daily records from 15th January to 3rd March the soil temperature were taken at 7:30 am and 2:00 pm. The study was done to know the effect soil temperature on different mulches in growth and production of crop.

Soil moisture measurement

Soil samples were collected randomly from the field at 15 and 30cm depth from the surface of the soil. Moisture content of the soil was determined by gravimetric method using the following relation. The soil samples of the experimental plots were collected from the specified locations and moisture contents of each soil sample was determined using standard methods.

$$Moisture\ content\ (percentage\ db) = \frac{(W_1 - W_2)}{W_2} \times 100$$

where, W_1 = Wet mass of soil, g, W_2 = Dry mass of soil, g

Soil moisture depletion

$$= \frac{(F.C - M.C.) \times Root\ zone\ depth \times B.D}{100}$$

F.C. - Field capacity, ***M.C.*** **-** Moisture content, *B.D.*- Bulk density.

RESULTS AND DISCUSSION

Effect of different mulches on soil temperature

During the study period, the soil temperature was recorded at 7:30 AM and 2:00 PM. The soil temperature status at 10 cm depth is presented in Fig. 2 and Fig. 3. From the graph, it is seen that the

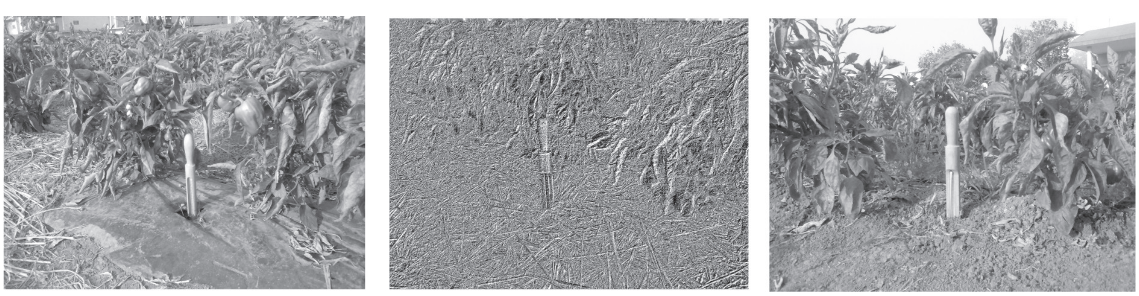

Fig. 1. Soil temperature recorded on plastic mulch, paddy straw mulch and without mulch

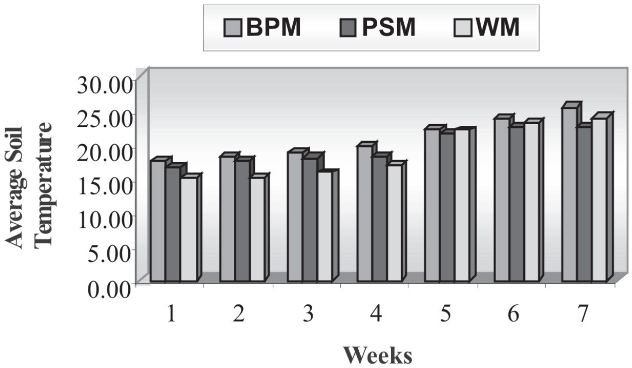

Fig. 2. Average weekly soil temperature at 7:30 AM

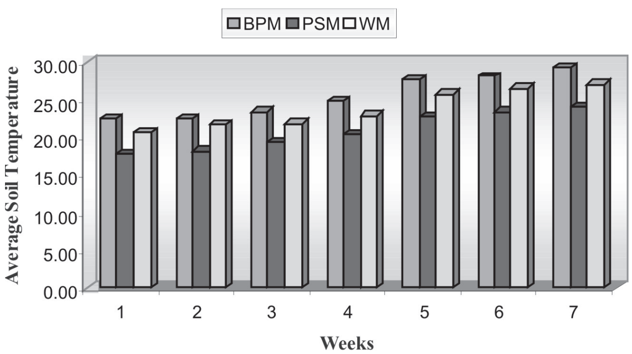

Fig. 3. Average weekly soil temperature at 2:00 PM

soil temperature of black plastic mulch (BPM) was found to be increasing till the last seventh week of study period with increase in atmospheric temperature. Soil temperature of BPM follows increasing trend with the daily atmospheric temperature. Similar trend was found in soil temperature from 1st to 7th week in case of paddy straw mulch (PSM) and without mulch (WM).

From visualization of Fig.1 it can be observed that in first four weeks of study period, soil temperature followed similar increasing trend in all three mulches as the atmospheric temperature was very low. From the 5th week of study period, the atmospheric temperature increase the soil temperature of paddy straw mulch reduced till the 7th week as compared to soil temperature in WM condition which still follows the increasing trend.

All the mulches BPM, PSM and WM, the soil temperature was recorded at 2 PM from 1st to 7th week during the study period. It can be observed from the Fig. 2 that the soil temperature in BPM follows increasing trend and shows the highest value of soil temperature as compared to PSM and WM. Also the soil temperature of PSM follows increasing trend but shows lowest value of recorded soil temperature than BPM and WM. Hence from the above observation it can be concluded that the PSM kept the soil temperature less than WM and BPM and when atmospheric temperature is low paddy straw mulch increase the soil temperature and the atmospheric temperature is high it reduces the soil temperature. Similarly Black plastic mulch increases the temperature of soil both day and night period.

It is concluded that at 7:30 AM the average soil temperature of BPM is 1.29 and 1.93°C higher as compared to the PSM and WM. At 2:00 PM the BPM increases the average soil temperature by 4.6 and 1.62 °C for PSM and WM respectively. At the same time the average soil temperature of WM is 3.0°C more as compared to the PSM. PSM kept the soil temperature less than WM. We also found that the soil temperature by PSM was higher than the WM when the atmospheric temperature is low in the morning. On comparison of variation in soil temperature between 7:30 AM and 2:00 PM for BPM, PSM and WM it was found that the 3.83 to 5.21°C and 3.17 to 6.07 °C for BPM and WM respectively but the variation in PSM was found to be 0.79 to 2.21 which is very less as compared to the BPM and WM. From the visualization it was also found that because of increased temperature in the BPM the increased growth rates of plants, healthy leafs, size, shape and quality of fruit is good as compared to the WM condition for capsicum

Table 1. Weekly average soil temperature recorded under different mulches

Weeks	Soil Temp. (°C) at 7:30 am			Soil Temp. (°C) at 2:00 pm		
	BPM	PSM	WM	BPM	PSM	WM
1	17.50	16.71	15.14	22.50	17.86	20.79
2	18.21	17.43	15.07	22.57	18.21	21.71
3	18.79	18.00	15.86	23.43	19.43	21.86
4	19.71	18.14	16.93	24.93	20.36	23.00
5	22.36	21.43	22.14	27.71	22.93	25.86
6	23.86	22.50	23.36	28.14	23.43	26.64
7	25.58	22.75	24.00	29.42	24.17	27.17

Table 2. Moisture depletion under different treatments in the experimental field

Mulch	Irrigation level	15 cm depth		30 cm depth	
		M.C. (%)	Soil Moisture Depletion (MM)	M.C. (%)	Soil Moisture Depletion (MM)
Black Plastic Mulch(25ì)	0.6V Epan	22.50	1.64	23.80	2.73
	0.8V Epan	23.98	1.33	24.31	2.51
	1.0V Epan	25.60	0.98	25.48	2.01
	Control	21.34	1.89	21.90	3.54
Paddy Straw Mulch	0.6V Epan	21.11	1.94	22.59	3.25
	0.8V Epan	22.45	1.65	23.43	2.89
	1.0V Epan	24.17	1.29	24.10	2.60
	Control	20.65	2.04	20.99	3.93
Without Mulch	0.6V Epan	19.87	2.20	21.30	3.80
	0.8V Epan	21.35	1.89	22.10	3.45
	1.0V Epan	22.73	1.59	22.60	3.24
	Control	18.76	2.44	19.32	4.64

crop. It is also concluded that BPM is best suited for winter season as it maintain high soil temperature and PSM is good in summer season because of it maintain low soil temperature. Also it is found that the variation in soil temperature in PSM condition was very less as compared to BPM condition under the atmospheric condition at 7:30 AM and 2:00 PM. Similar findings were made by Ramakrishna *et al*. (2006) and Singh and Kamal (2012) in their studies.

Soil moisture depletion pattern

The average moisture depletion of soil from the field for 0.6V Epan, 0.8V Epan, 1.0V Epan and Control levels of irrigation with three types of mulch for 15 cm and 30 cm soil depth was determined as present in Table 2 Soil moisture depletion for BPM at 15 cm depth below the surface was found 1.64, 1.33, 0.98 and 1.89 mm and similarly the water saving observed was 25.44, 29.68, 38.37 and 22.53 percent for 60, 80, 100 percent and control plots respectively. For PSM Soil moisture depletion found 1.94, 1.65, 1.29 and 2.04 mm and similarly the water saving observed was 11.99, 12.42, 19.25 and 16.51 percent for 60, 80, 100 percent and control plots respectively. Also for WM Soil moisture depletion found 2.20, 1.89, 1.59 and 2.44mm for 60, 80, 100 percent and control plots respectively.

Soil moisture depletion for BPM at 30 cm depth below the surface was found 2.73, 2.51, 2.01 and 3.54 mm and similarly the water saving observed was 28.06, 27.25, 37.84 and 23.69 percent for 60, 80, 100 percent and control plots respectively. For PSM Soil moisture depletion found 3.25, 2.89, 2.60 and 3.93 mm and similarly the water saving observed was 14.34, 19.71, 16.40 and 14.48 percent for 60, 80, 100 percent and control plots respectively. Also for WM soil moisture depletion found 3.80, 3.45, 3.24 and 4.64 mm for 60, 80, 100 percent and control plots respectively.

From the analysis we also concluded that the BPM save significantly higher soil moisture (49 percent) as compared to paddy straw mulch at 15 cm soil depth. Similarly, BPM save the soil moisture 44 percent more as compared to paddy straw mulch at 30 cm soil depth.

CONCLUSIONS

It was concluded that the BPM saves significantly higher soil moisture almost 49 percent as compared to paddy straw mulch at 15 cm soil depth. Similarly, BPM saves 44 percent more soil moisture as compared to paddy straw mulch at 30 cm soil depth.

Soil moisture depletion at 15 cm depth under BPM was found to be 1.64, 1.33, 0.98 and 1.89 mm and the water saving was 25.44, 29.68, 38.37 and 22.53 percent, similarly under PSM soil moisture depletion was 1.94, 1.65, 1.29 and 2.04 mm and the water saving was 11.99, 12.42, 19.25 and 16.51 percent respectively. Also under WM condition soil moisture depletion were 2.20, 1.89, 1.59 and 2.44 mm for 60, 80, 100 percent and control level of irrigation respectively.

Soil moisture depletion at 30 cm depth under BPM was found to be 2.73, 2.51, 2.01 and 3.54 mm and the water saving was 28.06, 27.25, 37.84 and 23.69 percent, similarly under PSM soil moisture

Table 3. Yield of Capsicum with combination of mulches and different level of irrigation

Sr. No.	Treatments (Black Plastic Mulch)	Yield (kg/ha)	Sr. No.	Treatments (Paddy Straw Mulch)	Yield (kg/ha)	Sr. No.	Treatments (Without mulch)	Yield (kg/ha)
1	BPM +0.6V Epan	16826.6	5	PSM + 0.6V Epan	12103.4	9	WM + 0.6V Epan	13899
2	BPM +0.8V Epan	20802.4	6	PSM + 0.8V Epan	16225	10	WM + 0.8V Epan	15529.8
3	BPM +1.0V Epan	20000	7	PSM + 1.0V Epan	17739.8	11	WM + 1.0V Epan	13915.3
4	BPM + Control	12349.1	8	PSM +Control	10522.9	12	WM +Control	10299.8

depletion was 3.25, 2.89, 2.60 and 3.93mm and the water saving was 14.34, 19.71, 16.40 and 14.48 percent respectively. Also under WM condition soil moisture depletion were 3.80, 3.45, 3.24 and 4.64 mm for 60, 80, 100 percent and control level of irrigation respectively.

By comparing soil temperature at 7:30 AM and 2:00 PM for BPM, PSM and WM, it was found that the variation in temperature is in the range of 3.83°C to 5.21°C and 3.17°C to 6.07 °C for BPM and WM respectively. But in PSM it was found to be 0.79°C to 2.21°C which is very less as compared to the BPM and WM.

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Drip irrigation scheduling of Mango cv. Langra under subtropical condition of Uttar Pradesh

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ABSTRACT

Drip irrigation scheduling is an important water management strategy in fruit crops wherein full water requirement of the crop is applied over its entire phenological stages based on evaporation replenishments. Keeping this in view, a field experiment was laid out under subtropical environment to evaluate the effect of phenology based irrigation scheduling on yield and water use efficiency of mango cultivar Langra for 4 years in a 20 years old orchards near Lucknow. Irrigation scheduling consisted of open pan evaporation (OPE) replenishments (90, 70 and 60% of OPE) under drip irrigation system and basin irrigation as control in association with three nitrogen levels (75 and 50% of the recommended dose of nitrogen and no fertigation as control). Drip irrigation irrespective of fertigation significantly increased fruit yield and water use efficiency over traditional basin irrigation. The percent increase in fruit yield over basin irrigation system was 12.2, 42.5 and 47.9% as compared to 0.90, 0.70 and 0.60 OPE respectively. The per cent yield improvement in 0.60 OPE was higher as compared to 0.90 and 0.70 OPE and it was around 31.6 and 36.1% respectively. The water use efficiency ranged between 5.25-9.94 kg fruits per m^3 of water applied in the drip irrigation system as compared to 3.69 kg fruits per m^3 of water applied in basin application of irrigation. Moreover, the per cent of irrigation water saved was quantified and it was found that the drip irrigation had saved 21.13, 35.40 and 45.20% irrigation water in 0.90, 0.70 and 0.60 OPE respectively over its basin application.

Key words: Drip irrigation scheduling, soil moisture, yield, water use efficiency, Mango

INTRODUCTION

Mango is a crop of major economic importance in India, produced during the dry season when irrigation is necessary to ensure stable yields of high quality. As local water resources are increasingly scarce, more efficient water usage in agriculture is important. Reorganization of best irrigation technique further emphasizes the need for evaluating water and nutrient requirement of fruit crops for maintaining fruit quality and orchard sustainability (Clark *et al*., 1996; Chopade and Gorantiwar, 1998; Patel and Rajput, 2002; Sujatha *et al*., 2006a; Gorantiwar *et al*., 2011; Adak *et al*. 2012). It becomes much more relevant in case of light textured soils having low fertility levels and water holding capacities. Till date, traditional knowledge of water application to the fruit crops is being followed by the farmers without considering climatic variability, soil factors and the plant requirement. Even the commercial orchardists were using the day old practice of application of water through flooding. Some progressive orchardists are using basin application of irrigation. On the other hand, use of drip-irrigation is rapidly increasing around the world, and is expected to continue in the foreseeable future. Drip irrigation offers a great promise due to its higher water use efficiency against lower amounts of water applied and avoiding moisture stress throughout the growing period by providing available moisture at critical crop growth stages (Franco *et al*., 2000; Melgar *et al*., 2008; Panigrahi *et al*., 2010; Adak *et al*., 2014a). Drip-irrigation provides unique agronomic, water and energy conservation benefits that address many of the challenges facing irrigated agriculture.

Actually drip irrigation scheduling involves pan evaporation based application of irrigation water during its entire phenological stages. This correct application requires thorough understanding of the yield response to water and of the economic impact in crop production (Simsek *et al*., 2004; Kumar *et al*., 2007). In semiarid and arid regions, where water resources are limited, pan evaporation based drip fertigation can be more profitable for farmers to maximize crop water productivity instead of maximizing the harvest per unit land (English *et al*., 2002; Bhriguvanshi, *et al*., 2012a). Nutrient may also be incorporated into drip

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Table 1. Rainfall distribution during the mango experiment

	Tmax			T min			Rainfall			Number of rainy days		
	1999-2000	2000-01	2001-02	1999-2000	2000-01	2001-02	1999-2000	2000-01	2001-02	1999-2000	2000-01	2001-02
April	39.7	39.9	36.5	20.2	20	19.5	0	9.8	0	0	1	1
May	39	38.5	37.4	25.6	25.5	25	0.7	66.2	16.8	0	5	5
June	37.6	34.1	35	25.9	25.9	24	67.6	200	245.4	7	8	8
July	34.1	32.7	33.2	26.2	25.9	26	190	203.2	286.3	12	13	13
August	32.7	33.2	33.4	25.5	26	26	169.8	200.8	214.3	15	10	10
September	31.8	32.5	34.5	24.5	24	23.9	207.5	78.3	37.7	8	6	6
October	31.7	33.7	32.5	19.7	18.9	20.1	69.2	0	119.7	6	0	0
November	29.1	29.5	29	11.3	12.4	12.2	0	0	4.3	0	0	0
December	24.4	24.9	22.9	7.7	6.3	8.2	9.4	0	0	1	0	0
January	21.2	20.3	21.3	6.9	5.9	6.9	4	4.9	16.4	1	0	0
February	23.7	26.6	25	8.1	9.5	10.6	0	11.2	23.7	0	1	1
March	30.4	31.6	31.6	13	13	15.2	3.8	12.7	0	2	2	2
						Total	**722**	**787.1**	**964.6**	**52**	**46**	**46**

Source: Annual report, IISR, Lucknow

system and thereby simultaneous application of water and nutrients to the targeted root zone. Since sufficient information is lacking on this aspect, there has been a great need for investigating efficient irrigation and fertigation schedule for drip irrigated sub-tropical fruit crop-Mango to get quality produce with better water use efficiency. Henceforth, the present study was undertaken under the ICAR networking project on drip irrigation with the objective of developing pan evaporation replenishments based irrigation technology and assessing its impact on yield and water use efficiency of mango cultivar Langra under subtropical conditions.

MATERIALS AND METHODS

A four years (1998-2002) field experiment was conducted in a split plot design at the experimental research farm of Central Institute for Sub-tropical Horticulture, Rehmankhera, Lucknow (26.54°N Latitude, 80.45^{0}E Longitude and 127 m above mean sea level). The soil of the experimental site was *Typic Ustochrepts* having pH 8.2, EC 0.27ds m^{-1}, bulk density (BD) 1.44 mg m^{-3}, water holding capacity (WHC) 30%, Infiltration rate 3.6 cm hr^{-1}, organic carbon 0.27 with available P (11.25 ppm) and K (74 ppm). The experiment was laid out consisting of drip irrigation system and basin application of irrigation water. Three evaporation replenishments rates: I_1-90%, I_2-70% and I_3-60% of open pan evaporation (OPE) and I_4- as a basin irrigation system as control along with three nitrogen fertilizer levels (N_1- 750g N/tree; N_2-500g N/tree and N_0-No fertilizer) were applied. The 20 years old trees of mango cv Langra placed at a spacing of 10 ×10 m were selected and fertilized with 1000g P_2O_5 and 1000g K_2O per tree during the month of September in 30 cm deep trenches dug at 2 m away from the trunk while nitrogen was applied through fertigation. The irrigation was done through drippers on the basis of OPE. Soil samples were collected at 25 cm interval up to 1 m depth in the horizontal distance of 1.0 (D1) and 1.5 m (D2) from the tree basin. Soil moisture, organic carbon, fruit yield and TSS (Total soluble solid) were recorded. Water use efficiency was calculated based on yield and amount of water applied to produce fruit yield. The pooled data obtained from the experiments was statistically analyzed and significance was concluded using SPSS version 12.0.

RESULTS AND DISCUSSION

Climatic condition during the course of experiment

The climatic condition during the course of this experiment was tabulated in Table 1. It was revealed that the average maximum temperature during April to July (fruit developmental and maturity stage) was 37.6, 36.3 and 35.5°C respectively in the three seasons while the minimum temperature ranged between 23.6 to 24.5^{0}C. The total amount of rainfall was recorded as 722, 787.1 and 964.6 mm in three seasons however it was 258.3, 479.2 and 548.5 mm received during April to July. The rainfall was well distributed in 2000 to 2002 (27 rainy days) as compared to 19 days in 1999-2000 season.

Table 2. Yield and water use efficiency of mango cv Langra under basin and drip irrigation system

Treatments	Fruit Yield (t ha $^{-1}$)	Water use (litre ha^{-1})	WUE (kg fruits per m^3 of water)	Saving of water (%)	Increase in yield over basin (%)	TSS (^{0}Brix)
I_1	4.14	78867	5.25	21.13	12.20	19.1
I_2	5.26	64600	8.14	35.40	42.55	19.6
I_3	5.45	54833	9.94	45.20	47.70	19.9
I_4	3.69	100000	3.69			18.9
C. D. (p = 0.05)	0.07	-	1.23	-	-	0.25

Yield and quality

The pooled mean yields obtained from the investigation over the years are presented in Table 2. It was revealed that the scheduling of irrigation in drip irrigated system (0.90, 0.70 & 0.60 OPE) gave higher fruit yield of mango cv Langra (41.40-54.50 kg ha^{-1}) as compared to basin application of irrigation (36.90 kg ha^{-1}). The percent increase in fruit yield over basin irrigation system (I_4) was 12.2, 42.5 and 47.9 per cent in 0.90, 0.70 & 0.60 OPE respectively. The per cent yield improvement in 0.60 OPE was also higher as compared to 0.90 and 0.70 OPE and it was around 31.6 and 36.1 per cent respectively. Application of nitrogen in the basin irrigation treatment also resulted in higher yield as compared to without application in basin water. Higher yield under drip irrigation may have resulted due to more uniform soil-water and nutrients distribution. Basin irrigation not only resulted in wastage of irrigation water in deep percolation below root zone, but also sets a chain of undesirable processes including leaching loss of available plant nutrients and consequently development of soil health problems and poor aeration resulting in reduced fruit yield. Deficit irrigation technology was reported in improving the yield of mango as well as other horticultural crops across diverse agroecological scenario (Srinivas, 1996; Patel and Rajput, 2000; Yuan *et al*., 2003; Spreer *et al*., 2007; Pérez-Pérez *et al*., 2008). When nutrient is coupled with irrigation water into drip system, the efficiency of nutrient Patel, 2006; Zotarelli *et al*., 2009; Ankegowda, 2011; Kaushik *et al*., 2011). The quality parameter TSS was statistically significant across different soil moisture and nutritional regimes (Table 3) indicating the fact that fertigation levels had appreciable impact on TSS contents of fruit. A similar finding was reported in Nagpur mandarin (Panigrahi and Srivastava, 2011).

Soil moisture and organic carbon variations in drip and basin system of irrigation

Soil moisture is an important parameter in water management study as its distribution is much more relevant particularly in the root zone area. Along with water, nutrients are also distributed in fertigation systems. Organic carbon is also associated with the dynamics of moisture content. The soil moisture depletion pattern revealed that the moisture content up to the effective root zone was higher; below which in the deep root system it was lower in all the treatments (Table 4). This spatial distribution of irrigation water recognizes the need for drip irrigated system so as to apply water within the root zone and to confine water within effective horizontal root distribution. This would definitely save irrigation water rather than basin application

Table 3. TSS (^{0}Brix) levels in Mango cv Langra under basin and drip irrigation system

Irrigation	Nitrogen levels					
levels	N_1	N_2	N_0	Mean	SE	CV (%)
I_1	19.1	19.5	18.8	19.1	0.04	2.4
I_2	19.2	19.8	20.0	19.6	0.15	4.8
I_3	19.6	19.9	20.3	19.9	0.08	3.6
I_4	18.7	19.2	18.8	18.9	0.03	2.3
Mean	19.1	19.6	19.5			
SE	0.05	0.04	0.18			
CV (%)	2.3	1.9	4.2			
C.D. (p = 0.05)				0.25		

Table 4. Pooled soil moisture depletion pattern in mango cv Langra under basin and drip irrigation system

Irrigation levels	Soil depth (cm)	Nitrogen Levels					
		N_1		N_2		N_0	
		D1	D2	D1	D2	D1	D2
I_1	0-25	17.47	16.53	16.83	17.79	17.76	17.31
	26-50	16.15	15.54	16.44	16.82	16.75	15.61
	51-75	16.15	15.41	16.57	16.51	16.04	15.71
	76-100	15.66	15.07	16.04	16.01	16.33	15.88
	Total	65.43	62.55	65.89	67.13	66.88	64.50
	SE	0.07	0.03	0.06	0.08	0.17	0.09
	CD (p = 0.05)	0.8	0.5	0.7	0.8	1.2	0.9
I_2	0-25	16.33	16.37	16.85	15.77	15.55	15.77
	26-50	15.43	15.62	16.35	15.91	15.88	15.41
	51-75	15.11	14.78	15.51	14.99	15.76	14.92
	76-100	14.68	14.68	15.31	14.78	15.37	14.48
	Total	61.55	61.45	64.02	61.44	62.56	60.58
	SE	0.09	0.05	0.05	0.08	0.01	0.03
	CD (p = 0.05)	0.9	0.6	0.7	0.8	0.4	0.5
I_3	0-25	16.53	16.11	16.19	16.16	16.05	16.11
	26-50	15.63	15.68	15.86	15.53	15.78	15.84
	51-75	15.11	15.72	15.53	15.34	15.69	15.88
	76-100	15.47	15.07	15.23	14.84	15.57	15.93
	Total	62.74	62.57	62.80	61.86	63.09	63.76
	SE	0.05	0.02	0.04	0.03	0.02	0.06
	CD (p = 0.05)	0.6	0.4	0.6	0.5	0.4	0.7
I_4	0-25	16.18	16.39	16.44	16.68	18.22	17.60
	26-50	16.34	16.04	16.34	16.64	17.56	17.26
	51-75	15.83	15.24	15.86	16.44	17.56	16.84
	76-100	15.23	15.46	15.32	16.08	17.00	16.52
	Total	63.58	63.13	63.96	65.84	70.34	68.22
	SE	0.03	0.04	0.03	0.02	0.05	0.03
	CD (p = 0.05)	0.5	0.6	0.5	0.5	0.7	0.5

SE is the standard error of mean

whereby seepage loss was much more. A similar finding was reported by Bhuva *et al*. (1991) wherein differential moisture extraction pattern in Sapota was observed under varying level of water regimes. Even Vijayakumar *et al.* (2011) inferred that mean moisture content was higher near the emitter as compared to higher lateral distance and higher nitrogen content was recorded in deficit irrigation at 0.75 OPE in a sandy loam soil. Higher organic carbon was recorded at the surface layer (50 cm) and it decreased down the depth. Relatively lower organic carbon was recorded at 1.5 m horizontal distance from the tree trunk as compared to 1m distance (Table 5). Adak *et al.* (2014a) also observed higher soil organic and associated dehydrogenase activity in mango orchard soil. The higher concentration of organic C in surface soil might be due to decomposition of leaf litters, grasses at the surface soils. Further it was revealed that relatively lower organic C prevailed in soils where fertilizer was not applied rather than fertilized one. This may be due to the fact that addition of N fertilizer increased biomass production and microbial enzymatic activity. The interrelationship between soil moisture and organic carbon showed that soil moisture had significant impact on organic carbon content variation of the experimental soil may probably be due to changes in microbial activation and leaf decomposition (Fig. 1). Under subtropical condition of Lukcnow region, Bhriguvanshi *et al.* (2012b) reported significant correlation between soil moisture dynamics with organic carbon and micronutrients at root zone depths and 1m away from tree trunk.

Table 5. Organic carbon content in mango cv Langra under basin and drip irrigation system

Irrigation levels	Soil depth (cm)	Nitrogen levels											
		N_1				N_2				N_0			
		D1	SE	D2	SE	D1	SE	D2	SE	D1	SE	D2	SE
I_1	0-25	0.44	0.0001	0.40	0.003	0.38	0.001	0.37	0.006	0.50	0.001	0.40	0.002
	26-50	0.38	0.0003	0.35	0.001	0.38	0.001	0.31	0.003	0.35	0.0002	0.39	0.002
	51-75	0.35	0.0003	0.30	0.001	0.37	0.004	0.32	0.004	0.24	0.0003	0.31	0.0005
	76-100	0.35	0.0003	0.28	0.000	0.34	0.003	0.30	0.003	0.24	0.002	0.28	0.00002
	Total	1.52		1.32		1.46		1.30		1.33		1.37	
I_2	0-25	0.45	0.0002	0.41	0.003	0.45	0.001	0.32	0.002	0.37	0.001	0.34	0.002
	26-50	0.43	0.0003	0.32	0.002	0.39	0.002	0.29	0.001	0.35	0.004	0.31	0.001
	51-75	0.40	0.0001	0.27	0.0002	0.36	0.001	0.26	0.0003	0.33	0.0004	0.30	0.002
	76-100	0.38	0.001	0.28	0.002	0.33	0.001	0.28	0.001	0.30	0.001	0.26	0.001
	Total	1.66		1.27		1.53		1.15		1.35		1.21	
I_3	0-25	0.45	0.0002	0.34	0.003	0.46	0.0003	0.36	0.002	0.38	0.004	0.31	0.001
	26-50	0.43	0.001	0.32	0.002	0.46	0.001	0.33	0.001	0.33	0.006	0.27	0.002
	51-75	0.41	0.001	0.30	0.002	0.43	0.000	0.30	0.001	0.33	0.002	0.26	0.001
	76-100	0.37	0.001	0.29	0.002	0.41	0.001	0.28	0.001	0.30	0.002	0.26	0.001
	Total	1.67		1.24		1.74		1.27		1.33		1.10	
I_4	0-25	0.42	0.002	0.34	0.001	0.46	0.002	0.40	0.003	0.38	0.004	0.40	0.004
	26-50	0.37	0.001	0.30	0.002	0.37	0.001	0.33	0.002	0.32	0.001	0.31	0.003
	51-75	0.34	0.002	0.32	0.001	0.32	0.000	0.31	0.001	0.30	0.001	0.25	0.001
	76-100	0.32	0.003	0.30	0.001	0.30	0.001	0.35	0.004	0.31	0.0003	0.23	0.001
	Total	1.44		1.26		1.44		1.40		1.30		1.19	

SE is the standard error of mean

Water use efficiency (WUE) and water production function

The water use efficiency ranged between 5.25-9.94 kg fruits per m^3 of water applied in the drip irrigation system as compared to 3.69 kg fruits per m^3 of water applied in basin application of irrigation (Table 1). The pooled analysis as well as analysis of individual year indicated that the WUE was maximum at DI 60 per cent of OPE along with fertigation with 500 g N tree^{-1}. Even when fertilizer was not applied the WUE was much higher in 0.60 OPE as compared to 0.70 and 0.90 OPE. Therefore, it was concluded that under this agro-ecological region, application of irrigation water through drip system of the order 60 per cent replenishment of OPE would be beneficial. Moreover, the per cent of irrigation water saved were quantified and it was recognized that under conditions of limited water supplies through drippers proved consistently superior over basin application of irrigation water; which significantly saved 21.13, 35.40 & 45.20 per cent in 0.90, 0.70 and 0.60 OPE respectively as compared to basin application. Reddy *et al*. (2009) reported a 33-66 per cent saving of water in drip irrigation system under semiarid region of Hyderabad condition. The effect of drip irrigation on increasing water use efficiency of mango was also noticed by Sujatha *et al*. (2006b). The yield-water relationship in mango cultivar Langra was established and presented in Fig 2a and 2b. The water production function of mango fruit yield sought through best-fit polynomial regression equations. The production function was found to be second-order quadratic and the equations were as follows:

1. $Y = 4E\text{-}07x^2 - 0.1018x + 10036$ ($R^2 = 095^{**}$)
   where Y = yield (kg/ha) and x = amount of water applied (l/ha)
2. $Y = 2E\text{-}09x^2 - 0.0005x + 30.949$ ($R^2 = 0.99^{**}$)
   where Y = water use efficiency (kg fruit per m^3 of water applied) and x = amount of water applied (l/ha)

Thus, the mathematical relationship indicated that highest fruit yield obtained with the water applied around 55000 l ha^{-1} and thereafter it was declined. It clearly indicated that further increase in seasonal water beyond above mentioned value is not desirable for enhancing the fruit yield. Henceforth, it may be concluded that irrigation water must be applied at 0.60 OPE rather than any other higher values. The relationship between yield

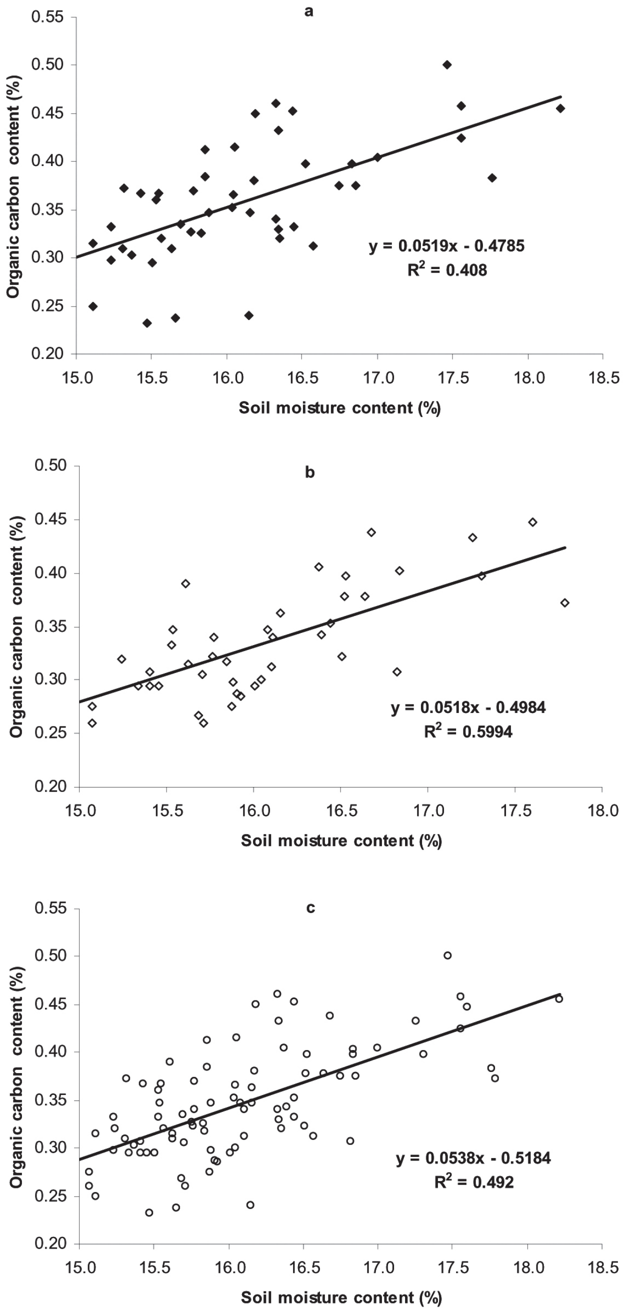

Fig. 1. Functional relationship between soil moisture and organic carbon content in drip irrigated mango orchard soil. a and b indicates at D1 and D2 distances and c stands for pooled values

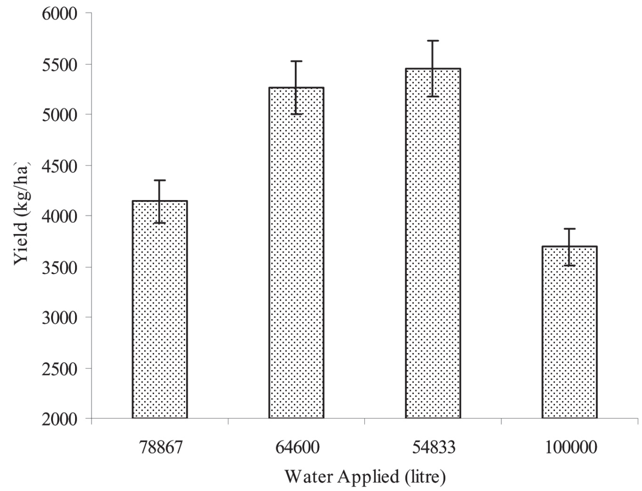

Fig. 2a. Water productivity functions in Mango

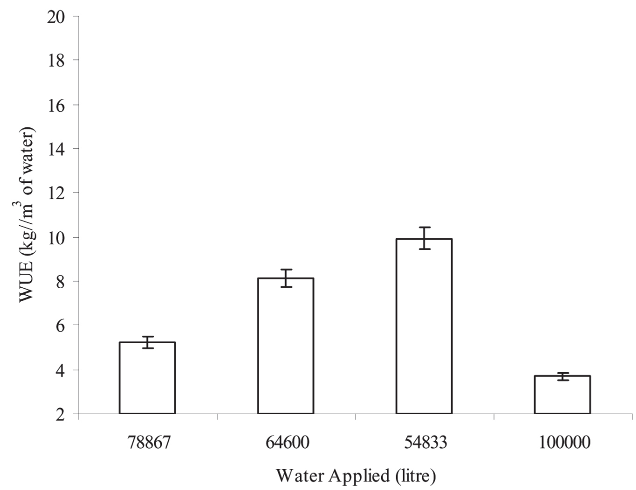

Fig. 2b. Water application in relation to water use efficiency in mango

and total water applied during fruit development was found to be polynomial in nature due to the fact that yield did not increase linearly with the increase in irrigation water. According to Imtiyaz *et al*. (2000), the polynomial relationship between yield and total water applied may be due to poor soil aeration and nutrient utilization caused by excessive water application. A similar finding of improved water use efficiency and water productivity was reported by Azevedo *et al*. (2006) under semiarid conditions of Brazil and Goswami (2011) in black cumin under differential irrigation and nitrogen levels.

CONCLUSION

Pan evaporation replenishments based drip irrigation technology was found to be an effective water saving technique in mango cultivar Langra under subtropical climate. The study also indicated the usefulness of drip irrigation system in attaining higher fruit yield, water use efficiency and improved water saving as compared to basin method of water application in mango fruit orchard. Higher soil moisture retention and organic carbon content indicated that this technology indeed fruitful in maintaining optimum water regimes in root zone. Thus, Langra should be irrigated with drip irrigation so as to apply water on critical phonological stages of the crop than its basin application. Under the drip irrigation system, irrigation should be given at 0.60 OPE for higher yield and water use efficiency. Similarly, fertigation particularly nitrogen @ 500 g/tree^{-1} is most desirable under this agro-ecological region of sub-tropical India.

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Effect of dripper discharge on spatio-temporal movement of water in soil under drip irrigation

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ABSTRACT

Drip irrigation is an advanced and efficient method irrigation to use water efficiently. Water distribution in soil is one of the most important parameters to design efficient drip irrigation system. Soil texture, structure, initial soil moisture, and dripper discharge are the important factors on which extent of wetting front in soil mainly depends. An actual field research was conducted to investigate the effect of dripper discharge at different system operating pressures on spatio-temporal soil moisture movement. The value of moisture contents varied significantly ($P<0.05$) under different operating pressures (0.5, 1.0 and 1.5 kg/cm^2) and at different locations below and away from the dripper. Highest values of soil moisture contents were observed below the drippers which decreased as the distance increased in both horizontal and vertical directions from the dripper. The values of moisture content in soil decreased as distance increase in both directions (horizontal and vertical) from the dripper. 9.4% and 14.3% higher values of soil moisture just below the dripper were observed with dripper discharges at 1.0 and 1.5 kg/cm^2 system operating pressures respectively, as compared to dripper discharge at 0.5 kg/cm^2 system operating pressure. Wetting front extended horizontally up to 15, 20 & 26 cm and vertically up to 30, 30 & 24 cm at dripper discharge at 0.5, 1.0 and 1.5 kg/cm^2 system operating pressure, respectively after 1 day of irrigation.

Key words: Drip irrigation, System operating pressure, Dripper discharge, Soil water distribution, Wetting front

INTRODUCTION

Drip irrigation is an advanced method of irrigation and has higher water efficiency method result in enhancement in water and nutrient productivity. The highest water application efficiency around 90% may be achieved in drip irrigation leading to 50-100% water saving as compared to surface method of irrigation. Drip irrigation allows frequent water and fertilizers application in small doses helps in maintaining optimum soil moisture and nutrients level in the crop root zone leading to higher water and nutrients use efficiencies and better quality of produce. Drip irrigation is a technique in which drop by drop application of water is done in the crop root zone in order to meet the crop water requirement and maintain the optimum soil water status around the vicinity of plant roots (Devi Aruna and Selvaraj, 2013).

In depth understanding of water application rate and soil properties that affect the soil wetting zone developed around the crop root zone is important consideration for proper designing and management of drip irrigation system. Moisture distribution pattern under a drip source is one of the basic requirements for efficient design of drip irrigation. Proper understanding of dripper type and injection devices used for fertigation in micro-irrigation systems is essential to improve nutrient distribution uniformity in a drip system (Kumar *et al.*, 2014). The extent of soil wetted volume in drip irrigation system determines the optimal amount of water needed to wet the effective root zone. The amount of water and nutrients stored in the crop root zone can be estimated by the volume of wetted soil. Design parameters, such as percent of root zone to be wetted, spacing and location of drippers, application rates, frequency and amount of irrigation, etc. are governed by the moisture distribution patterns in the soil profile in drip irrigation which need to be thoroughly investigated. The depth of the wetted volume should coincide with the depth of the root system while its width is related to the spacing between drippers and drip laterals (Zur, 1996). Water and nutrients movement in soil under drip irrigation is influenced by the type of soil and rate of water and nutrients application (Thabet *et al.*, 2008). The exact wetted volume of the soil needs to be determined for

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providing the adequate amount of water required by the crop (Al-Qinna *et al.*, 2001; Kumar, 2012).

It is clear from the above reviewed literature that information about water and nutrient movement in soil is the basic needs for better fertigation system design. Keeping this in view, the present investigation was carried out to study the water movement in soil under different drip discharges at different system operating pressures.

MATERIAL AND METHODS

A field experiment was conducted at the research farm of Water Technology Centre, Indian Agricultural Research Institute (IARI), New Delhi, India (Latitude 28°37′30″–28°30′0″ N, Longitude 77°88′45″–77°81′24″ E and AMSL 228.61 m). The soil samples were collected at 0.0-15.0, 15.0-30.0, 30.0-45.0, 45.0-60.0 cm soil depths below the soil surface. Soil of the experimental area was deep loam soil and comprising of 37.57% sand, 40.67% silt and 21.59% clay with an average bulk density, average field capacity and average saturated hydraulic conductivity of soil were 1.60 g cm^{-3}, 0.22 and 1.67 cm h^{-1}, respectively.

The drip irrigation system was installed in a field plot of 21 m x 100 m. The drip system has one hydro cyclone filter (flow rate 27 $m^3 h^{-1}$, 75 mm size), one sand media filter (flow rate 25 $m^3 h^{-1}$, 50 mm size, silica sand 0.7 mm) with back flush mechanism. The field was divided into three equal size sub-plots. Each sub-plot has 3 drip lines connected through a valve tree. Drip lines were connected with sub-mains (PVC pipes of 40 mm diameter) and sub-mains lines were connected with main lines (PVC pipes of 60 mm diameter). Flush manifolds were connected at the lower end of each block.

Field experiment was designed to determine the water movement in soil with various dripper discharges under different system operating pressures. The thin-walled drip line (Azud line, 16 mm diameter with 30 cm dripper spacing and dripper discharge 1.4 lph) was used for the experiment. The system was operated at three operating pressures (0.5 kg cm^{-2}, 1.0 kg cm^{-2} and 1.5 kg cm^{-2}). The discharge rates of the dripper at different system operating pressure were determined by collecting the volume of water in the catch cans for a particular duration. A relationship was developed between discharge and pressure of the selected drippers.

Water movement in the soil were observed on all system operating pressures. The drip irrigation system was operated continuously for one hour duration at all the system pressures (0.5, 1.0 and 1.5 kg/cm^2) without crop. The soil samples were collected through the pipe auger to observe water movement in the soil. The soil samples were collected in both horizontal (0, 15, 30 cm) and vertical (0-15, 15-30, 30-45 and 45-60 cm) direction across the dripper (Fig. 1), 1.0 hour, 1 day, 3 day and 7 days after the operation of the system.

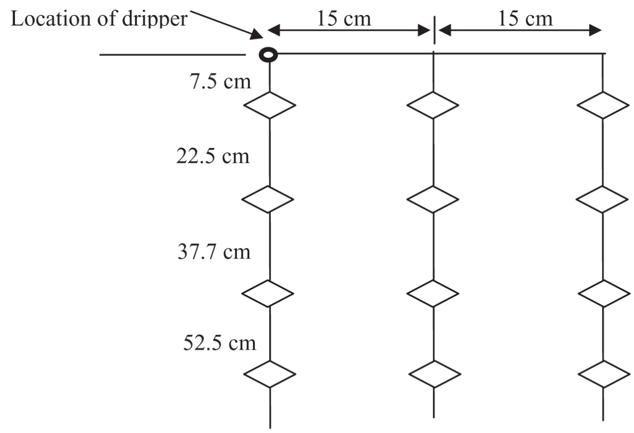

Fig. 1. Locations of soil sample

The wetting front was recognized by the colour difference of the wetted and surrounding soils (Fig. 2). The horizontal and vertical wetting distances on the wetted face were recorded by ordinary meter scale. Soil moisture content was estimated by gravimetric method.

Fig. 2. Soil wetting front under drip irrigation

RESULTS AND DISCUSSION

Discharge versus pressure relation

A relationship was developed between discharge and pressure of the selected drippers. Fig. 3 shows the discharge and pressure relationship of the selected emitters. The data collected during the experiment fitted to a conventional power function that takes the form of equation 1.

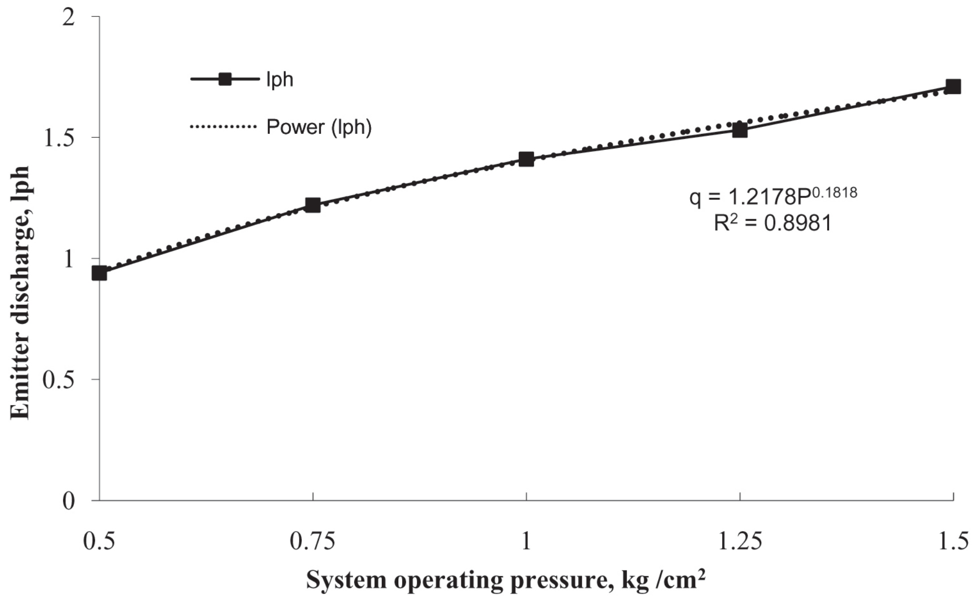

Fig. 3. Emitter discharge and system operating pressure relationship

$$q = kP^x \quad (1)$$

where

q = emitter discharge (lph),

P = system operating pressure (kg cm^{-2}),

x = emitter discharge exponent; and

k = a regression coefficient.

The values of k and x are 1.2178 and 0.1818, respectively as given in Fig. 3. By substituting these values, equation 1 can be written as:

$$q = 1.2178\ P^{0.1818} \quad (2)$$

The above power function regression for the tested emitter had exponent values of 0.1818 with R^2=0.8981. The measured discharges at the nominal pressure (1 kg/cm^2) for the tested emitter were almost same to the reported manufacturer values.

Spatio-temporal distribution of soil moisture

The soil samples were collected at 0, 15 and 30 cm away from the dripper and different depths (15 cm interval, up to 60 cm) below the dripper under different system operating pressures after 1 hour, 1, 3 and 7 days of irrigation for spatio-temporal soil moisture distribution. The soil wetting pattern was characterized by the radial distance of the wetting front and the depth from the emitting source (dripper).

Spatial distribution of soil moisture

The spatial soil moisture distribution after 1 hr duration under different system operating pressures were measured and are presented in Fig. 4. The spatial distribution of soil moisture was significantly ($P<0.05$) different at different locations in horizontal and vertical directions from the dripper 1 hr after the irrigation. However, it was not significantly ($P<0.05$) different at different locations 3 and 7 days after irrigation. The highest value of soil moisture content was observed below the dripper (a saturated condition) which decreased as the distance increased from the dripper. Maximum (25.4%) value of moisture content was observed near the dripper with dripper discharge at operating pressure of 1.5 kg cm^{-2} while minimum value (20.9%) of soil moisture content was observed below the dripper with dripper discharge at system operating pressure of 0.5 kg cm^{-2}. The wetting fronts resulting from higher system operating pressures (higher discharge rate of drippers) were more in the horizontal direction i.e. the lateral movement of water was comparatively higher than that of low operating pressures. This is evident from the figure 4 that wetting front extended up to 15 cm vertically at 0.5 kg cm^{-2} system operating pressure however at 1.5 kg cm^{-2} system operating pressure it reached up to 20 cm horizontally after one hour. It was observed that the moisture continent below the dripper at system operating pressure of 1.0 kg cm^{-2} and 1.5 kg.cm^2 were 9.4% and 14.3% higher respectively as compared to 0.5 kg cm^{-2} system operating pressure.

Temporal distribution of soil moisture

The temporal distribution of soil moisture below 15 and 30 cm away from the dripper after 1, 3 and 7 days at different locations away from the

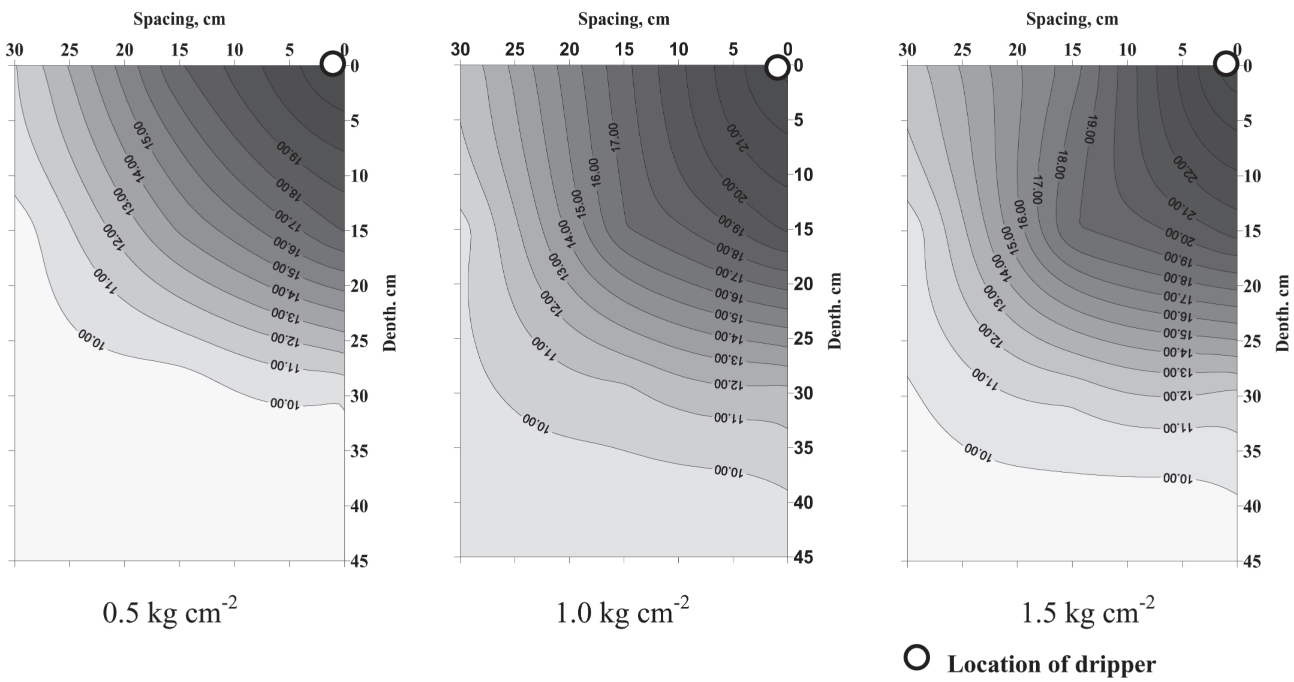

Fig. 4. Soil moisture distribution at different system operating pressure 1 hr after irrigation

dripper under different system operating pressures are presented in Fig. 5.

It is clear from figure 5 that highest value of moisture content was observed below the drippers after 1 hour at all operating pressures. Soil moisture moved in the soil 1 day after irrigation and higher values of soil moisture contents were observed at 15-30 cm soil depth. The higher values of soil moisture were present at upper soil layer (15-30 cm soil depth) at higher dripper discharges even after 3 days after irrigation. However, almost similar values of soil moisture were recorded in all the soil layers 7 days after irrigation.

Figure 4 shows that wetting front extended up to 15 cm horizontally and 30 cm vertically with dripper discharge at 0.5 kg cm^{-2} system operating pressure whereas, it extended up to about 20 cm horizontally and about 30 cm vertically at with dripper discharge at 1.0 kg cm^{-2} operating pressure after 1 day of irrigation. However, it reached to about 24 cm vertically and 26 cm horizontally with dripper discharge at 1.5 kg cm^{-2} operating pressure after 1 day of irrigation. Similar trends of wetted fronts were reflected from the observations taken after 3 days of irrigation.

At higher discharge rates, horizontal distances of water front were relatively larger as compared to vertical distances which may be attributed to less resistance to water flow in horizontal direction as compared to the vertical and negligible gravity forces for horizontal flow of water. Similar results were reported in other studies of Ah Koon *et al.* (1990), Li *et al.* (2004) and Badr and Taalab (2007). Ah Koon *et al*. (1990) and Badr and Taalab (2007) investigated the effect of drip discharge rate on the soil water distribution in soil and reported that increasing in the discharge rate of dripper resulted in an increased lateral movement of water and a decrease in wetted soil depth.

CONCLUSIONS

Soil moisture distribution in soil is one of the most important parameters for efficient design of drip irrigation system. Extent of wetting front in soil mainly depends on soil texture, structure, initial soil moisture, and dripper discharge. Highest values of soil moisture contents were observed below the drippers at all dripper discharges with different system operating pressures which decreased as the distance increased in both horizontal and vertical directions from the dripper. The value of moisture contents varied significantly ($P<0.05$) under different operating pressures (0.5, 1.0 and 1.5 kg cm^{-2}) and at different locations below and away from the dripper. The higher values of moisture content (25.4%) was recorded just below the dripper with dripper discharge at 1.5 kg cm^{-2} system operating pressure, however lower value of moisture content (20.9%) was recorded just below the dripper with dripper discharge at 0.5 kg cm^{-2} 1 hour after irrigation. The value of moisture content increases after passes of time in both directions (horizontal and vertical) away from the dripper.

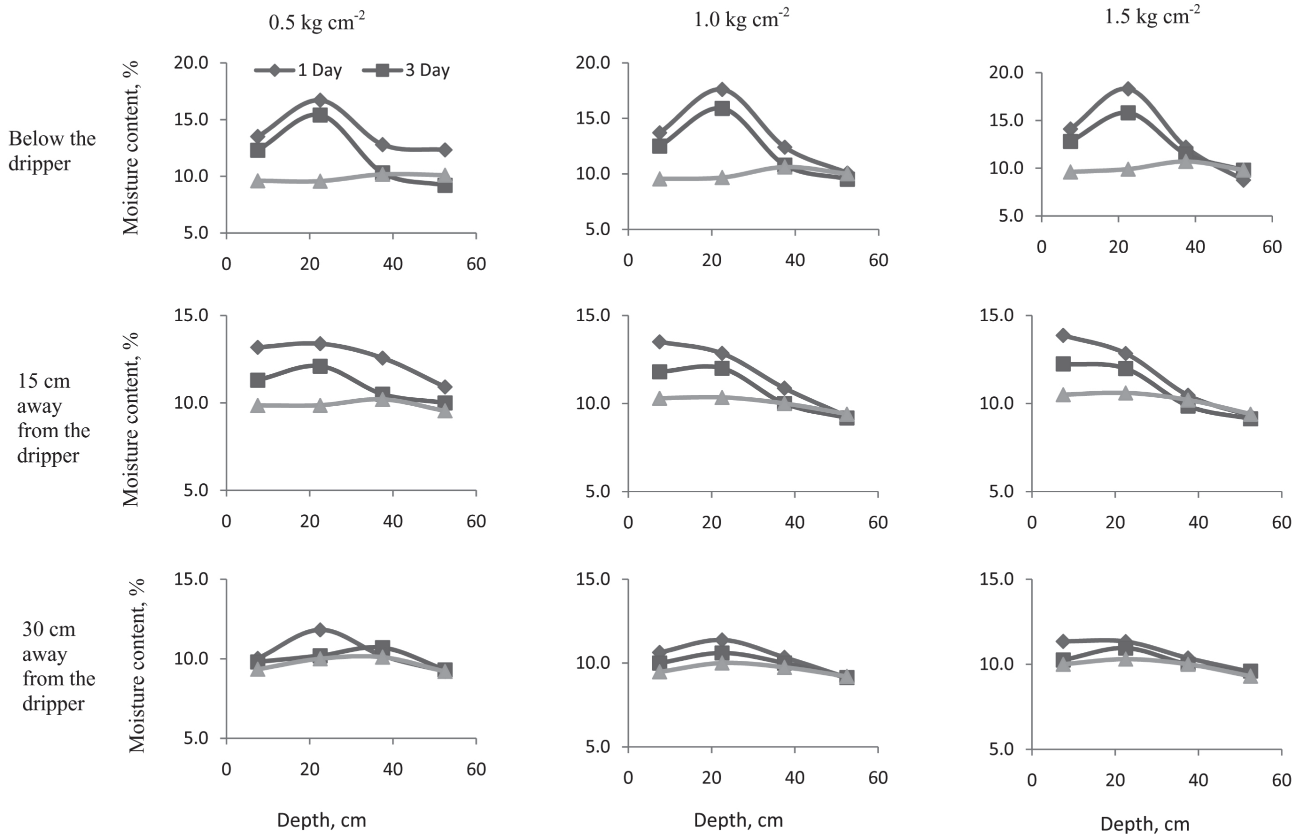

Fig. 5. Temporal distribution of soil moisture distribution at different locations away from the dripper with different dripper discharges at various system operating pressures 1, 3 and 7 days after drip irrigation

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Watershed planning using goal programming approach – A case study

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ABSTRACT

Efficient management of agricultural resources is becoming the key issue to feed the increasing population from limited resources. The basic resources of agriculture i.e. land and water should be optimally utilised to fulfil the requirement of the people. The present study utilises goal programming (GP) approach for watershed planning of Mandakini Balinala watershed No.1. The study was conducted considering six basic objectives such as maximisation of food production, fodder production, fuel wood production, net income generation from field crops, labour employment generation and runoff water augmentation along with constraints like available land, water and human resources of the watershed. The maximization in production of the watershed is very much necessary, to satisfy the requirement of the people. The maximization in production also helps to increase the net return from the watershed, thereby improving the socio-economic condition of the farmers. The present study gives a benefit-cost ratio of 1.34 and increase in benefit of 171.36%.

Key words: Optimal utilisation, Goal programming, Key issue, Efficient management

INTRODUCTION

Optimal utilisation of resources is a key issue today considering the growing population and climate change, with scarcity of available resources like land and water. In this context, rural people may be considered as the third resource because they are responsible for effective and sustained use of the resources of a particular area. So proper planning, management practices and efficient use of these resources are very much necessary, at present scenario In order to feed the growing population, agricultural production has to be increased. This can be achieved by increasing the area under cultivation or by increasing the crop production per unit area through optimal crop planning using the available land, water and human resources. The area under cultivation and water should be utilised in such a way that productivity from the area will be optimum. Watershed management is a multi disciplinary activity in which several goals are to be achieved. Watershed management programme constitutes of several objectives but we have to consider only those which are critical for the watershed. As there are multiple objectives in the watershed management programme, so it comes under multi- objective programming. Soni (2000) developed goal programming model (GPM) for Debra block of Midnapore district with objectives to maximize net return and agricultural production with optimal use of land and water. Vivekanandan and Viswanathan adopted GPM for optimization of multi-objective cropping pattern for Barna irrigation project. Venkatasubbaiah *et al.* (2003) applied GPM for land allocation problems for optimal production of seasonal crops. Simon *et al.* (2004) developed a goal programming model for the management of a fishery unit (North Sea Demershal)

The present paper employs goal programming (GP) approach to the planning of Mandakini Balinala watershed No.1. The objectives taken for the present paper were maximisation of food production, maximisation of fodder production, maximisation of fuel wood production, maximisation of net income generation from field crops, maximisation of labour employment generation and maximisation of runoff water augmentation. These objectives are treated against a set of constraints like land, water and human resources of the watershed. The land allocation for the watershed was done and benefit-cost ratio was determined to find out the economic viability of the programme.

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METHODOLOGY

Model Description of GP

Goal Programming Model (GPM) is a linear mathematical model in which the optimum attainment of multiple gaols is sought within the given decision environment. The decision environment determines the basic components of the model. Its general aim is to optimize several goals and at the same time to minimize the deviation for each of the objectives from the desired targets. A goal has the following general form

$$Z_k(x)+n_a-p_a = g_a \quad \ldots(1)$$

$$\text{Subjected to } \Sigma\Sigma\, a_{ij}\, x_j\, (\leq=\geq)\, b_j \quad \ldots(2)$$

$$x_j \geq 0$$

For i = 1, 2, 3,................x
j = 1, 2, 3..................n

where,

$Z_k(x)$ = attribute, n_a = negative deviational variable, g_a= target, p_a= positive deviational variable

It is advisable to be very selective regarding the number of objectives to be modelled, avoiding those that are closely related. Most agricultural decision making studies are focusing on farmer's welfare (utility) optimization and are using the goal programming techniques to satisfy economic, social and managerial criteria originated only from the farmers view point.

Model Formulation of GP

Model formulation is considered as one of the most important activities for obtaining the solution to the GP problem as it is the most difficult part in the application of management science to a particular problem. Because of the recent advances in the use of computers, finding a solution is not difficult when compared to model formulation. The objective function may be assigned with a positive or negative deviational or both regarding acceptance of achievement of desired goal.

In this paper, the priority given to different goals are in the order of maximisation of objectives like food production, net income from field crops, labour employment generation, fodder production, fuel wood production and runoff water augmentation.

Objective Functions

The objective functions of different objectives for the planning of Mandakini Balinala Watershed No.1 are in the form as given in table 1.

Constraints

Land constraint

The sum total of crops in any season should not exceed the total treatable area of the watershed. Also the area under cultivation in kharif and rabi season are less than the total cultivable are in both the seasons. Similarly the area allocated to different crops should be less than the available land. The land availability constraint is expressed as:

$$\Sigma\Sigma x_{ij} \leq AT$$

where x_{ij} is the area under j^{th} crop in i^{th} season respectively and i=1 for kharif season and 2 for rabi season. AT is the maximum allowable area for cultivation.

Water constraints

The water required by different crops for cultivation in kharif season must be met from the rainfall at desired probability levels and for rabi season, required water is less than the water available from the ponds. The constraint equation is expressed as

$$\Sigma\Sigma\, WR_{ij}\, x_{ij} \leq WR_a$$

Nutritional constraints

The protein and calorie available from different crops should be more than the protein and calorie

Table 1. Objective Functions and their Equations

Objective functions	Type of equation
1st Goal: Food production $Z_1(x)$	$\Sigma\Sigma\, Y_{ij}x_{ij}+n_1-p_1$
2nd Goal: Net income generation $Z_2(x)$	$\Sigma\Sigma\, N_{ij}x_{ij}+n_2-p_2$
3rd Goal: labour employment generation $Z_3(x)$	$\Sigma\Sigma\, L_{ij}x_{ij}+n_3-p_3$
4th Goal: Fodder production $Z_4(x)$	$\Sigma\Sigma\, f_{ij}x_{ij}+n_4-p_4$
5th Goal: fuel wood production $Z_5(x)$	$\Sigma\Sigma\, W_{ij}x_{ij}+n_5-p_5$
6th Goal: Runoff water augmentation $Z_6(x)$	$\Sigma\Sigma\, C_jx_{ij}+n_6-p_6$

requirement of the watershed. The constraint equation is expressed as:

$$\Sigma\Sigma\ P_{ij}x_{ij} \geq PR$$

$$\Sigma\Sigma\ C_{ij}x_{ij} \geq CR$$

Labour constraints

The month wise labour required for different crops should be less than the total mandays available in that month inside the watershed. The constraint equation is expressed as:

$$\Sigma\Sigma\ L_{ij}x_{ij} \leq LA$$

Bulk constraints

The production of food, fodder and fuel wood must be more than the requirement of the people of the watershed. The constraint equation is expressed as:

$$\Sigma\Sigma\ y_{ij}x_{ij} \geq R_e$$

Area required for Ponds

The total are under ponds should be more than the total area required to augment the water in rabi season.

$$x_8 \geq A_{tar}$$

APPLICATION

Study Area

The watershed selected for this study is Mandakini Balinala watershed No-1 which lies n the Begunia block of Khurda district (Odisha). The latitude of the area is $20^0 18'$ N and longitude 85^0 $62''$E. The total watershed area is 50.67 ha, out of which the net treatable area is 457 ha. The rest area comes under homestead, nallah roads and for other uses. Out of the total area, 282.22 ha come under agricultural land. The forest land, culturable wasteland and gochar land can be brought under fodder and fuel wood cultivation. Mainly the slope of the watershed is mild varies between 0-5%. The climate of the watershed area is hot and dry sub humid with mean average annual rainfall is 1499.29 mm. The main crop grown in the area is paddy. However, crops like maize, pigeonpea are grown in some areas in kharif season. Due to lack of irrigation facility most of the areas remain barren in rabi season. Most of the farmers inside the watershed are small and marginal farmers. The economic condition of the farmers is not good inside the watershed. The present study made an attempt to provide food security to the population, employment generation and also to generate some income from field crops.

Data Availability

The primary data of rainfall, land use, land capability data for the Mandakini Balinala watershed No.1 was collected. The cost of input and price of output and yield of different crops as per the existing method were collected from the watershed. The population data, livestock data were also collected. Basing on the above data, the total quantity of different crops, fodder and fuel wood requirement of the watershed were estimated. The rainfall data of 29 years (1978-2007) was collected and analyzed to find out the water availability in kharif season.

Data and data source

The data pertaining to existing crop area were collected from Soil Conservation Officer, Khurda, Odisha. The cost of cultivation were calculated as Annonymous, 1998. The multi-objective programming was solved using WIN-QSB software.

MODEL DEVELOPMENT FOR THE WATERSHED

Objective Function

Using the methodology of GP, efforts have been made to optimize the selected objectives with available land, water and labour constraints for the Mandakini Balinala Watershed No.1.The crops taken for the present study are upland paddy (paddy-I), medium land paddy (paddy-II), low land paddy, maize, arhar in kharif season and low land paddy, mustard, mung in rabi season. Besides this hybrid napier bajra grass and subabool plantation tree is proposed for both the seasons. The objective functions for the present study are given in table 2.

Constraints

Land constraints

The total area cultivable in both the seasons is less than or equal to the total treatable area of the watershed i.e. 457 ha. Similarly the total area suitable for agricultural crops must be less than or equal to the total cultivable land of the watershed i.e. 282.22 ha in kharif and 219.97ha in rabi season. The crops taken for upland are upland paddy, maize and arhar, which should be less than the total area under upland i.e. 62.25 ha. Simillarly the crops taken under medium land are medium land paddy

Table 2. Objective functions

1. Maximisation of food production: $Z_1(x) = 2.6x_{11}+3.2x_{12}+3.7x_{13}+4x_{14}+1.8x_{15}+4.3x_{21}+1.5x_{22}+x_{23} + n_1-p_1$
2. Maximisation of net income generation: $Z_2(x) = 9671x_{11}+11202x_{12}+11838x_{13}+15618x_{14}+48673x_{15}+10800x_{16}+6980x_{17} +16916x_{21}+15213 x_{22}+24740 x_{23}+7200 x_{24}+4980 x_{25} + n_2-p_2$
3. Maximisation of labour employment generation: $Z_3(x)=102x_{11}+132x_{12}+165x_{13}+160x_{14}+93x_{15}+60x_{16}+185x_{17}+165x_{21}+100x_{22} +65x_{23}+90 x_{24}+ 185x_{25} + n_3-p_3$
4. Maximisation of fodder production: $Z_4(x)= 6.5x_{11}+7.1x_{12}+8x_{13}+2x_{14}+30x_{16}+7x_{17}+8.5x_{21}+20x_{24}+3x_{25} + n_4-p_4$
5. Maximisation of fuel wood production: $Z_5(x) =10x_{17}+ 10x_{25} + n_5-p_5$
6. Maximisation of runoff water augmentation: $Z_6(x) = 3x_8 + n_6-p_6$

where $x_{11,}$ $x_{12,}$ $x_{13,}$ $x_{14,}$ $x_{15,}$ $x_{16,}$ x_{17} indicates the area (ha) under upland paddy, medium land paddy, low land paddy, maize, pigeonpea, hybrid napier bajra grass and subabool in kharif season respectively. Whereas $x_{21,}$ $x_{22,}$ $x_{23,}$ $x_{24,}$ x_{25} represents area (ha) under low land paddy, mustard, greengram, hybrid napier bajra grass and subabool in rabi season respectively. Besides this x_8 represents area required for construction of ponds.

and pigeonpea, which should be less than or equal to the total medium land i.e. 199.85.The crops suggested for low land is low land paddy, which should be less than the total low land i.e. 20.12 ha..The are under mustard and greengram in rabi season is less than the total medium land i.e. 199.85 ha and low land paddy is less than or equal to the total low land i.e.20.12 ha. The total area under hybrid napier bajra grass, subabool and construction of ponds is less than or equal to 174.78 ha. The constraint equations are given in table 3.

Table 3. Land constraints

$x_{11}+ x_{12}+ x_{13}+ x_{14}+ x_{15}+ x_{16}+ x_{17}+ x_8 \leq 457$

$x_{21}+ x_{22}+ x_{23}+ x_{24}+ x_{25}+ x_8 \leq 457$

$x_{11}+ x_{12}+ x_{13}+ x_{14}+ x_{15} \leq 282.22$

$x_{21}+ x_{22}+ x_{23} \leq 219.97x_{11}+ x_{14}+ x_{15} \leq 62.25$

$x_{12}+ x_{15} \leq 199.85$

$x_{13} \leq 20.12x_{22}+x_{23} \leq 199.85$

$x_{21} \leq 20.12$

$x_{16}+ x_{17}+ x_8 \leq 174.78$

$x_{24}+ x_{25}+ x_8 \leq 174.78$

$x_{16}- x_{24} = 0$

$x_{17}- x_{25} = 0$

Water constraints

The water required by crops in kharif season is met from the rainfall at desired probability levels**.** The water required for rabi season is met from the ponds. The water requirement should be less than or equal to the total water available in corresponding seasons. The constraint equations are given in table 4.

Nutritional Constraints

Protein and calorie are two important nutrients required for the people of the watershed. The available protein (kg) and calorie (Kcal) from the

Table 4. Water constraints

$1.2x_{11}+1.2x_{12}+x_{13}+0.45x_{14}+0.35x_{15}+0.4x_{16}+0.35x_{17} \leq 306$

$x_{21}+0.4x_{22}+0.4x_{23}+0.2x_{24}+0.1x_{25} \leq 127$

crops must be more than or equal to the requirement of the people of the watershed. The constraint equations are given in table 5.

Table 5. Nutritional constraints

$177x_{11}+218x_{12}+252x_{13}+340x_{14}+441x_{15}+292x_{21}+300x_{22}+240x_{23} \geq$ 25,556 kg

$8970x_{11}+11040x_{12}+12765x_{13}+13720x_{14}+6264x_{15}+14835x_{21}+ 4376x_{22}+3240x_{23} \geq 1119378$

Labour constraints

Month wise Labour requirement of different crops for kharif and rabi season was determined separately. The labour requirement in a month should be less than or equal to the total mandays available in the watershed. The labour constraints are given in table 6.

Table 6. Labour constraints

Jun $30x_{11}+30x_{12}+30x_{13}+35x_{14}+15x_{15}+25x_{16}+20x_{17} \leq 17160$

Jul $20x_{11}+35x_{12}+35x_{13}+30x_{14}+20x_{15}+10x_{16}+10x_{17} \leq 17160$

Aug $15x_{11}+20x_{12}+30x_{13}+15x_{14}+10x_{15}+10x_{16}+30x_{17} \leq 17160$

Sep $7x_{11}+12x_{12}+30x_{13}+20x_{14}+23x_{15}+5x_{16}+25x_{17} \leq 17160$

Oct $30x_{11}+35x_{12}+40x_{13}+60x_{14}+25x_{15}+10x_{17} \leq 17160$

Nov $10x_{16}+110x_{17} \leq 17160$

Dec $30x_{21}+20x_{22}+10x_{23}+10x_{24}+20x_{25} \leq 17160$

Jan $35x_{21}+15x_{22}+10x_{23}+10x_{24}+20x_{25} \leq 17160$

Feb $30x_{21}+10x_{22}+10x_{23}+15x_{24}+15x_{25} \leq 17160$

Mar $30x_{21}+25x_{22}+10x_{23}+15x_{24}+10x_{25} \leq 17160$

Apr $40x_{21}+30x_{22}+25x_{23}+10x_{24}+10x_{25} \leq 17160$

May $30x_{24}+90x_{25} \leq 17160$

Bulk constraints

The total production of individual food grains must be more than the requirement of the people of the watershed. Simillarly the production of fodder from the watershed must be more than the requirement of livestocks. The fuel wood produced from the watershed must be more than the fuel wood requirement. The constraint equations are given in table 7.

Table 7. Bulk constraints

Paddy	$2.6x_{11}+3.2x_{12}+3.7x_{13}+4.3x_{21} \geq 174$
Maize	$4x_{14} \geq 71.3$
Pigeonpea	$1.8x_{15} \geq 18$
Mustard	$1.5x_{22} \geq 17.2$
Green gram	$x_{23} \geq 15.14$
Dry fodder	$6.5x_{11}+7.1x_{12}+8x_{13}+2x_{14}+8.5x_{21} \geq 970$
Green fodder	$30x_{16}+7x_{17}+20x_{24}+3x_{25} \geq 970$
Fuel wood	$10x_{17}+10x_{25} \geq 1755$

Area under Ponds

The total are required to construct the ponds must be greater than or equal to the area required to augment the water for rabi crops. The constraint equation is given in table 8.

Table 8. Area under ponds

$x_8 \geq 40.39$

RESULTS AND DISCUSSIONS

In this paper six basic objectives were taken namely food production, net income generation, labour employment generation, fodder production, fuel wood production and runoff water augmentation. The models were run to find out the optimal land allocation planning of the watershed and also to optimize the objectives within the boundary of constraints. The optimal achievements of different objectives are given in table 9.

Table 9. Achievement level of objectives

Objectives	Optimal value
Food production	1,262 ton
Net income generation	Rs. 85,91,125/-
Labour employment generation	95,519 Mandays
Fodder production	3,819 ton
Fuel wood production	1,755 ton
Runoff water augmentation	188.34 ha-m

The solution of the objective equations along with constraints was giving the optimal land allocation plan for different crops and plantation activities proposed for that watershed. The optimal land allocation for the watershed is given in table 10. Besides this the area under ponds is 62.78 ha.

Table 10. Optimal land allocation plan

Kharif		Rabi	
1. Paddy (medium land)	182.05ha	1. Paddy (low land)	20.12ha
2. Paddy (low land)	20.12ha	2. Mustard	184.71ha
3. Maize	52.25ha	3. Greengram	15.14ha
4. Pigeonpea	10.00ha	4. Hybrid napier bajra grass	24.25ha
5. Hybrid napier bajra grass	24.25ha	5. Subabool	87.75ha
6. Subabool	87.75ha		
Total	**376.42ha**	**Total**	**331.97ha**

The results of the study are given below.

The goal programming (GP) approach was found suitable for the watershed planning as it is optimally utilises the available land, water and human resources of the watershed. The total area under crop in kharif season was 376.42ha and total area under crop in rabi season was 331.79 ha. The cropping intensity of the proposed planning was found to be 155% against the existing cropping intensity of 108.81%. The benefit-cost ratio of the proposed planning was found to be 1.34, which shows the economic viability of the programme. The results obtained from maximisation of production and maximisation of income appears to be more compromising and beneficial to government and to the farmers as the farmer is interested in maximum income from his crops and government has the aim for maximum production of food grains and fodder from unit land area. The production of paddy, maize, pigeonpea, mustard and green gram are743 ton, 209 ton, 18 ton, 277 ton and 15.14 respectively. The Fig 1 showing the variation of production against the requirement of different food grains is shown below.

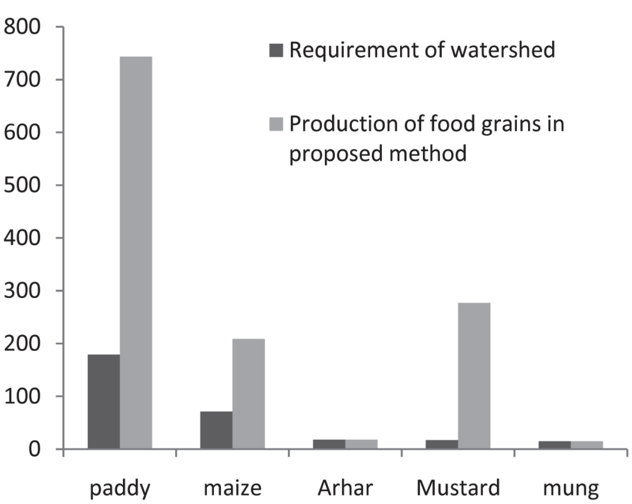

Fig. 1. Requirement of food grain vrs production

CONCLUSIONS

The paper presents the optimal crop planning for the Mandakini Balinala watershed No-1, using goal programming approach. The paper shows that the planning was giving a net return of Rs. 8591172/- .The paper also shows that the cropping intensity of the planning was 155%.The benefit-cost ratio of the proposed planning was found to be 1.34, which shows the economic viability of the programme. As it is shown from the results, goal programming approach was found suitable for the watershed planning.

ABBREVIATIONS

Y_{ij} = Yield of j^{th} crop in i^{th} season, ton/ha

N_{ij} = Net income from j^{th} crop in i^{th} season, Rs/ha.

L_{ij} = Labour required for j^{th} crop in i^{th} season, Mandays/ha.

f_{ij} = fodder yield from j^{th} crop in i^{th} season, ton/ha.

w_{ij} = Fuel wood yield of j^{th} crop in i^{th} season, ton/ha

C_j = Capacity per unit ha during storing, ha-m/ha.

WR_{ij} = Water required by j^{th} crop in i^{th} season, M.

WR_a = Water available, ha-m.

P_{ij} = Protein produced from j^{th} crop in i^{th} season, kg/ha.

C_{ij} = Calorie produced from j^{th} crop in i^{th} season, Kcal/ha.

LA = Total labour available in the watershed in a month, Mandays.

y_{ij} = Yield of j^{th} crop, grass and fuel wood in i^{th} season, ton/ha.

R_e = Requirement of crops for the watershed, ton.

A_{tar} = Area required for ponds, ha.

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Response of rapeseed to sulphur application under two soil series of Meghalaya

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ABSTRACT

Intensive cultivation on hill slopes is a major cause of soil degradation and depletion of soil fertility in hilly regions. To assess the status of an increasingly important plant nutrient, sulphur (S), an experiment was conducted with soils of two soil series, Nongpoh and Umsoing (Umsning), collected from different land uses such as maize-millets, ginger-turmeric, citrus orchard, low land paddy and tea plantation. The study was done with rapeseed as test crop in the *rabi* season of 2008-09. The objective of the experiment was to study the effect of S application on dry matter yield and uptake of sulphur in different soils of Meghalaya. Four levels of S, i.e. 0 (control), 20, 40 and 60 mg S kg^{-1} soil were taken for the study. The data showed that dry matter yield increase was significant up to the level of 40 mg kg^{-1} in five out of the eight soils studied and uptake of S was significant in three soils of Nongpoh series and two soils of Umsoing series. Average response to application of S as compared to control were 92, 132 and 162% for 20, 40 and 60 mg S kg^{-1} application levels.

Key words: Sulphur response, Sulphur uptake, Rapeseed, Soils of northeastern region

INTRODUCTION

Intensive agricultural practices with reduced use of organics and higher dependence on concentrated chemical fertilizers have resulted in nutrient imbalances in agricultural soils. This has led to emergence of multi-nutrient deficiency in different crops and declining response to fertilizers. In other words, the sustainable crop productivity has been adversely affected. This has necessitated adoption of sustainable agricultural practices, which includes scientific cultivation practices and optimum nutrient management so as to conserve natural resources (Dass *et al*., 2009). With increased intensity of cultivation, reduced use of organic matter, higher use of concentrated (high analysis low S) chemical fertilizers such as DAP, urea and due to erosion of soil fertility, deficiency of secondary plant nutrients like sulphur has been reported across different soils and agro-climatic regions of the country. Sulphur is essential for the formation of key amino acids - methionine, cysteine and cystine and in the synthesis of oil, proteins and chlorophyll. Despite being an essential nutrient, sulphur received little attention till reports of widespread deficiency in several crops.

In the early 1990s, sulphur deficiency in Indian soils was estimated to occur in about 130 districts. Recently, soil fertility surveys by ICAR and related research organizations have shown sulphur deficiencies to be a widespread problem (TSI, 2008 ; Singh *et al*. 2013; Kour *et al*., 2014). Survey of Indian soil under AICRP (Secondary & Micronutrients) revealed that on an average, 41% of Indian soils are deficient in S and it is widespread in coarse textured alluvial, red and lateritic, leached acidic and hilly soils and black clayey soils (Singh, 2004). The deficiency of S is emerging fast in areas where continuously S free fertilizers like DAP, urea etc are being used. Because of the widespread deficiency and growing importance of S in plant nutrition, it is being considered as the 4th major plant nutrient (Divito *et al*., 2013 ; Szulc *et al*., 2014).

Balanced fertilization to food crops assumes significance in context of not only maintaining sustainability and stability to crop production but also ensuring nutrition security. Reports of S deficiency causing health disorders have been reported by health researchers. In addition to better S nutrition in crops, S fertilization is also a feasible technique to enhance the fertilizer use efficiency of other important nutrients like N,P, K and Zn and

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to suppress the undesirable plant uptake of toxic elements such as selenium and molybdenum because of the synergistic relationship of S with the former elements and the antagonistic relationship with the latter (Aulakh, 2003). On an average, one tonne of cereal, pulse and oilseed grains remove about 4, 8 and 12 kg of S, respectively. Oilseeds show high response to S fertilization than cereals. Response of crops to S application was observed even up to 80 kg S ha^{-1} for dry matter yield (Tomar *et al.*, 1997 and Jaggi and Sharma, 1999) in raya (*Brassica juncea* var. Varuna). Response of mustard to S was also observed by Mishra (2003) with four levels each of S (0, 20, 40, 60 kg S ha^{-1}) and K (0, 30, 60, 90 kg K ha^{-1}) on *udic haplustalf* during *rabi* seasons of 1998-99 and 1999-2000. Sarangthem *et al*. (2008) with combined application of N @ 60 kg ha^{-1} and S @ 40 kg ha^{-1} in the soils of Manipur observed that uptake of S increased up to application of 40 kg S ha^{-1}. Soil fortification with 20 and 40 kg S ha^{-1} increased the grain yield of maize by 14.6 and 8.8%, respectively (Choudhary *et al*., 2013). In the acid soils of western Odisha, Dash *et al*. (2013) reported the economic highest pod yield of ground nut at 34 kg ha^{-1}, though the oil content was highest at the level of 60 kg S ha^{-1}. In the rainfed conditions of Jammu region, Sharma and Arora (2008) reported significant increase in oil content and yield of mustard up to 50 kg S ha^{-1}

North-eastern hill region of India in general, and the state of Meghalaya in particular, is primarily under the acidic soil zone with high rainfall (Saiborne *et al*., 2012) and shifting cultivation being one of the predominant agriculture practices by the tribal inhabitants. Because of the high altitude and hilly ecosystem, soils are however rich in organic carbon. Dominant land use systems found in the region are Jhum, lowland paddy, upland agri- horticultural crops, orchards and plantations. In spite of the constraint of terrain and land situations, more than 75% people depend on agriculture as their primary source of income. With agriculture practiced year after year without much of additional nutrients, there must have been depletion and mining of the native fertility status. Studies to report response of S under different crops in soils of northeastern region in general and Meghalaya in particular, are very few. Keeping this in view, the present study was carried out to see whether soils rich in organic carbon respond to S application, considering the fact that more than 90% of the plant available S remains in organic form.

MATERIALS AND METHODS

The study area was Ri-Bhoi district of Meghalaya which lies within the longitude 91°18′ to 92°8′ E and 25°40′ to 26°20′ N latitude. The district comes under warm humid subtropical hill zone, with altitude ranging from 200 m to 1200 m above msl and average temperature ranging from 12°C to 32°C with annual average rainfall of 1270 mm to 2032 mm. The soils of the district are mostly light to medium texture sandy loam and clay loam with depth ranging from deep to very deep. They fall under the red and laterite soil group, and the dominant soil order is Alfisols.

Soil sample collection and analysis

The bulk samples for pot experiment were collected from eight sites covering six land-uses from Nongpoh and Umsning (Umsoing) soil series (NBSSLUP, 1999). About 200 kg surface soils from the 0-15 cm soil depth in the selected fields were taken for the pot experiment. The sites selected were put under the particular land use for more than 20 years.

Series denote	Soil series	Name of site	Land use
1.1 (t)	Nongpoh	Mawsyntai	Tea plantation
1.2 (p-m)	Nongpoh	Marngar	Paddy fields
1.3 (p-i)	Nongpoh	Iewsier	Paddy fields
1.4 (o)	Nongpoh	Sohkhwai	Orchard (orange)
2.1 (t)	Umsoing	Umsning	Tea plantation
2.2 (h-u)	Umsoing	Lumnongrim	Upland horticulture (ginger – turmeric)
2.3 (h-mn)	Umsoing	Mawpun	Upland horticulture (ginger – turmeric)
2.4 (a)	Umsoing	Mawhati (15 mile)	Upland agriculture (maize-millets)

Details of pot experiment

The pot experiment was conducted with rapeseed (var. M-27) in the net house of Division of Soil Science of ICAR Research Complex for NEH region, Barapani. The mean monthly maximum and minimum temperature during the experiment period ranged from 21.5°C to 24.1°C, and 7.9°C to 10.1°C respectively, with average relative humidity of 79.5% (maximum) and 54.2% (minimum). In each pot, 4.5 kg soil (air dried and processed to pass through 2 mm sieve) was filled up and was compacted to a bulk density of about 1.15 Mg m^{-3}. Four different levels of sulphur were taken at the rate of 0 (control, T_1), 20 (T_2), 40 (T_3) and 60 (T_4) mg S kg^{-1} soil in three replications for soils of all the

Table 1. Effect of sulphur on dry matter yield (g pot $^{-1}$) in rapeseed

S dose	Nongpoh series				Umsoing series				Average
(mg kg^{-1})	Sr. 1.1 (t)	Sr. 1.2 (p-m)	Sr. 1.3 (p-i)	Sr. 1.4 (o)	Sr. 2.1 (t)	Sr. 2.2 (h-u)	Sr. 2.3 (h-mn)	Sr. 2.4 (a)	
T1 - S0	2.43	2.48	2.17	2.98	4.48	2.57	2.99	2.97	2.88
T2 - S20	3.69	4.02	2.78	3.05	4.47	2.64	3.29	3.53	3.43
T3 - S40	4.29	4.16	3.29	3.42	4.47	2.14	4.01	4.35	3.77
T4 - S 60	4.94	5.18	3.08	3.59	5.04	2.69	4.75	5.33	4.32
$LSD_{0.05}$	0.799**	0.548**	0.288**	0.0247**	NS	NS	NS	0.645**	

*&**indicate 'F' is significant at 5% and 1% level respectively; (n = 14); NS = non-significant
Sr. 1.1-4 = Nongpoh Series; Sr. 2.1-4 = Umsning series; (t) – tea plantation, (p-m) & (p-i) – Paddy fields, (o) – orchard, (h-u) & (h-m) – horticulture (ginger-turmeric) & (a) – agriculture (maize & millets)

eight sites covering six land uses. Sulphur was applied in the form of ammonium sulphate as basal. In all the pots, N, P and K at the rate of 50: 40: 40 mg kg^{-1} soil, in the form of ammonium sulphate, Potassium di-hydrogen orthophosphate and urea were applied as basal application. The fertilizers were applied in the top 5 cm soil in the pots and mixed properly. In each pot, five plants of rapeseed were maintained and the plants were harvested 50 days after germination at the flowering stage. After oven drying in a hot air oven at 70°C, the above ground biomass per pot (five plants) was recorded and the above ground biomass samples were ground for plant analysis.

Plant sample analysis

Plant samples without roots were used for analysis of S content by digestion mixture of 9:4 HNO_3 and $HClO_4$. Sulphur was estimated by barium chloride precipitation method (Jackson, 1973). The concentration of S multiplied by the dry matter yield constituted the S uptake under the particular treatment. The data on dry matter yield and mean S uptake by rapeseed was analyzed using one way ANOVA. The treatments were compared with least significant difference (LSD) test at a significance level of 0.05 and 0.01.

RESULTS AND DISCUSSION

Basic soil properties

The collected soil samples from the eight sites were analyzed for basic soil properties, viz. soil pH, organic carbon and available S, as per Baruah and Borthakur (1997). Soils were acidic with pH varying from 4.3 to 5.1. The soil organic C content was in the higher range with soil organic carbon content (Walkley and Black) values varying from 0.73 to 2.05%. The available S was near the critical range, with values varying from 4.30 to 12.0 mg kg^{-1}.

Response of rape seed to S application

Response of pot cultured rape seed plants to levels of sulphur fertilization were studied in terms of dry matter yield and S content and uptake in the plants, which are presented as follows:

Dry matter Yield

The mean dry matter yield of rapeseed (five plants from each pot) showed significant effect of S doses in five out of eight soils studied (Table 1). The mean dry matter yield under control ranged from 2.17 g pot^{-1} in Sr. 1.3 (p-i) to 4.48 g pot^{-1} in Sr.2.1 (t). The mean dry matter yield per pot in T2: S20, T3: S40 and T4: S60 ranged from 2.64 to 4.47 g pot $^{-1}$, 2.14 to 4.47 g pot^{-1} and 2.69 to 5.33 g pot^{-1}, respectively. The data showed that response of S application was observed up to 40-60 mg kg^{-1} in five out of the eight soils studied. In the Nongpoh series, there was response in all the four land uses studied. In the Umsoing series, there was no significant response in the tea and upland horticulture land use (of both the sites) which might be due to comparatively higher available S status (from 9-12.0 mg S kg^{-1}) in soils of these land uses. Only in the agriculture land use of this series, significant response was observed even up to 60 mg S kg^{-1}, indicating higher crop uptake of S under continuous agriculture land use. The average dry matter yield of rape seed plants due to S application at 20, 40, and 60 mg S kg^{-1} soil resulted in increase of yield up to 19.1%, 30.9% and 50.34% over control respectively. Response of S up to 100 kg ha^{-1} was observed by Khanpara *et al.* (1993) and up to 80 kg ha^{-1} by Tomar *et al.* (1997) in mustard crop. Similar findings were also reported by Jaggi and Sharma (1999) and Mishra (2003).

Table 2. Sulphur content (%) in above ground biomass of rapeseed at varied levels of S application

S dose	Nongpoh series				Umsoing series			
(mg kg^{-1})	Sr. 1.1 (t)	Sr. 1.2 (p-m)	Sr. 1.3 (p-i)	Sr. 1.4 (o)	Sr. 2.1 (t)	Sr. 2.2 (h-u)	Sr. 2.3 (h-mn)	Sr. 2.4 (a)
T1 - S0	0.46	0.37	0.44	0.41	0.26	0.4	0.44	0.22
T2 - S20	0.56	0.53	0.74	0.60	0.54	0.59	0.64	0.44
T3 - S40	0.57	0.56	0.76	0.66	0.63	0.63	0.76	0.52
T4 - S 60	0.62	0.55	0.63	0.69	0.66	0.72	0.61	0.52
$LSD_{0.01}$	0.0305**	NS	0.008**	0.0247**	0.093**	0.022**	0.026**	0.014**

* & ** indicate 'F' is significant at 5% and 1% level respectively; (n = 14); NS = non-significant
Sr. 1.1 - 4 = Nongpoh Series; Sr. 2.1 - 4 = Umsning series; (t) – tea plantation, (p-m) & (p-i) – Paddy fields, (o) – orchard, (h-u) & (h-m) – horticulture (ginger-turmeric) & (a) – agriculture (maize & millets)

Table 3. Sulphur uptake (mg S pot^{-1}) by rapeseed plants at varied levels of S application

S dose	Nongpoh series				Umsoing series			
(mg kg^{-1})	Sr. 1.1 (t)	Sr. 1.2 (p-m)	Sr. 1.3 (p-i)	Sr. 1.4 (o)	Sr. 2.1 (t)	Sr. 2.2 (h-u)	Sr. 2.3 (h-mn)	Sr. 2.4 (a)
T1 - S0	11.25	9.30	9.68	12.15	11.60	10.38	13.08	6.75
T2 - S20	20.85	21.13	20.63	18.33	24.70	15.75	21.05	15.85
T3 - S40	24.53	23.41	25.10	22.60	28.28	13.40	30.05	22.60
T4 - S60	30.55	28.71	19.38	24.85	33.50	19.58	28.95	27.98
$LSD_{0.01}$	2.258**	1.192**	0.905**	0.693**	NS	1.140**	2.191**	1.527**

* & ** indicate 'F' is significant at 5% and 1% level respectively; (n = 14); NS = non-significant
Sr. 1.1 - 4 = Nongpoh Series; Sr. 2.1 - 4 = Umsning series; (t) – tea plantation, (p-m) & (p-i) – Paddy fields, (o) – orchard, (h-u) & (h-m) – horticulture (ginger-turmeric) & (a) – agriculture (maize & millets)

Sulphur content

Sulphur application resulted increase in S concentration in rapeseed plants. The mean S content in rapeseed plants (Table 2) showed that average S content significantly increased over control up to 40 mg S kg^{-1} soil in four soils and up to 60 mg S kg^{-1} soil in three soils. S content ranged from 0.22% in 2.4 (a) series to 0.46 % in 1.1 (t) series under control and highest content was observed from soils of 1.3 (p-i) and 2.3(h-mn) at the application level of S40 (40 mg kg^{-1}). The average S content in S0, S20, S 40 and S60 were 0.38, 0.58, 0.64, 0.64%, respectively. Sulphur content in the above ground biomass increased with S level even in those soils of Umsoing series where significant impact in dry matter yield was not observed.

Sulphur uptake

Effects of different doses of S fertilizer on uptake of S by rapeseed plants are presented in Table 3. Under control, uptake of S ranged from 6.75 mg pot^{-1} in series Sr. 2.4 (a) to 13.06 mg S pot^{-1} in series Sr. 2.3 (h-mn). Mean S uptake significantly increased with S fertilization up to 60 mg S kg^{-1} in five bulk soils : Sr. 1.1 (t), Sr. 1.2 (p-m), Sr. 1.4 (o), Sr. 2.2 (h-u) and Sr. 2.4 (a) and up to 40 mg kg^{-1} soil in Sr. 1.3 (p-i) and Sr. 2.3 (h-mn). The average S uptake values under T1 S0, T2 S20, T3 S40 and T4 S60 were 10.52, 19.78, 23.74, 26.68 mg S pot^{-1} respectively. On an average, there was 2-3 fold increase in uptake of S at 40-60 mg kg^{-1} application than control. The results showed an increase in concentration and uptake of S by rapeseed plants to the level of S application from 20 mg S kg^{-1} to 60 mg S kg^{-1} soil in most soils of Umsning and Nongpoh soil series, which indicated the importance of S for sustainable crop production in this region. On an average, for both the soil series and soils from all the land uses combined, response as compared to control were 92, 132 and 162% for T2, T3 and T4 respectively (Table 4). The variation in the magnitude of response might be due to variation in soil properties. Jaggi and Sharma (1999) observed that S uptake by *raya* varied from 31 to 83 mg pot^{-1} with mean value of 53.5 in control, and the response in uptake over control with the application of S ranged from 74 to 162%.

The results thus indicated that sustainable crop production under different soils of the study region shall need S as a supplement in the nutrient

Table 4. Response (%) in terms of S uptake by rapeseed plants at varied levels of S application

S dose	Nongpoh series					Umsoing series					Average
(mg kg^{-1})	Sr. 1.1 (t)	Sr. 1.2 (p-m)	Sr. 1.3 (p-i)	Sr. 1.4 (o)	Average	Sr. 2.1 (t)	Sr. 2.2 (h-u)	Sr. 2.3 (h-mn)	Sr. 2.4 (a)	Average	
T2 - S20	85.33	127.20	113.12	50.86	*94.13*	112.93	51.73	60.93	134.81	*90.10*	92.12
T3 - S40	118.04	151.72	159.30	86.01	*128.77*	143.79	29.09	129.74	234.81	*134.36*	131.56
T4 - S60	171.56	208.71	100.21	104.53	*146.25*	188.79	88.63	121.33	314.52	*178.32*	162.28

management schedule in spite of high organic carbon content of soils. Further, sulphur needs to be a part of the long term fertilizer experiment trials under selected cropping systems of the region.

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Optimization of water use in summer rice through drip irrigation

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ABSTRACT

The experiment was conducted at Research Farm, IGKV, Raipur (C.G.) during summer season 2013. Treatment consisted of two rice varieties (MTU1010 and IR64) as main plots and five drip irrigations (0.6, 0.8, 1.0, 1.2 and 1.4 IW: CPE (irrigation water and cumulative pan evaporation ratio), micro sprinkler irrigation once in three days and flooding as sub plots. The maximum seed yield was recorded in drip irrigation at 1.4 IW: CPE ratio which was at par with traditional flooding. Water use efficiency in all the drip irrigation treatments (1.0, 1.2 and 1.4 IW: CPE ratio) was in the range of 2.5-2.9 kg/ha mm whereas it was 0.11 kg/ha mm in flooding. Net return and B:C ratio were significantly higher in drip irrigation at 1.2 and 1.4 IW:CPE ratio than other treatments. It can be concluded that drip irrigation (1.2 and 1.4 IW:CPE ratio) is superior to flooding for summer rice in relation to (i) water use efficiency, and (ii) harvest attractive seed yield and income.

Key words: Water use efficiency, Summer paddy, Drip irrigation, Seed yield, IW:CPE

INTRODUCTION

Aerobic rice with micro irrigation practices leads sustainable rice production methodology for immediate future to address water scarcity with more benefits and environmental safety in the scenario of global warming by reduced methane emission is an added advantage (Parthasarathi *et al*., 2012). Drip irrigation is a relatively new but revolutionary concept in applying water. Drip irrigation may save huge quantity of water in summer rice that may help in enhancement of area of summer rice crop even under available water resources and good plant health. Drip irrigation is an efficient method of water application as it allows efficient management of both water and fertilizer (Rajurkar *et al*., 2012).

MATERIAL AND METHODS

To optimize irrigation schedule with drip irrigation in summer rice an experiment was conducted in split plot design with three replications at Research Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during summer season of 2013. Treatment consisted of two rice varieties (MTU1010 and IR64) as main plots and five drip irrigations (0.6, 0.8, 1.0, 1.2 and 1.4 IW:CPE ratio), micro sprinkler irrigation once in three day and flooding as sub plots. The observations were recorded and statistically analyzed for different growth, yield and water use efficiency.

RESULTS AND DISCUSSION

Plant height

Plant height was recorded at 20 day interval after establishment of the crop. Growth of the plant was slowly owing to low temperature at early vegetative stage, thereafter linear increase in plant height was recorded up to 80 DAE. Significantly taller plants were recorded in drip irrigation at 1.4 IW:CPE ratio, followed by 1.2 IW:CPE ratio and flooding at all the growth intervals of observations(Table 1 and Fig. 1). Reduction in plant height increased with severity of water stress (Adriano *et al.,* 2005 and Gowri, 2005). Such trend in plant height was also reported by (Maheswari *et al*., 2007).

Crop growth rate

Crop growth rate (CGR) was the biomass gained at intervals of two stages. The CGR was very low and having nearly same pattern upto 80 DAE. The CGR increased between 80 to 100 DAE and highest between 100 DAE to harvest of rice crop(. The unit of CGR is g day $^{-1}$ plant ^{1}. Crop growth rate was calculated from the dry weight obtained

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Table 1. Plant height at different intervals of different rice varieties grown during summer season in relation to irrigation scheduling

Treatments	Plant height (cm) At harvest	Crop growth rate (g day^{-1} plant^{-1}) 100 DAE -At harvest	Seed yield (q ha^{-1})	Water use efficiency (kg ha^{-1} mm)	Net return (Rs. ha^{-1})
Irrigation scheduling					
Drip 0.6 IW:CPE	68.32	3.4893	24.32	2.95	11687
Drip 0.8 IW:CPE	70.46	4.1807	27.12	2.86	14444
Drip 1.0 IW:CPE	73.47	2.8747	29.40	2.89	15631
Drip 1.2 IW:CPE	74.27	2.4827	32.47	2.82	21516
Drip 1.4 IW:CPE	78.16	2.5802	33.06	2.55	22355
Sprinkler-3D	70.63	2.0312	29.44	2.07	17435
Sub-Trad	77.84	2.1458	32.86	1.05	17957
SEm±	01.31	0.56	01.01	0.09	1355.78
CD (P = 0.05)	03.82	NS	2.97	0.27	3957.39
Variety					
MTU1010	72.92	2.6158	28.68	2.37	16063
IR64	73.70	3.0369	30.94	2.54	18516
SEm±	01.54	2.4915	01.20	0.06	1472.02
CD (P =0.05)	NS	NS	NS	NS	NS

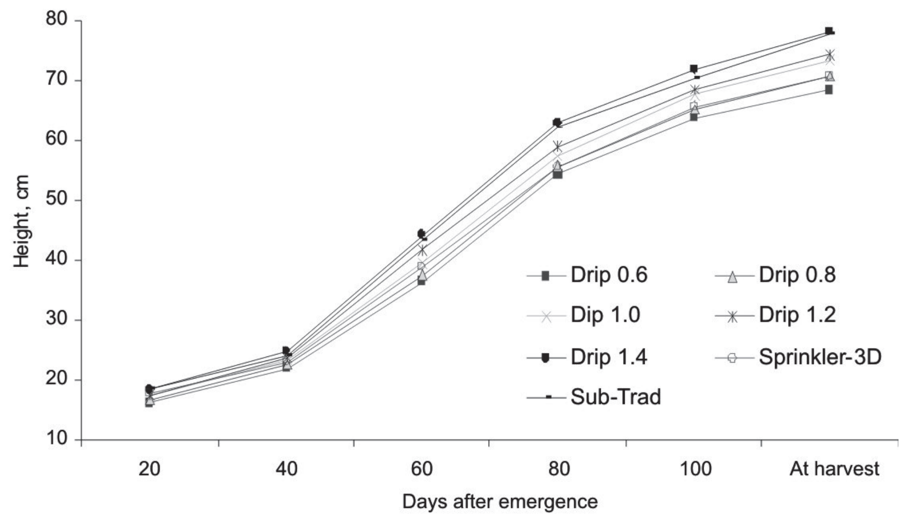

Fig. 1. Effect of irrigation scheduling and varieties on plant height of summer paddy

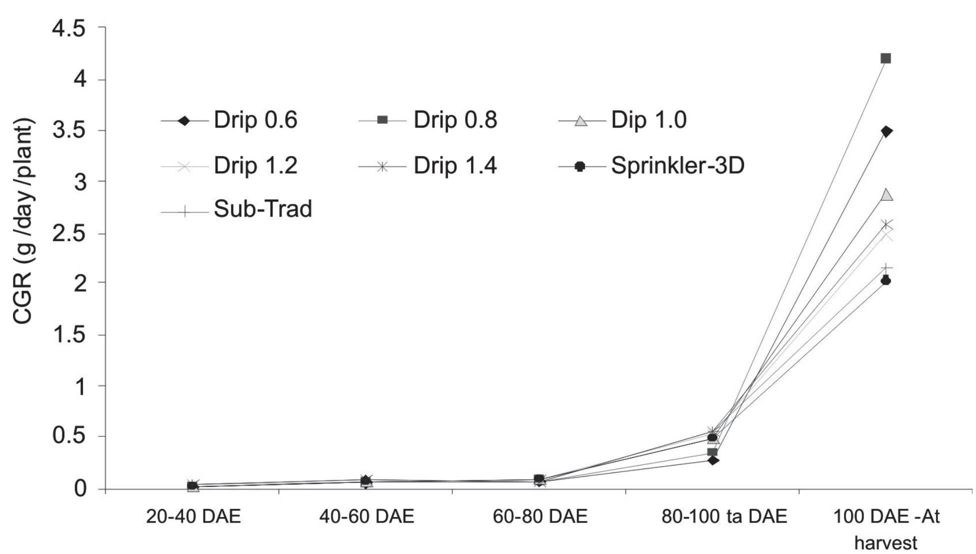

Fig. 2. Crop Growth Rate (CGR) of rice at different intervals as influenced by irrigation scheduling

at 80 to 100 DAE This indicates that however it takes time to accumulate biomass in plant at vegetative stage but the biomass accumulation and its translocation to sink per unit time was quite faster at reproductive stage. The values were calculated by using the following formula as suggested by Leopold and Kridemann (1975).

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

where, W_2-W_1 = Difference in oven dry biomass at the time interval (g), $t_2 - t_1$ = Time interval in days

Seed yield

The maximum seed yield was recorded in drip irrigation at 1.4 IW: CPE ratio which was at par to traditional flooding and drip irrigation at 1.2 IW: CPE ratio but these treatments were significantly superior over rest of the treatments. Aerobic condition was maintained in all drip and micro sprinkler irrigation treatments whereas, flooding in submergence treatments.

Water use efficiency

Water use efficiency in all the drip irrigation treatments (1.0, 1.2 and 1.4 IW:CPE ratio) was in the range of 2.7-2.9 kg/ha mm whereas it was 0.11 kg/ha mm in flooding.

Net return

Net return was significantly higher in drip irrigation at 1.2 and 1.4 IW:CPE ratio than other treatments. Similar results was found by Bharti *et al.* (2007) and Varade (2002)

CONCLUSION

In Chhattisgarh state area of Rabi crops is 1.71 million ha in which share of summer rice is 45%. Out of created irrigation potential for cropping during Rabi and summer season mainly utilized in production of summer rice, therefore cropping remained staggering over the years. Drip irrigation however using by the farmers in plantation crops but in this study it was used in rice. Present study concluded that drip irrigation (1.2 and 1.4 IW:CPE ratio) is superior to flooding for summer rice in relation to (i) water use efficiency, (ii) harvest attractive seed yield and income.

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Reference evapotranspiration estimation using artificial neural network for Tarai region of Uttarakhand (India)

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ABSTRACT

Reference evapotranspiration (ET_0) prediction is required in irrigation water management for the calculation of crop water requirement and its scheduling. Reference evapotranspiration (ET_0) is however, a complex and non-linear phenomenon because it depends on several interacting climatological factor, such as temperature, humidity, wind speed and sun shine hours. Artificial neural network (ANN) is effective tool that is able to solve accurately complex and non-linear input-output relationships. This paper has used feed-forward multilayer artificial neural networks of single and two hidden layer(s). These networks were trained with fixed iteration 1000 and tested for the prediction of daily evaporation for Tarai region of Uttarakhand (India). The daily temperature, relative humidity, wind velocity, sunshine hour of current and previous two day as well as evaporation of previous two days as input variables and current day evaporation as the output variable, thus there were 17 input nodes in the input layer and one node in the output layer in ANN model development. The daily meteorological data during period 1/1/2001 to 9/8/2007 were used for the training (calibration) of the model, whereas the data of years 10/8/2007 to 31/12/2011 were used for verification (testing) of the developed model. Training was conducted using back-propagation algorithm. ET_0 estimation performance of the ANN models was compared with most reliable and standard FAO-56 PM method. This study reveals that the use of ANN model resulted better performance for estimation of reference evapotranspiration (ET_0). The coefficient of correlation values between predicted ET_0 from ANN model and calculated from Penman-Monteith model was obtained as 0.9527. Based on this result, it can be concluded that the ANN can predict ET_0 better than conventional methods.

Key words: Artificial neural network, Reference evapotranspiration, Evapotranspiration, Penman-Monteith

INTRODUCTION

Evapotranspiration is one of the major components of the hydrologic cycle and the accurate estimation is essential for many studies such as hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. A common practice for estimation ET from a well-watered agricultural crop is to first estimate of reference ET from a standard surface and then to apply an appropriate crop coefficient which accounts for difference between the standard surface and crop ET.

ET_0 can be either directly measured using lysimeter or estimated indirectly using the climatological data. The directly Pan evaporation method is used extensively throughout the world to estimate ET_0 (Irmak *et al*. 2002). The evaporation rate from pans filled with water is easily obtained. Pans provide a measurement of the integrated effect of solar radiation, wind speed, temperature and humidity on the evaporation from an open water surface. Evaporation rate from the open pan (Ep) and the ET_0 rate from the vegetated surface differ (Snyder, 1992), ET_0 is computed by multiplying the Ep with a Pan coefficient (Kp) to account for differences between the grass and open water.

In this study, the performance of ANN model was compared with the indirect FAO-56 Penman–Monteith method (PM). This methods based on climatological data vary from empirical relationships to complex methods based on physical processes such as Penmen (1948). According to Kumar *et al.* (2002), ET-ref (ET_0) is a complex and nonlinear phenomenon, because it depends on the interaction of several climatic elements. The methods for measuring ET-ref (ET_0) require complex and very costly devices and are

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generally recommended only for specific research purposes (Kisi, 2007). Hence, the physically based complex Penman–Monteith (PM) equation is universally recommended by the Food and Agriculture Organization of the United Nations as the sole accurate method to calculate ET-ref (ET_0) (Allen *et al*., 1998,Walter *et al*., 2000). The PM method is the standard procedure when there is no measured lysimeter data (Irmak *et al.* 2003; Utset *et al*. 2004; Gavilan *et al*. 2006). The Penman-Monteith method ranked as the best method for all climatic conditions (Allen *et al*. 1989; Jensen et al. 1990; Chiew *et al*. 1995), however, ranking of other methods varied depending on their adoption to local calibrations and conditions.

ARTIFICIAL NEURAL NETWORK

The first successful artificial neural network was development in 1940's. ANNs are mathematical models whose architecture is inspired by biological neural networks and highly appropriate for the modeling of nonlinear processes (e.g. ET). Artificial neural network (ANN) modeling is the latest technique and described as a non-linear mathematical structure, which is capable of representing complex non-linear process that relates the input and output of any system. ANN has been proven to provide solution when applied to (i) complex system that may be poorly described or understood; (ii) problems that deal with noise or involve pattern recognition, diagnosis, abstraction, and generalization; and (iii) situation where input is incomplete of ambiguous nature.

Studies on ANN application in the area of hydrology include rainfall-modeling (Minns and Hall, 1996), river stage forecasting (Compolo *et al*. 1999), reservoir operation (Jain *et al*. 1999), pesticides concentration in soil (Yang *et al*. 1997,Goh 1999), and aquifer parameter estimation (Lingi Reddy, 1998). Some of the studies (Kumar *et al*. 2002) have also shown that ANN is more accurate than conventional methods. Keeping in view above scope and technique, in the present study ANN Model was developed to predict reference evapotranspiration.

MATERIALS AND METHODS

The study was conducted at the Crop Research Center of G.B. Pant University of Agriculture and Technology, Pantnagar, that is located in the Tarai region of Uttarakhand state (India) at the foot hills of the Shivalik range of Himalayas and lies at 29.5° N latitude, 79.3° E longitude and at an altitude of 243.83 m above mean sea level.

Estimation of reference evapotranspiration (ET_0)

1. Pan Evaporation Method: Reference evapotranspiration was obtained from the relationship given below.

$$ET_0 = K_p \times E_{pan} \quad \ldots(1)$$

where,

ET_0 = Reference crop evapotranspiration, mm/day

E_{pan} = Pan evaporation in mm/day and

K_p = Pan coefficient.

The value of K_p for USWB class-A pan for the study was taken equal to 0.85 (Doorenbos and Pruitt, 1977).

2. Penman-Monteith model

A particular form of Penman-Monteith equation for calculation of ET-ref (ET_0) is given by Allen et al. (1998) as following:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad \ldots(2)$$

where, ET_o = reference evapo-transpiration (mm day^{-1}), Δ = slope of saturation vapour pressure curve (kPa^0C^{-1}), R_n = net radiation (MJ m^{-2} day^{-1}), G = soil heat flux density (MJ m^{-2} day^{-1}), γ = psychometric constant (kPa $^0C^{-1}$), T = mean daily air temperature (^{0}C), e_s = saturation vapour pressure (kPa),e_a = actual vapour pressure (kPa), and u_2 = average daily wind speed at 2 m height (m sec^{-1})

Calculation of ET_o using equation (2) on daily basis required meteorological data consisting of maximum and minimum daily air temperatures (T_{max} and T_{min}), mean daily actual vapor pressure (e_a) derived from dew point temperature or relative humidity (Rh_1 and Rh_2) data, daily average of 24 hours of wind speed measured at 2 m height (u_2), net radiation (R_n) measured or computed from solar and long wave radiation or the actual duration of sunshine hours (n). The extra terrestrial radiation (R_n) and day light hours (n) for a specific day of the month was also computed. As the magnitude of soil heat flux (G) beneath the reference grass surface was relatively small, it was ignored for daily estimates.

3. ANN model

ANN is an information-processing system composed of many nonlinear and densely interconnected processing elements or neurons, which are analogous to the biological neurons in the human brain. The main function of the ANN paradigms is to map a set of inputs to a set of outputs. The most important attribute of a multilayer feed-forward network is that it can learn a mapping of any complexity (Zurada. 1992). A multilayer artificial neural network is shown in Fig.1. In this architecture, besides the input layer and the output layer, the network also has one or more than one intermediate layer(s) called hidden layer(s). Each layer is fully connected to the preceding layer by inter-connected strengths or weights. The learning (training) is carried out by the well-known error back-propagation (BP) algorithm. In the present study, the standard BP algorithm based on generalized delta learning rule (Rumelhart *et al.* 1986) is used, which in turn makes use of gradient decent in the multidimensional weight space. The error BP process consists of two passes through the different layers of the network: a forward pass and backward pass. In the forward pass, the input layer receive the input signals which are passed to the hidden layer and then to the output layer. The signals are multiplied by the current values of weights, and then the weighted inputs are added to yield the net input to each neuron of the next layer. The net input of a neuron is passed through an activation or transfer function to produce the output of the neuron.

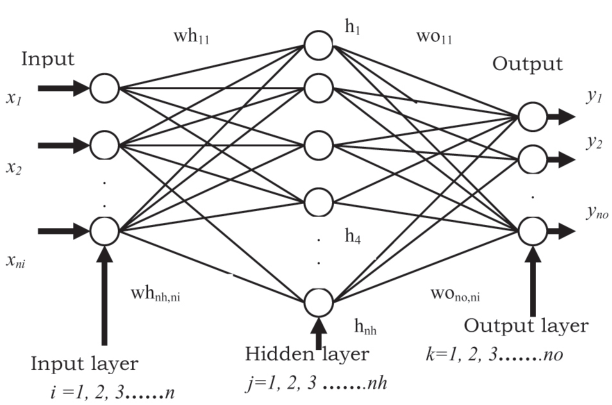

Fig. 1. Multilayer artificial neural network

Net input at any nodes, except the input layer nodes, is calculated as

$$neth_j = \sum_{i=1}^{ni} wh_{ji} x_i \qquad \ldots(3)$$

In which $neth_i$ = net input to j^{th} node of the hidden layer; ni is the number of neurons in the input layer and wh_{ji} is the connection weight between i^{th} node of the input layer and j^{th} node of the hidden layer.

The output of j^{th} node of the hidden layer is

$$h_j = f(neth_j) \qquad \ldots(4)$$

where $f(.)$ is the activation function, e.g. a sigmoid activation function. Thus

$$h_j = \frac{1}{1+\exp\left(-neth_j\right)} \qquad \ldots(5)$$

Similarly, the net input to k^{th} node of the output layer is given by

$$nety_k = \sum_{j=1}^{nh} wo_{kj} h_j \qquad \ldots(6)$$

where nh is the number of neurons in the hidden layer and wo_{kj} is the connection weight between j^{th} node of the hidden layer and k^{th} node of the output layer

$$y_k = f(nety_k) \qquad \ldots(7)$$

thus $$y_k = \frac{1}{1+\exp\left(-nety_k\right)} \qquad \ldots(8)$$

y_k = output of k^{th} node of the output layer ,

The sum of the differences between desired output (target value t_k) and computed output y_k define the error signal that is to be propagated back. Error computed at output layer (E)

$$E = \frac{1}{2}\sum_{k=1}^{no}\left(y_k - t_k\right)^2 \qquad \ldots(9)$$

In which no = number of output neurons. This error signal is propagated back, and weights are adjusted to reduce the difference between desired and computed output by using the gradient decent technique and the chain rule of the derivative are employed to modify the network weights. This may be summarized as

$$\Delta w_{kj} = \eta\left(\frac{\partial E}{\partial wo_{kj}}\right) \text{ and } \Delta w_{ji} = \eta\left(\frac{\partial E}{\partial wh_{ji}}\right) \qquad \ldots(10)$$

In which Δ represents the increment to be applied; η = learning rate. This updating of the weights is continued until the required level of accuracy is obtained between computed outputs and target values.

This study used NeuroSolution software version 5.0 presented by the NeuroDimension. The learning process starts with a random set of weights. During the training process, weights are updated through error back-propagation using

Eqn. (10) for output and hidden layers. One software *NeuroSolution* wizard viz. *Neural Builder* is used for model development and *Testing Wizard* is used for the validation of the developed model.

4. Development of ANN model

In this method, the observed time series of evaporation, temperature, relative humidity, wind velocity and sunshine hour of current day and previous two lag days as well as evaporation of previous two lag days are taken as the input variables and current day evaporation as the output variable. Let the observed values of temperature (T) (Max and Min), relative humidity (RH), wind velocity (V), sunshine hour (n) and evaporation (E) represented as $T_{i,j}$, $RH_{i,j}$,$V_{i,j}$ and $E_{i,j}$ respectively for j^{th} day of the i^{th} year (i = 1,2,….,M and j = 1,2,…..,N). The functional form of the model can be represented as

$$E_{i,j} = f\,(T_{i,j}\ ,\ T_{i,j-1},\ T_{i,j-2}\ (\text{Max and Min}),\ RH_{i,j},\ RH_{i,j-1},\ RH_{i,j-2},\ V_{i,j},\ V_{i,j-1},\ V_{i,j-2},\ n_{i,j},\ n_{i,j-1},\ n_{i,j-2,}\ E_{i,j-1}, E_{i,j-2}) \quad \ldots(11)$$

This functional form can also be represented diagrammatically as Fig. 2.

SELECTION OF NETWORK ARCHITECTURE

The network with minimum value of AIC and MSE is considered to be the best network. Time series data was standardized for zero mean and unit variation, and then normalized into 0 to 1. The activation function for the hidden and output layer was sigmoid axon and pure linear function, respectively, as these proved the best by a procedure of trial and error. The number of hidden nodes was determined by trial and error procedure.

MODEL PERFORMANCE CRITERIA

The performance of various models during calibration and validation were evaluated by using the statistical indices: the Mean Squared Error (MSE), Correlation Coefficient (CC), Akaike's information criterion (AIC) and Normalized Mean Square Error (NMSE). The Mean Squared Error (MSE) statistic measures the residual variance; which indicates a quantitative measure of the model error in units of the variable, the optimal value is 0. The Correlation Coefficient (R) measures the linear correlation between the observed and modeled values; the optimal value is 100%. Normalized mean square error (NMSE) is used as the third statistical indices, the optimal value is 0.

RESULT AND DISCUSSION

Artificial neural network (ANN) model

The daily evaporation prediction model for the study area has been developed using temperature, relative humidity, wind velocity, sunshine hour of current and previous two day as well as evaporation of previous two days as input variables and current day evaporation as the output variable, thus there were 17 input nodes in the input layer and one node in the output layer. The daily meteorological data during period 1/1/2001 to 9/8/2007 were used for the training (calibration) of the model, whereas the data of years 10/8/2007 to 31/12/2011 were used for verification (testing) of the developed model.

Feed-forward back-propagation algorithm (Rumelhart *et al.* 1986) was used to train the network for the evaporation prediction model. Various networks of single and two hidden layers were trained for a maximum iteration of 1000, with different combination of hidden neurons and the best suited network was selected based on the minimum values of mean square error (MSE), Akaike's information criterion (AIC) and maximum value of correlation coefficient (CC) described. It is clear from Table 1 that the network (17-6-1) with single hidden layer having very low values of MSE, AIC and higher value of CC. Therefore the performance of the network (17-6-1) is better in comparison to other networks.

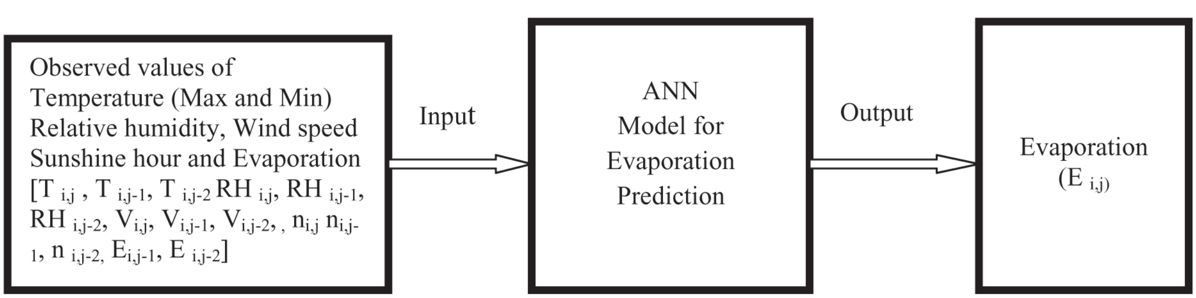

Fig. 2. Schematic diagram of the ANN model for Evaporation prediction

Table 1. Comparison of various networks, to help select the best network using trial- and-error

Network	MSE	AIC	R
17-5-1	0.008848	-11196.435	0.867518
17-6-1	0.004746	-12658.856	0.925307
17-7-1	0.005078	-12457.996	0.919852
17-8-1	0.005114	-12403.294	0.9192750
17-9-1	0.005081	-12380.680	0.919800
17-10-1	0.005617	-12100.944	0.910994
17-11-1	0.004977	-12354.290	0.921520
17-12-1	0.005204	-12209.109	0.917781
17-13-1	0.132707	-4369.242	0.670865
17-14-1	0.005523	-12121.200	0.917355
17-15-1	0.005041	-12162.375	0.920145
17-5-5-1	0.005188	-12422.330	0.918038
17-6-6-1	0.488685	-1410.932	0.062333
17-7-7-1	0.488672	-1344.997	0.508166
17-8-8-1	0.004985	-12320.591	0.921385
17-9-9-1	0.005344	-12079.114	0.915480
17-10-10-1	0.005208	-12063.350	0.917719
17-11-11-1	0.005159	-12003.827	0.918527
17-12-12-1	0.005225	-11887.195	0.917425
17-13-12-1	0.005205	-11806.823	0.917774
17-14-12-1	0.005195	-11717.314	0.917943
17-15-12-1	0.005887	-11317.911	0.906560

Qualitative or Visual observations evaluation

The graphical comparison between the observed and the predicted values is one of the simplest methods for the performance assessment of a model.

The predicted evaporation was compared visually with the observed evaporation. The observed and the predicted values of evaporation during training period (01/01/2001 to 09/08/2007) and testing period (10/8/2007 to 31/12/2011) is depicted in Fig.3 and Fig.4.

It is observe from Fig.3 that there is a fairly good agreement between the predicted and the observed evaporation and overall shape of the plot of predicted evaporation is similar to that of the observed evaporation. Therefore, the visual observations performance during the training has been found satisfactory.

It is observed from Fig.4 that there is a close agreement between observed and predicted values of evaporation. Thus, developed model may be regarded as satisfactory on the basis of the visual observations evaluation during testing period.

Quantitative evaluation

1. Statistical indices

The statistical indices are given in Table.2. The values of mean square error (MSE) and Akaike's information criteria (AIC) during training and testing periods are vary from 0.004746 to 0.004425 and -12658.856 to -8475.282. Based on low values of MSE, model indicates the goodness of fit of higher degree.

Normalize mean square error (NMSE) values for ANN models during training and testing periods range from 0.143815 to 0.132532. Hence the value of NMSE well within acceptable limits. The values of correlation coefficient (CC) during

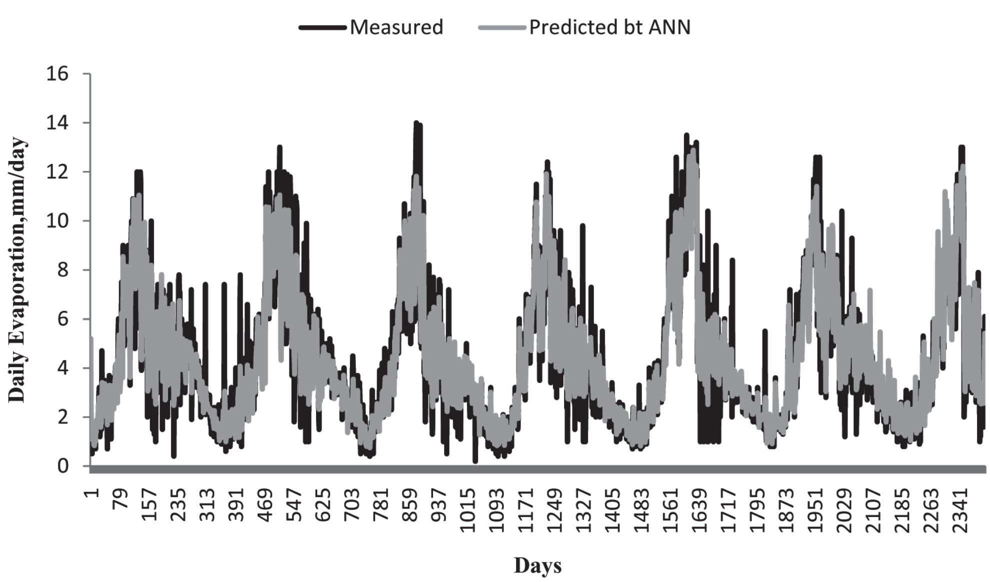

Fig. 3. Measured and predicted daily evaporation of ANN model during training pPeriod

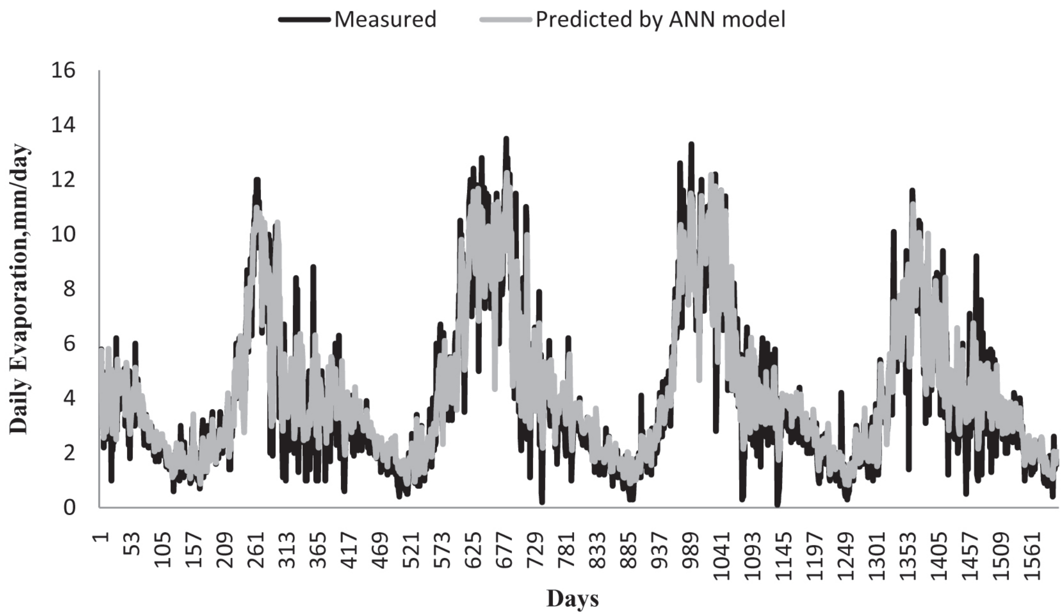

Fig. 4. Measured and predicted daily evaporation of ANN model during testing period

Table 2. Quantitative performance evaluation of the developed model during testing and training for the best chosen neural networks

S.No.	Quantitative performance indices	Best network structure for training	Best network structure for testing
1.	MSE	.004746	.004425
2.	NMSE	.1438152	.132532
3.	CC	92.53%	93.46%
4.	AIC	-12658.8566	-8475.282
5.	EV	0.000278	0.050984

calibration (training) and validation (testing) range from 92.53 to 93.46 percent. The values of correlation coefficient (CC) indicate the closeness of observed and predicted values during training as well as verification testing periods.

2. Hydrological indices

The quantitative performances of the models were also assessed by another measures i.e volumetric error and the values are tabulated in Table 2. It can be observed from the Table 2 that the values of volumetric error (EV) for ANN model during training and testing periods range from 0.027 to 5.09 percent. These values are well within the acceptable limits.

The performance evaluations of the developed models reveal that the models are able to predict the evaporation with adequate accuracy to estimate reference evapotranspiration than conventional method. Recently, Khoob (2008b) and Kumar et al. (2008) reported also that the performance of ANN is better than the conventional method.

Comparative variation of reference evapotranspiration (ET_0)

Comparative variation of predicted daily ET_0 by ANN model and daily ET_0 by Penman-Monteith and for testing periods are shown in Fig. 5. It can be seen that daily ET_0-ANN and ET_0-PM are similar. It can also be seen that ANN model captures the seasonal variations in ET_0. Average values of ET_0 predicted form ANN model and PM model were 3.34 mm/day and 2.66 mm/day, and the maximum and minimum values were 9.33 mm/day, 0.74 mm/day and 9.35 mm/day, 0.21 mm/day respectively. The coefficient of correlation (R) between ET_0-ANN model and ET_0-PM is 0.9527 respectively.

CONCLUSIONS

The following conclusions are drawn from the results of this study:

1. The qualitative performances, based on observed and predicted values during training as well as testing periods of developed models regarded as satisfactory.
2. Based on statistical and hydrological indices, performance of ANN model (17-6-1) is better than

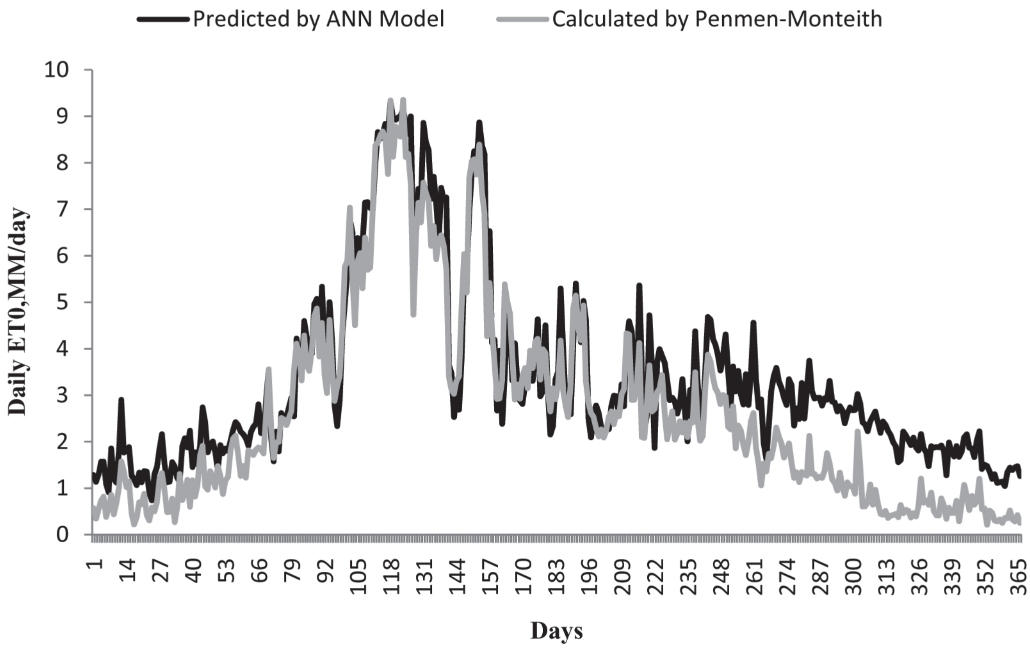

Fig. 5. Calculated (PM) and predicted (ANN) daily reference evapotranspiration (ET_0)

other models for evaporation forecasting by ANN method.

3. The values of mean square error, normalized mean square error, correlation coefficient, Akaike's information criteria and volumetric error were within the acceptable limits for all models.
4. The estimates of daily evaporation using proposed ANN model and measured evaporation were similar.
5. Average values of ET_0 predicted form ANN model and PM model were 3.34 mm/day and 2.66 mm/day, and the maximum and minimum values were 9.33 mm/day, 0.74 mm/day and 9.35 mm/day, 0.21 mm/day respectively. The coefficient of correlation (R) between ET_0-ANN model and ET_0-Penman-Monteith is 0.9527 respectively.

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Performance of pastoral, silvipastoral and silvicultural systems in Alkali soils of Indo-Gangetic plains

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ABSTRACT

A field study to find out the suitable agro forestry systems in a highly alkali soil and their effect on improving the soil properties was initiated during 1995 at Central Soil Salinity Research Institute, Regional Research station, Lucknow. The soil was poor in organic matter (0.08%) and available N (94kg ha^{-1}) but high in available P (25kg ha^{-1}) and K (237.44kg ha^{-1}). The treatments include: T_1, Kallar grass (*Leptochloa fusca*) for 4 years followed by Gutton panic (*Panicum maximum*) grass (without amendments); T_2, Vilayati babul (*Prosopis juliflora*) as sole tree crop; T_3, Deshi babul (*Acacia nilotica*) as sole tree crop; T_4, Vilayati babul (*Prosopis juliflora*) + Kallar grass (*Leptochloa fusca*) for 4 years followed by berseem (*Trifolium alexendrium*) for 3 years (without amendments) and T_5, Deshi babul (*Acacia nilotica*) + Kallar grass (*Leptochloa fusca*) for 4 years followed by Rhodes grass (*Chloris gayana*) for 3 years. After 84 months of planting all the growth parameters including survival percent, plant height, diameter at breast height (DBH), diameter at stump height (DSH) and lopped biomass of *Prosopis juliflora* and *Acacia nilotica* grown in combination with inter crops of grasses were higher as compared to the sole plantation. Plant height was recorded to be 20 and14% higher in *Prosopis juliflora* and *Acacia nilotica* respectively grown in combination with grasses than the sole plantation of these species. The pH, EC and organic carbon of the surface soil (0-15cm) with *Prosopis juliflora* in combination with Kallar grass (*Leptochloa fusca*) for 4 years followed by Berseem (*Trifolium alexendrium*) for 3 years silvipastoral system has reduced to the level of 8.87. However, pH was > 9.0 in case of the remaining treatments. Vilayati Babool (*Prosopis juliflora)* + Berseem (*Trifolium alexendrium*) silvipastoral system gave highest net return (Rs. 15155ha^{-1} yr^{-1}) followed by Gutton panic (*Panicum maximum*) as sole crop (Rs.7660 ha^{-1} yr^{-1}) than the sole plantation of *Prosopis juliflora* (Rs.5610 ha^{-1} yr^{-1}) and *Acacia nilotica* (Rs.3260 ha^{-1} yr^{-1}) and appeared to be the most suitable and economically viable alternate land use system for alkali soils.

Key words: Alkali soil, Indo-Gangetic plains, Agro-forestry systems, soil improvement.

INTRODUCTION

Acacia nilotica and *Prosopis juliflora* are the most promising woody species for alkali lands in indo-gangatic plains of India. Now it is promoted as a component of silvipastoral systems but the interaction of these trees with grasses has not been adequately studied. In India there are about 8.6 million ha. salt affected soils. The indo-gangetic plains constitute a major part of salt affected soils in the country. The farmers in the Indo-gangetic plains in India have reclaimed a sizeable area of alkali lands for crop production, but still a large part of common lands either government lands or village panchayat lands are not in any productive use. In addition to this a large part of alkali soils belongs to the small and marginal farmers is also lying unproductive. Judicious use of these lands can substantially contribute in increasing demands of food, fodder, fuel and timber in the country. Silvipastoral systems have been generally promoted for hilly areas as a means for reducing soil erosion and improving soil physical and chemical properties. Introduction of tree+ grasses in alkali soils provides an alternative to control further deterioration of these soils and also maintain the soil health. Several studies have measured to increase the N status of the soil under varying N_2- fixing tree species (*Acacia spp*.). The highly salt tolerant and high biomass producing grass species include: Kallar grass (*Leptochloa fusca*), Rhodes grass (*Chloris gayana*) and Gutton panic (*Panicum maximum*) has been found most suitable fodder species. Growing of these fodder species in combination with *Prosopis juliflora* and *Acacia nilotica* for a certain period of time improved the soil health to such an extent that less tolerant but more palatable fodder species such as Berseem (*Trifolium alexendrium*) and Senji (*Melilotus*

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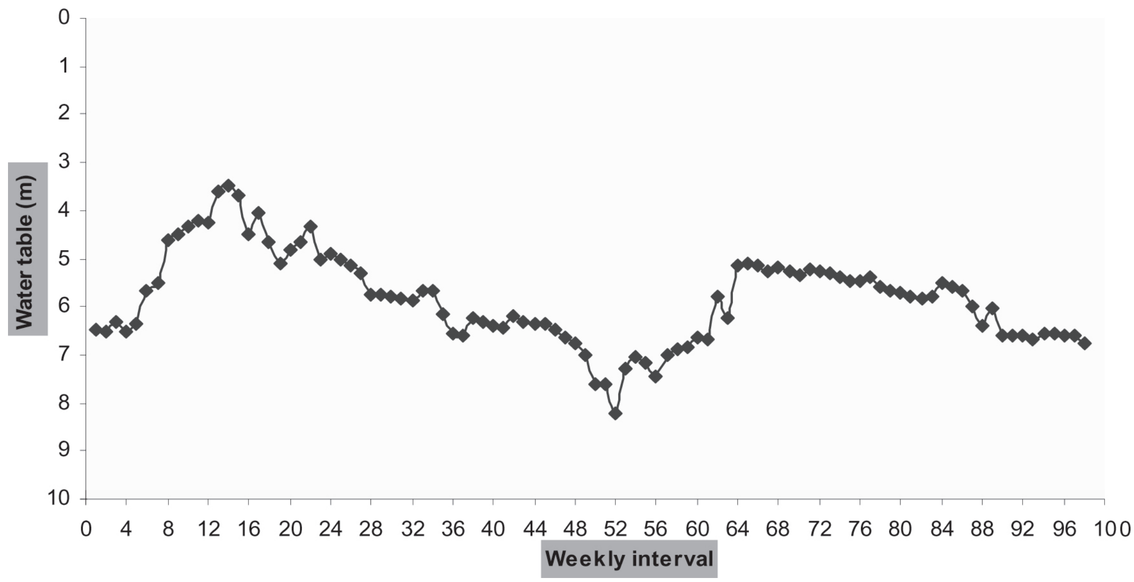
parviflora) could be grown. As the alkali soils are poor in organic carbon, the rates of organic carbon and N accumulation tends to be greatest in the first five years of plantation (Lukan and Fonda 1983). Therefore, the present study was initiated in 1995 with the twin objectives of sustainable use of highly alkali soils for fuel -fodder production and their amelioration. This study focuses on the impact of *Acacia nilotica* and *Prosopis juliflora* alone and in combination with different grass species in order to assess the effect of different combinations on growth of trees, yields of fodder grasses and improvement in soil properties.

MATERIALS AND METHODS

A field experiment was initiated during 1995 at Central soil Salinity Research Institute, Regional Research Station, Lucknow, (U.P.) (Lat. 26° 47′ N and Long. 80° 46′ E) in the Indo-gangetic plain zone of India to find out the suitable agroforestry system in highly alkali soils. The soil of the study area was having pH 10.2, EC 1.55 dSm^{-1} and ESP 89 in the upper 0-15 cm soil depth with a predominance of carbonate and by carbonate of Na+. The soil was poor in organic carbon (0.08%) but rich in available P (19.5 kg ha^{-1}) and K (388.00 kg ha^{-1}) (Table 1). The annual rainfall, mean maximum and minimum temperature and evaporation are shown in graph 1. The water table was deep fluctuating between 3-5 m in rainy season and 6-7 m in summer. Nearly 6-9 month old saplings of tree species viz. *Prosopis juliflora* and *Acacia nilotica* of uniform height, collar diameter and phenotype were planted during 1995 in auger holes of 45cm diameter at the surface and 20cm at the base and 120cm deep in a randomized block design (RBD) with 4 replications. Each auger hole was filled with a uniform mixture of original soil + 4kg gypsum+ 10kg FYM +20kg silt before planting. The trees have been planted keeping a distance of 5m between the rows and 4m between plants. Root slips of Kallar grass (*Leptochloa fusca*) at 50cm row to row and 30 cm plant to plant spacing were planted as sole crop and as inter crop with *Acacia nilotica* and *Prosopis juliflora* without any amendment for 4 years and after that Gutton panic (*Panicum maximum*), Rhodes grass (*Chloris gayana*) and Berseem (*Trifolium alexendrium*) were sown as sole and as inter crop between the rows of *Acacia nilotica* and *Prosopis juliflora* respectively for three years. Five treatments consisting T_1, Kallar grass (*Leptochloa fusca*) for 4 years followed by gutton panic (*Panicum maximum*) grass as sole crop (without amendments); T_2, Vilayati babul (*Prosopis juliflora*) as sole crop; T_3, Deshi babul (*Acacia nilotica*) as sole crop; T_4, Vilayati babul + Kallar grass for 4 years followed by Berseem (*Trifolium alexendrium*) for 3 years (without amendments) and T_5, Deshi babul (*Acacia nilotica*) + Kallar grass for 4 years followed by Rhodes grass (*Chloris gayana*) for 3 years (without amendments) were evaluated in the study. Natural grasses were allowed to grow in the treatments T_2 and T_3. The natural grasses regenerated under the trees were harvested annually and kallar grass, rhodes grass and gutton panic were harvested quarterly and used as fodder grass by the cattle. The berseem was grown during rabi season (October to April) and harvested 4-5 times during the cropping season and after that field was allowed to grow natural grasses during kharif season. All the grasses were sold in the market and prevailing market rates were considered to workout the economics of different agro-forestry systems. Lopping of side branches of trees were done during the dormant period to help the trees grow better and also improve the forage yield of inter planted grasses (Singh *et al* .1989). The

Table 1. Initial soil properties of the experimental field

Soil depth (cm)	pH	EC (ds m^{-1})	O.C. (%)	ESP (%)	G.R. (t ha^{-1})	$CaCO_3$ (%)	Available P (kg ha^{-1})	Av. K (kg ha^{-1})
0-15	10.2	1.55	0.08	85	30	2.41	25.0	237.4
15-30	10.4	2.80	0.08	89	32	1.26	19.5	324.4
30-45	10.4	2.55	0.06	91	33	2.34	18.5	388.0
45-60	10.1	1.86	0.08	-	-	2.26	17.7	404.0
60-75	10.1	1.33	0.08			3.46	17.1	290.0
75-90	9.7	0.86	0.08	-	-	3.77	16.7	287.0
90-120	9.3	0.45	0.06	-	-	7.75	16.1	278.0
120-150	9.0	0.21	0.06	-	-	32.54	15.4	190.0
150-180	8.7	0.22	0.04	-	-	22.46	16.3	170.4
180-210	9.0	0.14	0.05	-	-	25.34	16.6	151.0



Graph 1. Water table fluctuation pattern of CSSRI research farm Shivri, Lucknow (U.P.)

lopped biomass of the trees was used as fuel and the prices were fixed according to the prevailing market rate of the fuel. The observations on survival %, plant height (cm), DBH (cm), DSH (cm), lopped biomass (qha^{-1}) and yields of fodder grasses viz. Kallar grass, Rhodes grass, Gutton panic, Berseem and naturally regenerated grasses, was measured on green weight basis. Soil samples collected at different growth stages were analyzed for pH, EC, and organic carbon. Soil pH in water (1:2) was measured at depths of 0-15 and 15-30cm using the method described in blakemore *et al*. (1987). The organic carbon of the soil was measured by ignition (Wang *et al.*1996) where approximately 2g of dry soil (sieved to <2mm) were placed in ceramic crucibles in a muffle furnace at 375^0C for 16 h. The data were analyzed statistically to find out the treatment differences following the standard methods given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Tree growth

From the study, it is observed that the maximum survival percent up to 60 months of planting was recorded with *Prosopis juliflora* planted as sole. However, after 84 months of planting maximum survival was observed in *Prosopis juliflora* planted with inter crops of grasses. Higher plant mortality was observed in sole plantation up to 60 months of plantation and after that no mortality was observed in the trees grown in combination with grasses. Maximum plant height at 60 months crop growth stage was observed with *Acacia nilotica* grown in combination with kallar grass (*Leptochloa fusca*) as compare to the sole plantation. However, at 84 months growth stage *Prosopis juliflora* grown in combination with Berseem (*Trifolium alexendrium*) a nitrogen fixing fodder crop attains maximum plant height because of availability of additional moisture and nutrients to the plants but the difference between the treatments was not significant (Table 2). Similarly, diameter at breast height (DBH) and diameter at stump height (DSH) of *Prosopis juliflora* (10.10 and 15.57cm) and *Acacia nilotica* (8.22 and 13.49cm) species at 60 and 84 months after planting stages were higher with the trees grown in combination with inter crops of fodder grasses over the sole plantation of these species. After 60 months of planting, *Acacia nilotica* grown as sole crop produced significantly higher lopped biomass (25.10q ha^{-1}) as compared to *Prosopis juliflora* and *Acacia nilotica* grown in combination with different grasses species. However, at 84 months growth stage significantly higher lopped biomass (33.55q ha^{-1}) was obtained from the *Prosopis* + Berseem intercrop. Singh *et al*. (1989a) reported that the plant height of *Prosopis juliflora* was significantly increased with lopping of trees in highly alkali soils. Lopping of side branches of trees during the dormant period helps the trees grow better and also improve the forage yield of inter planted grasses (Singh *et al*. 1989).

Fodder yields

Observations on fodder yields obtained from natural grasses regenerated under the sole plantation of *Prosopis juliflora* and *Acacia nilotica* and

Table 2. Performance of tree species under different agro-forestry systems.

Treatments	60 months after planting					84 months after planting				
	Survival (%)	Height (m)	DBH (cm)	DSH (cm)	Lopped biomass (q ha^{-1})	Survival (%)	Height (m)	DBH (cm)	DSH (cm)	Lopped biomass (q ha^{-1})
Prosopis (sole)	100	4.33	5.78	11.92	13.25	93	4.83	6.82	12.84	29.40
Acacia (sole)	85	4.35	6.26	11.46	25.10	81	4.53	7.51	12.21	32.00
Prosopis + fodder grass	95	4.97	6.47	12.97	16.70	95	5.21	10.10	15.57	33.55
Acacia + fodder grass	90	5.11	6.41	11.25	18.50	90	5.16	8.22	13.49	25.60
CD (P=0.05)	NS	NS	NS	NS	2.78	NS	NS	NS	NS	2.20

Table 3. Green fodder yields under different agro-forestry systems at different growth stages

Treatments	Green fodder yields (q ha^{-1}) obtained after			
	48 months of planting	60 months of planting	72 months of planting	84 months of planting
T_1- Grasses (Sole)	103.0	174.74	207.44	219.43
T_2-*Prosopis* (sole)	34.82	54.82	79.00	47.40
T_3-*Acacia* (sole)	41.67	71.43	85.00	88.00
T_4-*Prosopis* + Karnal grass-Berseem	74.65	158.19	49.75	222.55
T_5-*Acacia* + Karnal grass-Rhodes grass	61.25	56.50	112.60	162.00

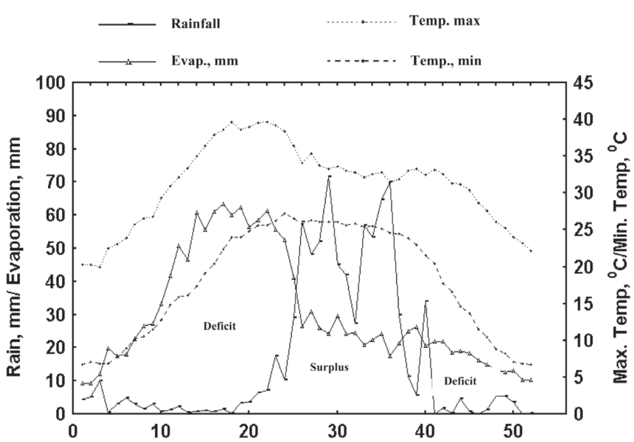


Fig. 1. Annual weather parameters of CSSRI, Research farm, Shivri

from the planted grass species like *Leptochloa fusca*, *Chloris gayqna*, *Trifolium alexendrium* and *Panicum maximum* planted as sole and as inter crop were taken at regular interval and it was found that the fodder yields in case of sole plantation as well as inter crop increased with every increase in time interval. Maximum fodder yield at 48 months of planting was obtained from the sole crop of *Leptochloa fusca* as compared to the yields obtained from the inter crops. Similar trend was also observed up to 72 months planting stages and after that the fodder yields under *Prosopis juliflora* increased as compared to other silvipastoral systems. The increments in fodder yields between 48 and 84 months of planting were higher in case of tree + grass cropping system as compared to the grass yields obtained from sole tree plantation and sole grass cropping systems because of more improvement in soil health with tree and grass combination system. Kumar *et al*. (1990-91) has found that under all tree canopies berseem yield was less affected as compared to other fodder crops (Table 3). Lopping of side branches of trees during dormant period helps the trees to grow better and also improve the forage yield of inter planted grasses. When large canopy-forming trees like *Prosopis* and *Acacia* are pruned of side branches, light penetrates through the cavities owing to their removal and increases productivity of under-story vegetation.

Soil improvement

With the introduction of trees, tree + grasses and grasses only under highly sodic soil conditions, it was found that there was remarkable improvement in soil properties. After 84 months of continuous observations, it was observed that the *Prosopis juliflora* + Kallar grass for 4 years followed by berseem silvipastoral system found most promising for reclamation of alkali soils. With this treatment combination, the pH of surface soil reduced to the level of 8.87 however, the pH with other treatments was > 9.0. Abrol and Prasad (1985), Singh *et al*. (1993) and Singh (1995) have also reported similar results. The organic carbon content

Table 4. Improvement in soil properties under different agro- forestry systems at different tree growth stages.

Treatments	Soil depth (cm)	60 months after planting			84 months after planting		
		pH	EC	O.C. (%)	pH	EC	O.C. (%)
T_1- Karnal grass-Gutton panic (Sole)	0-15	9.60	0.84	0.24	9.20	0.63	0.28
	15-30	10.20	1.20	0.17	9.76	0.87	0.11
T_2-*Prosopis* (sole)	0-15	9.50	0.84	0.14	9.00	0.29	0.26
	15-30	9.91	1.21	0.10	9.85	1.03	0.17
T_3-*Acacia* (sole)	0-15	10.0	1.03	0.14	9.21	0.86	0.27
	15-30	10.15	1.73	0.10	9.84	1.20	0.13
T_4-*Prosopis*+Karnal grass-Berseem	0-15	9.56	0.59	0.28	8.87	0.63	0.44
	15-30	10.03	1.23	0.19	9.51	0.87	0.23
T_5-*Acacia*+ Karnal grass-Rhodes grass	0-15	9.60	0.83	0.12	9.20	0.23	0.35
	15-30	9.95	1.37	0.10	9.68	0.62	0.22

Table 5. Cost economics of different agro- forestry systems.

Treatments	Fodder yield (q ha^{-1})	Fuel yield (q ha^{-1})	Cost of Production (Rs.ha^{-1})	Gross income (Rs.ha^{-1})	Net return (Rs.ha^{-1} $year^{-1}$)
T_1- Karnal grass-Gutton panic (Sole)	219.43	-	2340	10971	8631
T_2-*Acacia* (sole)	87.40	29.40	1700	7310	5610
T_3-*Acacia* (sole)	88.0	32.00	1700	4960	3260
T_4-*Prosopis*+Karnal grass-Berseem	222.55	33.55	8000	23155	15155
T_5-*Acacia*+ Karnal grass-Rhodes grass	242.14	25.60	3000	10660	7660

of surface soil (0-15 cm) has also increased more than 300% from the treatment in which *Prosopis* + Kallar grass for 4 years followed by Berseem was grown (Table 4). This might be due to production of certain allelo-chemicals/mixture of acids released from tree biomass as well as from root and shoot biomass of grasses. Gill *et al*. (1987) and Lal (1998) has also reported three and two fold increase in organic carbon of surface (0-15cm) soil in a span of 5 years under *Acacia nilotica* and *Eucalyptus territicornis* respectively. From the study it was also observed that the improvement in soil properties with *Acacia* (sole) and *Acacia* in combination with Kallar grass for 4 years followed by rhodes grass does not make any significant difference in soil pH at surface level however, at 15-30 cm soil layer *Acacia* + Rhodes grass silvipastoral system improved the soil more than *Acacia* as sole. The concentration of almost all nutrients in plant parts of *Prosopis juliflora* was more under tree + grass treatment than in sole crop. Total nutrient removal from the soil was higher in *Prosopis* + grass treatments compared with *Prosopis* and *Acacia* as sole. Even after such higher removal of nutrients in tree + grass treatments, the organic carbon and available N status of the soil was still better than the sole plantation of trees and grasses astoral treatments. The similar observations were also reported by Singh *et al*. (1987).

Economics

Economical interaction among pastoral, silvipastoral and silviculture systems was considered in order to assess their compatibility and economic viability, for alkali soils. The income from the different trees, grasses and Tree + grass intercropping systems started flowing from the first growing season, in the form of fodder and fuel. The income obtained from different combinations indicated that the *Prosopis juliflora* + *Kallar* grass *(Leptochloa fusca)* for 4 years followed by Berseem (*Trifolium alexendrium*) gave the maximum (Rs.15155 ha^{-1} yr^{-1}) net return as compared to rest of the treatment combinations because of great demand and higher market price of Berseem for fodder during the winter season when there is scarcity of green fodder (Table 5). However, Acacia as sole crop gave lowest (Rs. 3260 ha^{-1} yr^{-1}) net return. After harvesting of Berseem, natural grasses are allowed to grow under the *Prosopis juliflora* trees during the kharif season and harvested in the month of October. Abrol and Joshi (1984) have also reported the maximum benefit: cost ratio for intercropping of fodder grasses with trees in highly alkali soils.

CONCLUSION

After seven years of comparative evaluation of trees, grasses and tree + grasses combinations in highly alkali soils, the survival of *Acacia* and *Prosopis* in case of tree + grasses combination was 12.06 and 3.22 percent more over the sole plantation of these trees respectively. The height in case of trees grown in combination with fodder grasses were more as compared to the sole plantation because of moisture conservation and suitable hydrothermal conditions developed in the soil for better plant growth. *Prosopis juliflora* in combination with kallar grass*(Leptochloa fusca)* during the initial 4 years has reduced the soil pH to the level of 9.5 and after that less tolerant but more palatable fodder species such as Berseem (*Trifolium alexandrium*) can be grown successfully and gave higher fodder yields (22.25Mg ha^{-1}) and net returns (Rs. 15155 ha^{-1}). Thus it can be inferred that the *Prosopis juliflora* + kallar grass *(Leptochloa fusca)* for 4 years followed by Berseem for 3 years silvipastoral system has been found most promising for firewood and forage production and also for amelioration of alkali soils.

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Identification of potential sites for Jatropha plantation in Haryana through geoinformatics

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ABSTRACT

The increasing demand of diesel oil in the country has compelled the people to think towards bio- diesel production. Jatropha commonly known as Ratanjyot is found the most suitable plant specie for this purpose. Being hardy it can be used for ecological and economic rehabilitation of wastelands. A district wise study on mapping of wastelands on 1:50,000 scale was conducted in Haryana using Remote Sensing Technology. Digital data of IRS-IC/lD, LISS-111 for the months of February 2003 was used for the identification of these lands. The various wasteland classes found in the state are sandy areas, degraded grazing land, waterlogged areas, scrublands, salt affected lands and barren/ rocky hills. The major portion of sandy areas is found in Sirsa, Hisar, Bhiwani, Mahendergarh, Rewari and Mewat districts. The barren and rocky hills are also found in Bhiwani, Mahendergarh, Rewari and Mewat districts on the Aravalli Hills. The soils on these hills are skeletal and shallow to medium in depth. Waterlogged areas are found in Mewat, Jhajjar and Bhiwani districts in the state. The degraded grazing lands are found around most of the villages in the state. The scrublands are mostly found in Bhiwani, Mahendergarh, Gurgaon, Mewat and Faridabad districts. The salt affected lands, which have been sown either in one season or have vegetation/ plantation on it were not included in this category. These lands are found in Mewat, Karnal and Panipat and Sonipat districts. As Jatropha is a very hardy plant and can be grown in varying range of soil texture, and have less requirement of water, so, these wastelands can be used for Jatropha plantation.

Key words: Mapping, Wasteland, Jatropha, Scrub land, Waterlogged, Salt affected, Barren

INTRODUCTION

The ever-increasing population explosion needs food, fuel, fibre, shelter, and fodder for meeting its various demands. After becoming self- dependent in grain production, the major problem of the country in the coming years will be diesel or petroleum oils. So, scientists have to think on these lines for bio- diesel production. Jatropha commonly known as Ratanjyot is found the most suitable plant specie for this purpose. It is well adapted to arid conditions and its water requirement is extremely low. It is suitable for sand dune stabilization and for soil conservation purposes. Being hardy it can be used for ecological and economic rehabilitation of wastelands. Regional Research Station, Bawal reported that it could be grown even in sodic waters in light textured soils.

Taking into consideration the requirements of this plant, the various kinds of wastelands lying in the state can be used for this purpose. Efforts have been made to map the wastelands in Haryana from time to time. National Remote Sensing Agency (NRSA), Department of Space, Govt. of India during 1982 initiated a country level project for wastelands mapping on 1:1m scale through remote sensing technique. After successful completion of this project, NRSA in its second phase started wastelands mapping on 1:50,000 scale for the whole country. Five districts of Haryana were also selected under this project. Sharma *et al*. (1990) conducted this study to map wastelands in five districts of Haryana using remote sensing techniques. The rest of the districts were also covered at HARSAC during 1992. Now, HARSAC has also completed districtwise wasteland mapping for the state using satellite data of February, 2003.

DESCRIPTION OF THE STUDY AREA

Location and extent

Haryana is a small state situated between $27^0 29'$ to $30^0 56'$ N latitudes and 74^0 $27'$ to $77^0 36'$E longitudes, covering an area of about 44212 sq. km. It occupies 1.35% of the total area of the country having seventeenth position in area as compared to other states and Union Territories. The state is covered by Survey of India toposheets Nos. 44k, 440, 44P, 53C, 53D, 53F, 53G, 53H, and 54E on

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1:2,50,000 scale. The state imperceptibly slopes from north to south with height ranging from 200 to 900m above mean sea level but the slope becomes reverse in further south and south -west due to the presence of the Aravalli hills in the south.

It mainly occupies the Indo-Gangetic water divide and forms a part of the Indo-Gangetic Alluvial Plain. The Siwaliks extend into its north-eastern corner, in which originate the present day seasonal rivers, *viz.* the Ghaggar, the Tangri, the markanda and the Chautang, which flow taking a south- western course. The Aravalli Hills, which form a part of the peninsular shield, conspicuously appear in the southern extremity; in which originate the several ephemeral streams *viz.* the Sahibi and Dohan flowing from south to north. The aeolian tracts with sand dunal activities are common in the south, south-western and western districts, in which outcrops of the Aravalli Hills occur intermittently. All the peripheral features have a distinct relief and have higher elevations than the central structural basin, which represents a characteristically closed basin comprising flat alluvial plain.

It is an agriculturally dominant state and about 88% of the total geographical area can be classified as cultivable while there is 82% net sown area. The cropping intensity in the state is more than 150%, which indicates that the state has higher cropping intensity than the national average. The forest area in the state is very low which is mainly due to plain and leveled agricultural land available for the purpose of crop production throughout the state, except some hilly areas in northern and southern most parts of the state.

The main food crops grown in Haryana are bajra (*Pennisetum typhoides*), paddy (*Oryza sativa*), maize (*Zea mays*) during Kharif season and wheat (*Triticum aestivum*) and gram (*Cicer arietinum*) in Rabi season. Sugarcane (*Saccharum officinarum*), cotton (*Gossypium herbaecium*), rape and mustard (*Brassica sp*.) are important commercial crops.

The flora of Haryana may resemble to those of Iran, Arabia and North Africa. The largest of the truly indigenous trees are Shisham (*Dalbergia sissoo*) and Kikar (*Acacia arabica*). The scrub jungle consists mostly of Jal (*Salvadora oleoides*), Jand (*Prosopis specigera*) and coral flowered leafless Karir (*Caprylis aphylla*). In the northern districts of Panchkula and Ambala, vegetation of sub-tropical, broad-leaved forest type is found and sub-tropical pine forests are found in the Siwaliks.

Geomorphologically, following major units have been delineated in the state. These geomorphic units are Siwalik hills, piedmont, Yamuna flood plain, Ghaggar flood plain, Kaithal upland plain, Rohtak upland plain, Drishadavati plain with aeolian landform, Basin with kankar, Fluvio-aeolian plain and Aravalli hills. Except some hills of the Siwalik system in the north and Aravalli system in the South, the state has plain area having a height of 650 to 975 above mean sea level. The river Yamuna forms boundary between Haryana and U.P. for over 320 km., on the eastern side, whereas, Ghaggar flows on the northwest of the state.

Soils in the state are mainly derived from these major geological units *viz.* extra peninsular region of Siwalik range, alluvial plains and peninsular part comprising districts boundary Delhi and Rajasthan state in the south-east.

Bio-climatically, the Haryana state has been divided into five zones. These are hot and humid zones comprising parts of district Panchkula, Ambala, Yamunanagar; hot and sub-humid zone comprising of parts of Ambala,Yamunanagar, Kurukshetra and Kaithal; Hot and semi-dry zone consisting of Kurukshetra, Karnal, Kaithal, Jind, Panipat, Sonipat, Gurgaon, Faridabad, districts and parts of Rohtak district. Hot and dry zone comprising of Mehendergarh, Rewari and parts of Sirsa, Fatehabad, Hisar, Bhiwani, Jhajjar and Gurgaon. Hot and arid zone consisting of parts of district Sirsa, Fatehabad, Hisar and Bhiwani. The main annual rainfall varies from 1000 mm in the north-eastern Siwalik hilly tract to about 300mm in the western extremity. The normal rainfall decreases from northeast to southwest in the state.

METHODOLOGY

A district wise study on mapping of wastelands on 1:50,000 scale in all districts of Haryana was conducted using Remote Sensing Technique. Digital data of IRS-IC/lD, LISS-III for the months of February 2003 was used for the identification of these lands. Collateral data such as latest publications and maps relating to soils, cropping patterns, and present land use was used for reference purposes. Topographical maps were also used for identifying village location, major transport network, cultural features and annotation of major towns and cities. Due to variability of Wasteland conditions and terrain characteristics, ground truth in each district was collected. Interpretation "keys" were developed for various Wastelands categories by correlating satellite data

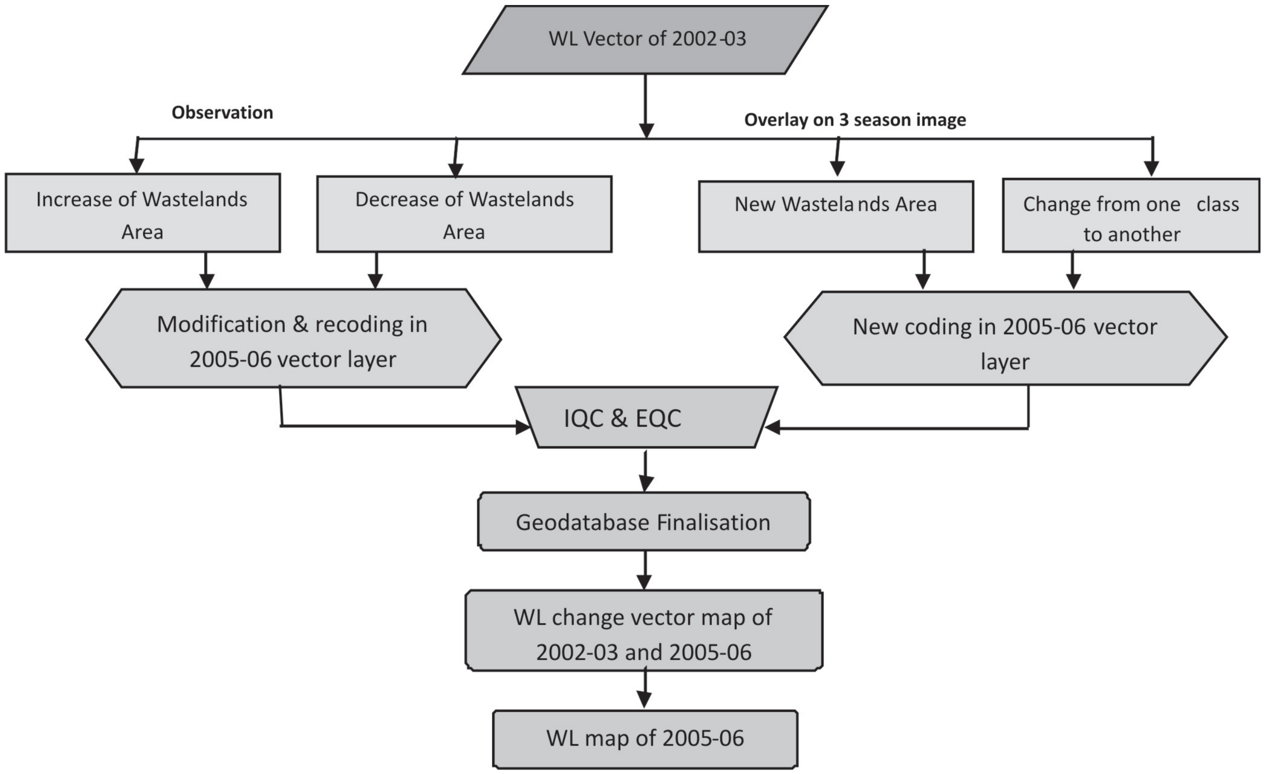

Fig. 1. Methodology flowchart

with ground data. These interpretation "keys" formed the base for classification of the satellite data. The satellite data was geo- referenced and the administrative boundaries (district boundaries) were transferred on it. On screen visual interpretation technique was followed in wastelands identification from satellite data. The heads up interpretation methodology essentially involves interpretation of enlarged satellite false colour data based on image characteristics such as tone, colour, texture, pattern, shape, size, location and association to identify and delineate different types of wastelands. Old vactors were also used in preparation of these maps. Digitization of various settlements/ habitat and transport network was done on the satellite data.

The schematic diagram of the methodology is given in Fig. 1. Toposheet wise maps for all the districts on 1:50,000 scale were prepared.

RESULTS AND DISCUSSION

The various wastelands classes were found in the state. These are sandy areas, degraded grazing land, waterlogged areas, scrubland, salt affected land and barren/ rocky hills. The district wise extent of these wastelands is given in the Table 1. Some of the physical properties of these wastelands are given in Table-2. The description of the wastelands found in the state is as under:

Sandy areas: The major portion of sandy areas is found in Sirsa, Hisar, Bhiwani, Mahendergarh and Rewari districts. Sandy areas are those areas, which have stabilized accumulation of sand, in desert, coastal, riverine or inland areas. In Haryana, it occurs mostly in southern districts but it was also found in Karnal, Panipat and Sonipat districts due to deposition of sand by rivers. The total area of this category in the study area is 147.76 sq. km.

Barren hills: The barren hills are found in Bhiwani, Mahendergarh, Rewari and Mewat districts on the Aravalli Range of Hills. The soils on these hills are skeletal and very shallow to moderately deep. But at the top and very steep slopes, there are rock exposures of varying litho logy often barren and devoid of soil cover and vegetation. The total area under this class in these districts is 112.10 sq. km.

Waterlogged areas: The Waterlogged land is that land where the water is at/or near the surface for most of the year and is not cultivated in both the seasons. Waterlogged areas are found in Mewat, Bhiwani and Hisar districts in the state. The total area under this class in these districts is 36.87 sq. km.

The degraded grazing lands: These are found around most of the villages in the state. These are the lands in non-forest areas whether or not they are permanent grazing lands, which have become

Table 1. District wise case in Haryana

S.No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
District→ Category	Amb-ala	Panch-kula	Bhiw-ani	Farida-bad	Gur-gaon	Hisar	Fateha-bad	Jind	Karnal	Panipat	Kuru-kshetra	Kaithal	M/ Garh	Mewat	Rewari	Rohtak	Jhajjar	Sirsa	Sonipat	Y-Nagar	Total
Gul./Ra.(s)	0.00	0.00	0.00	1.40	11.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.68	0.00	0.00	0.00	0.00	0.00	0.00	23.30
Gul./Ra.(m)	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	3.24
Ld. (Scrb.)	28.25	45.47	124.61	209.04	128.35	28.81	5.37	1.06	29.50	14.41	13.83	11.84	94.77	155.39	43.80	10.82	39.80	26.08	46.53	39.46	1097.19
Ld.(w-out Scr.)	4.10	4.71	5.41	2.60	0.95	0.13	0.18	1.16	0.02	0.00	2.16	0.00	13.00	1.81	5.32	0.00	0.46	0.00	0.06	3.75	45.80
WL(Per.)	0.00	0.00	2.54	0.00	0.37	2.07	0.00	0.03	0.03	0.00	0.00	0.00	0.00	1.16	0.00	1.15	5.09	0.13	0.00	2.01	14.57
WL(Seasn.)	0.51	0.00	0.46	1.79	0.00	0.38	0.21	0.00	0.00	0.00	0.00	0.03	0.00	6.86	0.24	0.00	0.38	8.12	0.47	2.84	22.30
LS(Str.)	0.00	0.00	0.00	0.00	0.11	0.23	0.00	0.18	0.00	0.81	0.00	4.09	0.00	4.80	0.00	0.03	1.62	0.00	0.11	0.00	11.97
LS(Mod.)	0.00	0.00	0.05	0.59	4.48	2.37	0.18	1.16	0.04	48.51	0.00	0.01	0.00	5.41	0.00	1.03	0.57	0.00	25.03	0.00	89.42
LS(Sligt.)	0.00	0.00	0.00	2.59	1.98	0.91	0.00	0.08	0.96	6.23	0.00	0.00	0.00	6.68	0.00	0.06	0.00	0.00	2.13	0.00	21.62
De. For.	1.14	336.66	1.50	1.28	1.54	5.05	0.46	0.00	2.94	0.00	0.40	7.13	0.00	21.94	2.76	0.00	5.10	0.00	5.76	93.01	486.68
De. For.(Ag.)	0.00	8.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	8.44
P/Gr.Land	15.14	0.18	75.72	29.37	14.29	135.47	64.87	92.68	29.20	30.57	6.41	43.17	47.67	33.01	32.76	61.49	67.68	69.02	72.15	2.77	923.63
De.Plant	14.42	0.21	8.08	5.45	6.44	17.21	0.39	1.68	14.49	3.45	3.06	5.97	58.50	2.13	22.89	15.30	8.51	6.88	6.72	4.98	206.74
Sand(FP)	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	1.23	3.79	5.47
Sand(low)	0.00	0.00	46.84	0.00	0.00	53.46	4.48	3.63	0.00	0.00	0.19	0.07	15.86	0.00	0.91	5.03	4.61	6.51	0.00	0.02	141.61
Sand(dunal)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68
Mining	0.21	0.64	0.00	11.08	0.61	0.00	0.00	0.05	0.25	0.82	2.93	0.29	0.46	2.65	4.52	2.31	10.28	0.00	2.11	0.51	39.72
Industrial	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	1.25	0.00	0.00	0.00	3.23
Rocky	0.00	0.00	11.20	0.51	1.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.14	17.43	22.39	0.00	0.00	0.00	0.00	0.00	112.10
TOTAL WL	63.84	395.99	276.42	265.70	174.77	246.09	76.13	102.18	77.43	105.00	28.98	72.60	290.07	270.18	137.08	97.54	145.35	116.93	162.31	153.14	3257.72
TGA	1574	898	4778	1792	1267	3983	2520	2702	2538	1268	1530	2317	1859	1858	1582	1745	1834	4277	2122	1768	44212
% TO TGA	4.06	44.10	5.79	14.83	13.79	6.18	3.02	3.78	3.05	8.28	1.89	3.13	15.60	14.54	8.66	5.59	7.93	2.73	7.65	8.66	7.38
% TO TWL	1.96	12.16	8.49	8.16	5.36	7.55	2.34	3.14	2.38	3.22	0.89	2.23	8.90	8.29	4.21	2.99	4.46	3.59	4.98	4.70	100.00

Table 2. Important physical properties of wastelands

	Barren/rocky Hills	Sandy areas	Scrub land	Degraded grazing land	Water-logged areas	Salt affected
Landform	Hills	Dunes, Aeolian plain	Aeolian/ Alluvial plain	Alluvial plain	Alluvial plain	Alluvial plain
Slope	>35%	5-10%	3-5%	1-3%	0-1%	0-1%
Soil depth	Generally shallow but moderately deep at some places. Exposed rocks are also found at hill tops or very steep slopes.	Very deep	Very deep	Very deep	Very deep	Very deep
Texture	Sandy loam to Loam	Sand	Sand to sandy loam	Sand to sandy loam	Loam to clayloam	Sandy loam to loam
Water Table	–	Very deep	Moderately to very deep	Moderately to very deep	Shallow	Shallow to moderately deep

degraded due to lack of proper soil conservation and drainage measures. These are Panchayat lands and the total area under this class was found 923.63 sq. km.

Scrublands: These are mostly found in Bhiwani, Mahendergarh, Gurgaon and Hisar districts. These are the lands, which are generally prone to deterioration due to erosion and may or may not have scrub cover. Such lands occupy relatively high topographic locations. The total area under this class is 1142.99 sq. km.

Salt affected lands: The lands, which are cultivated either in one season or have even sparse vegetation on it, were not included in this category. Salt affected land is generally characterized as land that has adverse effects on the growth of most plants due to the action or presence of excess soluble salts (saline) or high exchangeable sodium. These lands are found in Mewat, Karnal, Sonipat and Panipat districts.

CONCLUSIONS

To undertake the remedial/reclamation measures, systematic upto date information of location extent and nature of wastelands is a pre-requisite. But due to the non-availability of up to date statistical information and a consolidated map, showing the geographical location and spatial distribution/ pattern of wastelands in the state, a long felt need has been realized to have a reliable and anaccurate base line information about the wastelands. Remote Sensing Technology is a powerful tool for survey, mapping and regular monitoring of wastelands, which is not only fast and accurate but also cost effective.

As Jatropha is a very hardy plant and can be grown in varying range of soil texture and have less requirement of water, so, the sandy areas and the hilly areas specifically Aravali hills are the potential sites which can be taken on priority where as other categories of wastelands can be studied further for Jatropha plantation. The monitoring of these plantations can be done using remote sensing technology.

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Effect of organic, bio-fertilizer and inorganic sources of nutrients on productivity and nutrient status of soil in garden pea based cropping sequence under Lahaul valley of Himachal Pradesh

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ABSTRACT

A field experiment was carried at the research farm of Highland Agricultural Research and Extension Centre, Kukumseri (Lahaul & Spiti), CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (Himachal Pradesh) with an objective to evaluate the impact of organic/bio-fertilizer and inorganic sources of nutrients on yield and available nutrient status of soil in garden pea-buckwheat/sarson cropping system. Significant increase was observed in yield attributes such as pods per plant, seeds per pod, green pod yield and straw yield with the application of FYM 2.5 t ha^{-1} in combination with *Rhizobium* and the application of 150% or 100% of recommended NPK through chemical fertilizers. This combination also showed a significant improvement in nutrient status of soil in garden pea based cropping system during both the years. Application of FYM 2.5 t ha^{-1} + *Rhizobium* found to be significantly better than FYM and *Rhizobium* alone in influencing yield attributes and yield of pea, and over all nutrient status of the soil. Increase in chemical fertilizers level from 50% to 150% recommended NPK also showed a significantly increase in pea yield and nutrient status of soil during both the years. From the study it can be concluded that for realizing higher yield of pea crop in garden pea based cropping sequence, combination of FYM 2.5 t ha^{-1} + *Rhizobium* in integration with 100% of recommended NPK through chemical fertilizers was as good as with 150% of recommended NPK under dry temperate conditions of Lahaul valley.

Key words: Farmyard manure, *rhizobium*, Garden pea, Buckwheat, Sarson, Dry temperate region

INTRODUCTION

Garden pea (*Pisum sativum* L.) belonging to family *Leguminosae* is one of the most important cash crop grown in winter season in plains of India. However, in Lahaul valley, it is cultivated during summers owing to low summer temperatures.

Therefore, green pods in this region are available at such a time when there is great scarcity in the market and demand exceeds supply. As a result, farmers get premium prices of green produce. Lahaul and Spiti one of the remotest tribal districts of Himachal Pradesh representing high hill temperate zone is characterized by paucity of rainfall, high wind velocity, low relative humidity, high evapo-transpiration rates and uneven variation in temperature. Soils of these regions are also coarser with low water holding capacity. Therefore, this area needs special attention for successful cultivation and higher productivity of crops. Further, incorporation of legume in an intensive cropping system is preferred by the growers of this region for in situ N replenishment in the soil. However, being a legume, pea crop after seed inoculation with *rhizobium* leguminosarum fix around 55-70 kg N ha^{-1} (Srivastava and Ahlawat, 1995). Farmers of this region are not acquainted with the use of bio-fertilizers in pea crop. Response of seed inoculation with *rhizobium* in pea crop is well established (Kanaujia *et al.*, 1997; Pandey, 2003). The incorporation of locally available organic input like farmyard manure which is a rich source of N besides other major and micronutrients can accelerate the productivity of pea besides maintaining the soil health. The recycling of disposable organic and their utilization in crop production is gaining momentum with the increasing awareness in soil and environmental pollution. Chemical fertilizers known for starter, respond well in this area for early maturity and prove beneficial in better utilization of soil moisture and nutrients and ultimately enhances yield. Since these chemical fertilizers are costly therefore, economic/optimal use of every gram of is highly

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desired. Hence, keeping above facts in mind, the present study was planned to generate information on the effectiveness of the integrated use of organic, bio-fertilizer and inorganic sources of nutrients on the productivity and residual soil fertility status for widely grown garden pea-bukwheat/sarson cropping system in dry temperate high hills condition of Himachal Pradesh.

MATERIAL AND METHODS

The present investigation was undertaken during the *summer* seasons of 2006 and 2007 at Research Farm of Highland Agricultural Research and Extension, Centre Kukumseri (Lahaul & Spiti), CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (Himachal Pradesh). The experimental site is situated at 32°44′ 55″ N latitude and 76°41′ 23″ E longitude at an altitude of 2734 m amsl in the trans-Himalayas where monsoon fails and rainfall is almost negligible. The soil of the experimental site was sandy loam in texture, slightly alkaline in reaction (pH 7.66), high in organic carbon (7.62 g kg^{-1}), medium in available nitrogen (325.0 kg ha^{-1}) but high in available phosphorus (30.0 kg ha^{-1}) and potassium (327.0 kg ha^{-1}) contents. The treatment combinations comprised of eighteen treatments, having six combination of two crop sequences (Pea-Buckwheat and Pea-Sarson) and three sources of organic fertilizer (FYM 5 t ha^{-1}, *Rhizobium* 200 g/10 kg seed and FYM 2.5 t ha^{-1} + *Rhizobium*) as main plot factors and three levels of chemical fertilizers (50%, 100% and 150% of recommended NPK i.e. 20:60:30 kg N, P_2O_5 and K_2O ha^{-1}, respectively) as sub-plot treatments. The field experiments were conducted in split-plot design with three replications having plot size 8.1m^2 each. The entire recommended dose of N (20 kg ha^{-1}), K_2O (60 kg ha^{-1}), P_2O_5 (30 kg ha^{-1}) was applied using IFFCO mixed fertilizer (12:32:16 NPK) at the time of sowing. Garden pea seeds (var. Palam Priya) were soaked in bavistin (0.1%) solution for 24 hours before sowing. Local varieties of buckwheat and sarson were used. The garden pea crop was sown on 4th May and 10th May 2006 and 2007, respectively with row to row spacing of 30 cm. The organics/ bio-fertilizers/chemical fertilizers were applied only to the main crop of garden pea as per the treatment. FYM was applied on oven dry weight basis as per treatment before the sowing of crop. Pea seeds were inoculated with *Rhizobium* 200 g/10 kg seed. Regular cultural operations as well as plant protection measures were done according to need of the crops. Growth in terms of plant height, yield attributes such as pods per plant, seeds per pod were recorded. The green pod and straw yields were recorded on plot basis and were converted into quintals per hectare. Soil samples were collected after harvesting of garden pea and buckwheat/ sarson crops during both years and were analyzed for pH, organic carbon content, and available NPK status using standard procedures (Jackson, 1973).

RESULTS AND DISCUSSION

Crop growth

Crop growth in terms of plant height did not show significant difference with respect to cropping

Table 1. Effect of crop-sequence, organic/bio-fertilizer and chemical fertilizers on growth, yield attributes, and yield of garden pea

Treatment	Plant height (cm)		Pods per plant		Seeds per pod		Green pod yield (q ha^{-1})		Straw yield (q ha^{-1})	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Crop-sequence										
C_1 : Pea-Buckwheat	62.5	59.3	14.8	13.0	7.1	6.9	113.4	106.9	16.0	15.8
C_2 : Pea-Sarson	62.6	59.4	15.2	13.2	7.1	7.0	114.1	107.1	16.0	15.9
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Organic/bio-fertilizer										
O_1 : FYM 5 t ha^{-1}	61.8	58.7	14.5	12.6	7.1	7.0	111.8	104.5	15.6	15.4
O_2 : *Rhizobium*	58.0	55.5	13.9	11.9	6.7	6.5	108.8	102.6	14.7	14.6
O_3 : FYM 2.5 t ha^{-1} + *Rhizobium*	67.9	63.9	16.7	14.8	7.5	7.4	120.6	113.9	17.7	17.5
LSD (P=0.05)	1.8	2.0	1.5	0.9	0.3	0.4	5.3	5.0	0.9	1.0
Chemical fertilizers										
F_1 : 50% NPK	53.6	50.7	12.1	10.4	6.4	6.2	102.2	96.0	13.1	13.0
F_2 : 100% NPK	64.6	61.1	15.1	13.6	7.3	7.2	115.2	108.3	16.3	16.1
F_3 : 150% NPK	69.6	66.2	18.0	15.3	7.7	7.5	123.9	116.8	18.6	18.4
LSD (P=0.05)	2.3	2.2	1.3	1.0	0.3	0.4	4.7	4.5	0.8	0.8

sequence in any one of two experimental years (Table 1). Because under both sequences, the garden pea crop received the similar amount of nutrition. Plant height of garden pea improved significantly due to different organics and bio-fertilizers. Application of FYM 2.5 t ha^{-1} + *Rhizobium* resulted in tallest plants of garden pea during both the seasons. This treatment was statistically followed by FYM 5 t ha^{-1} and *Rhizobium* alone. This could be ascribed to combined effect of farmyard manure and *rhizobium*. Farmyard manure improved the soil physical conditions provided for plant growth and also increased the availability of nutrients especially N, P_2O_5 and K_2O from the early stages of crop (Ramana *et al*., 2010). *Rhizobium* enhanced availability of nitrogen in *rhizobium* inoculated plots. Bhandal *et al*. (1989) reported similar response of *rhizobium* inoculation. Plant height increased significantly and consistently with increasing levels of chemical fertilizers from 50% to 150% NPK during both the years (Table 1). The reasonably better performance of super-optimal doses of NPK may be due to better initial availability of nutrients to the crop. Mishra and Solanki (1996), during their study on cowpea were also in the opinion that phosphorus fertilization might have improved the root system which in-turn helped more assimilation of nutrients resulting in increased growth.

Yield attributes and Yield

Yield attributes and yield was not significantly affected by cropping sequence during both the years. However, organic/bio-fertilizers showed a significant influence on yield attributes and yield of garden pea crop during both the crop seasons. Highest pods per plant and seeds per pod were obtained when the pea crop was grown under the combined application of FYM 5 t ha^{-1} and *Rhizobium*. Though, FYM 5 t ha^{-1} and *Rhizobium* alone were statistically equal in influencing number of pods per plant and seeds per pod during both the years. The application of FYM 2.5 t ha^{-1} + *Rhizobium* resulted in highest green pod yield during both the years. *Rhizobium* alone was as good as FYM 5 t ha^{-1} in influencing green pod yield of garden pea during both the years. FYM 2.5 t ha^{-1} + *Rhizobium* increased the mean garden pea yield by 8.4% and 10.9% over FYM and *Rhizobium* alone, respectively. Application of FYM 2.5 t ha^{-1} + *Rhizobium* also resulted in highest straw yield of garden pea during both the years. *Rhizobium* alone was at par with FYM alone during 2007, while the later gave significantly higher straw yield of garden pea over the former in 2006. Such a higher yield can be attributed to better expressions of various yield attributes. This was due to the cumulative effect of farmyard manure and *rhizobium*. The beneficial effect of organic manure on yield and its attributing characters might be because of additional supply of plant nutrients as well as improvement in physical and biological properties of the soil (Majumdar *et al*., 2002). Increase in yield attributes and yield of garden pea crop might be also due to the inoculation of pea seeds with *rhizobium* because it helps in greater synthesis of carbohydrates and their translocation due to better nutritional environment. These views are in conformity with the results of Asgher *et al*. (2003). The effects of fertility levels on yield attributes and yield of pea crop were significant during both the years of study (Table 1). Application of 150% recommended NPK also registered highest pods per plant during both the years. This was significantly followed by 100% and 50% recommended NPK consecutively. Whereas, increase in seeds per pod was significant upto 150% NPK during 2006. However, during 2007 seeds per pod increased significantly upto 100% NPK only. The grain and straw yields markedly increased with the increasing levels of N, P and K upto 150% of recommended NPK. The highest green pod yield (123.9 and 116.8 q ha^{-1} during 2006 and 2007, respectively) was recorded with 150% NPK. On an average, 150% NPK increased green pod yield by 7.7% over the recommended NPK and 21.4% over 50% NPK. The higher yield could be attributed to increased growth and yield attributes. This might be owing to accumulation of more photosynthates in sink (Rana *et al*., 2009). Increase in yield attributes and yield of pea crop with the application of fertilizers, particularly nitrogen (N) and phosphorus (P) might be due to the reason that N requirement of the high yielding varieties is fairly high, and P is known to enhance the activity of *rhizobia* and thus atmospheric nitrogen fixation (Yadav *et al*., 1996).

Nutrient status of soil

Nutrient status of soil did not show any variation with respect to cropping sequence during both the years (Table 2). Organic/bio-fertilizers showed a significant influence on soil available nutrient status after harvest of garden pea and buckwheat/sarson. Organic/bio-fertilizer could not bring about significant variation in pH value of soil. However, available N, P, K status and organic carbon of soil were significantly affected with the application of varying levels of organic/bio-fertilizer. Treatment FYM 5 t ha^{-1} remaining at par

Table 2. Effect of crop-sequence, organic/bio-fertilizer and chemical fertilizers on soil properties and available NPK status of soil after harvest of garden pea and buckwheat/ sarson

Treatment	Soil pH				Organic carbon (g kg^{-1})				Available N (kg ha^{-1})				Available P (kg ha^{-1})				Available K (kg ha^{-1})			
	2006		2007		2006		2007		2006		2007		2006		2007		2006		2007	
	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s	After pea	After b/s
Crop-sequence																				
C_1 : Pea-Buckwheat	7.1	7.1	7.1	7.0	7.78	7.93	7.99	8.11	392.2	388.7	394.8	390.5	32.5	35.0	32.9	35.3	327.0	324.2	329.1	326.0
C_2 : Pea-Sarson	7.1	7.0	7.1	7.0	7.72	8.01	7.92	8.16	391.7	387.4	394.9	389.4	32.6	35.1	33.1	35.2	327.0	324.3	328.8	326.3
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Organic/bio-fertilizer																				
O_1 : FYM 5 t ha^{-1}	7.1	7.0	7.1	7.0	8.22	8.41	8.37	8.49	388.5	384.9	392.5	386.9	31.7	34.4	32.1	34.6	325.8	322.8	327.7	324.8
O_2 : *Rhizobium*	7.0	7.0	7.0	6.9	7.16	7.42	7.37	7.58	378.9	375.6	381.7	377.4	27.9	31.0	28.3	31.3	320.8	318.5	322.7	320.1
O_3 : FYM 2.5 t ha^{-1} + *Rhizobium*	7.1	7.1	7.1	7.1	7.87	8.10	8.12	8.33	408.5	403.6	410.3	405.7	38.0	39.6	38.4	39.8	334.3	331.5	336.5	333.6
LSD (P=0.05)	NS	NS	NS	NS	0.66	0.31	0.40	0.29	6.5	10.2	4.8	5.5	3.0	1.8	2.0	1.7	5.2	5.4	2.3	4.3
Chemical fertilizers																				
F_1 : 50% NPK	6.9	6.9	6.9	6.9	7.68	7.88	7.87	8.03	365.2	361.1	367.3	362.6	23.2	25.6	23.7	26.0	314.6	312.1	316.2	313.8
F_2 : 100% NPK	7.1	7.1	7.1	7.0	7.74	7.97	7.93	8.13	396.1	391.8	399.3	393.6	34.2	37.2	34.7	37.4	328.6	325.7	331.2	328.4
F_3 : 150% NPK	7.2	7.1	7.2	7.1	7.83	8.07	8.06	8.24	414.6	411.1	417.9	413.7	40.2	42.2	40.5	42.3	337.8	335.0	339.4	336.3
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	8.5	7.4	8.2	7.0	2.2	1.4	2.1	1.5	4.1	3.5	4.1	3.1

with FYM 2.5 t ha^{-1} + *Rhizobium* except after buckwheat/sarson during 2006, resulted in significantly higher soil organic carbon over *Rhizobium* alone after pea and buckwheat/sarson during both the years. Soil organic carbon content showed tremendous increase from 7.16 to 7.58 g kg^{-1} under *Rhizobium*, 7.87 to 8.33 g kg^{-1} under FYM 2.5 t ha^{-1} + *Rhizobium* and from 8.22 to 8.49 g kg^{-1} under FYM alone within a period of two years of experimentation. Increase in organic carbon with the application of farmyard manure might be due to reason that it provides organic matter to the soil. The increase in organic carbon with the application of organic manure (FYM and vermicompost) was also reported by Maheshwarappa *et al*. (1999). The available soil N, P and K contents after harvest of garden pea and buckwheat/sarson were significantly higher under plots receiving FYM 2.5 t ha^{-1} + *Rhizobium* in garden pea crop. This was followed by FYM 5 t ha^{-1} and *Rhizobium* alone in the order during both the years. Further, FYM 5 t ha^{-1} showed a significant increase in available nitrogen status of soil over *Rhizobium* after pea during both the seasons. However, in the first year available soil nitrogen content after buckwheat/ sarson did not differ significantly amongst these two treatments. Treatment FYM 5 t ha^{-1} showed a significant increase in available soil potassium content after the harvest of each crop over *Rhizobium* during second year of study. The significant build up of the soil available N, P and K status due to farmyard manure and *rhizobium* application could be attributed to increased activity of nitrogen fixing bacteria thereby, resulting in higher accumulation of N in soil, besides additional supply of N, P and K to soil through farmyard manure (Miller *et al*., 1987; Datt *et al*., 2003). Dinesh and Dubey (1999) also reported that mineralization of net nitrogen was significantly higher in soil amended with organic matter as compared to unamended soil. Chemical fertilizers also showed an improvement in nutrient status of soil during both the years (Table 2). Different chemical fertilizer levels did not significantly influence pH and organic carbon content of soil after garden pea or buckwheat/sarson during both the crop seasons. However, a significant increase in available soil N, P and K content was recorded with the application of chemical fertilizers after harvest of garden pea and buckwheat/sarson. Increasing levels of chemical fertilizers from 50 to 150% NPK resulted in significant and consistent increase in soil N, P and K contents after harvest of garden pea and buckwheat/sarson during both the years. Increase in fertilizer doses resulted in increased level of soil available nutrients (NPK) contents. This may be attributed to the fact that with higher fertilizer doses, higher amount of fertilizer nitrogen could be converted into available form by the bio-chemical reactions of fertilizer N with the soil organic matter. Further, P status of soil increased with the increasing level of fertilizers due to lower utilization of P by crop from the applied source, resulting in building of soil phosphorus status (Prasad, 1994). The enhanced status of K could be attributed to the higher amount of potassium being added through chemical fertilizer IFFCO (12:32:16).

Integrated effect of organic/bio-fertilizer and chemical fertilizers

Integration of organic and inorganic sources of nutrient in legumes is beneficial because it maintain soil health and productivity of crops. Interaction between organic/bio-fertilizer and chemical fertilizers was significant for green pod yield and soil available N, P and K contents (Tables 3 & 4). Treatment combination O_3F_3 being at par with O_3F_2, gave highest green pod yield of garden pea over rest of the treatment combinations during both the crop seasons. Similarly, interaction effect different levels of organic and inorganic fertilizers on nutrient status of soil showed that combination of FYM 2.5 t ha^{-1} + *Rhizobium* with 150% of recommended NPK remaining at par with 100% of recommended NPK gave significantly higher available N, P and K contents in soil after the harvest of garden pea and buckwheat/sarson during both the years. This may due to added supply of nutrients. Since all the applied nutrients are not utilized totally in the one or two cropping seasons, their carry over for a longer period of time is obvious for being utilized by subsequent crops. Therefore, available soil N, P and K contents after the harvest of garden pea and buckwheat/sarson were significantly higher under O_3F_3 and O_3F_2 each year. Tolanur and Badanur (2003) have also reported similar build-up of P with the application of FYM or vermicompost. Build-up of available nutrient status of soil also might be attributed to the reason that pea is a legume crop, the build-up of N in soil through biological nitrogen fixation by the *rhizobium* present in the root nodules of pea crop seems reasonably explained. The higher available K may probably due to the conversion of unavailable K to available K in the soil solution. Since integration of FYM 2.5 t ha^{-1} + *Rhizobium* with 100% NPK (O_3F_2) was as good as 150% NPK (O_3F_3) in influencing green pod yield of garden pea and

Table 3. Interaction effect of organic/bio-fertilizer and chemical fertilizers on green pod yield (q ha^{-1}) and available N (kg ha^{-1}) in soil after harvest of garden pea and buckwheat/sarson

Treatment	Green pod yield(q ha^{-1})						Available N(kg ha^{-1})											
	2006			2007			2006						2007					
							After pea			After buckwheat/sarson			After pea			After buckwheat/sarson		
	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3
F1	102.2	100.6	103.8	95.4	94.6	97.9	364.7	359.7	371.1	361.0	357.6	364.8	366.0	361.7	374.2	362.6	357.7	367.7
F2	111.8	106.5	127.4	104.1	100.4	120.4	388.5	376.1	423.6	384.0	370.2	421.3	395.0	378.6	424.3	385.3	373.0	422.5
F3	121.6	119.5	130.5	114.0	112.9	123.5	412.2	400.7	430.9	409.6	399.0	424.8	416.5	404.8	432.5	412.7	401.4	426.9
LSD (P=0.05)																		
Fertilizer levels at the same organic/ bio-fertilizer level		8.2			7.8			14.8			12.8			14.1			12.1	
Organic/bio-fertilizer level at the same or different fertilizer levels		8.5			8.1			13.7			14.6			12.5			11.3	

O_1 : FYM 5 t ha^{-1}; O_2 : *Rhizobium;* O_3 : FYM 2.5 t ha^{-1} + *Rhizobium*; F_1 : 50% NPK; F_2 : 100% NPK; F_3 : 150% NPK

Table 4. Interaction effect of organic/bio-fertilizer and chemical fertilizers on available P and K (kg ha^{-1}) in soil after harvest of garden pea and buckwheat/sarson

Treatment	Available P(kg ha^{-1})												Available K(kg ha^{-1})											
	2006						2007						2006						2007					
	After pea			After buck wheat/sarson			After pea			After buck wheat/sarson			After pea			After buck wheat/sarson			After pea			After buck wheat/sarson		
	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3	O_1	O_2	O_3
F1	23.4	21.1	25.2	25.4	23.1	28.3	23.9	21.4	25.6	25.7	23.5	28.7	315.0	311.2	317.4	313.0	310.5	313.0	316.8	312.6	319.3	314.5	311.0	316.0
F2	31.9	27.1	43.7	35.8	31.3	44.6	32.3	27.7	44.1	35.9	31.5	44.9	326.2	318.7	340.8	322.0	316.1	339.0	328.7	321.5	343.5	326.5	318.0	340.6
F3	39.7	35.6	45.1	42.1	38.7	45.8	40.2	35.9	45.4	42.2	38.9	45.8	336.0	332.6	344.8	333.5	329.1	342.5	337.6	333.9	346.6	333.6	331.4	344.1
LSD (P=0.05)																								
Fertilizer levels at the same organic/bio-fertilizer level		3.9			2.5			3.7			2.5			7.1			6.1			7.1			5.4	
Organic/bio-fertilizer level at the same or different fertilizer levels		4.3			2.7			3.6			2.7			7.8			7.4			6.2			6.1	

O_1 : FYM 5 t ha^{-1}; O_2 : *Rhizobium;* O_3 : FYM 2.5 t ha^{-1} + *Rhizobium*;F_1 : 50% NPK; F_2 : 100% NPK; F_3 : 150% NPK available nutrient status of soil, there was no need to apply NPK fertilizer beyond 100%. Hence, it is easily concluded from the present study that we can save 50% NPK by applying 100% NPK in combination with 2.5 t FYM on dry weight basis and the pea seed be inoculated with *rhizobium*. This may be due to the fact that *rhizobium* inoculation is very effective in harnessing atmospheric nitrogen for improving nitrogen status of the soil. Kumar *et al*. (2005) reported a saving of 25% NPK in rajmash by treating seeds with *Rhizobium*.

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