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Land Modification Models for Restoring Waterlogged Sodic Soils in Uttar Pradesh – The Innovations, Economics and Financial Viability

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ABSTRACT

Canal irrigation in some part of the Indo-Gangetic plain led to twin problems of waterlogging and sodic soil formation. Inadequate drainage and continuous seepage from the canal resulted in a rise in water table (less than one meter) coupled with subsequent upward movement of salts on the surface soil made the land highly alkaline (pH over 9) and unproductive. After realising benefits for some years, the negative externalities offset the positive impact which led to crop losses, estimated to the extent of 45 and 62 per cent for rice and wheat yields. Land and water productivity diminished and caused severe loss of livelihoods for the farmers adjacent to the canal area. Efforts to restore such land through conventional methods of gypsum-based reclamation, intercept drainage through perforated pipe lines and eucalyptus biodrainage belt were not found successful. Finally, the innovative land modification models (LMM) were evolved to harvest and use the seepage water from the canal and demonstrated in the farmers' fields successfully. Land and water quality improved and multiple crops were possible to grow on this degraded land. Economic evaluation in terms of financial feasibility, socio-economic suitability and sustainability of LMM models were assessed. The break-even size of interventions of the models was calculated to be 0.44 ha and 0.38 ha for crop based and fish based systems. The innovative models can be a solution to problems which are techno-economically sustainable, challenged by socio-economic constraints to some extent, which can be addressed through policy initiative, have been suggested.

Key words: *Land modification models; degraded land; waterlogged; sodic soil; crop losses; impact assessment; financial viability;*

INTRODUCTION

The United Nation Decade on Ecosystem Restoration 2021-2030, declared on 1 March 2019 by the UN General Assembly, aims to massively scale up the restoration of degraded and destroyed ecosystems as a proven measure to fight climate change and enhance food security, water supply and biodiversity towards achieving multiple sustainable development goals (SDG). Restoration of degraded salt-affected land can contribute to achieving at least three SDG goals such as poverty, hunger and life on lands. It is estimated that 96.40 million ha of land (29% of total geographical area) are under the process of land degradation in India (ISRO, 2016). Land degradation in the form of salt-affected soils (6.73 million ha) is one of the challenges for food production and threatening agricultural growth and overall economic development of the country. Unless preventive/ameliorative attempts are taken the areas under salt affected soils in the country are estimated to increase to 16.2 million ha by 2050 (ICAR, 2015), an increase from 5 to 11 per cent of total net sown area of the country (141 million ha) and it may turn large areas of cultivable land to completely barren. About 2.46 million ha of land in irrigated commands of the country suffers from waterlogging, either seasonally or permanently (Sharma et al., 2016). Poor management of critical soil, water resources and unscientific agricultural intensification directly affects the land quality. Often irrigation development project has led to formation of salt-affected areas primarily due to inadequate attention to drainage problem. Thus, in many instances, after realising benefits for some years, the negative externalities offset the positive impact (Singh, 2009; Joshi, 1987; Joshi & Jha, 1991; Joshi, 2011).

Sharda Sahayak Canal, commissioned in 1968 (year of approval by Planning Commission of India), aimed to provide irrigation to 1.78 million ha of arable area spread over 15 districts of Uttar Pradesh. After the introduction of the canal, agriculture productivity markedly increased in the command area. However, inadequate drainage and continuous seepage from the canal resulted into a rise of water table and subsequently upward movement of salts accumulation on the surface soil. Currently, about 0.50 million ha sodic lands are affected with shallow water table conditions in *Sharda Sahayak Canal Command* area, not suitable for cultivation economically. Even after conventional method of gypsum-based reclamation efforts (Planning commission of India, 2007), part of it (0.18 million ha) are suffering from twin problem of shallow groundwater water table (less than one meter) and high sodic (soil pH over 9) conditions (Singha et al., 2008; Bhardwaj et al., 2019). This has led to diminishing land-water productivity and loss of livelihoods for the farm families in the affected reach of the canal area. The land which was once highly productive, gradually became severely degraded (called '*ushar*' in local language) and unsuitable for cultivation of any crop. Farmers were desperately trying to make the degraded lands productive by using alternative such as incorporation of water hyacinth, farm yard manure (FYM), cow dung or leaving straw on the fields for decomposition, but all these were not good enough to provide them positive return to added cost. Taking up the challenge, ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI) through its Regional Research Station (RRS), Lucknow, Uttar Pradesh attempted different kinds of land modification of land to harvest and use the seepage water from the canal. Harvesting and management of canal seepage water through such land modification, was demonstrated in the farmers' fields and viewed as one of the possible ways to grow multiple crops on such land, which otherwise remained unproductive. The land modification models (LMM) were developed to harvest the canal seepage water at farmers' fields in alongside the canal. Water balance study indicated that an average depth of 0.60 m of seepage water could be harvested in the excavated ponds in the LMM for a period of 8-11 months in a year, which was sufficient for growing crops and fish in the system (Verma et al., 2016). The efforts have resulted into possibility of growing several crops on this waterlogged sodic soil. Similar to this, different kinds of land modification (known as land shaping technology) was successfully demonstrated in large scale for coastal saline management in lower gangetic plain region in India in which rainwater instead of canal seepage water was harvested, stored and utilised through creation of on-farm reservoir (Bandypadhyay et al. 2009; Mandal et al., 2018; Mandal et al., 2013; Mandal et al., 2015; Burman et al., 2015; Mandal et al., 2019). Such innovative LMM was first attempted to manage the highly degraded waterlogged and sodic soil land in this central Indo-Gangetic plain of India. Economic evaluation in terms of financial feasibility, socio-economic suitability and sustainability of such models are essential to understand how far the success of this new technology can be out-scaled in larger areas. Based on the field level data from the demonstrated LMM, the economic evaluation study was conducted with specific objectives, analyzing the impact of land modification models on farm-level economy under waterlogged sodic soils; examining the financial viability of land modification models in waterlogged sodic soils; and to understand various constraints and socio-economic suitability in large scale adoption of LMM by the farmers.

METHODOLOGY

Study Area

Sharda Sahayak Canal, a major irrigation project in central Indo-Gangetic plain region of India, initiated in 1968 with approved cost of ₹19.90 million, was completed in 2000 at final cost of ₹133.60 million. The irrigation project had culturable command area of 0.15 million ha with ultimate irrigation potential of 0.18 million ha and targeted to benefit spread over 15 districts of Uttar Pradesh. However, benefits of irrigation water were realised during 2-3 decades, after that the twin problem of waterlogging and sodicity (or alkalinity) emerged. Continuous seepage from unlined canal, inadequate drainage provision, low gradient, dispersed soil and blockage of natural drainage system of the area resulted in extensive waterlogging and salt accumulation in the soil. Currently, over 0.18 million ha of cultivable land along both sides of the canal is severely affected by waterlogging and salinity. Raebarelly and Lucknow are two among those 15 districts in which part of the agricultural land is severely affected by the seepage water from the canal (Fig., 1). With a multidisciplinary team of scientists comprising of experts from soil science, water management, crop sciences and agricultural engineers, initiated the LMM in the affected area since 2005. These models were designed and re-designed several times during 2005-2012 based on the experience and actual performance of the models and considering various parameters, such as, elevation, length and breadth of the raised land, area under excavated land/pond, water flow in the canal, rate of seepage, water available through rain and evapotranspiration, (Verma et al., 2016). This study is based on the actual field data generated from the 7 number of LMM demonstrated at the farmers' fields during 2006-2018.

Fig. 1. Location and physiography of the study area as prevailig (A) and after the land modification (B)

Data Sources

Information on socio-economic characteristics of the farmers was collected from both collaborative (farmers who provided land for LMM demonstration) and other (farmers whose land was similarly affected) farmers in the study villages during 2018-20. Primary survey was focused to understand the current agricultural practices of 7 collaborative farmers and 55 other farmers, thus constituting a total of 62 farmers. All these farmers' lands were affected by waterlogged and sodic salts at varying extent due to seepage water from the *Sharda Sahyak Canal* in Raebarelly and Lucknow districts. The study villages were *Kashrwan* and *Mahraura* from *Bachrwan* block of Raebarelly district, *Patwakhera* and *Lalaikhera* village from *Mohanlalganj* community development block of Lucknow district. LMM were constructed in various years during 2005-06 to 2017-18 in the fields of collaborative farmers. Primary survey for the economic evaluation study was conducted during 2018-19 and 2019-20 for collection of detailed information on farm size, educational status, occupation, cropping systems and pattern, income sources, costs and returns of crops grown, production and marketable surplus of crops, selling of crops, agricultural risks and constraints in farming. Inclusion of other farmers in the primary survey was to understand their opinion on the demonstrated LMM and to assess the socio-economic suitability of out-scaling of such models in larger areas. The results from the data analysis was presented and consulted with 68 scientists who are actively engaged in research on salt affected soils in India, having varying experiences in the range of 4 to 30 years. Their views and concern was synthesised to draw out possible implications of large scale implementation such LMM in the problem areas. Some relevant secondary information was also collected and used in the study from various published sources such as ICAR-CSSRI Annual reports (CSSRI, 2014-15 to 2017-18), the *Krishi Vigyan Kendra (KVK)* of two districts, Raibarelly (https://raebareli.kvk4.in) and Lucknow (https://lucknow.kvk4.in), technical bulletin (Singh et al., 2008), resource book on successful adaptations in salt affected agro-ecosystems of India (Singh et al., 2019) and Uttar Pradesh Bhumi Sudhar Nigam (Govt. of UP, 2019).

Economics of cropping systems

Since 2012, five LMM were constructed at farmers' fields, later on 3 more models were constructed and farmers are using all these systems extensively. Out of these, one model was constructed in waterlogged area but without high sodic problem, hence was not included in the evaluation study. Economics of the crops, fish and cropping systems was analysed applying farm budgeting analysis. Detailed expenditures and return data were collected from the farmers for management of the LMM. The economics of the crops was calculated following the norms of cost of cultivation methods of Commission for Agricultural Costs and Prices (CACP), Government of India (Govt. of India, 2008). Costs components included are, input costs incurred like seed, fertilisers, irrigation, human labour (hired and own) required for all activities (land preparation, sowing, applying irrigation/ pesticides/ fertilisers, intercultural operation, harvesting etc), machine labour (mainly power tiller and tractor), fertilisers, organic manure/compost, irrigation charges, pesticides (insecticides/ fungicides/ herbicides), interest rate on working capital as opportunity cost of capital expenditure (maximum six month for annual crops), depreciation charges (if any) and miscellaneous (like watch and ward, unforeseen expenditures etc). Cost of family labour was accounted as imputed value of labour based on available open market prices. Economics of fish rearing was also computed based on the cost of input applied (fingerlings, feed and labour) and value of output (fish production multiplied by farm-gate price received on selling of the fish). Multiple crops were grown on the LMM in which crop area under individual crops were very small and most of the operations (such as intercultural operation, irrigation, application of fertilisers, pesticides and harvesting) were carried out simultaneously, therefore expenditures and return on the entire system was computed as a system.

Cropping intensity and extent of diversification and crop losses

Cropping intensity on sample farmers was calculated based on average gross cropped area divided by average net cropped area multiplied by hundred. The extent of crop diversification under LMM and farmers practices was estimated by employing Simpson Diversification Index (SID), where $SID = 1 - \sum(Xi / \sum Xi)^2$ and Xi = area under i^{th} crop. Estimation of crop losses due to waterlogged and sodic condition of land was computed by taking the difference in return obtained by the farmers' practiced cropping system in the degraded area (plots located up to 300 m distance from the canal) and in the normal/good land (plots located beyond 300 m, not affected by the seepage), based on the actual field situation in the study area. Cropping intensity was calculated under normal and degraded land to estimate the extent of crop losses. Further, extent of crop losses at region level was estimated by multiplying per hectare crop losses by extent of degraded land (0.18 million ha) and adjusting with cropping intensity factor (k). The value of 'k' is the ratio of prevailing cropping intensity (185 per cent) divided by the maximum cropping intensity (300 per cent) that can be achieved with the cropping systems (rice-wheat-mint) under study.

Soil and water sample analysis

To understand how far the system would be environmentally sustainable, soil scientists regularly monitored the key soil parameters (Electrical conductivity/ECe for salinity, pH for alkalinity and Exchangeable Sodium Percentage/ESP) and water quality parameters (ECe and pH) for the system. The initial soil samples were collected (0-30 cm depth) in the month of April 2013 and were separated segment wise before configuration of LMM. Similarly, the surface and sub-surface soil samples were collected in the subsequent four years after configuration of LMM in each system. The depth wise soil samples were dried in air and ground to pass through 2 mm sieve for individual analysis. Soil pH and electrical conductivity (EC) were determined in 1:2 soil:water ratio by potentiometric method using ion analyser (Thermo Orion make) with the help of pH and EC electrode. The ESP of the soil was estimated by the method of Soil Survey Staff (2011), using following equation:

$$ESP = \frac{Na_{Exch}}{CEC} X 100$$

Where, ESP = exchangeable sodium percentage; Na_{Exch} = NH4OAc extractable Na, and CEC = cation exchange capacity (Cmol kg^{-1}).

Financial analysis of the investment on land modification models

Financial analysis was carried out by employing investment criteria, internal rate of return (IRR), net present value (NPV), benefit-cost ratio (BCR) and payback period (Gittinger, 1982). After construction of the LMM models, farmers were using the systems for growing both crops and fish. But some farmers preferred to grow fish as main interventions over crops and others followed vice versa i.e., growing crops were preferred over fish. Viewing this actual practices, financial analysis for the LMM was carried out focusing on two different kinds of LMM, with crop-fish based (0.60 ha and more return from crop component) and other fish-crop based (0.46 ha and more return from fish component) model. The initial investment was calculated, assuming the prevailing rate (₹ 90 cu.m^{-1} of soil) of soil excavation in the area, following the National Bank for Agriculture and Rural Development (NABARD) guideline in the Uttar Pradesh state for pond excavation (NABARD, 2019). These two kinds of models were being utilised by the farmers intensively over the years after construction. Various assumptions were considered for investment analysis such as, (i) economic life 10 years (beyond which major investment will require for system, cost-return flows might be changed significantly due to policy or structural change in economy; (ii) discount rate was assumed 14% (maximum lending interest rate by bankers, will take care of time value of money); (iii) cost and return will change in same magnitude during the economic life of the system. Incremental costs and returns streams for the LMM were analysed under two scenarios, without any opportunity cost, when the model is constructed in the highly degraded land (completely barren or '*ushar*' land and no 'next best alternative' available, hence 'zero' return), hence no return; alternatively, with opportunity cost, model is constructed on land that is still productive to some extent through practicing rice-wheat-mint cropping system. Net return from this rice-wheat-mint cropping system was taken as opportunity cost for constructing LMM. Few farmers were seen to grow mint in relatively less affected lands with low productivity. These scenarios were assumed based on the actual practices in the study area learned through the primary survey. Besides, the simulation of investment analysis was also carried out under the scenarios, (a) investment made through own capital (private investment) without any assistance from government and (b) with subsidy assistance (assuming 25% of initial capital) from the government. Government of India normally promotes good agricultural practices through different financial schemes, therefore such alternative policy option was also analysed. The investment analysis criteria, payback period, IRR, NPV and BCR are explained below:

(I) Payback Period: It is the time required for the investment on land modification models to generate sufficient increments of cash to recover the initial capital expenditure. Thus, it takes into account the capital expenditure on a model and relates that to the net cash flow (undiscounted) of the project. It takes no account of cash flows emanating after the payback period, and it does not take into account of the pattern of flows within that period. This criterion is preferred for decision making where risk perception of decision maker is high.

(ii) Benefit-Cost Ratio (BCR): The benefit cost ratio is the ratio of present worth of incremental benefit stream (cash inflow) to present worth of incremental cost stream (cash outflow) of the land modification model.

$$\text{BCR} = \frac{\text{present worth of incremental benefit stream}}{\text{present worth of incremental cost stream}}$$

$$= \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}$$

(ii) Benefit-Cost Ratio (BCR): The benefit cost ratio is the ratio of present worth of incremental benefit stream (cash inflow) to present worth of incremental cost stream (cash outflow) of the land modification model.

Where, B_t = incremental benefit in t^{th} period
C_t = incremental cost in t^{th} period
n = number of years
i = discount rate

If the ratio is greater than one, the investment is financially viabl**e**

(iii) Net Present Value (NPV): Net present value was computed as the difference between the present worth of increment benefits and present worth of incremental costs from an investment on land modification models.

Where, the notations on right hand side of the equation stand for the same meaning as given under BCR. If the NPV is positive, the investment in question is worthwhile. It is an absolute measure of profitability showing the size of profit.

$$\text{NPV} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

(iv) Internal Rate of Return (IRR): The internal rate of return is that discount rate which makes the net present value of an investment on a project equal to zero. Thus, IRR is that discount rate 'i' which makes

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0$$

The notations are same as above. In other words, IRR is the maximum rate of earning that an investment on land modification models can internally generate. The internal rate of return is compared with the project's cost of capital in order to determine its financial feasibility. If IRR is greater than cost of capital, the project is accepted. It is worked out as follows:

$$\text{IRR} = \text{lower discount rate} + \text{difference between two discount rate} \times \left[\frac{\text{NPV at lower discount rate}}{\text{absolute difference between the two NPV at two discount rate}}\right]$$

Break-even analysis for land modification models

Break-even point is that point at which total value of benefits generated from the investment on LMM will breaks even with present value of total cost and therefore it attains no-profit-no-loss position over economic life of the systems. The break-even size of operation was determined under three alternative satiation, *first* entire investment made with own cost and without any opportunity cost. Such unproductive land prevails at a distance within 50 m from the canal; *second* investment is made with own cost with some opportunity cost (net return obtained from rice-wheat-mint cropping system). Such situation prevails for land located at a distance between 50-300 m from canal; and *third* investment is made with own cost along with 25 per cent subsidy receipt from the government. This situation was hypothesised as a policy option, in view of likely government assistance, which may be available in future. Size of operation which yielded incremental benefits in present value terms equal to cost stream in present value term was computed as the break-even size of proposed land modification models. Thus, to find out break-even size of land modification models, the present worth of incremental benefits under a given scenario was linearly adjusted to equal present worth of the cost stream.

RESULTS AND DISCUSSION

Innovation and developmental pathways of land modification models

The adverse impact in terms of production and income losses of the major irrigation project, the *Sharda Sahayak Canal* in Uttar Pradesh started emanating after 3-4 decades due to continuous seepage from canal water. This called for an urgent attention of agro-scientist to make such lands again productive through innovative land management ways (Table 1). The water table in the adjoining canal area increased (within 2 m from surface) and led to waterlogged sodic soil problem that turned large culturable area completely barren or poorly productive. In the study area, it was observed that the severely affected land was extended up to 50 m (completely barren or called '*ushar*') where no crops could be grown and up to 300 m distance from the canal, the land productivity declined drastically along both side of the canal. As the water table was within 2 m from surface, the gypsum application was not successful and not recommended as amelioration option for sodic land. Following unsuccessful amelioration by gypsum application, interceptor drainage through perforated drain pipe and bio-drainage belt was attempted for managing the waterlogging condition in the field. Intercept drainage was also attempted in small area but could not be

Table 1: Genesis and developmental pathways of land modification models

Causes/Rational/ Description	Efforts/ Initiatives	Experiences/ Lesson	Success/ Failure
Sharda Sahayak Canal for irrigation to culturable command area of 0.15 m ha	Initiated in 1968 and completed in 2000. Providing irrigation to 17.80 lakh ha of land	During 1980s cultivation was good, later land alongside the canal becomes waterlogged.	After initial success leads to waterlogging & sodic, affected 0.18 m ha
Seepage increased in water table (< 2 m) and affected land productivity of about 250-300 m area in both sides of canal	Intercept drainage and bio-drainage	Decreased water table but not sufficient for growing crops, community approach was needed	Drainage system didn't work, plants growth affected, long waiting time needed for effective bio-drainage, single drain interceptor was not effective
Increased sodicity (pH >9)	Gypsum application	As water table too high (<2m) was not feasible	Didn't work, Not recommended
Waterlogging due to absence of drainage	Intercept drainage system was installed in a small area, open drains heavily weed infested and almost choked.	Gradient was not available, drainage choked in wet season, large area needed to cover. Carrying capacity of the drain was inadequate.	Benefits were not significant due to inadequate drainage
Land Modification techniques (early design, 2005)	Raised and Sunken bed constructed in 1:25 ratio, depth of pond was 1.5-2 m. The width of the bed was not optimised	Distance from canal was crucial, design needs to be changed. Salt accumulation after two years on surface of raised bed where width was 40m	Crop growth was possible, successful but needed further refinement
Land Modification techniques (design during 2009)	Raised and sunken bed was constructed with top of raised bed was only 2 m and depth of sunken bed was 0.60 m. Expenditure was minimum.	Operation problem due to narrow width of raised bed and poor seepage water, not sufficient for growing fish	Seasonal vegetables could grow but highly labour intensive. Seasonal vegetables grown successfully but labour intensive
Land Modification techniques (re-designed, 2012 onwards)	The ratio of raised and sunken was 1:1, width of raised bed was optimized, maintained 10-25m according to actual field conditions, depth of pond was 2m	Adequate water stored for fish and irrigation to crops, sodicity problem was managed	Successful, cropping systems possible, fish grown without any further re-sodification

Source: Authors compilation based on interview with agro-scientists involved in development of the land modification models

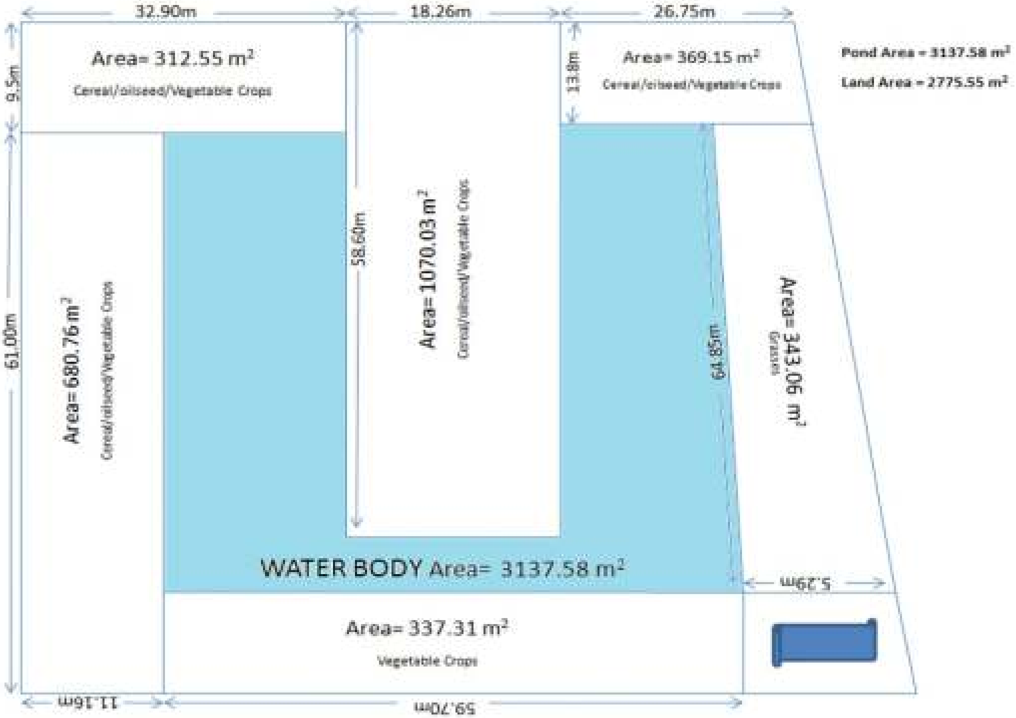

Fig. 2: Schematic diagram of innovative land modification layout at a farmer's field (0.60 ha)

made successful due lack of community approach in the area. Also, the single drain interceptor drain was found not sufficient to intercept canal seepage. Bio-drainage through planting eucalyptus trees were tried but not succeeded. Finally, the LMM with '*raised and sunken bed*' was innovated and demonstrated at farmers' field in 2005-06. These models were successful, several crops were feasible to cultivate, fish was grown in harvested seepage water in sunken beds and the system was found to be profitable. Experiences on the demonstration of LMM at farmer's field suggested there was a need to redesign the system, particularly optimizing the bed sizes. Based on these experiences LMM was redesigned (25 m) and integrated farming systems (crop-fish) became a successful intervention (Fig. 2). The unproductive land was turned into productive through these innovative land modification models again.

Estimation of extent of problems and farm level crop losses

Study area was located along the *Sharda Sahayak* irrigation canal and most of the land was affected by twin problems of waterlogging and sodicity up to 300 m of distance from canal. Some of the land beside the canal was turned into completely barren and unproductive. However, farmers were still trying to grow some crops, mainly rice, wheat and mint (mentha), wherever possible. Average area under operation was estimated to be 1.03 ha, out of which more than half of their land (55 per cent) were severely affected by waterlogging and sodicity problem. The lands operated by the farmers were divided into

Table 2: Cropping pattern, profitability and extent of loss of existing cropping systems

Particulars	Normal land(beyond 300 m from canal)				Salt-affected land (50-300 m from canal)				Extent of loss due to waterlogged & sodic problem			
	Rice	Wheat	Mint	Total	Rice	Wheat	Mint	Total	Rice	Wheat	Mint	Total
Yield (kg ha^{-1})	4267	2933	113	7313	1920	1100	62	3082	2347 (55)	1833 (62)	51 (45)	4231 (58)
Total cost (₹ ha^{-1})	35317	33760	52558	121635	30012	25008	36971	91991	5305	8752	15587	29644
Gross return (₹ ha^{-1})	61872	43995	113000	218867	27840	16500	62000	106340	34032 (55)	27495 (62)	51000 (45)	112527 (51)
Net return (₹ ha^{-1})	26555	10235	60442	97232	-2172	-8508	25029	14349	28727	18743	35413	82883
Output-input ratio	1.75	1.30	2.15	1.74	0.93	0.66	1.68	1.09	0.82	0.64	0.47	0.65
Cropping intensity (%)	-	-	-	185	-	-	-	125	-	-	-	60

Note: 1. Almost no crops were grown in the salt affected areas up to 50 m of distance from canal, yield of mint represents mint oil.
2. Figures in parentheses per cent loss to affected land as compared normal land.

several sub-plots (2-4 numbers). The agricultural land beyond 300 m of distance from canal was almost normal, receiving regular irrigation water from canal and productive. Rice-wheat was the dominant cropping system, followed by rice-wheat-mint cropping system was prevailing in the study area. Same cropping system was followed in the salt-affected land (50-300 m distance from canal) but suffering from severe crop losses as compared to the normal land. The crop losses were estimated to be 45-62 per cent in terms of production and gross return (Table 2). Productivity of rice (4.3 t ha^{-1}), wheat (2.9 t ha^{-1}) and mint oil (113 kg ha^{-1}) reduced significantly (1.9 t ha^{-1}, 1.1 t ha^{-1} and 62 kg ha^{-1} for rice, wheat and mint, respectively), due to the waterlogging and sodic problem in the area. The problem was so acute that only rice-wheat could be grown with very low productivity. The net return was calculated to be negative for rice and wheat cultivation when the family labourer was accounted in the cost. Only cultivating mint was found to be somewhat profitable in the affected area in relatively good soil. Cropping intensity was reduced by 60 per cent (from 185 to 125 per cent) due to this twin problem in the study area. Still farmers, who have available family labour and no other alternatives, were trying to grow few crops, wherever possible. With prevailing 185 per cent of cropping intensity and 0.18 million ha under salt and waterlogged affected land, the total production loss was estimated to be valued at ₹12490 million (2018-19 prices).

Effectiveness of land modification models at farmers' fields

After experiencing the unsuccessful attempts to manage waterlogged and sodic problems through bio-drainage, intercept drainage, sub-surface drainage (SSD) and gypsum application, altering the land configuration was attempted as a solution to the problem and finally, the alternative land use system, called land modification models (LMM) were developed and successfully demonstrated in the farmers' field since 2006 (Table 3 & 4). Further, based on the field experiences the models were re-designed in 2012 to suit the field conditions and total demonstration area under seven such models were 3.71 ha. The initial

Table 3: Details of land modification models constructed in the study area

Farmers	Location (Village, Block, District)	Types of Land Modification	Year of construction (ha)	Area under intervention	Dist. from Canal (m)	Major crops grown		
						Kharif	Rabi	Summer
LMM 1	Kashrwan, Bachhrwan, Raebareli	Pond Based IFS Model	2006	1.00 (1.50)	175	Rice	Mustard, Wheat	Vegetables
LMM 2	Kashrwan, Bachhrwan, Raebareli	Pond Based IFS Model	2008	0.36 (1.50)	42	Rice	Mustard	Vegetables
LMM 3	Patwakhera Mohanlalganj, Lucknow	Pond Based IFS Model	2012	0.60 (1.00)	185	Vegetables	Vegetables	Vegetables
LMM 4	Patwakhera, Mohanlalganj, Lucknow	Pond Based IFS Model	2015	0.21 (0.50)	100	Rice	Wheat	Vegetables
LMM 5	Lalaikhera, Mohanlalganj, Lucknow	Pond Based IFS Model	2015	0.46 (3.75)	73	Rice	Wheat, tomato, moong	Vegetables
LMM 6	Salempur, Achaka Mohanlalganj, Lucknow	Farm Pond based (waterlogged area)	2015	0.33	83 (0.75)	Rice	Vegetables.	Vegetables
LMM 7	Mahraura, Bachrwan (Raebareli)	Pond Based IFS Model	2017	0.60 (1.00)	50	Rice	Vegetables	Vegetables

Note: Figures in parentheses indicate total land holdings of the respective farmers. Besides crops fish was reared in all LMM systems, kharif (wet), rabi (dry) and summer season indicates July-October, November-March and April-June months, respectively.

Table 4: Area distribution under land modification models under demonstration

Farmer	Area under LM (ha)	Initial investment (₹)	Pond area (sq m)	Raised area Pond area	%Sunken/ (sq m)	% Raised
LMM 1	1.00	250000	4000	6000	40	60
LMM 2	0.36	31000	2293	1266	64	36
LMM 3	0.60	156000	3138	2775	47	53
LMM 4	0.21	70000	817	1336	26	74
LMM 5	0.46	201000	2356	1307	64	36
LMM 6	0.60	110000	2850	3150	48	53
LMM 7	0.33	210000	1225	2041	38	62
Overall	3.71	1028000	16679	19462	46	54

costs (actual cost at respective current prices) of the construction of these models were in the range of ₹ 31000 to 250000 with an average of ₹ 277000 ha^{-1}. The models were demonstrated in the farmers' field at a distance of 42 to 185 m from canal. The area under pond/sunken bed was 26-64 per cent and the raised bed was 36-74 per cent across the different LMM systems. The area distribution (raised or sunken) and the distance from canal were critical for the success/failure of the models. The LMM has two major components raised bed and sunken bed. The sunken bed was used for harvesting and storing of water, drawn through natural seepage from the canal water. Also, same pond area was used for rainwater harvesting during rainy season. Water stored in the ponds was used for irrigating crops and growing fish throughout the year. Raised bed with reduced salt accumulation was suitable for growing a number of crops such as cereals, fruits, vegetables, oilseeds, pulses, mint and fodder.

Impact of land modification on soil and water quality

The configuration of LMM through raised and sunken bed improved the soil quality in terms of improving the soil quality parameters pH, ECe, ESP significantly, and land become suitable for growing multiple crops (Table 5). In LMM, the quality of harvested seepage water was very good throughout the year and least affected over the period of time. The pH of pond water varied between 7.37- 8.33 after four years which was favourable for growing fish in the pond as well as irrigation for crops. The variation in ECe in pond water was found to be non-significant as compared to initial value due to the continuous inflow of good quality canal water into the ponds. It was observed that both soil and water quality in the LMM system was either improved significantly or remained unaffected, made suitable for growing multiple crops and fish over the years, hence the system can be considered as technically sustainable.

Table 5: Impact of land modification model on soil and water quality

Parameters	Initial value (2013)	After 4 years (2017)	Increased/ Decreased	Impact
Soil quality (0-30 cm)				
pH_2	9.95	8.25	-1.70	Reduced significantly and improved soil quality
EC_2 (dSm^{-1})	0.31	0.12	-0.19	Reduced marginally and soil quality remained same
ESP	60.15	13.95	-46.20	Reduced significantly and improved soil quality
Water quality				
pH_w	7.37	8.32	0.95	Increased and water quality marginally reduced
EC_w (dSm^{-1})	0.71	0.82	0.11	Increased marginally

Economics of land modification models

The LMMs were used by the farmers intensively to grow crops (primarily vegetables) and rearing of fish. Some farmers preferred to grow more vegetables and others preferred to rear fish intensively. Therefore, realising the motives of the farmers, the economic analysis was carried out focusing on two major scenarios, vegetable crop based and fish based. In both scenarios crops and fish was integrated but with varying degree of priority by the farmers. Detailed economics of the land modification systems was calculated from the average cost-return data pertaining to the year 2017-18 and 2018-19. The system yield was higher (incremental) by 1.86 t ha^{-1} and 4.69 t ha^{-1} as compared to the prevailing rice-wheat-mint cropping systems practiced in the area (50-300 m distance from canal) (Table 6). Vegetable based and fish based integrated cropping system provided incremental net return of ₹130000 ha^{-1} (contribution of fish was 45%) and ₹314000 ha^{-1} (contribution of fish was 84%),

Table 6: Incremental cost-return of the land modification models (2018-19 prices)

(ha^{-1})

Particulars	Salt-affected land (50-300 m)	Enterprises under Land Modification		Incremental cost/return	
	Rice-Wheat-Mint	Crop-fish based	Fish-crop based	Crop-fish based	Fish-crop based
System Yield (kg ha^{-1})	3082	4942	7775	1860	4693
Total cost (₹ ha^{-1})	91991	122512	731326	30521	639335
Gross return (₹ ha^{-1})	106340	267372	1060115	161032	953775
Net return (₹ ha^{-1})	14349	144860	328789	130511	314440
Output-input ratio	1.09	2.18	1.45	1.09	0.36
Cropping intensity	125	300	220	175	95
Rental income (₹ ha^{-1}) without cost sharing	12000	35000	35000	25000	25000

respectively, over the rice-wheat-mint cropping system. Overall the output-input ratio increased from 1.09 to 2.18 (vegetable-fish based) and 1.45 (fish-vegetable based) in the evolved cropping systems under the models. The cropping intensity of the system increased to 300 per cent and 220 per cent as compared to 125 per cent of existing cropping system. The rental income willing to pay by other farmers for the LMM increased to ₹ 45000 ha^{-1} (without cost sharing) as compared to ₹ 10000-12000 ha^{-1} for the prevailing cropping systems.

Financial viability of the land modification models

Economics of the evolved LMM were found to be favourable with consideration of the operational and maintenance cost (O&M cost) and gross return from the system. However, such models needed large amount of initial investment for excavation of land and followed by expenditures on O&M for the system over the subsequent years. For this analysis the time value of money needed to consider, therefore financial feasibility of the investment on such systems were computed in terms IRR, BCR, NPV and payback period of the system. The financial feasibility analysis was carried out on the two most successful models (fully managed by the farmers themselves) based on the actual area, 0.60 ha (crop-fish based) and 0.46 ha (fish-crop based) (Table 7). The initial investment was calculated assuming the existing rate (₹ 90 cu m^{-1} of soil) for soil excavation. While assuming the rate, NABARD's guideline in the Uttar Pradesh state for pond excavation was consulted. The pond excavation areas for 0.60 ha and 0.46 ha of LMM were 3138 sq. m and 2356 sq. m., respectively. Thus, the initial investment was calculated as ₹ 282000 and ₹ 212000 for the area of 0.60 ha and 0.46 ha, respectively, at 2018-19 prices. Financial feasibility analysis indicated both types of models were quite attractive in terms of future investment with positive IRR (37 per cent and 56 per cent) and NPV (₹ 249741 and ₹ 368752), BCR (1.37 and 1.22). The initial investment was quickly returned by pond based (fish-crop) system (1.75 years) as compared to crop-fish based (2.6 years). The pond based system was seen to be using the system very intensively (high cost and high return) with high density of fish rearing, whereas crop-fish (vegetables-fish mainly) was utilised more intensively by growing crops, mainly vegetables. All the financial analysis criteria were also found to be favourable for investment on such models when the opportunity cost of the land was included. The

Table 7: Economics and financial viability of the land modification models (2018-19 prices) *(on actual area)*

Particulars	Land modification as crop-fish based (0.60 ha)	Land modification as fish-crop based (0.46 ha)
Area under intervention (ha)	0.60	0.46
Per cent area under pond	53	64
Initial Investment (₹)	282000	212040
Economic life (years)	10	10
Economics		
Average annual O&M cost (₹)	91884	336410
Average annual gross return (₹)	200529	487653
Average annual net return (₹)	108645	151243
Output-input ratio	2.18	1.45
Financial viability (with no opportunity cost)		
Internal rate of return (per cent)	37	56
Net present value (₹)	249741	368752
Benefit-cost ratio	1.37	1.22
Payback period (years)	2.6	1.75
Break-even size of intervention (ha)	0.44	0.38
Financial viability (with opportunity cost)		
Internal rate of return (per cent)	34	53
Net present value (₹)	210350	338549
Benefit-cost ratio	1.34	1.20
Payback period (years)	2.82	1.85
Break-even size of intervention (ha)	0.45	0.38
Financial viability (with 25 per cent subsidy for initial investment without opportunity cost)		
Internal rate of return (per cent)	51	76
Net present value (₹)	311583	415252
Benefit-cost ratio	1.62	1.25
Payback period (years)	1.95	1.31
Break-even size of intervention (ha)	0.37	0.36

Opportunity cost is net return (₹ 14349 ha-1) from prevailing rice-wheat-mint cropping system for average area of 0.60 ha (₹ 8609) and 0.46 ha (₹ 6601). No opportunity cost indicates no return from 'next best alternative' option ie., land become unsuitable for any growing any crops. Such is prevailing near to the canal (within 50 m of distance from canal).

analysis indicated investment on such models was quite attractive in the study area. The investment analysis considering the opportunity cost (net return from prevailing cropping system) indicated that all the investment criteria was favourable in terms of IRR (34 per cent and 53 per cent, BCR (1.34 and 1.20), NPV (₹ 210350 and 338549) and pay-back period (2.82 year and 1.85 year) for both crop-fish based and fish crop based interventions. The investment was more attractive when the subsidy component was included as benefits in the analysis with the amount of subsidy (25 per cent of initial investment) and pay-back period was further reduced. Incentives in terms of subsidy by the government could be an alternative proposition particularly for the resource poor farmers through government supported schemes.

Break-even size of land modification models

Based on the incremental cost-return realised during the entire economic life, the break-even size of interventions of the models was calculated to be 0.44 ha and 0.38 ha for crop-fish based and fish-crop based systems, respectively, under *first* scenario (with own cost). The beak-even size was almost at par with the other alternate scenarios, without opportunity cost and with subsidy assistance. The break-even analysis suggested such models can be constructed in smaller land and suitable even for the small-holder farmers prevailing in the affected area. However, based on actual field operation experience it was observed that an area of around 1.0 ha under crop-fish based system and 0.50 ha under fish crop based system would be suitable for carrying out agricultural operation, particularly to facilitate the farm machineries, otherwise the system would remain heavily dependent on the human labour only. The break-even analysis indicated that depending on the farmers' choice, aspiration and available financial assistance, they can choose the models. For resource rich farmers, who have adequate investment capacity and higher risk bearing ability, can practice intensive fish based system and for other farmers crop-fish based models can be proposed.

Farm level impact and socio-economic suitability of land modification models

Farm-level impact of land modification models

Farm-level impact of LMM was analysed through identifying and estimating values of different indicators, such as, cropping pattern, cropping intensity, level of crop diversification, employment opportunities, income, crop productivity, production risk, asset creation by farmers and externalities. The demonstrated models in the salt-affected areas created the options to grow a number vegetables, spices, fruits, fodder, potato etc., beyond the usual practices of rice, wheat and mint. The models were utilised to grow crops throughout the year, hence increased the cropping intensity (from 125 per cent to over 250-300 per cent), crop diversification (from 0.24 to 0.86 of Simpson crop diversification index) and provided employment to the whole family throughout the year (Table 8). The crop

Table 8: Farm-level impact of land modification models at demonstration field

Indicators	With Land Modification Model (N=7)	Without Land Modification Model (N=55)	Remarks
Cropping pattern (choice)	Rice, wheat, vegetables fruits, spices, mint, fodder, potato	Rice, wheat, mint	Any crops can be taken in LMM
Cropping intensity (%)	250 to above 300	125	Increased more than double
Crop diversification (Simpson Index)	Very high (0.86)	Low (0.24)	Multiple crops choice
Employment (man-days)	Year round	55-70 days	Gainful engagement
Income (₹ year^{-1})	145000 to 350000	negative to meager	Increased many folds and continuing benefits
Crop productivity (t ha^{-1} system yield)	3.08 to 7.78	1.5 to 2.0	Increased and benefits continuing
Risk (% yield losses)	Low	Very high(45-62)	Often returns are negative, high instability
Asset creation (₹)	35000 to 55000	Meager	Buying livestock, bike, pucca house etc
Externalities	Positive	Neutral to negative	LMM improved quality of other land too

productivity of the system was increased (3.08 – 7.78 t ha^{-1}) from prevailing productivity (1.50-02.0 t ha^{-1}) of the crops. The crop production losses in the affected areas (45-62 per cent) were also minimised due to adoption of such models. The incremental benefits arising out of the crop cultivation helped farmers to buy new assets such as buying livestock, bikes, constructing *pucca* houses, increased affordability to bear medical cost and empower them financially. Implementation of LMM increased the rental value of land as well as land value, which otherwise remained un-productive.

Socio-economic suitability for adoption of land modification models

Average farm size of the farmers in the study area was 1.03 ha, in which 39 per cent of their land was highly degraded due to sodic and waterlogged problems (Table 9). The LMM are suggested for the degraded land only as other land were of good quality and farmers could grow crops as per their choice. Although break-even size for LMM was estimated to be 0.38-0.44 ha however, considering the issue of ease of operation by farm machineries, it was observed that a plot size of around 1.0 ha or more of land will be ideal. LMM for the farmers who aspire for crop-fish based interventions, 53 per cent area under crop and rest (47 per cent) area under pond will be suitable. Such area will facilitate easy operation of machineries for cultivation of raised lands. On the other hand, a plot size of 0.50 ha with 64 per cent pond and 36 per cent area under crop cultivation will be suitable for farmers who aspire for intensive fish cultivation. Keeping in view of this, farm size characteristics, it indicated that around 43 per cent of the farmers were having similar kind of suitable land and out of which 65 per cent were willing to adopt such models, given the condition that partial or full financial support is provided to cover initial investment needed for the land excavation. Implementation of such models can reduce the share of food deficient households (52 per cent) and also might help providing gainful employment opportunities to the land less farmers (5 per cent) in the affected areas.

Table 9: Socio-economic characteristics of the farm households

Particular	Unit	Value	SD
Average farm size	Hectare	1.03	± 0.93526
Average family size	No of person	5.15	± 3.1754
Average degraded *(usher)* land with households	Hectare	0.41	± 0.36198
Share of degraded *(usher)* land to total land	Per cent	39.23	± 35.9081
Households with above 1.00 ha of land	Per cent	43.33	-
Willingness to adopt land modification models	Per cent	65.45	-
Landless households	Per cent	5.45	-
Share of food deficit households	Per cent	52.14	-
Average net income from agriculture (yearly)	₹ $households^{-1}$	13931	± 11234.93
Off-farm income	₹ $households^{-1}$	30500	± 25342.85
No. of observations	No of households	62	-

Perception of farmers and technology developers on land modification models

The LMM was successfully demonstrated in the farmers' field since 2006 and the current socio-economic study was carried out to find out the perception of farmers as well as technology developers (scientists and technical personnel) on effectiveness/adoptability of such models in the problem area. Farmers perceived that the models were feasible for growing a number of crops, land quality improved and the interventions were profitable (Table 10). As water was available from the canal throughout the year, number of crops and fish were grown continuously in the system. It provided them regular income and gainful employment throughout the year. However, major constraints were high initial investment and labour intensive. Farm families having available family labourers could manage the systems but given other alternative livelihoods options, management of these labour

Table 10: Perception of farmers vis-à-vis technology developers about land modification techniques

Criteria	Scientists/Technical experts (N = 68)	Farmers (N=62)	Remarks
Technical			
Sustainability	Viable in short term, long term technical sustainability not yet known fully, distance from canal ifs crucial	Several crops and fish can be grown, no major issue	What if another model constructed in between canal and LMM plots - need further research on distance between models
Economic	Feasible	Profitable	Investment feasible
Social	Full time farmer can manage the labour intensive system well	Land divided into sub-plot needs cooperation from others	Fish is a taboo for some farmers and renting of the system could be good option for them
Land quality	Sodicity reduced, water table lowered	Improved, rental value of land increased by many folds	Multiple crops feasible, highly degraded land become productive again
Water quality	Remained same even after 7 years of cultivation	Good, suitable for all crops and fish	Crop and fish can be grown, integration feasible
Initial investment	High and might be unaffordable for resource poor farmers	High and unaffordable at private cost	Need government support
Income, livelihoods, food security	Increased by manifolds, more food production	Some were utilising system intensively, others kept uncared after initial few years	Income from agriculture less than other alternatives available like small business or industry workers
Management	Needs under cultivation continuously to avoid rising of sodicity	As water was available, cultivation was profitable, can be managed well without major issues	Highly Labour intensive, good proposition for the full-time farm families
Water availability	Available throughout the year from the canal	Available throughout the year	Might be a challenge if large number of LM are constructed without consulting technical experts

intensive systems could be challenging. Due to this some farmers were seen to manage the system very profitably but few others were reluctant to use the systems intensively, particularly after the active project period (agro-scientists were involved and inputs were made available to them). Besides, rearing fish was a social taboo for some farmers in the region and against the social norms, making the system underutilsed, sometime. This might be the reason few farmers who managed the systems very effectively at early years, now keeping the system somewhat uncared. Scientists perceived the models were problem solving and techno-economically sustainable. The land quality improved, good quality irrigation water was made available for using in crop cultivation and fisheries, water quality remained good even after years of establishment and intensive use of the systems, provided regular income and employment to the farm families and such models can be constructed in many other fields. However, high initial investment and need for continuous cultivation (keeping fallow may lead to salt accumulation again) might be major issue for its large scale adoption. Overall, scientists and technical experts agreed that such models can be constructed in the problem areas as these models were not only profitable but also has positive externalities impact on the neighbouring land through intercepting the seepage water flow, keeping the water table down.

Challenges to out-scaling of land modification models and future issues

The demonstrated land modification models for waterlogged sodic land in Uttar Pradesh were found to be technically and financially viable proposition in the study area. However, willingness of farmers having land but not sure how much land to be converted, land owners having larger plots but reluctant to convert land for fisheries as rearing fish is a social taboo, farmers were willing but land was not in their name (or shared with multiple ownership), were some of the key challenges for large scale implementation of such models in the affected area. The innovation was found technically feasible, profitable, opened up several opportunities for the farmers but its large-scale adoption will be depending on socio-economic factors such as land size, land fragmentation, investment capacity, labour intensive management, distance from canal, size of land modification and available alternative livelihood options competitive to farming. The challenge of consolidation of fragmented land for suitable economic size for constructing the models can be addressed through aggregation of land by attracting private investment through leased out land. As the land was already highly degraded, farmers were willing to lease-out their land to the private investors and therefore such models might be promoted through public, public-private or private investment. Leasing out of land to private investors can be a good option but calls for formation of guidelines to avoid exploitations of farmers to avoid losing land permanently to the unscrupulous private investors, negative externalities to other farmers due to over-exploitation of canal water – which might lead to unwanted social tension in future. Also, few questions like, what will happen to the water availability to a model if another model is constructed in between canal and the LMM system, how many such models can be constructed in the area, what if canal water flow becomes critically low, remains unanswered yet. Some experts felt this can be a short term solution as there might be salt accumulation again after some years. This calls for need of further research on the designing of the system particularly to find the optimum number of systems to be constructed, ideal distance from the canal considering the seepage rate or soil structure and salt-water dynamics for long term sustainability of the systems.

CONCLUSION AND WAY FORWARD

The innovative land modification models can be considered a solution to existing problems (waterlogged and sodic salt affected) which is techno-economically sustainable. The innovative system could improve the land quality and made degraded land suitable for growing multiple crops and fish. Break-even analysis of the interventions suggested that such systems are suitable even for the small-holder farmers, prevailing in the targeted area. However, there is a need for financial support for the initial investment to be made. Viewing its successful demonstration the concerned state government has already planned to support such land modification to over 1100 hectare of land in the affected area. Utilization of government schemes like Reclamation of Problem Soil Scheme under *Rashtriya Krishi Vigyan Yojana (RKVY)* or available financing schemes of NABARD for land excavation (already available for pond excavation in the state) could be good option. Farmers can be aggregated through promotion of leasing systems of land will be helpful to out-scaling of the proposed land modification models. On one hand, some farmers having affected land but may not be interested for cultivation as they are engaged in other alternative livelihoods like small business or industrial worker, but at the same time many other farmers are engaged full time in farming and dwelling in the villages are interested to manage such system on lease after construction. Mutual collaboration between these two groups of farmers can pave the way to promote such land modification models and productive use of the degraded land, which otherwise remained unproductive. Besides, promoting multi-functionality approach (agriculture plus other services like catching fish as recreation) in agriculture can be another opportunity to disseminate the systems in the study area, as the location is near to the Lucknow city. Promotion of agro-tourism with these models might be a good option and possible entrepreneurship development based on this land modification system may attract the private investment which might be beneficial for the farmers in terms of earning good return, gainful employment and making the degraded land productive.

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Glimpse of the problems areas before and after the implementation of land modification models


(a) (b) (c)

Fig. 1. *Sharda Sahyak* irrigation canal (a), degraded land (b) and salt crust (c) on soil beside the canal


(a) (b) (c)

Fig. 2: Land use situation and fallow land in the study area


(a) (b) (c)

Fig. 3: Farmers interaction during collection of socio-economic information

(a) (b) (c)

Fig.4: Land modification models demonstrated at farmers' fields

(a) (b) (c)

Fig. 5: Land use (a) and mint crop in fields at various distances from the canal area (b and c)

(a) (b) (c)

Fig. 6: Crop performance on land modification plots (a and b) and newly constructed models ©

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