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ARTICLES

# Managing Waterlogged Sodic Soil through Land Modification in Canal Irrigated Indo-Gangetic Plain of India – A Socio-Economic Evaluation

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ABSTRACT

Advancement of canal irrigation without adequate drainage provision led to twin problems of waterlogging and sodic soil formation in parts of the Indo-Gangetic plain. Continuous seepage of water from the canal increased the water table of the adjoining fields, induced upward movement of salts on the surface soil and the land become salt-affected (sodic soil). After realising benefits for some years, the negative externalities offset the positive impact of the canal irrigation system in terms of crop losses (45 and 62 per cent for rice and wheat) and severely affecting the livelihoods for the farmers adjacent to the canal area. Several efforts were made to restore such degraded land through conventional methods of gypsum-based reclamation, intercept drainage through perforated pipe lines and bio-drainage belt but could not found successful enough to provide positive return to investment. Finally, the land engineering option, the land modification technique was evolved in which the excess seepage water was harvested and used for crop and fish cultivation. Soil and water quality improved and diversified crops were possible to grow on this land. The socioeconomic evaluation in terms of financial feasibility, suitability to land holdings pattern and sustainability of this model was assessed. The model was techno-economically sustainable, however, challenged by few socio-economic constraints, which can be addressed through appropriate policy measures.

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

**JEL: O13, Q15, Q54**

I

## INTRODUCTION

The United Nations 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 land to achieving multiple sustainable development goals (SDG). Restoration of salt-affected land can contribute to achieving at least three SDG goals, poverty, hunger and life on lands. It is estimated that 96.40 mha (million hectares) of land (29 per cent of total geographical area) are under the process of land degradation

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in India (ISRO, 2016). Salt-affected soils (6.73 mha) are 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 are estimated to increase to 16.2 mha by 2050 (ICAR, 2015), an increase from 5 to 11 per cent of total net sown area of the country (141 mha) which may turn large areas of cultivable land to completely barren. About 2.46 mha of land in irrigated commands in the country suffers from waterlogging, either seasonally or permanently (Sharma *et al.,* 2016). Poor management of soil, water resources and unscientific agricultural intensification directly affects the land quality. Often irrigation development projects have led to formation of salt-affected areas primarily due to inadequate attention to drainage. Thus, in many instances, after realising the benefits for some years, the negative externalities offset the positive impact (Singh, 2009; Joshi, 1987; 2011; Joshi and Jha, 1991).

*Sharda Sahayak Canal*, commissioned in 1968 (approval year of Planning Commission of India), aimed to provide irrigation to 1.78 mha of arable area spread over 15 districts of Uttar Pradesh. After introduction of the canal irrigation, agricultural 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 mha sodic lands are affected with shallow water table conditions in *command* area, not suitable for cultivation economically. Even after conventional method of gypsum-based reclamation efforts (Government of India, 2007), part of it (0.18 mha) are suffering from twin problem of shallow groundwater water table (less than two meters) and high sodic (soil pH over 9) conditions (Singh *et al*., 2008; Bhardwaj *et al*., 2019). This has led to diminishing land-water productivity and loss of livelihoods for the farmers in the affected reach of the canal area. The land which was once highly productive, became severely degraded (called '*ushar'* in local language) and unsuitable for cultivation of any crop. Farmers are desperately trying to make the degraded lands productive by using alternatives like incorporation of water hyacinth, farm yard manure, cow dung or leaving straw on the fields for decomposition, but all these were not good enough to provide a 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 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. The land modification models (LMM) were developed to harvest the canal seepage water at farmers' fields, along both sides of 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 (land shaping technology) were 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 (Bandyopadhyay *et al*. 2009; Mandal *et al.*, 2013; 2015; 2018; 2019, Burman *et al*., 2015). 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 LMM are essential to understand how far the success of this model can be out-scaled in larger areas. The overall objective of the study was to understand the performance of the demonstrated LMM in terms of profitability and socio-economic suitability in the land affected by waterlogging and sodicity problems. Based on the field level data from the demonstrated LMM, the economic evaluation study was conducted with specific objectives, (1) analysing the impact of LMM on farm-level economy under waterlogged sodic soils; (2) examining the financial viability of LMM in waterlogged sodic soils; and (3) to understand various constraints and socio-economic suitability in large scale adoption of LMM by the farmers. The null ($H_0$) hypothesis of the study was to test that farmers would be indifferent to choose the proposed LMM as a solution to the management of waterlogged sodic lands against alternative hypothesis ($H_a$), otherwise.

*Innovation 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 after it was commissioned. This called for an urgent attention of agro-scientist to restore degraded lands again productive through innovative land management (Table 1). The water table in the adjoining canal area increased (< 2 m from surface) and led to waterlogged sodic soil problem that turned large cultivable area completely barren or poorly productive. Severely affected land was extended up to 50 m, where no crops could be grown and up to 300 m distance from the canal. With such high water table, gypsum application was not successful as an amelioration option for this land. Interceptor drainage through perforated drain pipes was attempted for managing the waterlogging condition in the field but could not be made successful due to lack of community approach in the area. Also, the single 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 (Figure 1). Several crops were feasible to cultivate, fish was reared 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 further suggested there was a need to redesign the system, particularly optimising the bed sizes. These models were designed and re-designed several times during 2005-2012 based on the field experience, actual performance of the models and considering various parameters, such as, elevation, length and breadth of the raised land, area under excavated land, water flow in the canal, rate of seepage, water available through rain and evapotranspiration, (Verma *et al*., 2016). Finally, the LMM was redesigned with 25 m width spacings and crop-fish integrated farming systems became successful. Unproductive land was restored through these innovative LMM, again.

TABLE 1: GENESIS AND DEVELOPMENTAL PATHWAYS OF LAND MODIFICATION MODELS

| Causes/Rational/ Description (1) | Efforts/Initiatives (2) | Experiences/Lesson (3) | Success/Failure (4) |
|---|---|---|---|
| *Sharda Sahayak Canal* for irrigation in central Indo-Gangetic region | Initiated in 1968 and completed in 2000. Providing irrigation to 1.78 Mha of land | During 1980s cultivation was good, later land alongside the canal becomes waterlogged. | After initial success leads to waterlogging and sodic, affected 0.18 Mha |
| 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.

II

RESEARCH METHODOLOGY

*Study Area*

*Sharda Sahayak Canal*, a major irrigation project in central Indo-Gangetic plain was initiated in 1968 with approved cost of ₹19.90 million and completed in 2000 with final cost of ₹133.60 million. The irrigation project had culturable command area with ultimate irrigation potential of 1.78 mha and targeted to benefit covering 15 districts of Uttar Pradesh. However, after realising the initial benefits of irrigation (2-3 decades), waterlogging and sodicity problem emerged. *Raebarelly* and *Lucknow* are most affected among a total of 15 districts in which part of the agricultural land is severely affected.

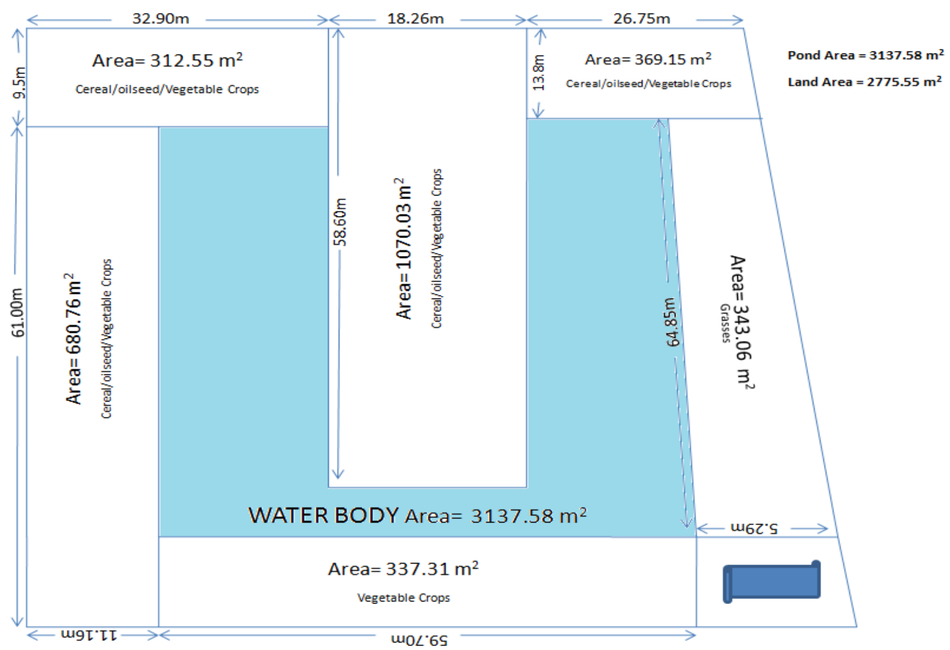


Figure 1. Schematic Diagram of Innovative Land Modification Layout at a Farmer's Field (0.60 ha)

*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 but no LMM models were constructed) farmers. 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. The construction of LMM systems required consent of individual farmers as the lands were modified through soil excavation. The production data for LMM systems were collected from the demonstrated plots (7 LMMs) through purposive selection. The selection of 'other' farmers was done through random sampling from the farmers whose lands were similarly affected in the study area. Farm survey schedule was prepared, tested and used for the primary data collection through personal interview with the respondents. Data pertaining to 7 'collaborative' farmers were merged with the 55 'other' farmers as far as socio-economic data was concerned. But LMM systems data was recorded only from those 7 'collaborative' farmers and the LMM systems performance were compared with the prevailing production practices of the 'other' farmers. Since construction of the LMM was required change in land configuration (soil excavation), entailing initial investment and time consuming therefore, each and every LMM models were demonstrated after consultation with the farmers and also depending on the severity of problems. Higher the magnitude of problems, more priority was given to those lands. Farmers' lands were affected by waterlogged and sodic salts due to seepage water from the canal along both sides of the canal. 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 during 2005-06 to 2017-18 in the fields of 'collaborative' farmers. Primary survey was conducted during 2018-2020 for collection of data 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. The LMM was used for crop and fish production throughout the year and the primary survey was conducted during 2018-19 and 2019-20 to cover the system details across the seasons. A large number of crops were taken in the LMM systems, so to obtain detailed production data survey was stretched over two years to cover all the crops grown in the production systems. 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 LMM in larger areas. All the farmers were provided note book for recording of input used, output realised, quantity sold in the market and kept for home consumption. Besides, regular visit of Scientists from ICAR-CSSRI, RRS, Lucknow was held to oversee the performance of the LMM systems. These records were tabulated in MS Excel spreadsheet for data analysis. Later on, the results from the data analysis were 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 were synthesised to draw out possible implications of out-scaling LMM in similar problem areas. Relevant secondary information was also collected from various published sources (ICAR-CSSRI, 2014-15 to 2017-18; Singh *et al*., 2008; Singh *et al.*, 2019; Government of Uttar Pradesh, 2019). Besides, soil samples were collected regularly and analysed at soil science laboratory of ICAR-CSSRI, RRS Lucknow by soil scientists to understand the changes in soil and water qualities over the years due to construction of LMM.

*Economics of Cropping Systems*

Economics of the crops, fish and cropping systems was analysed applying farm budgeting analysis following the norms of cost of cultivation methods of Commission for Agricultural Costs and Prices (CACP), Government of India (Government of India, 2008). Costs components included are, input costs incurred like seed, fertilisers, irrigation, human and machine labour (hired and own) required for all activities (land preparation, sowing, applying irrigation/ pesticides/ fertilisers, intercultural operation, harvesting etc.), 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), and miscellaneous charges (watch and ward, unforeseen expenditures etc.). Cost of family labour was imputed as value of labour based on available open market prices. Economics of fish rearing was computed based on the cost of inputs applied (fingerlings, feed and labour) and value of output (fish production multiplied by farm-gate price received). Multiple crops were grown on the LMM in which crop area under individual crops were very small and most of the operations were carried out simultaneously, therefore expenditures and return on the entire system was computed as a system for a season. The incremental costs and return of the system has been calculated based on the costs/return of LMM systems under demonstration (either crop-fish based or fish-crop based) minus the cost/returns obtained in the prevailing cropping practices (rice-wheat-mint) by the farmers in the study area. The annual cost and return of the systems have been calculated based on actual operational and maintenance cost incurred and return realised from the systems. The irrigation water was available in the system (pond or excavated area) through the seepage of canal water and the cost of irrigation was very minimum i.e., lifting of water from the pond to raised bed area. The pumping cost in terms of diesel/electricity used was the irrigation cost in the production system.

*Cropping Intensity, Extent of Diversification and Crop Losses*

Cropping intensity was calculated taking average gross cropped area divided by average net cropped area multiplied by hundred. Cropping intensity was calculated under normal and degraded land for comparison. The extent of crop diversification under LMM and farmers' practices was estimated by employing Simpson Diversification Index (SID), where $SID = 1 - \sum (Xi / \sum Xi)$ 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 land (plots located >300 m distance from canal), based on the actual field situation in the study area. Further, extent of crop losses at region level was estimated by multiplying per hectare crop losses by extent of affected/degraded land (0.18 mha) 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 under study.

*Financial Analysis of the Investment on Land Modification Models*

The LMM was constructed during 2005-06 to 2017-18 in the farmers' fields. While doing financial analysis, all the input and output data was taken from the average of 2018-19 and 2019-20 production data to get data of complete production cycles of annual, perennial crops and fish. The initial investment was calculated, assuming the prevailing soil excavation rate (₹ 90 / $m^3$ of soil) in the area, following the National Bank for Agriculture and Rural Development guideline in the Uttar Pradesh state for pond excavation (NABARD, 2019). It is expected that the performance of the future LMM systems would be similar to the already constructed LMM systems in the study area over the years. The demonstrated LMM systems were stabilised and performing consistently over the years since 2005-06 in terms of crop and fish production. In future, if some extreme events like heavy rain or flood occurs, the systems may be damaged but the constructed dykes can be repaired by using machinery or human manpower to it to make it productive again. Financial analysis was carried out by employing investment criteria of Discounting Cash flow technique viz., internal rate of return (IRR), net present value (NPV), benefit-cost ratio (BCR) and payback period (Gittinger, 1982). 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 preferred crops over fish. Viewing this actual practices, financial analysis was carried out focusing on two different kinds of LMM, crop-fish based (more return from crops) and other fish-crop based (more return from fish) model. 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 @ 14 per cent (maximum lending interest rate by bankers, will take care of time value of money); The higher discount rate was considered to cover the future time value of money may arise due to unforeseen risk, uncertainty and inflationary situation. (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, *one* without any opportunity cost, when the model is constructed in the highly degraded land (completely barren, hence no *'next best alternative'* available), hence no return; alternatively, with opportunity cost, when 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. These scenarios were assumed based on the actual practices in the study area learned from the farmers. 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 25 per cent subsidy assistance as initial capital from the government. Government of India normally promotes good agricultural practices through different financial schemes; therefore, such alternative policy options were also simulated.

### *Break-Even Analysis for Land Modification Models*

Break-even size, 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 situation over economic life of the systems. Alternatively, this size may be considered as the minimum economic size of LMM system that could be promoted in the problem area. 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 LMM. Thus, to find out break-even size of LMM, the present worth of incremental benefits under a given scenario was linearly adjusted to equal present worth of the cost stream. The break-even size was determined under three alternative satiations, *first* entire investment made with own cost 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, located at a distance between 50-300 m from canal; and *third* investment is made with own cost along with 25% subsidy receipt from the government. This situation was hypothesised as policy options, in view of likely government assistance, which may be available in future.

## III

## RESULTS AND DISCUSSION

### *Estimation of Extent of Degradation and Farm Level Crop Losses*

The LMM were demonstrated in the farmers' field at a distance of 42 to 185 m from canal. Average area under operation was 1.03 ha, out of which more than half of their land (55 per cent) were severely affected by waterlogging and sodicity problem. Land beyond 300 m of distance from canal was almost normal, receiving regular irrigation water from canal. Rice-wheat was the dominant cropping system, followed by rice-wheat-mint cropping system 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 (Figure 2 and Table 2). Productivity of rice (4267 kg/ha), wheat (2933 kg/ha) and mint oil (113 kg/ha) reduced significantly (1920 kg/ha, 1100 kg/ha and 62 kg/ha for rice, wheat and mint, respectively), due to the waterlogging and sodic problem. Net return was 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. Cropping intensity reduced by 60 per cent (from 185 to 125 per cent) due to these problems. Still farmers, who have available family labourers and no other alternatives, were trying to grow few crops, wherever possible. With prevailing 185 per cent of cropping intensity and 0.18 mha under affected land, the total value of production loss was estimated as ₹ 12490 million (2018-19 prices).

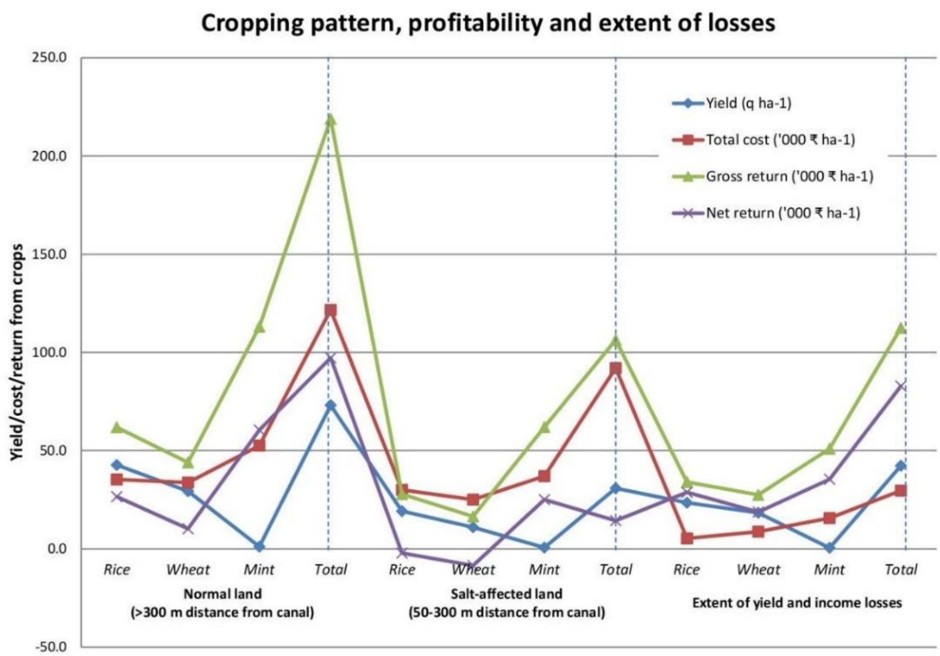


Figure 2: Cropping Pattern, Profitability and Extent of Loss of Existing Cropping Systems

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 and sodic problem | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice | Wheat | Mint | Total | Rice | Wheat | Mint | Total | Rice | Wheat | Mint | Total |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
| Yield (kg/ ha) | 4267 | 2933 | 113 | 7313 | 1920 | 1100 | 62 | 3082 | 2347 (55) | 1833 (62) | 51 (45) | 4231 (58) |
| Total cost (₹ / ha) | 35317 | 33760 | 52558 | 121635 | 30012 | 25008 | 36971 | 91991 | 530 5 | 8752 | 15587 | 29644 |
| Gross return (₹ / ha) | 61872 | 43995 | 113000 | 218867 | 27840 | 16500 | 62000 | 106340 | 34032 (55) | 27495 (62) | 51000 (45) | 112527 (51) |
| Net return (₹ / ha) | 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 (per cent) | - | - | - | 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.

*Farm-Level Impact of Land Modification Models*

Based on field experiences LMMs were re-designed in 2012 to suit the field conditions and total demonstration area under 7 models were 3.71 ha (Table 3). The initial 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 per ha. The area under pond/sunken bed was 26-64 per cent and the raised bed was 36-74 per cent across the different LMMs. The area distribution (raised or sunken) and the distance from canal were crucial for the success/failure of the models. 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.

TABLE 3. AREA DISTRIBUTION UNDER LAND MODIFICATION MODELS UNDER DEMONSTRATION

| Demonstration model | Area under LM (ha) | Initial investment (₹) | Pond area (sq. m) | Raised area (sq. m) | Percent sunken/ pond area | Per cent raised area |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 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 | 0.33 | 110000 | 2850 | 3150 | 48 | 53 |
| LMM 7 | 0.60 | 210000 | 1225 | 2041 | 38 | 62 |
| Overall | 3.71 | 1028000 | 16679 | 19462 | 46 | 54 |

Farm-level impact of LMM was examined 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 of 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. 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 unproductive.

*Impact of Land Modification on Soil and Water Quality*

The configuration of LMM through raised and sunken bed improved the soil quality parameters, pH, ECe, ESP significantly, and land become suitable for growing multiple crops (Table 4). In LMM, the quality of harvested seepage water was normal (<4 dS/m) throughout the year and not 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. 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 4. IMPACT OF LAND MODIFICATION MODEL ON SOIL AND WATER QUALITY

| Parameters<br>(1) | Initial value (2013)<br>(2) | After 4 years (2017)<br>(3) | Increased/ Decreased<br>(4) | Impact<br>(5) |
|---|---|---|---|---|
| *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*

Incremental yield in the LMM system were 1.86 t/ha and 4.69 t/ha as compared to the prevailing rice-wheat-mint cropping systems practiced in 50-300 m distance from canal (Table 5). Crop- based (mainly vegetables) and fish based integrated

TABLE5: INCREMENTAL COST-RETURN OF THE LAND MODIFICATION MODELS (2018-19 PRICES)

*(per ha)*

| 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 |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 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 |

cropping system provided incremental net return of ₹ 130000 per ha (contribution of fish was 45 per cent) and ₹ 314000 per ha (contribution of fish was 84 per cent), respectively, over the rice-wheat-mint cropping system. Overall, the output-input ratio increased from 1.09 to 2.18 (crop-fish based) and 1.45 (fish-crop 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 per ha as compared to ₹ 10000-12000 per ha for the prevailing cropping systems.

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. The LMMs were used by the farmers intensively to grow crops (primarily vegetables) and rearing fish. Some farmers preferred to grow more vegetables and others preferred to rear fish intensively. In both scenarios crops and fish was integrated but with varying degree of priority by the farmers. The analysis indicated investment on such models was quite attractive in the study area. 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 larger the area under the system, it would be more 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 other farmers can adopt crop-fish based models. Incentives in terms of subsidy by the government could be an alternative proposition for promotion of these models particularly for the resource poor farmers.

*Financial Viability and Break-Even Size of the Land Modification Models*

The financial feasibility analysis was carried out on the two kinds of models based on the actual area, 0.60 ha (crop-fish based) and 0.46 ha (fish-crop based) (Table 6). The pond excavation areas for 0.60 ha and 0.46 ha of LMM were 3138 sq. m and 2356 sq. m., respectively. 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 LMMs 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 fish-crop based system (1.75 years) as compared to crop-fish based (2.6 years). The investment analysis considering the opportunity cost 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 and fish-crop based interventions. The investment was more attractive when the subsidy (25 per cent of initial investment) component was included and pay-back period reduced further. IRR calculation is heavily dependent on the initial investment in any project. In case of LMM under crop-fish based or fish-crop based, initial investments required were similar as the land excavation cost was same. However, under fish-crop based LMM, the system provided higher return than crop-fish based LMM but at the same time it required high operational cost also for purchasing fish seeds, feeds and medicine. Most of the fish seeds and feeds were required to bring from faraway places like West Bengal and also skilled manpower was involved to look after the fish cultivation in pond. Therefore, despite yielding higher IRR under fish-crop based LMM, it provided marginally lower BCR as compared to

TABLE 6. FINANCIAL VIABILITY OF THE LAND MODIFICATION MODELS (2018-19 PRICES)

*(on actual area)*

| Particulars | Land modification as crop-fish based | Land modification as fish-crop based |
|---|---|---|
| Area under intervention (ha) | 0.60 | 0.46 |
| Per cent area under pond | 53 | 64 |
| Initial Investment (₹) | 282000 | 212040 |
| Economic life (years) | 10 | 10 |
| *Annual costs/return* | | |
| 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 (without 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 |

*Notes:* 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).

crop-fish based LMM. Based on the incremental cost-return realised during the entire economic life, the break-even size of LMM 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.

*Socio-Economic Suitability for Adoption of Land Modification Models*

Out of the average farm size of households (1.03 ha), 39 per cent of the land was highly degraded due to sodic and waterlogged problems. 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. LMM with a hectare of land for the farmers who aspires for crop-fish based interventions, with 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 the existing 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 by the government 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.

*Perception of Farmers and Technology Developers on Land Modification Models*

Farmers perceived that the LMM were feasible for growing a number of crops, land quality improved and the interventions were profitable. As water was available from the canal throughout the year, number of crops mainly vegetables in all seasons (tomato, cucumber, chilli, brinjal, bottle gourd, spinach, potato, sponge gourd, okra, onion etc.) mint, fodder 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 well. 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, because rearing fish was a social taboo for them in the region and against the social norms, making the system under-utilised. As a result, 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) is needed. 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 and reducing upward movement of salts.

## IV

## CONCLUSION

The innovative LMM can be considered as a solution to existing problems (waterlogged and sodic salt affected) which is techno-economically viable. The innovative LMM improved 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. Therefore, the study disproved the null hypothesis that the farmers would be indifferent to adopt the proposed land modification system and accepted the alternate hypothesis, which stated that such systems could be a preferred solution for management of the waterlogged sodic soil in the affected area. However, there is a need for financial support for the initial investment to be made. Farmers can be aggregated through promotion of leasing systems of land, which will be helpful to out-scaling of the proposed LMM. On one hand, some farmers whose land got affected but not interested for cultivation as they have left agriculture and engaged in alternative livelihoods like small business or industrial worker, but at the same time many other farmers who are engaged full time in farming and dwelling in the villages are interested to manage such system through leased-in, after construction. Mutual collaboration between these two groups of farmers can pave the way to promote such LMM and productive use of the degraded land, which otherwise remained unproductive. The LMM systems can be constructed along both sides of the canal and highly degraded land can be made productive again. The initial investment for construction of LMM can be supported through ongoing Reclamation of Problem Soil scheme launched under Rashtriya Krishi Vigyan Yojana. This effort also fulfills the objectives of multiple Sustainable Development Goals such as no poverty and zero-hunger, as has been targeted by United Nations. Besides, promotion of LMM might be a good option and possible entrepreneurship development may attract the private investment which might be beneficial for the farmers in terms of earning good return, gainful employment and restoring the degraded land and productive, again.

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