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# Optimization technique for alternate cropping systems in different lift irrigation schemes in India and other countries: A review

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**Abstract**
The paper critically reviews various methods exclusively used for alternate crop planning and point our suggestions for improvement in techniques used for plan, objectives and constraints, approaches and various computer software packages used in computing the optimum models. With such extensive coverage, it intends to help the end users to decide upon an appropriate method corresponding to their situation and scenarios to frame the best and most practical optimum crop model. The paper also highlights some studies with their scope, approaches, objectives and constraints.

**Keywords:** Optimization, crop plan, lingo, lift irrigation schemes, etc.

## Introduction

Land and water are finite natural resources in our country. These resources are diminishing gradually due to indiscriminate and unscrupulous exploitation. In order to meet out the food and fodder requirement of ever-increasing human and livestock population, the need of hour is to enhance land and water productivity from limited resources. Also, it is equally important for farmers to know the optimum option of allocating different parcels of agricultural lands under various interventions related to agriculture so that their profit is maximized from available land and water resources and other prevailing constraints.

The ever-increasing population growth and industrialization are putting constant pressure on water resources and it is more likely that the available water resources may not be able to meet the future water demands. The shortage of water resources has become more severe due to the uneven distribution of available water resources among various water demand sectors and is a major constraint to economic development in many countries around the world. (Ijaz *et al* 2014) [15]. The world's readily available fresh water resources are becoming increasingly scarce due to higher demands by municipal, industrial, recreational, and agricultural sectors. This is not only because of population increase and higher standards of living in many areas, also due to changes in land use and global climate change as a result of rapid development. Irrigation accounts for 70% of total freshwater withdrawals globally, whereas industrial and domestic sectors accounting for the remaining 20% and 10%, respectively. With expected increases in population by 2030, food demand is predicted to increase by 50% (70% by 2050). Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050. Irrigation accounts for more than 40% of the world's production on less than 20% of the cultivated land. Globally, irrigated crop yields are 2.7 times those of rain fed farming; hence irrigation will continue to play an important role in food production. However, the increasing competition for water usage in different sectors is making this resource scarcer and more valuable. Hence, today, the agricultural sector around the world is under more pressure for limiting its water use, not only because of the increasing water demand, but also because of climatic changes and more frequent droughts. (Birhanu *et al*. 2015) [4]. In agriculture, as in any other business, the efficiency is achieved by an optimum utilization of resources. Resources include land, labour, capital, irrigation facilities etc. Optimum allocation of land and other resources is defined as what crops to undertake, how

much land to allocate to each crop activity and what method and combination of inputs to use for each crop so that the farm returns are maximum. To meet the requirements mathematical models and irrigation management methodologies are essential in crop planning. In this regard Linear Programming (LP) technique is widely used by many researchers for irrigation planning problems for real case studies. Some of the relevant studies are as follows:
Radhkrishnan (1962) [16] and Raj Krishna (1963) [17] proposed the LP technique for determining the optimal farm planning. Keith (1985) suggested that in the current economic climate, linear programming could well be worth reconsidering as a maximizing technique in farm planning. This particularly applies when it is used in conjunction with integer programming, which allows many of LP's problems to be overcome.
Lakshmi Narayanan and Rajagopalan (1992) [18] used linear programming model for maximizing the irrigation benefits for Bari Doab basin in Northern India. Sensitivity analysis on the tube well capacity against the area available for irrigation was also carried out. Maji and Heady (1980) [19] developed an optimal cropping pattern and reservoir operation policy for the Mayurakshi irrigation project on Hoogli river in Jharkhand, India, where the objective was to maximize the net benefits by considering the average inflows and chance constrained inflows by assuming the gamma distribution.
Paudyal and Gupta (1990) [20] solved complex problem of irrigation management in Tinao river basin, Nepal, by multilevel LP models. Developed two level optimization (LP) model to a case study of Dadu canal command of the lower Indus basin. Presented an optimization model for a case study of minor irrigation scheme. It is concluded that an increase in the cropped area by approximately 50% is possible over that under intensive irrigation approach.
Srinivasa Raju and Nagesh Kumar (2000) [21] developed fuzzy LP model for the evaluation of management strategies for a case study of Sri Ram Sagar Project, India. The study demonstrated how vagueness and imprecision in the objective function values can be quantified by membership function in a fuzzy framework. Similar studies are reported by Paul *et al*. (2000) [22].

**Scope of optimization techniques**

Optimal crop enterprise combination enables small scale farmers to earn the highest possible income under resource limiting conditions. Adoption of an optimal crop combination plan has been considered one of the most important means of increasing agricultural production, farmers' incomes and increasing food security in the world.
Optimal irrigation system planning and operation are having scope for optimization. The success of irrigation system operation and planning depends on the quantification of supply and demand and equitable distribution of supply to meet the demand if possible, or, to minimize the gap between the supply and demand. For this purpose, optimization models are required to select optimal solutions, systematically, under agreed-upon objectives and constraints, (Birhanu *et al*. 2015) [4] Among the available optimization techniques such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA), it is LP model that is more popular because of the proportionate characteristic of the allocation problems. Moreover, LP model can handle a large number of constraints and thus, an effective tool to aid in the optimization process. Linear programming-based optimization methods are popularly used to derive the policies and are found as an effective tool in dealing with the allocation of resources during irrigation planning. The LP is also easy to apply with the problem of irrigation planning using several available programs. (Birhanu *et al*. 2015) [4]

**Objectives and Constraints**

The objective function for the model was to maximize the annual net returns on the farm (from crop enterprises) subject to the resource constraints. The net returns were measured by deducting variable expenses from gross margin. The various items of variable costs were cost of seeds, manures, fertilizers, water, hired human and bullock labour, insecticides, pesticides, electricity charges etc. The harvest prices were taken as output prices and the actual market prices of inputs at the time of application were taken as input prices.
The objective of model is aimed to evolve a suitable optimum cropping pattern to yield maximum net benefits while meeting the other requirements of the reservoir. The Ukai project is a major project located on the banks of river Tapi. The objective function was formulated to allocate the land area between various crops in order to maximize the net return from the command area. The objective function is subjected to the following constraints: Water availability constraints, Crop area constraints, non-negativity constraints (Bhuvandas *et al*. 2010) [23].
The model is: benefit and cost coefficients in the objective function, water requirements of various crops for each month, hydrological inputs for different months at various sites, downstream flow requirements at the Subernarekha barrage for downstream use, coefficients of return flows from irrigation and industrial water supplies and coefficients of reservoir losses in each month. In the objective function, the coefficients required are: value of each crop net of variable farm costs, fixed farm costs, unit revenue from the sale of industrial water, the annualized investment costs of reservoirs and canals and annual maintenance costs of reservoirs and canals.
There were two objective functions benefit maximization and maximization of cropped area in Nanakamatta canal command of Uttarkhand using fuzzy linear programming. The model was subjected to the following constraints: Water requirement, Annual groundwater extraction constraint, Total cultivable land constraint, affinity constraint, non-negativity constraint.
The objective function is to maximize net benefit from irrigated area which includes returns from the irrigated area and the operations costs for canals and tube wells M.R.B.C Command area Kheda.
The objective function of the model is to get maximum net benefit at different water availability in the reservoir, which is subjected to the following constraints: water availability, crop land requirement, Human labour cost, Animal and Machine power cost, Seed cost, Fertilizers and Manure cost, Fixed cost etc.

**Various approaches for crop planning**

The general methods available for optimization through programming models can be classified as follows: (1) Linear Programming (LP); (2) Dynamic Programming (DP); (3) Non-Linear Programming (NLP); and (4) Simulation. To be more specific, LP is a viable tool in the optimization of reservoir operations, both for real time and planning purposes. Salman *et al*. (2001) [24] present a linear programming model to derive regional water demands based on optimized regional cropping pattern with variable water prices based on quality.

Linear Programming (LP) based irrigation planning model is formulated and applied to command area of Kakrapar Right Bank Main Canal (K.R.B.M.C) which is a part of the Ukai project, Gujarat, India. (Bhuvandas *et al*. 2010) [23].

Linear programming (LP) was used to determine the optimal crop combination in maize, coffee and sugarcane crop farming system, and the maximum profits obtained was going to be compared with the calculated Gross Margins (GM) in monetary terms to determine the level of household income. The technique is a common mathematical modelling technique that is used to solve optimization problems in which the objective function is optimized subject to various linear constraints.

The objective of this study is to develop fuzzy linear planning model for optimization of land and water resources in Nanakmatta canal command of Udham Singh Nagar district of Uttarakhand (India). The multi objective fuzzy linear programming (MOFLP) was applied for maximization of the crop sown area and net return (NR). The fuzzy objective function is characterized by its membership function, which plays as substitute characterization of preference in determining the preferred outcome for each of the objectives.

Leung (1988) [25] used fuzzy linear programming (FLP) to study the allocation of water to three farming areas. The goal was to program water consumption to enhance profitability. Bender and Simonovic (2000) [26] used the fuzzy-compromise method for water resources programming under uncertainty. McPhee and Yeh (2004) [28] studied simulation and optimization of groundwater usage based on fuzzy logic. Abolpour *et al*. (2007) [27] developed a model for the allocation of water resources in a large basin. Used a genetic algorithm (GA) for training the fuzzy rules and developed if-then rules with linguistic expressions. He also developed two different FIS models to predict the discharge of the Euphrates River in Turkey. One was developed based on the Mamdani system; the other drew on the Takagi-Sugeno system. He compared the results of the two models and concluded that the Mamdani type of fuzzy-inference modeling outperforms the Takagi-Sugeno approach in error criteria comparisons.

Groundwater flow modeling and interaction between surface water and groundwater is simulated using Modflow-2000 and fuzzy regression is used to consider the uncertainty in the data required for estimating the simulation model.

Linear Programming is a method of identifying constraints, both of a technical (e.g., water) or of an institutional (e.g., credit) nature, which have a significant effect on a multi-product or multi- activity farming system. The sensitivity analysis further enables to analyze the effects of any change in the constraints on the overall farm activity.

The bi-level model has been applied to the Swat River basin in Pakistan for the optimal allocation of water resources among competing water demand sectors and different scenarios have been developed. (Ijaz *et al* 2014) [15]

Chance constraint linear programming (CCLP) models were developed by incorporating uncertainty of inflows.

Most of the optimization problems have the specific objective of maximizing revenue and yield of agricultural crops. Ishtiaq Hassan *et al*. (2005) 29] proposed the model for optimal cropping pattern, land allocation and production for crops such as wheat, basmati rice, IRRI rice, cotton, sugarcane by including the farmer’s income as an important parameter. Proposed a linear programming technique to determine the optimum land allocation to maximize the profit for 10 major crops with various expenditure factors. formulated linear programming model to suggest the optimal cropping pattern for surface irrigation in a command area. Main objective of the model was to achieve the maximum net benefits subjected to the constraints such as the total available water and land during different irrigation periods.

Developed LP technique for optimum land allocation and achieving efficiency in agriculture production planning of food crops (rice, maize, wheat, pulses and other crops) to maximize the profits with respect to various factors *viz*. Daily wages of labour and machine charges for the period 2004-2011.

Pushpavalli *et al*. (2018) [30] developed a linear programming (LP) technique for optimization of resource allocation and achieving efficiency in planning for agricultural production. Developed a model for the potential production and profit performance of smallholder crop production systems under alternative crop land allocation scenarios formulated a model for optimal cropping pattern and area under the different types of rice crop to maximize the profit gain of farmers proposed a LP model for optimal land allocation of four crops namely rice, corn, soy, peanuts to maximize the net income levels. Manju *et al*. (2019) [31] developed a LP model to allocate the optimal crop area of cotton, guar and jowar crops such as to maximize the net return with various expenditure factors.

**Table 1:** Some studies with their scope, approaches, objectives and constraints

| Author | Study Area | Approach | Objectives | Constraints |
|---|---|---|---|---|
| Coelho *et al*. (1997) [6] | Senator Nilo Coelho project | Linear programming model | Maximize net income | Water availability, cropping area. |
| Bansude and Nair (2000) [12] | Chamravattom regulator-cum-bridge Malappuram (Kerala) | LINDO Software | Maximize the net profit | Water available for irrigation and area available for cultivation |
| Srinivas and Nagesh (2000) [21] | Sri Ram Sagar Project | LP model | Maximize net benefits | Continuity equation, land and water requirement, water quality, storage restriction, crop surface and ground water release. |
| Jaiswal *et al*. (2001) | Shahi distributory, Barielly, UP | LP using Simplex method | Maximize net returns | Total available water and land, farmer socio economic conditions. |
| Srinivas and Nagesh (2000) [21] | Bisalpur Project, Rajasthan | Mathematical Modelling | Net benefit from different crops to be maximized | Crop area, irrigation release, canal capacity, live storage |
| Bhuvandas *et al*. (2010) [23] | Kakrapur right bank main canal | LP model | Maximized net revenue | Crop area, Cropping pattern, Continuity equation, Minimum and Maximum storage, canal Capacity, water requirements of crops |
| Majeke *et al*. (2013) [11] | Masvingo, Zimbabwe | LP model | Total net income | Resource constraints |
| Birhanu and | Koga Irrigation Dam, | LINGO,Chance | Maximization of | Land and water availability |

| | | | | |
|---|---|---|---|---|
| Alamirew (2015) [4] | Ethiopia | Constraint Linear Programming (CCLP) | Total yield and Total Benefit | |
| Hiremath and Shreedhar (2015) [13] | Markandaya command area | CROPWAT, LP model | Maximize net benefit | Water availability, crop land requirement, Human Labour cost, Animal and Machine power cost, Seed cost, Fertilizer and manure cost, Plant Protection cost,Fixed cost, Unforeseen expenditure |
| Abdelwahab *et al.* (2016) [10] | Mehako Scheme inTigray, Ethiopia | LP model | Maximize the farming benefit | Agronomic pratices, farmer knowledge, food security requirement |

**computer software used for optimum crop planning**

Rapid and effective calculations of long and complex mathematical procedures in many real-life quantitative models have been enabled by computer software packages, which are now effective part of quantitative approach to problem solving. Due to availability of various software packages for mathematical models a large number of activities and constraints are possible to be incorporated in the model and the output of such analysis could be easily made available to the decision makers.

Some of the leading software packages for quantitative approach are MS Excel solver, LINGO/LINDO, QSB, QSOM, LiPS, and GAMS. Modeller who wishes to develop crop planning model may select a software based on, purpose, expertise available and the nature of the problem. For example, MS Excel solver is simple and useful for learning modelling and dealing with smaller problems. It becomes difficult for multiple scenario analysis, which requires frequent modifications. The detail of the software, documentation, download options, instructions and license pricing etc. are easily searchable from the internet.

## Conclusion

The present study is an attempt to review the various approaches and techniques used specifically for optimum crop planning. We comment upon the various possible mathematical programming set ups for crop planning and their suitability. Considering various aspects of optimization of crop plans, the study is organized into various sections such as scope, objective, function and constraints, approaches, sensitivity analysis and software packages used for optimization in crop planning. Thus, the reader can have a quick grasp of various tools, software and techniques, which are required for optimal crop planning.

## Future scope

This review article gives a brief idea about the various researchers who have worked under different lift irrigation schemes in India and other countries using linear programming model. Various approaches used by the authors are summarized which help them to choose the best of the various approaches and the one which is suitable for their studies.

## Author's contributions

Conceptualization of review work (AA, CS, KS, KS); Evaluation of various studies that were carried out (AA, CS, KS, KS), Recent softwares used in the optimization techniques (AA, CS, KS, KS); Preparation of Manuscript (AA, CS, KS, KS)

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## Conflict of interest

The authors do not have any conflict of interest.

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