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Optimization techniques for crop planning: A review

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ABSTRACT

The paper critically reviews various methods exclusively used for crop planning and points out suggestions for improvement in techniques used for crop planning. Specifically, the study examines scope for optimization of crop plan, objectives and constraints, approaches, seasonality issues, sensitivity analysis 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/suitable method corresponding to their situation and scenarios to frame the best and most practical/realistic optimum crop model. The paper also lists many model management options for developing such models. Finally, the paper presents a brief case study of Punjab state to illustrate an improvement in the methodological approach especially pertaining to aspects of sustainability, food security and seasonality in crop cultivation.

Key words: Crop planning, General Algebraic Modelling System, Mathematical programming, Optimization, Sensitivity analysis

In traditional agriculture, crop planning decisions were mainly guided by the farmer's judgment and experience. However, with advancement in agriculture and increasing pressure on land and other resources, coupled with increased specialization and the adoption of capital-intensive production systems, the development of more formal planning methods based on the construction and analysis of a mathematical model has been stimulated. Since its inception, mathematical programming models have been applied directly or indirectly in agricultural sector and have contributed significantly in the analysis of policy issues such as resource allocations, investment decisions, comparative advantage, risk analysis etc. They are imperfect abstractions but by virtue of their logical consistency frameworks, they can provide the analyst and policy maker with a valuable economic representation of the farm or sector for testing ideas and policy proposals (Hazell and Norton 1986). Earlier crop planning studies were done based on farm level allocations (Waugh 1951, Heady 1954). Later, such exercises have been extended to a regional level to aid in planning at broader horizons (Norton and Schiefer 1980).

A few surveys were made in the past in reviewing some aspects of agriculture planning methods. Norton and Schiefer (1980) highlighted various mathematical programming models broadly used for agricultural sector planning with special emphasis on questions of appropriate model structures for replication of sector behaviour and on the reliability of computed results. However, the review was focused mainly on the approaches and did not consider how to deal with practical issues related to development of such models under various different situations. Further, there was not many sophisticated model management software available for implementing such models at that time. Glen (1987) made a survey on mathematical models in farm level planning. However, the study was exclusively for problems related to developed world and did not consider regional level planning. Weintraub *et al*. (2001) presented a review on operation research models and management of renewable natural resources. Gomaa *et al.* (2011) reviewed the works done related to crop planning and water management. However, to the best of our knowledge, no recent study has exclusively reported review on techniques for optimum crop planning along with the implementation details.

In this backdrop, the present study is an attempt to review the various approaches and techniques used specifically for optimum crop planning. However, we do not attempt to evaluate the policy applications which have been made using various programming approaches because that would require considering institutional settings for each application. However, we comment upon the various possible mathematical programming set ups for crop planning and their suitability. Considering various

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aspects of optimization of crop plans, the study is organized into various sections such as scope, objective, function and constraints, approaches, seasonal issues, 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.

Scope of optimization techniques

In general, analysts have formulated various models at the farm, regional and national level in the agricultural sector (Glen 1987). Norton and Kutcher (1982) classified the use of mathematical programming model for agriculture into five distinct levels: the farm, the district, the region, the sector, and for multiple countries which engage in mutual agricultural trade. The district constitutes a collection of farms, which is sufficiently small so that variations in its aggregate output are not likely to affect prices. Such studies provide the spatial basis for analyzing specific investment choices, e.g. irrigation project. The region, however, is sufficiently large so that changes in its output may affect prices, although the price consequences have not always been taken into account by analysts (Norton and Kutcher 1982). Optimization may also be attempted based on FAO (1993) guidelines on land use planning which defines three broad levels: national, district and local. In these guidelines district level refers not necessarily to administrative districts but also to land areas that fall between national and local level. Local level refers to a village or group of villages or a small water catchment. However, Weintraub *et al.* (2001) in their review of operational research methods grouped scope of optimization into two broad models: farm level and regional level. Comparisons between different levels of optimization are presented here.

Most of the earlier studies deal with a single farm or extend to a particular area of land having similar features in terms of land and other resources such as a group of sample farms or a group of villages (Maleka 1993, Tajuddin *et al.*1994). Few models are available for a particular catchment area (Heady and Love 1954, Mohaddes and Mohayidin 2008, Sethi and Panda 2011, Rani 2012, Shrivastava *et al.* 2012, Mirkarimi *et al*. 2013). At the local level, decisions may vary subject to the prevailing farm physical and financial constraints, and often in the face of considerable uncertainties that may arise in expected yields, costs and prices of commodities (Hazell and Norton 1986). Objective functions at this level mainly emphasize on farmers' immediate needs in terms of food and financial requirements of the households and enough resources for the next cropping season. Basic objective functions are profit maximization (Hazell and Norton 1986, Tajuddin *et al* 1994) and/or minimizing cost to a farmer (Barnard and Nix 1973). Local people's knowledge and contributions help in formulating models and policies that fit the objective of the people (FAO 1993). The technical coefficients are also easy to estimate at local level as each farmer has limited resources at their disposal for any planning period (Hazell and Norton 1986). However, the production possibilities of a farm are limited as it is constrained by fixed resources for a particular period of time (Weintraub *et al*. 2001). Conflicts of interests also arise, as the local interests may not align with regional or national interests or sustainable objectives (FAO 1993). Thus, crop planning at broader level becomes imperative in consultation with the micro level planning objectives.

Major challenge in developing mathematical models for crop planning at national level come from unavailability of accurate recorded data such as farm incomes, input uses, prices etc. This feature is common especially in developing nations (Norton and Kutcher 1982). Another important challenge in case of regional planning was the aggregation problem (Weintraub *et al* 2001). When the analyst moves from farm level to regional level, representative farm-level data are used after required modifications in technological coefficients from the farm levels. As farms considered in a region or sector model are not alike, it is, therefore, impossible to consider the region or sector as a single farm. Hence, it is important to choose the appropriate aggregation rules in order to minimize the aggregation bias (Hazell and Norton 1986, Weintraub *et al.* 2001). The modifications should mainly constitute weighted aggregations with respect to objective function and constraints. In order to deal with the aggregation problems, references can be drawn from the studies of Day (1963), Miller (1966), Lee (1966), Buckwell and Hazell (1972) and Kennedy (1974). Norton and Schifer (1980) suggested four main practical categories such as irrigated-non irrigated, farm size, basic cropping regime categories, e.g. livestock vs. annual crops and spatial categories in reducing the aggregation bias.

District-level studies have either used selective blocks or farmers and there were hardly any studies which considered the whole cultivable land into consideration (Sharma *et al.* 2007, Varalakshmi *et al.* 2011, Pradhan 2012, Otoo *et al.* 2014, Pravin *et al*. 2015). Kaur *et al.* (2010, 2015) carried out state-wide crop planning for determining optimum cropping pattern that ensures maximum profit with sustainable ground water use for the state of Punjab. The study emphasized on the sustainable ground water use and hence they selected 72 tehsils having intensive paddy-wheat crop rotation and high ground water use associated with the problem of falling ground water table.

At the national level, planning is concerned with national goals and the allocation of resources. In many cases, national land-use planning does not involve the actual allocation of land for different uses, but the establishment of priorities for district-level projects. National goals are complex while policy decisions, legislation, and fiscal measures affect many people and wide areas. The responsibility of planners is to present the relevant information in terms that the decision-makers can both comprehend and act on (FAO 1993). Some commendable models at regional or national level include Germany (Heidhues 1966), Sweden (Folkesson 1968), Thailand (Faber *et al*. 1978), Bangladesh (Sarkar and Lingard 2002) and Spanish agricultural regions (Martin *et* *al*. 2015). These studies did the aggregation mainly through the restraints in each of the zone models. These studies use import and export constraints in the national models.

Norton and Kutcher (1982) discussed some problems of researchers during the development of agricultural planning models. Authors mentioned that complexity of the agricultural decision making is increased by the multiple and often conflicting objectives of governments. Typically, the policy objectives of the agricultural sector include:(i) Provision of an adequate supply of food and fibres for the populace at affordable prices. (ii) Simulation of foreign exchange earnings or savings from agricultural exports or import substitution. (iii) Generation of adequate levels of employment and income for farm workers. (iii) Improvement of income in backward regions. (v) Preserve ecological balances.

Unfortunately, these worthy objectives are frequently, mutually inconsistent, and policy instruments can influence them to some extent only. Raising the income of farmers and farm workers by wage or price policy will almost certainly raise food prices for urban consumers, and hence, it may result in a decrease in nutrition levels for the poorer urban groups. Likewise, attempts to promote national self-sufficiency in food grains may displace some crops, which are more employment intensive than grains, giving the net results of a decrease in agricultural employment. In these circumstances, the proper role of analysis is not necessarily to derive a "best" program, but more usually to assist in the policy decision by illuminating the varied consequences of multiple choices (Norton and Kutcher 1982).

Objectives and constraints

The programming model guides the stakeholders to adopt the farm plans to achieve their desired objectives such as maximization of benefits or minimization of costs or both under the given constraints, prices, yields and resource availability (Norton and Schiefer 1980). The most commonly used objective functions in crop planning are maximization of net revenue, profit, income, overall contribution of agriculture sector, employment or minimization of input costs, water usage, erosion and natural resources (Gomaa *et al*. 2011). Any of the selected objectives is further subjected to various constraints such as land, labour, capital, risks and uncertainty. For obtaining realistic results, sometimes 150 to 200 constraints are considered by the researchers in the economic studies (Reddy *et al*. 2008). Profit maximization is observed as the most common objective of crop optimization under the given resources and constraints (Love 1956, Maleka 1993, Mainuddin *et al*. 1997, Weintraub *et al*. 2001, Sethi *et al*. 2002, Sarker and Lingard 2002, Srinivasa *et al*. 2005, Kaur *et al*. 2010, Wankhade and Lunge 2012, Sofi *et al*. 2015). The specifications for the above-mentioned objective functions and the usual constraints can be referred from various published works (Table 1). Some researchers have gone beyond the conventional constraints to improve the practicability. For example, Maleka (1993) used a constraint, namely, cost of risk taking along with conventional constraints like land, labour, cash capital and soil moisture and objective function based on maximization of gross margins from seven crops. The model yields three outputs such as the mix of crops to be grown, the amount of credit to be given to the farmer and the expected gross margins to be realized. For soil moisture constraint, the water requirement for all the crops considered for model should be less than or equal to the amount of rainfall from the simulated rainfall values measured in ha-mm for a particular zone. The constraint, cost of risk taking was set within the framework of a decision maker wanting to seek a trade-off between maximizing crop output and hence, revenue on the one hand, and minimizing the risk of undertaking cropping activities on the other. The risk in the study was assumed to be caused solely by the uncertainty pertaining to the amount of rainfall. Tajuddin *et al*. (1994) developed optimum crop mix based on minimum cereal requirement as one important constraint along with others restrictions like land, labour, bullock labour, tractor, power tiller, and capital. The authors formulated an optimum crop mix for some sample farms in Bangladesh aiming at maximizing the net return. Minimum cereal production was set based on the annual minimum cereal requirement for household consumption. Credit was found to be the most influential constraint in achieving a desired farm income. Sarker *et al*. (1997) introduced a constraint on import bound for cereals along with other constraints as discussed above while developing an optimum model for Bangladesh aiming at maximizing overall contribution of crop sector. The model was first run without area and import restriction, which gave high contribution because of low cost of imports and high contribution of other crops. Nevertheless, the model was unrealistic and hence the model was modified by introducing import restriction mainly on cereals at different level and the results were compared to obtain the best model, which can contribute to achieve self-sufficiency in food grains.

From farm to regional level, stakeholders are confronted with various limited resources and multiple options to achieve the desired benefits. Thus, researchers emphasized that agricultural planning problems involve multiple conflicting goals such as maximizing crop production, maximizing overall profit, minimizing labour expenditures, minimizing water use and other input costs without compromising with sustainability of natural resources (Sarker and Quaddus 2002, Mohaddes 2008, Soltani *et al.* 2011, Agha *et al.* 2012, Rani 2012, Mirkarimi *et al.* 2013, Mortazavi *et al.* 2014). Lately, various researches and planning have been carried out with the multiple objective functions. In many cases, some constraints are formulated as objective functions (Boustani and Mohammadi 2010, Rani 2012). However, it is not possible to achieve all desired objectives simultaneously as certain objectives can be achieved with the expense of others (Sharma *et al.* 2007). A trade-off occurs among the multiple objectives to obtain a satisfactory solution in the decision making process (FAO 1993).

Table 1 Highlights of some studies with their scope, approaches, objectives and constraints

Studies	Scope	Approach	Objective(s)	Constraints
Maleka (1993)	Farm (Gwembe Valley, Zambia)	Target MOTAD	Maximize net revenue	Land, labour, credit, soil moisture, cost of risk taking
Tajuddin *et al*. (1994)	Farm (Bangladesh)	LP	Max net returns	Land, labour, capital, min cereal requirement
Sarker and Lingard (2002)	Country (Bangladesh)	LP (QSOM)	Max over all contribution of agriculture sector	Land, capital, area & import bound, minimum food requirement
Sethi *et al*. (2002)	Farm (Coastal river) basin of Odisha)	DLP & CCLP (QSB)	Maximize net revenue	Land, water
Sharma *et al*. (2007)	District (Ghaziabad, India)	FGP (Lingo)	Max crop production, net profit, labour, min water, machine	Land, capital, food
Mohaddes and Mohayidin (2008)	Farm (Atrak Watershed, Iran)	FGP	Max profit, Max employment, min erosion	Land, water
Sharma *et al*. (2009)	State (Himachal Pradesh)	DNLP (GAMS)	Max profit	Land, labour, capital
Sethi and Panda (2011)	Farm (Costal River Basin, Odisha, India)	LP based DSS (QSB+)	Max net returns	Land, water
Soltani *et al*. (2011)	Local (Kerman province, Iran)	FGP & LP (QSB)	Max crop production & net returns, min labour employment, water & machinery inputs	Land, labour, water, machine
Rani (2012)	Farm (Mahabubnagar, AP, India)	LP	Max profit, input cost min & water usage min	Land, water, min-max yield requirement
Karunakaran *et al*. (2012)	Regional (Bhavani basin, Tamil Nadu)	LP (GAMS)	Max net income	Land, water, soil
Mirkarimi *et al*. (2013)	Farm (Amol, Azandaran, Iran)	FGP (Lingo)	Max profit,	Self sufficiency
Mortazavi *et al*. *(*2014)	Country (Iran)	LP, GP,FP, FGP (MCDA/ MCDM)	Max gross revenue, max employment, min water consumption,	Land, labour, water
Kaur *et al*. (2010) Kaurv *et al*. (2015)	State (Punjab)	LP	Max profit	Land, labour, water, capital , crop maxima and minima
Martin *et al*. (2015)	Country (Spanish region of EU)	LP (GAMS)	Max net return	Greening constraints based on CAP of EU

LP - Linear programming**;** MOTAD - Minimization of total absolute deviations; FGP - Fuzzy/Fractional goal programming; DSS - Decision support system; DLP- Deterministic LP; CCLP-Chance constrained LP; CAP - Common agricultural policy; EU- European Union

Various approaches for crop planning

Optimization approaches can be broadly put into linear and non-linear categories. Linear programming (LP) has been widely applied in agriculture since 1950s. The earlier application of linear programming technique in farm planning problems includes Waugh (1951), Heady (1954), Love (1956), Heady and Candler (1958), etc. Whole farm planning for beginning farmers was done by Love (1956) while Waugh (1951) applied LP technique to the problem of minimization of cost of feed for dairy cows. Many studies have suggested Linear Programming as an effective tool in various decision-making problems in agriculture as it can efficiently handle a large number of linear constraints and variables simultaneously (Weintraub *et al*. 2001). Many researchers used LP for optimization of crop plan (Sarkar and Lingard 2002, Sethi *et al*. 2002, Sethi *et al.* 2006, Kaur *et al*. 2010, Gomaa *et al.* 2011, Wankhade and Lunge 2012, Aparnathi 2014, Sofi *et al*. 2015 and Martin *et al.* 2015). Some used LP to determine the optimal area under different crops and amount of surface and ground water used to get maximum benefit in Punjab (Laxminarayan and Rajagopalan 1977, Khepar and Chaturvedi 1982). Mai *et al*. (1984) employed LP technique to obtain an optimum crop combination to get maximum benefit for *rabi* season in Debra block of Midnapore district, West Bengal and suggested paddy, gram, mustard and potato to be grown under lift irrigation without canal supply for achieving maximum benefit. Karunakaran *et al.* (2012) used LP based approach to assess the sustainability of the current land use pattern in crop agriculture in the Bhavani Basin of Southern India based on soil characteristics, land and water availability.

However, despite of these wide applications, simplicity, and versatility of linear programming approach in optimization problem in crop planning, there are situations in farm planning, which cannot be accurately modelled with the use of the basic LP models. There are cases where the decision variables cannot take continuous values or where a certain activity, if it is to be produced, must be set, at least, to a certain minimum level, or cases involving risk and uncertainty etc. Further, many of the real world or agricultural variables are not linear in function. As a result, basic LP models become inefficient in cases where assumptions of linearity does not hold good. In order to deal with such issues other models, e.g. modified linear, non-linear or mixed models are in use. A few of such models are Deterministic Linear Programming (DLP) model, Chance Constraint Linear Programming Model (Sethi *et al.* 2006), multiple stage linear programming (Martina *et al.* 2015), dynamic programming (Sharma *et al.* 2009), Fuzzy Goal Programming (Sharma *et al.* 2007, Mirkarimi *et al.* 2013), Quadratic programming (Manos and Kitsopanidis 1986), target MOTAD model (Maleka 1993, Boustani and Mohammadi 2010, Zareian *et al*. 2013 and Wondimagegn 2014). Some studies developed a computer program so-called P-RISCO for the application of risky simulations on linear programming models (Borges- Junior *et al*. 2008, Pant *et al*. 2010). Sethi *et al.* (2006) developed the Deterministic linear programming (DLP) and chance-constrained linear programming (CCLP) models as a non-structural measure to allocate available land and water resources optimally on seasonal basis to maximize the net annual return from the study area. Tsai *et al.* (1987) developed a combined network optimization-simulation model for optimal sequencing of multiple cropping systems. Many researchers supported Fuzzy Goal Programming (FGP) to be an effective tool in most agricultural planning problems where values of some parameters are not be known precisely and when in addition to economical goals, environmental goals are considered (Sharma *et al.* 2007, Mohaddes and Mohayidin 2008, Abadi *et al.* 2009, Soltani *et al.* 2011).

The findings from these studies suggested that whenever computer-based models can be run interactively and the results can be made available quickly, the use of LP techniques could have a significant impact on farmers' decision-making behaviour. Although the objective is to improve decision-making, yet very few models are in use directly by farmers (Glen 1987). LP techniques are useful for making user-friendly decision support systems (Papathanasiou *et al.* 2005, Sethi and Panda 2011). Martina *et al*. (2015) has also developed one such DSS based on new Common Agricultural Policy of European Union and applied it to Spanish agricultural regions.

Seasonality

Cropping activities are seasonal in nature and are confined to particular periods of the year when climatic factors are conducive to their growth and production (Hazell and Norton 1986). They illustrated that seasonality characteristic of farming leads to particular pattern in resource use, such as land, labour and other factors of production. If seasonality issues are ignored in constructing a model, the results obtained will be unrealistic. Thus, incorporating seasonality increases the practicability of the model though it will restrict the model solution that leads to lower values of the objective function. Therefore, seasonal allotment of resource use needs utmost care and attention. Some researchers have developed models for annual crop planning by dividing the available land into different types such as single cropped, double cropped, triple cropped area, etc. and accordingly fixing the lower and upper bound constraint on land (Sarkar and Lingard 2002, Chetty and Adewumi 2013). Most of the researchers consider two main cropping seasons such as monsoon (*kharif*) and winter (*rabi*) while allotting land for various crop activities in formulating an optimal crop model (Sarkar and Lingard 2002, Sethi *et al.* 2002, 2006 and 2011, Kaur *et al.* 2010, Dahiphale *et al.* 2015). However, total land in each season does not exceed the net cultivable area for a farm or region. Some cases emphasise on crop planning for a particular season (Shrivastava *et al.* 2012). Such kind of planning is useful to achieve the full potential of a region in a particular season. For example, Shrivastava *et al.* (2012) devised an optimum model for *rabi* season to obtain the maximum returns with special reference to major irrigation projects in Bango command area of Chhattisgarh. In this case, *kharif* season occupied 100% of the available area for cultivation while in *rabi* season, crop coverage varies according to the availability of the water in reservoir. Due to lot of variability in the growing months of various crops, it is more beneficial to capture the seasonality by use of monthly crop calendar (Jain *et al*. 2015). Crop calendar can provide information on availability of fallow land during some months and can easily incorporate some other constraints like month wise labour, capital and irrigation water (Kaur *et al.* 2010, Dahiphale *et al.* 2015). Any one or any mix of the above approaches is useful for dealing with seasonality in crop models. For instance, Alam *et al.* (1995) considered 12 months for land restrictions, eight peak months for human labour, five peak periods for bullock labour, four periods (quarterly) for capital availability and two peak periods (April and November) for tractor/power tillers.

Sensitivity analysis

Sensitivity analysis means the investigation of the potential changes and errors arising from parameter values and assumptions of an economic model, and their impacts on conclusions from the model (Pannell 1997). It is the study of how the uncertainty in the output of a mathematical model (numerical or otherwise) leads to different sources of uncertainty in its inputs. Therefore, it is considered as a prerequisite for model building in any setting, be it a diagnostic or prognostic, and in any field where models are used (Saltelli 2002). Panell (1997) described many possible uses of sensitivity analysis within the categories of decision support, communication, increased understanding and model development. The author also highlighted various approaches to sensitivity analysis in terms of what to vary and what to observe.

The common approach to sensitivity analysis is to vary the value of a numerical parameter through several levels. For example, in crop planning models, one can vary the availability of credit, fertilizer, groundwater, seeds, minimum and maximum allowed values. However, one might choose to vary one or many of these variables and understand the contribution of the changes to the objective (Kalantari *et al.* 2014). The objective function may be changed during sensitivity analysis, e.g. minimise risk of crop failure instead of maximising profit. However, usually changes in constraints are frequently observed, e.g. varying constraint limits (Maleka 1993, Sethi *et al*. 2006, Varalakshmi *et al.* 2011, Rani 2012), the number of constraints (Tajuddin *et al*. 1994), the number of activities and technical parameters (Morrison *et al.* 1986; Kingwell and Pannell 1987, Shrivastava *et al.* 2012). In selecting the parameter levels for sensitivity analysis, a common and normally adequate approach is to specify values in advance, usually with equal sized intervals between the levels (Nordblom *et al.* 1994). Some studies on sensitivity analysis illustrating various purpose in crop planning are as follows. 1. Sethi *et al.* (2006) carried out sensitivity analysis by varying three ranges of cropping scenarios (20, 40 and 50% deviation from the existing cropping pattern) and combinations of surface water and groundwater at various risk levels (10, 20, 30 and 40%) for optimal crop planning and water resources allocation in a coastal groundwater basin, Odisha, India. 2. Sharma *et al*. (2007) performed sensitivity analysis on different weight structures for the goals as specified by the decision maker in fuzzy goal programming (FGP) model for optimal allocation of land under cultivation in Ghaziabad district of Uttar Pradesh, India. 3. Shrivastava *et al*. (2012) conducted a sensitivity analysis to test the effectiveness of optimization model among all the variable input parameters, viz. sale price of crops, cost of cultivation and the cost of canal water. It helped to find the most sensitive input parameter that changes the result of model (optimal solution) related to the objective function parameters varied from -20 to 20% of their respective value. 4. Sarker and Lingard (2002) executed sensitivity analysis by changing the import bound restrictions of cereals to obtain optimum crop mix model for Bangladesh nation as a whole. 5. Maleka (1993) applied sensitivity analysis to cost of credit and cost of risk to safeguard against the uncertainty in the estimation of model parameters and to test the validity of the optimal results from the model.

Sensitivity analysis measures changes in model in relation to change in objective function values, decision variables, ranking of decision variables, constraint slacks, shadow costs and shadow prices. It is a powerful tool for assisting a decision maker. Researchers should avoid conducting sensitivity analysis in an aimless or mechanical fashion as the approach needs adjustment to suit the decision problem (Panell 1997).

Computer software for solving mathematical models

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 (Reddy *et al.* 2008) and the output of such analysis could be easily made available to the decision makers (Sharma 2010). Some of the leading software packages for quantitative approach are MS Excel solver, LINGO/LINDO, QSB, QSOM, LiPS, and GAMS (Table 2).

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.

A case study of Punjab in India

Punjab is one of the most fertile states in India with agriculture as its largest industry. Its share of agriculture in gross sate domestic product (27%) is higher than the national average of 18% during 2014-15 . However, in recent years, a drop in productivity and profitability has been observed due to falling water table (one meter/year) on which almost 72% of the agriculture depends. To ensure sustainable use of groundwater and to sustain productivity and profitability, linear programming based optimum crop model for Punjab state has been developed using plot-level-cost of cultivation survey data (TE 2010-11) for estimation of various coefficients (Table 3). The model specifications (equations 1-5) as given in Table 3 are self-explanatory. Equation 1 is objective function related to maximization of net income constrained by the equations 2-5. Equation 2 specifies the land constraint, equations 3 and 4 deals with affinity constraints from food security point of view and equation 5 deals with ground water constraint. Sensitivity analysis may be done by varying the level of ground water availability (RWA *a*) and the results can be compared considering the highest profit with minimum use of ground water or either of them.

Based on sensitivity analysis, the above model provided optimum cropping pattern for current use of ground water, unrestricted use of ground water, available rechargeable ground water for agriculture and saving water up to 10% of the existing use (Jain *et al*. 2017a). The results can help the policy makers in taking decisions about the crop plan. The discussion of the results is beyond the scope of this paper. However, the results are discussed in detail by Jain *et al*. (2017b). The unique feature in this model is

Table 2 Software packages used for mathematical modelling

Software Packages	Some Features
MS Excel solver	Available with MS Excel, easy to use, window based, online help available, not applicable for complex problems
Quantitative Systems for Business Plus (QSB+, WinQSB) https://winqsb.jaleco.com	Free, easy, available for both DOS and Window OS, easy to follow for beginners but no advance options for experienced users, manual available
Quantitative Systems for Operations Management (QSOM)	Free, easy, DOS based, paid manual available on print
Linear Interactive Discrete Optimization (LINDO-API /LINGO) http://www.lindo.com	Demo version free, easy, stochastic Programming Features, window based, API with MATLAB compatibility, analyze infeasible and unbounded models, LINDO-API creating web and intranet applications, manual available
Linear Program Solver (Lips) http://linear-program- solver.soft112.com	Free, easy, window based, supports sensitivity analysis, goal and mixed integer programming solver
General Algebraic Modelling System (GAMS) https://www.gams.com	Free demo version, coding skills needed, complex problems can be handled, window based, manual and model library available

Table 3 Model specifications for Punjab case study

Eq. no.	Equation functions	Variable description
(1)	$Max\ Z = \sum_{c=1}^{n}(Y_c P_c - C_c)A_c$	Z: Net Income Yc: Yield of crop c Pc: Market Price of crop c Cc: Cultivation cost of crop c Ac: Area covered by a crop c
(2)	$\sum_{t=jan}^{Dec}\sum_{c=1}^{n} a_{tc}A_c \leq NS_t - OA_t$	a_{tc}: Crop calendar coefficients NSt: Net sown area OAt: Orchard area
(3)	$A_c \geq Amin_c$	Minimum allowable area for each crop c
(4)	$A_c \leq Amax_c$	Maximum allowable area for each crop c
(5)	$\sum_c W_c A_c \leq RWA_{-a}$	W_c: ground water drafted for a crop c RWA_*a*: Total rechargeable ground water available for agriculture

the incorporation of crop calendar concept, which takes care of monthly availability of land. Further, besides market price, authors used different price scenarios like economic price and NRV price, i.e. after considering valuation of greenhouse gases and nitrogen fixation for each crop. The code for implementing the above model specifications has been developed using General Algebraic Modelling System (GAMS) and can be accessed from Jain *et al*. (2015).

Researchers have attempted various techniques and approaches for optimum cropping plan at various levels (farm, regional, country) with various objectives and constraints depending on the situation and objectives of the farms or region. However, many models have been set up as a research tools or a teaching aid. Farmers or the end users have directly used very few models. Extension services may come into aid in creating awareness and giving advisory services to implement the models with the expert guidance for necessary modifications based on the individual farmers and the regions. In order to develop regional and national crop model also farm level planning may be used with aggregation. However, researchers pointed out that aggregation is the major issue and requires expertise and guidelines while planning for regional or national level. With increasing and conflicting goals of agriculture for profit maximization, judicious use of inputs and sustainable use of natural resources, models dealing with the multiple objectives are of better efficiency. Various programming tools and decision support system based on linear programming have been developed in the recent years with the advancement in computer applications to deal with the multiple objective models. Some studies have developed annual copping plan considering types of land that grows single, double or multiple crops in a year while most of the studies considered two to three season in allotment of available land for various crops in a year. Thus, a crop calendar concept introduced in the case study contributes to better understanding of land availability of land on monthly basis and the cropping sequence can be adjusted accordingly. Sensitivity of the model is usually observed in relation to change in objective function values, decision variables, ranking of decision variables, constraint slacks, shadow costs and shadow prices. It is a powerful tool for assisting a decision maker, albeit researchers should avoid conducting sensitivity analysis in an aimless or mechanical fashion. Some models suggested are comprehensive in terms of approaches, objective, constraints but they are not easy to implement by the lay users while other simple models are not so inclusive. Thus, it can be inferred from the study that there is still a tremendous scope for improvement in exhaustive yet easy-to-use model for optimum crop plans.

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REFERENCES

Abadi F S R, Kakhki M D and Sahnoushi N. 2009. The determination of optimal crop pattern with aim of reduction in hazards of environmental. *American Journal of Agriculture and Biological Science* **4**: 305–10.

Agha R S, Nofal L G, Nassar H A and Shehada R Y. 2012. Multi criteria governmental crop planning problem: An analytic hierarchy approach. *Management* **2**(4): 96–105.

Alam M S, Elias S M and Rahman M M. 1995. Optimum land use pattern and resource allocation in a growing economy: A closed model approach. *Bangladesh Journal of Agricultural Economics* **18** (2): 15–37.

Aparnathi M G. 2014. Linear programming model for optimal cropping pattern for economic benefits of MRBC command area. *International Journal of Innovative Research in Science and Technology* **1**(1): 47–54.

Barnard C S and Nix J S. 1973. *Farm Planning and Control*. Cambridge University Press, Cambridge.

Borges-Junior J C F, Ferreira P A, Andrade C L T and Hedden-Dunkhorst B. 2008. Computational modeling for irrigated agriculture planning. Part II: Risk analysis. *Engenharia Agricola Jaboticabal* **28**(3): 483–93.

Boustani F and Mohammadi H. 2010. Determination of optimal cropping pattern due to water deficit: A case study in the South of Iran. *American-Eurasian Journal of Agricultural and Environmental Sciences* **7**(5): 591–5.

Buckwell A E and Hazell P B R.1972. Implications of aggregation bias for the construction of static and dynamic linear programming supply models. *Journal of Agricultural Economics* **23**(2): 119–34.

Chetty S and Adewumi A O. 2013. Three new stochastic local search metaheuristics for the annual crop-planning problem based on a new irrigation scheme. *Journal of Applied Mathematics* **2013**: 1–14.

Dahiphale P, Singh P K, Kothari M and Gharde K. 2015. Optimal cropping pattern for Jaisamand command of Udaipur district. *Research Journal of Recent Sciences* **4**(ISC2014): 1–7.

Das P. 2006. Cropping pattern (agricultural and horticultural) in different zones, their average yields in comparison to national Average/Critical Gaps/Reasons identified India, Ministry of Agriculture, Department of Agriculture. 33–47. Retrieved from http://scholar.google.com.

Day R H. 1963. On aggregating linear programming models of production. *Journal of Farm Economics* **45**: 797–813.

Faber D C, Heady E O, Ellingson W D Stoecker A L, and Nicol K J. 1978. Normative study of the supply response of rice in Thailand, DAE-Card Sector Analysis Series No. 13. Iowa State University.

FAO. 1993. Guidelines for land-use planning available at http://www.fao.org/ocrep/ last accessed on February 28, 2017.

Folkesson L. 1968. A linear programming analysis of the agricultural sector in Sweden. *Annals of the Agricultural College of Sweden* **34**: 391–435.

Galán-Martína A, Pozoa C, Guillén-Gosálbeza G, Vallejoa A A, and Esteller L J. 2015. Multi-stage linear programming model for optimizing cropping plan decisions under the new Common Agricultural Policy. *Land Use Policy* **48**: 515–24.

Glen J J. 1987. Mathematical models in farm planning: A survey. *Operation Research* **35**(5): 641–66.

Gomaa W, Harraz N and El Tawil A. 2011. Crop planning and water management: A survey. (*In*) *The 41st International Conference on Computers & Industrial Engineering,* pp 319–24.

Hazell P B R and Norton R D. 1986. Mathematical Programming for Economic Analysis in Agriculture. Macmillan Publishing Company, New York.

Heady E O. 1954. Simplified presentation and logical aspects of linear programming technique. *Journal of Farm Economics* **36**(5): 1035–48.

Heady E O and Candler W. 1958. Linear Programming Methods. Iowa State College Press, Ames, IA.

Heidhues T. 1966. A recursive programming model of farm growth in northern Germany. *Journal of Farm Economics* **48**: 668–84.

Jain R, Raju S S, Kingsly I, Srivastava S K, Kaur A P and Singh J. 2015. Manual on Methodological Approach for Developing Regional Crop Plan. NIAP Publications pp 20–9.

Jain R, Kingsly I, Chand R, Raju S S, Srivastava S K, Kaur A P and Singh J. 2017a. Methodology for region level optimum crop plan. (In) *4th International Conference on "Computing for Sustainable Global Development,* held on 01st - 03rd March, 2017.

Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi (India), pp 78–81.

Jain R, Kingsly I, Chand R, Kaur A P, Raju S S, Srivastava S K and Singh J. 2017b. Farmers and social perspective on optimal crop planning for ground water sustainability: A case of Punjab State in India. *Journal of the Indian Society of Agricultural Statistics* **71**(1): 75–88.

Kalantari A S, Victor E, Cabrera V E and Solis D. 2014. A comparison analysis of two alternative dairy cattle replacement strategies: Optimization versus simulation models. *Economia Agraria* **8**: 12–24.

Karunakaran K R, Nedumaran S and Chandrasekaran M. 2012. Is the current land use pattern in crop agriculture is sustainable in the Bhavani Basin of Southern India? Application of a Bio-economic model. (*In*) *Tri-annual conference of the International Association of Agricultural Economists*, 18-24 August 2012, Foz do Iguaçu, Brazil, pp 1–17.

Kaur B, Vatta K and Sidhu R S. 2015. Optimising Irrigation water use in Punjab agriculture: Role of crop diversification and technology. *Indian Journal of Agricultural Economics* **70**(3): 307–18.

Kaur B, Sidhu R S and Vatta K. 2010. Optimal crop plans for sustainable water use in Punjab. *Agricultural Economics Research Review* **23** (2): 273–84.

Kennedy J O S. 1974. Using Regression Analysis to Reduce Aggregation Bias in Linear Programming Supply Models, Report No. t, Aggregative Programming Model for Australian

Agriculture, Department of Agricultural Economics and Business Managment. Australia: University of New England.

Khepar S D and Chaturvedi M C. 1982. Optimum cropping and groundwater management. *Water Resource Bulletin.* **18**(4): 655–60.

Kingwell R S and Pannell D J (Eds).1987. MIDAS, A Bioeconomic Model of a Dryland Farm System. Pudoc, Wageningen.

Lakshminarayan V and Rajagopalan S.1977.Optimal cropping pattern in a river basin. *Journal of Irrigation and Drainage ASCE* **103**: 53–70.

Lee J E Jr. 1966. Exact aggregation-a discussion of Miller's theorem. *Agricultural Economics Research* **18** (2): 58–61.

Love H C. 1956. An application of linear programming to farm and home planning. Ph D thesis, Department of Agricultural Economics, Iowa state University. Iowa State University.

Mai B C, Mishra A P and Jaswantsingh. 1984. Conjunctive use of surface and subsurface water resources – A case study for optimal planning. *Journal of Agricultural Engineering* **21**(3): 79.

Mainuddin M, Das Gupta A and Raj Onta P. 1997. Optimal crop planning model for an existing groundwater irrigation project in Thailand. *Agricultural Water Management* **33**(1): 43–62.

Maleka P. 1993. An application of target MOTAD model to crop production in Zambia: Gwembe Valley as a case study. *Agricultural Economics* **9**(1): 15–35.

Manos B D and Kitsopanidis G I. 1986. A quadratic programming model for farm planning of a region in Central Macedonia. *Interfaces* **16**(4): 2–12.

Martina A G, Carlos Pozoa, Guillén-Gosalbeza, Vallejoa G A A and Esteller L J. 2015. Multistage linear programming model for optimizing cropping plan decisions under the new Common Agricultural Policy. *Land Use Policy* **48**: 515–24.

Miller T A. 1966. Sufficient conditions for exact aggregation in linear programming models. *Agricultural Economics Research* **18** (2) : 52–7.

Mirkarimi S H, Joolaie R, Eshraghi F and Abadi F S B. 2013. Application of fuzzy goal programming in cropping pattern management of selected crops in mazandaran province (Case study Amol township). *International Journal of Agriculture and Crop Sciences* **6**(15): 1062–7.

Mohaddes S A. 2008. Application of the fuzzy approach for agricultural production planning in a watershed, a case study of the Atrak Watershed, Iran. *American-Eurasian Journal of Agriculture and Environmental Science* **3**(4): 636–48.

Morrison D A, Kingwell R S, Pannell D J and Ewing M A. 1986. A mathematical programming model of a crop-livestock farm system. *Agricultural Systems* **20**(4): 243–68.

Mortazavi S A, Hezareh R, Kaliji S A and Mehr S S. 2014. Application of linear and non-linear programming model to assess the sustainability of water resources in agricultural patterns. *International Journal of Agricultural Management and Development* **4**(1): 27–32.

Nordblom T, Pannell D J, Christiansen S, Nersoyan N. and Bahhady F. 1994. From weed to wealth? Prospects for medic pastures in Mediterranean farming systems of Northwest Syria. *Agricultural Economics* **11**: 29–42.

Norton R D and Kutcher G P. 1982. Operations research methods in agricultural policy analysis. *European Journal of Operational Research* **10**(10): 333–45.

Norton R D and Schiefer G W. 1980. Agricultural sector programming models: A review of alternative approaches. *European Review of Agricultural Economics* **7**(October): 229–64.

Otoo J, Ofori J K and Amoah F. 2014. Optimal selection of crops: A case study of small scale farms in Fanteakwa district, Ghana. *International Journal of Scientific and Technology Research* **4**(5): 142–6.

Pannell D J. 1997. Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. *Agricultural Economics* **16**(2): 139–52.

Pant M, Thangaraj R, Rani D, Abraham A and Srivastava D K. 2010. Estimation of optimal crop plan using nature inspired metaheuristics. *World Journal of Modelling and Simulation* **6**(2): 97–109.

Papathanasiou I, Manos B, Vlachopoulou M, and Vassiliadou I. 2005. A decision support system for farm regional planning. *Yugoslav Journal of Operations Research* **15**(1): 109–24.

Pravin D, Singh P K, Kothari M. and Gharde K. 2015. Optimal cropping pattern for Jaisamand command of Udaipur district in Rajasthan, India. *Research Journal of Recent Sciences, International Science Congress Association* **4**: 1–7.

Pradhan K K. 2012. A quantitative approach to profit optimization and constraints of mixed cropping pattern in Bargarh district of western Orissa. *International Journal of Advanced Research Science Technology* **1**(1): 81–5.

Rani Y R. 2012. Multi objective crop planning for optimal benefits. *International Journal of Engineering Research and Applications* **2**(5): 279–87.

Reddy S S, Ram P R, Sastry T V N and Devi I B. 2008. Application of operations research techniques to farm management. *Agricultural Economics,* pp 255–97. Oxford & IBH Publication Co. Pvt Ltd, New Delhi.

Saltelli A. 2002. Sensitivity analysis for important assessment. *Risk Analysis* **22**(3): 579–90.

Sarker T S and Haque A. 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. *Applied Mathematical Modelling* **21**(10): 621–32.

Sarker F I M G W and Lingard J. 2002. An optimal cropping plan for farmers in a shallow tubewell irrigated area in Bangladesh. *Bangladesh Journal of Agricultural Economics* **1&2:** 39–55.

Sarker R A and Quaddus M A.2002. Modelling a nationwide crop planning problem using a multiple criteria decision making tool. *Computers and Industrial Engineering* **42**(2-4): 541–53.

Sethi, L. N, Nageshkumar D, Panda S N and Mal B C. 2002. Optimal crop planning and conjunctive use of water resources in a coastal river basin. *Water Resources Management* **16**: 145–69.

Sethi L N, Panda S N and Nayak M K. 2006. Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India. *Agricultural Water Management* **83**(3): 209–20.

Sethi L N and Panda S N. 2011. Development of decision support system for optimum cropping and water resources management of a costal river basin. *Assam University Journal of Science & Technology: Physical Sciences and Technology*. **7**(11): 18–28.

Sharma D K, Jana R K and Gaur A. 2007. Fuzzy goal programming for agricultural land allocation problems. *Yugoslav Journal of Operations Research* **17**(1): 31–42.

Sharma J K. 2010. *Quantitative Methods: Theory and Applications*. Macmillan Publishers India Ltd.

Sharma R K, Sankhayan P L and Singh R. 2009. Analysis of profitability and risk in new agriculture in a Himalayan watershed by using dynamic non-linear programming model (*In*) *International Association of Agricultural Economists' Conference*, Beijing, China, August 16-22, 2009, pp 1–20.

Shrivastava S K, Verma M K and Devatha C P. 2012. Optimization modelling for crop planning of hasdeo bango command. *International Journal of Engineering Research and Technology* **1**(9): 1–5.

Sofi N A, Ahmed A, Ahmad M and Bhat B A. 2015. Decision making in agriculture: A linear programming approach. *International Journal of Modern Mathematical Sciences* **13**(2): 160–9.

Soltani J, Karbasi A R and Fahimifard S M. 2011. Determining optimum cropping pattern using Fuzzy Goal Programming (FGP) model. *African Journal of Agricultural Research* **6**(14): 3305–10.

Srinivasa G, Chengappa P G, Achoth L, Reddy K and Nagaraja G N. 2005. Optimum cropping pattern for sericulture-dominant farms in southern dry zone of karnataka. *Agricultural Economics Research Review* **18**(1): 117–32.

Tajuddin R, Talukder K and Alam M. 1994. Optimal cropping plan for a sample of farms in a farming system area of Bangladesh. *Bangladesh Journal of Agricultural Economics* **17**(1&2): 85–96.

Tsai Y J, Mishoe J W and Jones J W.1987. Optimization multiple cropping systems: simulation studies. *Agriculture Systems* **25**: 165–76.

Varalakshmi K, Handigol J and Yeledhalli R A. 2011. Optimum crop enterprise mix for the farmers in Kurnool district of Andhra Pradesh. *Karnataka Journal of Agricultural Science* **24**(5): 661–7.

Wankhade M O and Lunge H S. 2012. Allocation of agricultural land to the major crops of saline Track by linear programming approach: A case study. *International Journal of Scientific and Technology Research* **1**(9): 21–5.

Waugh F. 1951. The minimum cost diary feed. *Journal of Farm Economics* **33**(3): 299–310.

Weintraub A, Romero C, Bjorndal T and Lane D E. 2001. Operation research models and management of renewable natural resources: A Review. Working paper no 11/01, Centre for Fisheries Economics, Foundation for Research in Economics and Business Administration, Bergen.

Wondimagegn M. 2014. Crop mix and resource use pattern under risk: The case of smallholder farmers in eastern highlands of Ethopia. *International Journal of Agriculture and Crop Sciences* **7**(5): 251–61.

Yih-Long Chang.1991.QSOM: *Quantitative Systems for Operations Management* (version 2.0). Prentice-Hall.

Zareian R, Garibi S and Imani A A. 2013. Analyzing and choosing the optimal pattern of products cultivation different methods based on MOTAD model. *International Journal of Farming and Allied Sciences* **2**(23): 1124–8.