Role of Interactive Multiple Goal Linear Programming in Land Use Planning: Linking Biophysical Evaluation with Socio-Economics – An Illustration for the State of Haryana

A.K. Vasisht[1] and S. Sujith Kumar[2]

Summary*: Food is a basic need of any society and safeguarding the food supply has been a major consideration in policy development. Food demand of humans has increased dramatically over the last fifty years. The explosive increase in food production in the western world has led to a situation of supply exceeding demand. These surpluses of food were absorbed by the developing countries during 1950s but, in the '60's; imports by the latter shrank because of the Green Revolution. After enjoying self-sufficiency in food during the last three decades, many Asian countries are once again at the crossroads, facing tremendous new challenges because of continued population growth, globalization, environmental degradation and stagnation in farm productivity in intensive farming areas. Rapidly increasing population necessitates that the productivity of the land be further increased. This has to be achieved without increasing environmental degradation while maintaining or increasing farmer's income. From an ecological point of view, land use/land cover change is a major factor affecting the health and stability of an ecosystem. Therefore, economically viable optimal solutions for land use can be determined by the use of a systems approach where the biophysical potential of the resources available and the socio-economic constraints, which are often inherently conflicting in nature, are considered to determine the consequences and trade-offs of different sets of policy aims on agriculture.*

The approach of Multiple Goal Linear Programming (MGLP) used for the current study provides such a framework for considering biophysical and socioeconomic resources, and constraints. An optimization framework, consisting of linear programming or other techniques, represents a normative approach that is often used to search for the best solution with limited resources. In this approach, an objective function is maximized or minimized by selecting from different possible activities and subject to several regional constraints. Prior knowledge of the decision makers' choices has prime importance in formulating objective functions. Their preferences are expressed as objective functions and targets in the model. It requires decision makers to specify maximum allowable levels for the (n-l) objectives to solve the n-dimensional multi-objective problem. This method can be used to generate the non-inferior set for all types of objectives. The result of each iteration is presented to decision makers to seek their preferences and then articulated back to the model through modified values of objective functions and targets. The process continues till the decision makers are satisfied with their choices and an optimal solution is obtained. In the first iteration, all targets are set to a minimum value, resulting in an optimal solution that satisfies the entire minimum requirement simultaneously. This process is repeated sequentially for all objective functions, which will result in the definition of technically feasible objectives, targets and constraints. Moreover, the maximum attainable value for each objective function is also achieved. In the next step, the target values are further tightened, reflecting the aspirations of the decision makers. This will reduce the technically feasible solution space. The process continues till the decision makers reach a Pareto optimal solution, that is no further feasible solution can be achieved with the same or better performance for all criteria under consideration.

[1] Principal Scientist, Div. of Ag. Economics, IARI, New Delhi.

[2] Scientist, Div. Env. Sci., IARI, New Delhi.

This paper draws heavily from the project report entitled, "Land use analysis and planning for sustainable food security: with an illustration for the state of Haryana, India", by P.K. Aggarwal et al (eds), 2001. IARI-India, IRRI-Philippines and WUR-The Netherlands.

The results revealed that Haryana has ample opportunities to increase food production and agricultural income compared with current levels, provided additional water resources could be made available. The current natural constraints of land and water limit maximum food production to 17 million t. Here, the model assumes that all water and capital within a land unit can be shared. It implies that groundwater resources available within a farm can be transported to other farms without cost, irrespective of distance involved. This does not look feasible, even with the current policy of an almost free water supply in the region.

Haryana has considerable potential to withdraw agricultural land from cultivation, without affecting basic food production and income at the aggregate level. This would require that the small farmers who cannot use alternative, efficient and capital intensive technologies not cultivate their land and that their water and other resources be made available to other farmers who presumably could use these more efficiently. Alternatively, technologies that are affordable and can be applied on small farms should be developed.

Food is a basic need of any society and safeguarding the food supply has been a major consideration in policy development. Food demand of humans has increased dramatically over the last fifty years. The explosive increase in food production in the western world has led to a situation of supply exceeding demand. These surpluses of food were absorbed by the developing countries during 1950s but, in the ‘60’s, imports by the latter shrank because of the Green Revolution. After enjoying self-sufficiency in food during the last three decades, many Asian countries are once again at the crossroads, facing tremendous new challenges because of continued population growth, globalization, environmental degradation and stagnation in farm productivity in intensive farming areas. Rapidly increasing population necessitates that the productivity of the land be further increased. This has to be achieved without increasing environmental degradation while maintaining or increasing farmer’s income. From an ecological point of view, land use/land cover change is a major factor affecting the health and stability of an ecosystem. Therefore, economically viable optimal solutions for land use can be determined by the use of a systems approach where the biophysical potential of the resources available and the socio-economic constraints, which are often inherently conflicting in nature, are considered to determine the consequences and trade-offs of different sets of policy aims on agriculture.

In this paper a methodology has been developed for exploratory land use analysis and planning using Interactive Multiple Goal Linear Programming (IMGLP) approach. The use of this Decision Support System (DSS) has been illustrated for the State of Haryana in northwestern India.

Methodology

Regional land use analysis and planning for food security should be oriented toward maximization of the welfare function of society from the non-renewable resource land. It should recognize land as a resource that provides space, is indestructible and can be viewed as a source of flow of production/consumption services whose composition depends on the use to which the space is allotted. This spatial pattern is variable over time, depending on human activity and, therefore, intertemporal allocations of these services have their consequences. Land use planning is thus an interdisciplinary task that needs both biophysical and land economics evaluation.

The approach of Multiple Goal Linear Programming (MGLP) used for the current study provides such a framework for considering biophysical and socioeconomic resources, and constraints. An optimization framework, consisting of linear programming or other techniques, represents a normative approach that is often used to search for the best solution with limited resources. In this approach, an objective function is maximized or minimized by selecting from different possible activities and subject to several regional constraints. Prior knowledge of the decision makers' choices has prime importance in formulating objective functions. Their preferences are expressed as objective functions and targets in the model. Decision making for many real-world problems is often the responsibility of a group of individuals, each with its own goals and aspirations, rather than of a single individual. Besides, in any society, preferences of the people are likely to be multidirectional. Therefore, it is necessary to develop a land use-planning model for food security in a multi-objective framework.

The MGLP approach has been used in several studies for land use analysis and planning at the farm level (Schans, 1991), village level (Huizing and Bronsveld, 1994), subregional and regional level (Schipper *et al.*, 1995; Veeneklaas *et al.,* 1991) and even at the continental level (WRR, 1992). It requires decision makers to specify maximum allowable levels for the (n-l) objectives to solve the n-dimensional multi-objective problem. This method can be used to generate the non-inferior set for all types of objectives. The result of each iteration is presented to decision makers to seek their preferences and then articulated back to the model through modified values of objective functions and targets. The process continues till the decision makers are satisfied with their choices and an optimal solution is obtained. This implies that this approach needs a series of iterations to arrive at the desired output. In the first iteration, all targets are set to a minimum value, resulting in an optimal solution that satisfies the entire minimum requirement simultaneously. This process is repeated sequentially for all objective functions, which will result in the definition of technically feasible objectives, targets and constraints. Moreover, the maximum attainable value for each objective function is also achieved. In the next step, the target values are further tightened, reflecting the aspirations of the decision makers. This will reduce the technically feasible solution space. The process continues till the decision makers reach a Pareto optimal solution, that is no further feasible solution can be achieved with the same or better performance for all criteria under consideration.

The Multiple Goal Linear Programming Model (MGLP) for Haryana

The aim of IMGLP is to quantify the upper limits of production of food and other commodities in the State of Haryana and to identify production systems that are both economically viable and agronomically efficient and have a minimal impact on the environment. Rice and wheat, commonly grown in double cropping rotation, are the major cereal crops of this region and their average productivity ranges between 3 to 5 t / ha.

The MGLP model for Haryana covers 16 districts (as per the 1991 census database), which can be viewed as a combination of various land units. A land unit is delineated overlaying agro-ecological units and district boundaries. The model contains:

Five resources: land, water, labour, capital and fertilizer. Land and water resources have been defined in two dimensions - administrative and agro-ecological - because of the distinct heterogeneity in different properties of land units in the same district. Since the district is the basic planning and production unit, labour, capital and fertilizer resources have been defined at the district level;

Various production functions have been specified through input-output relations for 15 land use types at 5 technology levels. Land use types represent different farming regimes (irrigated versus non-irrigated). These are summarized in Table 1. A specific technology level through its uniqueness input-output combinations characterizes each land use type. Input-output combinations are determined by several factors related to land use and technology level;

Milk is also an important product related to land use in Haryana. Therefore, besides cropping activities, livestock activities with three animal types, cow, buffalo and hybrid cow, are also considered in the model;

These land use types result in 11 products, including milk from each animal type;

The behaviour of the producers is described by assuming that they aim at maximum returns from the land unit under existing resource constraints. Five farm types varying in the size of landholding are considered. This is used as a proxy variable to represent the technology adoption capability of producers;

Since the livelihood of most of the population of Haryana basically depends on agriculture, it was assumed in all analyses that at least 98% of the land has to be used for agriculture;

The market for agricultural products is assumed to be unaffected by producers' decisions at the district level. Irrespective of the quantities, all products can be sold or purchased at a fixed price for a district. This may not always be true but this assumption allows us to keep the model simple and explore all possible opportunities for the future irrespective of trade scenarios so that finally a limited policy environment can be explored in different scenarios.

Table 2 shows the number of combinations of land units, land use types and technology levels. Table 3 shows the indices and abbreviations used in the equations of the MGLP model.

Table 1. Districts, land use types, technologies, products and farm types in Haryana used for land use analysis.

Districts	Land use types	Technologies	Products	Farm types
Ambala	Rice-rice-wheat	Curren	Rice	Small
Bhiwani	Rice-wheat	Potential	Basmati Rice	Medium
Faridabad	Basmati rice-wheat	Current	Wheat	Medium-Large
Gurgaon	Rice-mustard	25% yield gap	Sugar	Large
Hissar	Cotton-wheat	Current	Mustard	Very Large
Jind	Maize-chickpea	50% yield gap	Pearl Millet	
Kaithal	Maize-mustard	Current +	Cotton	
Kamal	Maize-potato-wheat	75% yield gap	Maize	
Kurukshetra	Sugarcane-wheat		Gram	
MohinderGarh	Irrigated pearl millet-wheat		Potato	
Panipat	Rainfed pearl millet-wheat		Milk	
Rewari	Fallow-wheat			
Rohtak	Fallow-chickpea			
Sirsa	Fallow-mustard			
Sonipat	Pearl millet-fallow			
YamunaNagar				

Table 2. Number of combinations related to land use in Haryana. In irrigated land units, all 15 land use types *(luts)* were considered, whereas, in rainfed land units, only 5 *luts* were considered.

Item	Abbreviation	Size
Number of agro-ecological units	NAE	58
Number of land units	NDU	257
(District agro-ecological combinations) Number of land unit-land use type combinations	NDULut	2,855

Table 3: Indices and abbreviations used for defining land use types and input/output relationships in the MGLP model.

Index	Description	Classes
u	Agro-ecological units	58 agro-ecological units
d	District	16 districts
du	Land unit	257 land units (combinations of district, agro-ecological units and irrigated/unirrigated areas)
lut	Land Use Type	15 land use types
p	Product	11 products, including milk from each animal species
t	Technology Level	Five technology levels
m	Months	12 months
a	Animal	Three types of animals: cows, buffaloes, hybrid cows
at	Combinations of an animal and livestock technology level	Two technology levels (current and improved) for each animal
F	Type of Fertilizer	Three types of fertilizer: N,P,K
S	Season Code	Three seasons: summer, kharif(monsoon), rabi(winter)

*Land Unit (du) is used as a basic unit in the model, but a variable can vary either by district (d) or by agro-ecological unit (u) of this combination (du).

Land use activities

Two types of activities are included in the MGLP model for Haryana: cropping activities and livestock activities. For each activity, only those items of input-output that are needed for objective functions and constraints considered in the model are quantified.

Cropping activities are expressed as land use types (lut) applied at a certain technology level (t). We defined 15 land use types for Haryana (Table 1). Inputs and outputs of these cropping activities are differentiated by land unit (u) and technology (t) and they also may vary by month or season. Inputs required for cropping activities are fertilizers, labour force, water and capital. Outputs from cropping activities are main products and by-products of the crop and residues used as feed for animals.

Animal types specify livestock activities. Inputs required for livestock are feed and capital. Livestock activities are linked to cropping activities through the availability of crop residues for feed in each land use type.

Because both cropping activities and livestock activities generate outputs for objective functions, a land use activity is defined as a combination of a cropping activity (lut, t) and a livestock activity (a, at). The variable $\text{LU-Area}_{du,lut,t,a,at}$ used in the MGLP model is the area allocated to each land use activity in each land unit (du).

$\text{LU-Promising}_{du,lut,t}$ is applied in the MGLP model as a promising land use indicator, which enables the model to handle different policy scenario analyses in a simple way and improves efficiency by reducing the size of the matrix. The value of this indicator is switched between 1 and 0 to identify whether a land use type (lut) can be applied in a land unit (du) or not.

Objective functions

Objective functions for the model were formulated considering social, economic and environmental aspects of development for Haryana. These objective functions are as follows:

1. Social objective functions: Food grain production and employment
2. Economic objective function: Income
3. Environmental objective functions: Agricultural area, water use and biocide residue index and N leaching

Each objective function comprises six cases each of which is characterized by a combination of constraints:

1. Land resource, which is always a constraint
2. Land + water resources
3. Land + technology adoption levels applicable by farm size groups
4. Land + technology adoption + water resources
5. Land + technology adoption + water resources + capital availability
6. Land + technology adoption + water + capital + labour availability

Social objective functions: Food grain production and employment

Haryana is one of the major food-producing states in India and it contributes significantly to the public food distribution system of the federal government. Therefore, food grain production (Food) is one of the social objective functions to be maximized:

$$Food = \Sigma_{du}\Sigma_{lut}\ \Sigma_{t}\Sigma_{a}\Sigma_{at}\ (Productivity_{u\ in\ du,lut,t} \times LU\text{-}Promising_{du,lut,t} \times LU\text{-}Area_{du,lut,t,a,at}) \quad (1)$$

where $Productivity_{u\ in\ du,lut,t}$ is the yield of grains (rice, basmati rice, summer rice and wheat) in each land unit by various land use types at different technology levels.

Creating more gainful employment in the agricultural sector is essential for sustaining the development of the state. To realize this objective, we selected 'Employment' as another social objective function to be maximized:

$$Employment = \Sigma_{du}\Sigma_{lut}\ \Sigma_{t}\Sigma_{a}\Sigma_{at}\ (Labor_{u\ in\ du,lut,t,a,at} \times LU\text{-}Promising\_{du,lut,t} \times LU\text{-}Area_{du,lut,t,at}) \quad (2)$$

where Labor $_{u,lut,t,a,at}$ is the total labour required in a year for land use activities calculated from the labour requirement in each month.

$$Labor_{u.lut,t,a,at} = \Sigma_{m}\Sigma_{p}\ MonthlyLabor_{u,lut,t,p,m} \times Lut\text{-}Product_{lut,p} \quad (3)$$

However, the labour input for livestock activity was not considered because in Haryana this homestead activity is generally taken care of by the family members in their spare time.

Economic objective function: Income

Income from agriculture is a major factor that determines crop and technology selection. This was selected as an objective function to be maximized to express the goal of economic development of the farmers and the region:

$$Income = \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at}\ (Income\text{-}Ha_{du,lut,t,a,at} \times LU\text{-}Promising_{lut,p} \times LU\text{-}Area_{du,lut,t,a,at}) \quad (4)$$

where Income-Ha is the net revenue from both cropping and livestock activities and is equal to the total revenue from the sale of all products, including milk, after subtracting the production cost of all inputs.

Income-Ha was calculated from operational costs and gross returns per hectare. Operational cost per ha does not include the fixed cost of the land and was derived by the following expression:

$$Operational\ Cost_{du,lut,t,a,at} = \Sigma p\ [(VariableCost_{u\ in\ du,lut,t,a,at,p} + PumpCost_{du,lut,t,a,at,p}) \times Lut\text{-}Product_{lut,p}] + (NoAnimal_{u\ in\ du,lut,t,a,at} \times MilkCost_{a,at}) \quad (5)$$

In the model, the cost of pumping water (PumpCost) is separated from other input costs because it varies over seasons and across crops depending on the amount of water pumped:

$$PumpCost_{du,lut,t,a,at,p} = \Sigma m \text{ Month-Pump}_{u \text{ in } du,lut,t,a,at,p,m} \text{ x Month-Pump-Price}_{du,m} \quad (6)$$

Month-Pump $_{u,lut,t,a,at,p,m}$ is the amount of water pumped for irrigation for a specific crop and month and Month-Pump-Price$_{du,m}$ is the unit cost of pumping water in a month. VariableCost$_{u,lut,t,a,at,p}$ is the cost for crops excluding the costs of water pumping and rearing livestock, NoAnimal$_{u,lut,t,a,at}$ is the number of animals per hectare and MilkCost$_{a,at}$ is the annual cost of producing milk from one animal. This leads to

$$GrossReturn_{du,lut,t,a,at} = (NoAnimal_{u \text{ in } du,lut,t,a,at} \text{ x } MilkIncome_{a,at}) +$$

$$\Sigma p \text{ ((Productivity}_{u \text{ in } du,lut,t,p} \text{ x } FGPrice_{u \text{ in } du,lut,t,p} \text{ x } PriceAdjust_{dindu,p}) \text{ x}$$

$$\text{Lut-Product}_{lut,p}) + (RevResidue_{u \text{ in } du,lut,t,a,at}) \text{ x Lut-Product}_{lut,p}) \quad (7)$$

where Productivity $_{u,lut,t,p}$ is the yield level of a product, FGPrice $_{u,lut,t,p}$ is the farm-gate price of a product and PriceAdjus$_{d,p}$ is a factor used to adjust the price across districts for different products. This price difference occurs mainly because of changes in market accessibility. RevResidue $_{u,lut,t,a,at}$ is the income from crop residues except for wheat and pearl millet (which have been used for livestock).

Net income is calculated as the difference between gross returns and costs:

$$\text{Income-Ha}_{du,lut,t,a,at} = GrossReturn_{du,lut,t,a,at} - \text{Operational Cost}_{du,lut,t,a,at} \quad (8)$$

Environmental objective functions: Agricultural area, water use and N Leaching

The pressure on land is increasing because of the increase in population, industrialization and the requirements for various other non-agricultural activities. Moreover, there is concern that, ideally, about one-third of the land should be left for forest for environmental sustainability. Therefore, agricultural area in Haryana is considered as an objective function to be minimized:

$$AgriArea = \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at} \text{ (LU-Promising}_{du,lut,t} \text{ x LU-Area\_}_{du,lut,t,a,at}) \quad (9)$$

There are also concerns in Haryana about sustainability as the state moves into the post-Green Revolution era. The environmental goals for agricultural development in Haryana are to minimize two other environmental objective functions - water use and Nitrogen Leaching:

$$WaterUse = \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at} \text{ (ET}_{u \text{ in } du,lut,t} \text{ x LU-Promising}_{lut,p} \text{ x}$$

$$\text{LU-Area\_}_{du,lut,t,a,at}) \quad (10)$$

where ET $_{u,lut,t}$ is the total water needed in a year for each land use activity calculated from its monthly water requirement. Drinking water required for animals is a relatively low amount compared with the water required 'for crops and has therefore been ignored.

$$ET_{du,lut,t} = \Sigma_m \text{ MonthlyET}_{du,lut,t,m}$$

The model provides total nitrogen leached out (NLoss) at different levels of nitrogen application:

$$NLoss = \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at}\Sigma_{p} \text{ (Nleaching}_{u \text{ in } du,lut,t,p} \text{ x LU-Promising\_}_{du,lut,p,t} \text{ x}$$

$$\text{LU-Area}_{du,lut,t,a,at}) \quad (11)$$

where Nleaching $_{u,lut,t,p}$ is leaching of nitrate-N below 150 cm of the soil profile.

Constraints

Many biophysical characteristics and socioeconomic factors constrain regional land use. These can be broadly grouped into natural resource constraints and external input constraints. In the model, a target of development, such as total production of certain products to satisfy the demand of the local population, has the same formulation as a constraint.

Natural resource constraints: Land and water resources

As mentioned earlier, the land resource has been defined with two dimensions - agroecological unit *(u)* and district (d) - to enable the model to capture biophysical homogeneity at the land unit level and homogeneity in socioeconomic variables at the district level. The first constraint in land resource is that the total area of all land use types in each land unit ($DUArea_{du}$) should not be greater than the available land resource ($AvLand_{du}$):

$$DUArea_{du} = \Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at} (LU\text{-}Promising_{du,lut,t} \times LU\text{-}Area_{du,lut,t,a,at})$$

$$<= AvLand_{du} \qquad (12)$$

where $AvLand_{du}$ is the available land in all land units (du).

In Haryana, 20.4% of the land is made up of small holdings (< 2 ha) and 35.5% of the holdings are from 2 to 5 ha (Table 4). Only 6.3% of the holdings are larger than 20 ha. Resource availability can greatly vary depending upon the size of the landholding and other production resources of farmers. Since household modelling is not directly considered in our model, we have restricted, as a surrogate, the land area that can be used for different technologies depending upon the size of the landholdings. Thus the entire area of Haryana, irrespective of size of landholding, can use 1st (current) and 2nd levels of technologies. The adoption of higher technologies requires more capital and a larger knowledge base. It was assumed that small farmers cannot adopt the 3rd, 4th and 5th level of technologies, whereas large and very large farmers can adopt the 4th level of technology. Only very large farmers can adopt the 5th level of technology (Table 5).

Table 4: Categories of farmers in Haryana by area and size of landholding.

Category	Size of land- holding (ha)	Number of land holdings (%)	Area (ha)	Area (%)
Small	< 2	60.5	757,731	20.4
Medium	2-5	27.5	1,318,110	35.5
Medium-Large	5-10	9.0	925,968	25.0
Large	10-20	2.5	476,677	12.8
Very Large	> 20	0.5	232,729	6.3

Table 5: Capability of farmers of Haryana to adopt different technologies.

Technology Level	Farmers	Total Area (%)
1	Small, Medium, Medium-Large, Large and very Large	100
2	Small, Medium, Medium-Large, Large and very Large	100
3	Medium, Medium-Large, Large and very Large	79.6
4	Large and very Large	19.1
5	Very Large	6.3

The share in total area in Table 5 is used to estimate the maximum land resource available to each technology level ($AvTechLand_{du,t}$):

$$A vTechLand_{du,t} = A vLand_{du} \times CF_{d,t} \quad (13)$$

where $CF_{d,t}$ is the share of a technology level in the total area.

Thus, another land constraint is that the total area of all land use types by each technology level ($DUTArea_{du,t}$) should not be greater than the land resources available for that level ($AvTechLand_{du,t}$):

$$DUTArea_{du,t} = \Sigma_{lut}\Sigma_{a}\Sigma_{at}(LU\text{-}Promising_{du,lut,t} \times LU\text{-}Area_{du,lut,t,a,at})$$

$$<= AvTechLand_{du,t} \quad (14)$$

Water resources

Both groundwater and surface water are considered when estimating total water available for irrigation. The model assumes that different land use types within it can share the water available within a land unit.

Total water use in a year in each land unit ($Water_{du}$) should not be greater than the available water resources in that land unit ($AvWater_{du}$):

$$Water_{du} = \Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at} (ET_{du,lut,t} \times LU\text{-}Promising_{du,lut,t} \times LU\text{-}Area_{du,lut,t,a,at})$$

$$<= A vWater_{du} \quad (15)$$

where $ET_{du,lut,t}$ is the total water requirement of a land use type in a year aggregated from water requirements in each month.

Socioeconomic constraints: Labour, capital and input supply

Similar to water, the constraint in labour availability by month is considered. The following constraint is applied for labour:

Labour use ($Labor_{dist,m}$) in each district in each month should not be greater than the available labour force ($AvLabor_{dist,m}$)

$$Labor_{dist,m}= \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at} ((MonthlyLabor_{u,lut,t,a,at,m} \times LU\text{-}Promising_{du,lut,t} \times$$

$$LU\text{-}Area_{du,lut,t,a,at} \text{ I with d in du = dist}) <= A vLabor_{dist,m} \quad (16)$$

where $MonthlyLabor_{u,lut,t,a,at,m}$ is the labour requirement in each month.

It was assumed that capital could be shared or borrowed within the district. The constraint in capital was therefore formulated as the total capital requirement ($Capital_{dist}$) should not be greater than the available capital ($AvCapital_{dist}$):

$$Capital_{dist}= \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at}(Capital\text{-}Ha_{du,lut,t,a,at} \times LU\text{-}Promising_{du,lut,t}$$

$$\times LU\text{-}Area_{du,lut,t,a,at} \text{ I with d in du = dist}) <= A vCapital_{dist} \quad (17)$$

where $Capital\text{-}Ha_{du,lut,t,a,at}$ is the total cost for land use activity.

Fertilizer availability is also considered as a major constraint to agricultural production. Therefore, the total fertilizer requirement ($Fertilizer_{dist,f}$) should not be greater than the available fertilizer ($AvFertilizer_{dist,f}$):

$$FertiIizer_{dist,f}= \Sigma_{du}\Sigma_{lut}\Sigma_{t}\Sigma_{a}\Sigma_{at}(Fertilizer\text{-}Ha_{uin\ du,lut,t,f} \times LU\text{-}Promising_{du,lut,t} \times$$

$$LUArea_{du,lut,t,a,at} <= A vFertilizer_{dist,f} \quad (18)$$

where $Fertilizer\text{-}Ha_{u,lut,t,f}$ is the total fertilizer required for a land use activity.

Results and Discussions

Since the majority of the population of Haryana depends on agriculture for its basic livelihood, the model was forced to cultivate all agricultural land of the state in all cases except in the scenario in which agricultural land use was minimized. The upper limits of different objective functions were determined by optimizing each one separately and deriving the 'extreme points' to identify the feasible solution space under the specified restrictions. Thus, the model first calculates the value of each objective function by imposing land as a constraint plus the lower bounds for production of the different commodities, defined as the production figures for 1996-97 (Table 6, last column). Subsequently, all other constraints were introduced successively in the subsequent rounds of optimizations to evaluate the effect of each constraint on the feasible solution space. In the final run, all constraints and current targets for other crops were imposed concurrently.

In this paper the analysis has been presented for two objective functions, viz; Maximization of food and minimization of water use.

Maximizing food grain production

The results of maximization of food showed that the maximum attainable food production (rice + wheat) in Haryana was 39.1 million t when land was the only constraint and the current targets for other products were met (Table 6). Corresponding milk production was 6.8 billion litres. To produce this, however, Haryana would need, besides arable land, 56.4 billion cubic meters of water, 1.5 million t of N fertilizer, 666 million labour days and 114.2 billion rupees of capital for operational costs. These requirements are several times higher than what is currently (1996-97 level) available in the state. This case also indicated that, if such resources were made available, farmers could generate an income of 109.9 billion rupees per annum. The associated land use would result in a loss of 61.4 thousand tons of N through leaching.

Table 6. Production of different commodities, income, resource requirements and environmental impact at an aggregated level when maximizing food production in Haryana.

Item	Unit	Constraints						Current level (1996-97)
		Land	Land + Water	Land+Tech+	Land+Tech+ Water	Land+Tech +Water+Capital	Land+Tech+Water+Capital+Labour	
Food**	**Million tons**	**39.1**	**17.4**	**28.0**	**11.4**	**11.4**	**11.1**	**10.5**
Rice	Million tons	27.3	5.1	19.0	2.8	2.7	2.5	2.5
Wheat	Million tons	11.8	12.2	9.0	8.6	8.7	8.6	8.0
Oilseed	Million tons	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Chickpea	Million tons	0.28	0.28	0.28	0.28	0.28'	0.28	0.28
Cotton	Million bales	1.53	1.53	1.53	1.53	1.53	1.53	1.53
Sugar (jaggery)	Million tons	0.90	0.9	0.90	0.90	0.90	0.90	0.90
Milk	Billion litres	6.8	6.3	5.5	5.4	4.5	4.6	4.2
Income	Billion rupees	109.9	73.8	77.8	54.3	56.3	54.9	46.1
Land used	%	100	100	100	JOO	100	100	100
Irrigation	Billion m3	56.4	17.8	51.2	16.3	16.2	15.5	18.2
N fertilizer	Million tons	1.51	0.79	1.25	0.64	0.64	0.61	0.65
Employment	Mill. labour days	666	384	674	364	361	347	387
Capital	Billion rupees	114.2	56.9	92.1	54.1	53.7	52.0	56.4
N loss	Thousand tons	61.4	37.6	62.5	39.6	39.1	37.4	31.6
Biocide index	-	95	94	97	132	129	125	81

Each bale of cotton = 170 kg.

** Objective function maximized.

This case provides information on the maximum food production possibilities in Haryana. However, it is not considered a feasible solution because of the extremely high amount of resources needed to produce these levels. These resources are neither currently available nor do they appear to become available in the next 10 to 20 years.

The availability of irrigation water was imposed as the next constraint, in addition to land, to determine the maximum possible food production in Haryana with only the natural resources as constraints. Food grain production in the second case decreased to 17.4 million t. Rice production, being the largest consumer of water, dropped to 5.1 million t from 19.0 million t. Production of other commodities was maintained at their minimum demand level (Table 6). These results indicate that the spatial and temporal availability of water is now the major limiting factor for increasing food grain production in Haryana. In spite of this drastic reduction in food production, milk production decreased only marginally to 6.3 billion litres (Table 6). To realize these levels of production, all land available for agriculture was used and 17.8 billion cubic metres of water were needed. It is interesting to note that 2% of the water available now was still not used. The available water in the *kharif* season was completely used, whereas that of the *rabi* and summer seasons was not fully used. With food production as the main goal, the model allocated all area to rice in the *kharif* season, the only food grain crop in that season, whenever water availability allowed. Since the minimum targeted demand of less water-consuming crops, such as chickpea and mustard in the *rabi* season, had to be fulfilled as well, a considerable area was allocated to these land use systems and hence some water remained unused.

Fertilizer, labour and capital requirements as well as farm income also decreased drastically (Table 6). A reduction in nitrogen loss could be observed compared to the first case. This is the result of a drastic shift in cropping pattern from rice-rice-wheat, the cropping system that consumes the highest amount of nitrogen fertilizer, to rice-wheat and fallow-wheat.

In the third case, in addition to land, the constraint of technology adoption was introduced to mimic the limited capacity of small and medium farmers to adopt capital intensive technologies. Water availability was not included as a constraint in this scenario. Optimal food grain production decreased to 28 million t and corresponding milk production to 5.5 billion litres. Production of all other commodities was at their 1996-97 levels (Table 6). Relative to the land constraint, the requirements of water, fertilizer and capital decreased and total farm income decreased by 30% (Table 6).

When land, water and technology adoption were simultaneously introduced as constraints in the fourth case, food grain production decreased further to 11.4 million t. Rice production declined to 2.8 million t, which was very close to the minimum targeted demand. For wheat, the situation was almost the same. Production of other commodities was maintained at their minimum demand level (Table 6). To achieve this level of production, all land available for agriculture was used and 16.3 billion litres of water were used. Almost 10% of the available water remained unused, largely in the rabi and summer seasons, possibly because the technology adoption constraint limits the use of higher level technologies that efficiently use water.

Fertilizer, labour and capital requirements also decreased drastically and were lower than their current (1996-97) level of use in the state. This is perhaps because now the primary goal of farmers is to maximize income and not necessarily food production, as aimed at in this scenario.

The introduction of capital and labour availability as additional constraints in the fifth case resulted in similar total food grain production (11.4 million t), but milk production dropped to 4.5-4.6 billion litres. The use of all inputs for production as well as outputs remained similar to the third case (Table 6).

The results indicate that at the aggregate state level, even with all constraints (land, technology, water, capital and labour) imposed in the sixth case, production and income could be somewhat higher than what are currently (1996-97) achieved.

Minimizing water use

The earlier scenario analyses revealed that restricted availability of water was the major constraint to increasing food production in Haryana. Therefore, in this scenario, a minimum water requirement was determined to produce current levels of food grains, oilseed, pulses, cotton and sugar. Results showed that, if the land resource was the only constraint, the current levels of production in Haryana could be attained .with only 9.9 billion cubic metres of water, which is almost half the current water use. This scenario still generates higher milk production and income than the 1996-97 baseline, but drastically reduces employment opportunities in the agricultural sector. At the same time, resource requirements in terms of capital and N fertilizer also decreased. N loss was maintained at the same level, but the biocide residue index declined drastically because only 6.8% of the area was allocated to cotton-wheat and maize-potato-wheat, the two most biocide-consuming land use systems (Tables 7 and 8). Fallow-wheat occupied 60.6% of the arable area of the state. Other important cropping systems were rice-wheat, maize-mustard and pearl millet-wheat.

Table 7. Production of milk, income, resource requirements and environmental impact at the aggregate level when minimizing water use in Haryana. Production of all crops was at their 1996-97 level in all scenarios and hence is not shown.

		Constraints						
Item	Unit	Land	Land + Water	Land+Tech	Land+Tech+Water	Land+Tech+Water+Capital	Land+Tech+Water+Capital+labour	Current level (1996-97)
Milk	Billion litres	4.9	4.3	4.9	5.0	4.3	4.4	4.2
Income	Billion rupees	58.5	52.3	55.0	50.1	51.8	51.6	46.1
Land used	%	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Irrigation	**Billion m3**	**9.9**	**12.3**	**11.4**	**13.7**	**13.7**	**13.8**	**18.2**
N fertilizer	Million tons	0.56	0.59	0.59	0.57	0.57	0.57	0.65
Employment	Million labour days	236	310	301	341	341	341	387
Capital	Billion rupees	46.0	47.7	47.7	50.3	50.4	50.4	56.4
N loss	Thousandtons	31.9	27.6	33.3	34.6	34.6	35.1	31.6
Biocide index		31	93	77	122	122	121	81

* Objective function minimized.

When other constraints were gradually added in this scenario, water use still remained below 75% of the current use, while maintaining the current level of production of different commodities and income (Table 7). This was attained by the predominance of fallow-wheat, cotton-wheat, rice-wheat, maize-mustard and pearl millet-wheat cropping systems.

Table 8. Area (% of agricultural land) under different land use types when water use was minimized.

Land use type	Constraints: Land	Land + Water	Land + Tech	Land + Tech + Water	Land + Tech + Water + Capital	Land + Tech + Water + Capital + Labour
Rice-rice-wheat	0.0	0.0	0.0	1.2	1.2	1.3
Rice-wheat	6.8	5.01	8.8	9.5	9.5	9.5
Basmati rice-wheat	0.0	0.0	0.0	0.0	0.0	0.0
Rice-mustard	2.4	6.55	3.1	6.5	6.5	6.4
Cotton-wheat	6.8	7.02	11.7	20.0	20.0	19.2
Maize-mustard	6.0	0.17	7.5	7.2	7.2	7.2
Maize-chickpea	2.3	0.0	3.0	3.6	3.6	3.5
Maize-potato-wheat	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane-wheat	2.7	2.45	3.4	3.8	3.8	3.9
Irrigated pearl millet-wheat	1.4	0.0	2.5	5.4	5.4	5.5
Rainfed pearl millet-wheat	11.1	18	10.3	7.1	7.1	7.1
Fallow-wheat	60.6	51.17	49.8	35.7	35.7	36.3
Fallow-chickpea	0.0	0.0	0.0	0.0	0.0	0.0
Fallow-mustard	0.0	9.68	0.0	0.0	0.0	0.0
Pearl millet-fallow	0.0	17.98	0.0	0.0	0.0	0.0

Conclusions

The results presented in this paper are exploratory in nature. The main purpose of this paper was to develop a methodology for exploratory land use analysis and planning using Interactive Multiple Goal Linear Programming (IMGLP) approach. It reveals that Haryana has ample opportunities to increase food production and agricultural income compared with current levels, provided additional water resources could be made available. The current natural constraints of land and water limit maximum food production to 17 million t. Here, the model assumes that all water and capital within a land unit can be shared. It implies that groundwater resources available within a farm can be transported to other farms without cost, irrespective of distance involved. This does not look feasible, even with the current policy of an almost free water supply in the region.

Haryana has considerable potential to withdraw agricultural land from cultivation, without affecting basic food production and income at the aggregate level. This would require that the small farmers who cannot use alternative, efficient and capital intensive technologies not cultivate their land and that their water and other resources be made available to other farmers who presumably could use these more efficiently. Alternatively, technologies that are affordable and can be applied on small farms should be developed.

References

Conway, G.R., 1987. The properties of agroecosystems. Agricultural Systems 24, 95- 117.

Hazel, P.B.R & R.D. Norton, 1986. Mathematical programming for economic programming in agriculture. Macmillan, New York, USA.

Huizing, H. & K. Bronsveld, 1994. Interactive multiple-goal analysis for land use planning. ITC Journal 4, 366-373.

Schans, J., 1991. Optimal potato production systems with respect to economic and ecological goals. Agricultural Systems 37, 387-397.

Schipper, RA., D.M. Janssen & J.J. Stoorvogel, 1995. Sub-regional linear programming models in land use analysis:

A case study of the Neguev settlement, Costa Rica. Netherlands Journal of Agricultural Sciences 43, 83-109.

Stomph, T.J., La. Fresco & H. Van Keulen, 1994. Land use system evaluation: Concepts and methodology. Agricultural Systems 44, 243-255.

Stoorvogel, J.J., RA. Schipper & D.M. Jansen, 1995. USTED: A methodology for a quantitative analysis of land use scenarios. Netherlands Journal of Agricultural Sciences 43,19-29.

Veeneklaas, F.R, S. Cisse, P.A. Gosseye, N. Van Duivenbooden & H. Van Keulen, 1991. Competing for limited resources: The case of the fifth region of Mali, Report 4. Development Scenarios. CABO-DLO, Wageningen, The Netherlands.

WRR - Netherlands Scientific Council for Government Policy, 1992. Ground for choices: Four perspectives for the rural areas in the European Community. Reports to the Government no. 42, Sdu, The Hague, The Netherlands, 149 pp.