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Crop income optimization analysis under crop diversification scenarios in a village near Roorkee; District Haridwar, India

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Abstract

The agricultural resources are limited while the demand of agricultural products keeps on increasing along with population. Optimum productivity with limited land will only be a quick solution which farmers can adopt easily and fill the gap. This paper depicts different crop production scenarios as a way out to agricultural net benefit optimization. The study considered five main cropping scenarios, *viz.* LP1, LP2…LP5 as possible plans which were carried out for each of the three seasons; *Kharif*, *Rabi* and *Zaid*. The study reveals that, for getting optimum net return from available land and water resources in *Kharif* season farmers need to grow 280 ha of sugarcane, 69 ha of rice, 10 ha of maize, 50ha of chili, 130 ha of floriculture and 130 ha of folder *(Jowar)* which can give net return of Rs. 46,682,310. It was observed that the proposed LP model is appropriate for finding the optimal land allocation to the major food crops in *Kharif* season. Sensitivity analysis showed that crop water requirement is the most sensitive parameter and its changes have the highest effect on the amount of net return in the study area. Farmers can get higher optimum net return in *Kharif* season by making some slightly adjustment in the existing cropping pattern and adopting some in-situ water saving techniques.

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Introduction

LP is utilized by all sorts of firms in making decisions about establishment of new industries and in deciding upon different methods of production, distribution, marketing and policy decision making. LP is perhaps the most important and best-studied tool for optimization problem. A lot of real world problems can be formulated as linear programming problems mentioned by (H. 2012). The LP model for agricultural land allocation problem has been formulated by considering the period of a year and the three cropping seasons. The total time period is divided into number of seasons according to the climatic and environmental conditions which are assumed to normal. The *Kharif* season July to September, Rabi season December to March and *Zaid* April to June as designated by Indian Meteorological Department.

Different crops have different cropping cycle. These cycles are distributed throughout the year with overlapping periods. A particular land can be used for a particular crop whereas others can be used for two or three crops in succession. This leads to multiple choices available to select from for crop area selection. Each choice has different impact on the farmer's net income. In order to find the best possible combination for maximum net income, cropping pattern and crop area allocation should be brought into consideration study by (Hasan Symum 2015).

Hasan Symum 2015 suggested that in order to plan the water supply distribution for irrigation, in relation to the production level and to the water needs, the factors that are necessary are seasonal and monthly needs of water supply, crop production and crop selection. In addition to water supply facility, availability of fertilizer also plays a great role for on time production of seasonal crops. The demand is based on the type of area of cultivation, type of crops and growth rate. There are different types of irrigation project that have been undertaken for proper irrigation management which includes ground water irrigation, surface water irrigation through public and private ventures. But due to scarcity of resources, it is found that such projects cannot always manage to satisfy farmer needs for proper yield. That is why farmers often face shortage of water and in many cases they use empirical way to maximize profit. That there is scope for improvement of the situation of the farmers by distribution of water resource for each area and land allotment for particular crop through the help of optimization tool. This optimization problem can be represented by a profit maximization function. The function is the difference between gross income and production cost subject to land availability, water supply, cropping pattern, market demand and other specific restrictions. (Pant *et al.* 2008) compared the performance of Differential Evolution (DE) with LINGO, which is another popular software tool for solving Linear Programming Problems. The numerical results showed that, for 50% water year dependable flow, both DE and LINGO gave exact results. However for 75% and 90% water year dependable flow performance of DE was superior to LINGO in terms of net profit.

The study results by (Ramezani Etedali *et al.* 2015) revealed that using new management, total net income increases in rainfed and irrigated lands as compared with the conventional management. The increased values are 11.2, 13.5, 19.2, 16.6 and 15.8% in normal climatic condition, 9, 10.9, 17, 15.9 and 13.4% in wet climatic condition, and 8.1, 12.5, 16.1, 19.1 and 19.9% in dry climatic condition for the conveyance distances of 2000, 4000, 6000, 8000 and 10000m, respectively. It has been observed by (Sofi *et al.* 2015) that for some LP problems simplex algorithm takes less number of iterations as compared to other algorithms. The study proposed LP model for optimum land allocation to the 5 major food crops in agriculture. Linear programming (LP) technique is relevant in optimization of resource allocation and achieving efficiency in production planning particularly in achieving increased agriculture production of food crops (Rice, Maize, wheat, Pulses and other crops).

The study by (D.Nikkami, M.Shabani 2009) showed that, the economic interpretation of dual variables as shadow price is extremely useful for deciding which changes should be considered. The shadow price (y_i) for resource i measure the marginal value of the resource, that is, the rate at which Z could be increased by slightly increasing the amount of this resource being made available. In particular if $y_i > 0$, then the optimal solution changes if B*i* changed, so B*i* is a sensitive parameter. The investigation continued on A_{i1} and C_i parameter; It was found that, which referred to the restriction of area under orchad was the most sensitive parameter.

In order to have sustainable agricultural development, agricultural inputs must be reduced. The priority of reduction should start with the most threaten resource(s). In some areas where so much of fertilizer has been used, Nitrogen and Phosphorus may be reduced first due to these fertilizer environmental effects such as greenhouse gas emissions and severe water pollution. Definitely most populated countries or areas will soon or have use (d) every piece of available land for agriculture. In such area the potential to increase grain area will therefore be limited in the future; more food will need to be produced from fixed or less amount of land. Moreover most arable land in some areas has poor soil quality, which makes it so difficult to achieve high crop yields. On the other hand rising temperature, unequal distribution of rainfall patterns and more frequent extreme events will affect crop production in most of these areas. Some regions are receiving less and less precipitation while other heavy rain falls. This makes optimization of agricultural resources not the only solution to meet the increasing agricultural products demand and increased agricultural productivity constraints.

Materials and methods

The Study Area

The study area (i.e. Ibrahimpur Masahi revenue village) is falling under Shipla Nadi-Halzora Nadi watershed, District Haridwar (Uttarakhand). The location map of the study area is given in Fig. 1.1. The Shipla Nadi-Halzora Nadi watershed lies from 29°56' to 30 °05' North latitude and 77°48'to 77°55' East longitude under SOI Toposheet Nos. 53 F/16 and 53 G/13 (1:50,000). The geographical area of the Shipla Nadi-Halzora Nadi watershed is 101.5km² up to River Bridge at village Imlikhera. The area of Ibrahimpur Masahi revenue village is 14.26km² (1426ha) which represents about 1/7th of the watershed area upto Imlikhera bridge. The Ibrahimpur Masahi revenue village consists of the five sub-villages under its jurisdiction, namely; Ibrahimpur, Masahi Kala, Belki, Inayatpur and Halzora as reported by (RMOD, National Institute of Hydrology, Roorkee 2016). Masahi Kala, Belki and Inayatpur are small villages which located in Ibrahimpur gram Panchayat of Bhagwanpur Tehsil of Haridwar District (Table 1.1). It comes under Ibrahimpur Masahi Panchayat in Bhagwanpur Division. It is located 34km towards West from District headquarters Haridwar and 18km from block office Bhagwanpur as reported by (A.Sahu 2016).

The Halzora village has a different scenario as compared to other villages in the gram panchayat. Most of the people in this village are illiterate, landless and unemployed. Most of the people of this village are laborers. The Ibrahimpur village is located in a small hill and the management of water in this village is very poor in comparison to any other village nearby. Though the village is having resource, but villagers are not aware of the efficient use of the water and its management. The host organization facilitated to have an overview and basic demographic knowledge about the village. In Ibrahimpur the number of households Surveyed is 65 out of 223 households and in Halzora the number of households surveyed is 19 out of 108 households. For the entire village the total number of households is around 370. The main crops grown by the farmers are Wheat, Rice, Maize and Sugarcane as reported by (A.Sahu 2016) and (P.S.Mishra 2016).

The Necessity of the Study

Comparative Analysis of different cropping scenarios and prioritizing the most optimum cropping patterns. There are several advantages of crop diversification, which could be listed as follows;

Comparatively high net return from crops
Food security promotion
Soil conservation by growing some specific crops
Higher net returns per unit of labour
Optimization of resource use
Higher land utilization efficiency
Increased job opportunities

A report by FAO (Papademetriou, Minas K, Dent 2001) states that, in order to achieve the above benefits the process of diversification should be changed from very simple forms of crop rotations, to intensive systems such as relay cropping and intercropping or specialization by diversifying into various crops, where the output and processing etc., could be different. This process could be similar at farm level and national level.

Crop Water Requirement

The development of irrigation schedules and evaluation of irrigation practices are based on daily soil-water balance using various options for water supply and irrigation management conditions. Procedures for calculation of crop water requirements and irrigation requirements are based on methodologies presented by (Doorenbos & Pruitt 1977).

Reference crop evapotranspiration can be estimated using CROPWAT model based on FAO, Penman-Monteith approach.(RMOD, National Institute of Hydrology, Roorkee 2016). The input climatic data in the Pen-Monteith equation, *viz.* maximum and minimum temperature, wind speed relative humidity and sunshine radiation. The effective rainfall can be estimated using USDA SCS method. The crop data required for estimation of crop water requirement including planting height, length of growing stages, and crop coefficient for different growing stages. The crop factor was determined for each decade and Evapotranspiration of crop can be determined by

$ET_{crop} = K_c \times ET_o$

And Irrigation water requirement was determined from ET_{crop} and effective rainfall by:

Irrigation water requirement = ET_{crop} - Effective rainfall. The computed total crop water requirement of *Kharif* season was 49.65 cm, *Rabi* season was 12.65 cm and *Zaid* season was 11.35cm. The crops commonly grown in the watershed were all considered for estimation of crop water requirement (Table 1.4). The water availability in the study area for all the entire year was collected (Table 1.5). There was no shortage of water availability for all the three seasons, *viz.* Kharif, Rabi and Zaid season. In the present study planning of agricultural input and maximizing output considered as of the people concern to the farming sector. As per the report by (RMOD, National Institute of Hydrology, Roorkee 2016), the total crop water requirement of *Kharif* season was 49.65 cm, *Rabi* season 12.65 cm and *Zaid* season 11.35 cm.

Model formulation:

A linear programming problem with "n" decision variables and "m" constraints can be mathematically modeled as

Maximize $Z = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n$ (1)

s.t

$$a_{11} x_1 + a_{12} x_2 + \ldots + c_{1n} x_n \le b_1 \quad (2)$$

$$a_{21} x_1 + a_{22} x_2 + \ldots + c_{2n} x_n \le b_2$$

$$a_{m1} x_1 + a_{m2} x_2 + \ldots + c_{mn} x_n \le b_m$$

$$x_j \ge 0,\ j = 1,2,3.....n$$

x_j represent the vector of variables while c and b are vectors of known matrix of coeffient. The expression to be maximized is called the objective function. The equation (2) is the constraint which specifies a convex polytypic over which the objective function is to be optimized. The coefficients c_1, $c_2 \ldots c_n$ are the unit returns coming from each production process $x_1, x_2, \ldots x_n$.

By converting above general linear programming problem in standard form using slack variable as x_{n+1}

This can be written as

$$\text{Max } Z = \sum_{i=1}^{n} c_i x_j$$

s.t,

$$\sum a_{ij} x_j + x_{n+1} = b_i ,$$

$$x_j \ge 0$$

$$i = 1,2,3.........m$$

$$j = 1,2,3.........n$$

Where,

$$z_j = \sum_{i=1}^{n} (c_j)(a_{ij})$$

Z = The objective function to be maximized

x_j = Input/basic variables

c_j = Cost coefficients of the objective function

b_i =Maximum limit of the constraints

a_{ij} = Coefficients of the functional constraint equations

Solution procedure

To maximize the problem, the inequalities describing the problem were set and converted the inequalities to equalities by adding slack variables. Enter the equalities in a table for initial basic feasible solutions with all slack variables as basic variables. The $c_j - z_j$ values for this solution where c_j is the coefficients of objective function can be calculated. Variable j and z_j represents the decrease in the value of the objective function that will result if one unit of the variable corresponds to the column of a matrix is brought into the basis. The entering variable was chosen by $c_j - z_j$ with the highest positive value and determined the row to be replaced by dividing the solution column b_i by corresponding optimum column values and choosing the smallest positive quotient.

The values for the entering rows and the remaining rows were computed. Then $c_j - z_j$ for this solution were calculated. If there is negative or zero $c_j - z_j$ value, then maximum optimal solution has been obtained otherwise go to next steps optimal solution is obtained when all the entries in $c_j - z_j$, is negative or zero. For maximum optimality $c_j - z_j \leq 0$ and for minimum $c_j - z_j \geq 0$.

Result and discussion

The existing cropping pattern for every season was derived from informal interview at the villages, the information obtained were collectively compared with cropping pattern study by (B.Soni 2003), only the necessary improvement in the cropping pattern was done (Table 3).

Scenario analysis for the Seasons

The Linear Programming model (LINGO) was used for optimum allocation of available land and water for maximizing the net return from various agriculture crops in the study area. Five main scenarios were considered in each crop season for modeling, *viz.* in *Kharif* season: Existing scenario, Need based of some crops scenario, Limitation with cash crop scenario, Scenario under System of Crop Intensification (reduction of 20% crop water requirements) and Scenario under increasing 10% of crop water requirements.

Existing Scenario (LP1)

In this scenario, farmers grow their normal crops with available resources. Rice is one of the best cereal crop choices which are followed by Maize (Table 3.1a). The net income from Rice crop is Rs. 134,050 per hectare which is higher than rest of the cereals. The Chili crop is the most dominant cash crop in the *Kharif* season with net income (Rs. 119,650 per hectare) followed by Fodder (Rs. 85,337 per hectare) and Sugarcane (Rs. 60,475 per hectare). The net income from the other crops is low, but still these crops are grown in the study area as per local preferences. Crops which give good return, such as chilies and vegetables are expected to attract farmers, although very limited amount is currently produced in the area. The net benefit in *Kharif* season with the existing cropping pattern is Rs. 45,745,656.

In *Rabi* season, wheat is one of the best cereal crop choices which are followed by pulses (Table 3.1b). The net income from wheat crop is Rs. 46,261 per hectare which is higher than rest of the cereals and pulses crops. The Vegetables crop is the most dominant cash crop in the Rabi season with net income (Rs. 293,125 per hectare) followed by Fodder (69,500 per hectare). The net benefit in Rabi season with the existing cropping pattern is Rs. 35,023,712.

In *Zaid* season, black gram is one of the best cereal crop choices (Table 3.1c). The net income from black gram crop is Rs. 88,890 per hectare which is higher than rest of the cereal crops. The Fodder crop is the most dominant cash crop in *Zaid* season with net income (Rs.

121,312 per hectare) followed by Mango (Rs. 21,000 per hectare). The net benefit in *Rabi* season with the existing cropping pattern is Rs. 3,581,639.

Need based of some crop scenario (LP2)

In *Kharif* season, observation was done after providing some restriction which was based on people`s eating habit and preferences in the watershed. The area of crops which were considered as less required were reduced considering the first digit, when the first digit was zero the second digit was considered for reduction. The reduced area was added to the mostly required crops, viz. Rice, Maize and Chili crop (Table 3.2a). For getting maximum net return from available land and water resources, there is need to be planting of 280ha of Sugarcane, 57ha of Rice, 15ha of Maize, 57ha of Chili, 130 ha of Floriculture and 130ha of Fodder *(Jowar)* crop. Under this scenario, the net return will be Rs. 46,550,535 which is 1.76% higher than the existing scenario.

In *Rabi* season, the reduced area was added to the mostly required crop, *viz.* Vegetable crop (Table 3.2b). There was no feasible solution for optimum benefit in *Rabi* season after providing some restriction through the used model. The farmer can get atleast Rs. 39,761,175 net return from available land and water resources by planting 250ha of wheat, 77 ha of vegetables, 50 ha of fodder and 50 ha of pulse crops. The net return is 13.5% higher than the existing scenario.

In *Zaid* season, the reduced area was added to the mostly required crop, *viz.* Black gram crop (Table 3.2c). There was no feasible solution for optimum benefit in *Rabi* season after providing some restriction through the used model. The farmer can get atleast Rs. 3,597,850 net return from available land and water resources by planting 66ha of Mango, 17.5ha of Fodder, 1ha of Black gram crop. This net return is 0.45% higher than the existing scenario.

Limitation with cash crops (LP3)

It was found that in the above two scenarios (Table 3.1 and 3.2), there was massive planting of Sugarcane (285ha), Wheat (250 ha) and Mango (66ha) crop in LP1 and Sugarcane (280ha), Wheat (250ha) and Mango (66ha) in LP2. It is only feasible when there is large size market available. In the third scenario, it is suggested that if farmers of the study area grow their normal crops with some cash crops based on the market condition**.** In *Kharif* season, LP3, net return increased up to 0.28% as compared to LP2 and increased up to 2.05% compared to LP1 (Table 3.3). However to get optimum results the model suggested to grow only 114ha of floriculture leaving 16 ha for other economic uses. If farmer take this suggestion, LP3 net return will decrease by 0.28% as compared to LP2 and increase up to 1.47% compared to LP1 (Appendix VI).

In *Rabi* season, under LP3, the net return is 6.2% higher as compared to LP2 and increased by up to 20.6% compared to LP1.

In *Zaid* season, under LP3, there is no change in of net return as compared to LP2 but there is an increase up to 0.45% compared to LP1.

Scenario based on Crop water availability

For optimum allocation of available land and water for maximizing the net return from various agriculture crops in the study area two sub-scenarios were considered with some irrigation water restrictions. Scenario under System of Wheat Intensification, *viz.* reducing 20% of irrigation water and Scenario under increasing 10% irrigation water.

(a) Scenario under System of Crop Intensification (LP4)

It was observed that after opting for the System of Crop Intensification method for all crop 20% of crop water requirement was being saved, *viz.* (171.419ha-m) as compared to the conventional method. With the amount of water saved, the cropping area can be increased as per the appropriate field intervention techniques, *viz.* regarding cropping pattern, irrigation facilities and inputs budget. There were no changes on the net of return when the water saved was not utilized (Table 3.4a). Annually, there was an increase of 6.6% in net return and 9.7% when LP1 was compared with LP2 and LP3 respectively.

(b) Scenario under increasing 10% of irrigation water (LP5)

It was found that if only 10% of irrigation water is increased, there was a possibility of increasing the cropping area by 133ha, provided availability of more land resource. This is nonly possible with land resource increase option possibilities, extension of irrigation facilities and adjustment inputs budget (Table 3.4a). The linear programming model was used to formulate the problem for maximizing the net return from agricultural field by optimum allocation of available land and water resources. Multi objective optimization functions were used for maximizing net return under various constraints for *Kharif*, *Rabi* and *Zaid* crops. Five different scenarios were considered for optimization one plan after another was carried through all the three seasons repetitively until all the five scenarios were completed. The results of linear programming model simulation show that in *Kharif, Rabi* and *Zaid* seasons, the whole cultivable land can be sown with the available water available in the study area. In the fourth scenario (LP4) 20% of irrigation water was saved and in the fifth scenario (LP5) 10% of water was increased, with these water practices options; the cropping area can be increased by 266 ha and 133ha respectively.

The study suggest to give priority in water saving practices in the watershed so that to obtain the best net return from the crops. Annually, the net return for LP3 was found to be 9.7% higher than LP1, followed by LP2 which was 6.6% (Table 3.4a). In *Kharif* season, LP3 gave the highest net return, followed by LP2. In *Rabi* season, LP3 gave the highest net return, followed by LP2. And in *Zaid* season, both LP2 and LP3 gave the highest net return followed by LP1.

The study deduces that water saving practices increases availability of water for other crops, hence mutual increase in net return. For instance, under the LP1; Chili crops have higher net water productivity followed by maize crop (Table 3.5). In future would like to conduct multi-objective function study and compare results from more than one model at field and agro processing industries.

Conclusion

The solutions are obtained by Simplex algorithm. For getting optimum net return from available land and water resources in *Kharif* season farmers need to grow 280 ha of sugarcane, 69 ha of rice, 10ha of maize, 50ha of chili, 130ha of Floriculture and 130ha of fodder *(Jowar)* which will give net return of Rs. 46,682,310. While in *Rabi* season, the current model could not find an optimum solution, there is need to consider another model or validation of the existing cropping pattern, crop productivity, market limitations and local preferences in the study area. The farmers can grow 240ha of wheat, 87ha of vegetables, 50ha of fodder *(Berseem or Jayee)* and 50ha of pulses in order to get at least net return of Rs. 42,229,815. In *Zaid* season, the current model could not find an optimum solution as well. Farmers can grow 66 ha of mango, 17.5ha of fodder (Maize or *Bajra*) and 1ha of black gram *(Urad)* which can gives at least net return of Rs. 3,597,850. The study conclude that farmers can get more net return in *Kharif* season by making some slightly adjustment in the existing cropping pattern and adopting some in-situ water saving techniques.

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