Developing Suitable Cropping Pattern for Irrigated Agriculture at Chacha Irrigation Scheme in the Amhara Region.

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Abstract

With the rapid change in population and land fragmentation, land and water resources are becoming very limited. Consequently, crop optimization has received extensive attention in recent years. It is the key factor for sustainable agricultural development with the increasing trend of the population and availability of fresh natural resources is under threat. A poor cropping pattern is one of the crucial causes that reduce the quantity and degrades agricultural products quality. For example, at Chacha irrigation scheme farmers produce once a year with a mono-cropping system. Therefore, this study was conducted to develop an appropriate cropping pattern that maximizes annual return from the irrigation scheme and to develop a crop rotation system that improves soil fertility, pest control, and maximize farm income. The experiments were laid out in Randomized Complete Block Design with three replications. Both rain-fed and irrigable crops were planted according to the corresponding with agronomic recommendations implemented for two consecutive years, twice in a year at Chacha. Simple linear programming model was employed to optimize the allocation of resources and maximize the profit or minimize the cost. Resource optimization techniques are used for limited use of resources such as land, production cost, manpower, fertilizers, seeds, and pesticides. The results showed that capital for seed used only 86.61 %, for labour used 90 %, for fertilizer, used 78 % of the available capital allocated for fertilizer in the optimal solution. Cultivation of 72 % of the area with Beat root-Food Barely-Potato-Fababean-Carrot-Wheat-Garlic *and 28 %* Beat root-wheat-Potato-Food barely-carrot-Fababean-Garlic *cropping pattern provided better farm benefit of 177,720 Et. Birr per year per hectare. Therefore, cropping pattern that offer better farm benefit is recommended to improve the existing barley based production at Chacha irrigation scheme. Hence, the cropping pattern has to be decided optimally depending on the available economic basis.*

Keywords: *Characterization, cultivation, linear programming, optimization,*

Introduction

The 21st century faces multiple challenges like climate change, population growth, food shortage, poverty, hunger, accelerated land cover change, and environmental degradation *(Neamatollahi et al.*, 2017). The readily available freshwater resources are becoming scarce due to growing demands by municipal, industrial, recreational, and agricultural sectors. This is mostly because of population increase and higher standards of living in many areas, but also due to changes in land use and global climate change as a result of rapid development (Birhanu *et al.,* 2015). Management of water resources is not an easy job mainly when the problem is national. It becomes harder if an area is considered unstable or when the events and climate are unpredictable (Juwono *et al.*, 2018). Irrigation accounts for 70% of total freshwater withdrawals globally, with the industrial and domestic sectors accounting for the remaining 20% and 10%, respectively (WWAP 2014). The World is now filled with more than 7 billion people and increasing at an alarming rate of 1.2 percent per annum and by 2050, the world population is projected to reach 9.6 billion. Due to the inadequate food supply, about 1 billion people stay hungry every day globally and the figure will increase to 2 billion by 2050 (UNFPA, 2012). With expected increases in population by 2030, food demand is predicted to increase by 50% (70% by 2050) (Bruinsma J. 2009).

In this regard, better management practices are essential to enhance productivity. A cropping pattern is one of the crucial causes that reduce the quantity of water and degrades the quality of the agricultural products (Neamatollahi et al. 2017). Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050 (Birhanu *et al.,*2015; Seleshi Bekele *et al.*, 2010). Globally, irrigated crop yields are 2.7 times those of rain-fed farming; hence irrigation will continue to play an important role in food production. However, the increasing competition for water usage in different sectors is making this resource highly scarce. Hence, today, the agricultural sector around the world is under more pressure for limiting its water use, not only because of the increasing water demand but also because of climatic changes and more frequent droughts (Seleshi Bekele *et al.*, 2010). Due to the rapid change in population and urbanization, land and water resources are becoming very limited. Subsequently, crop optimization has received extensive attention in recent years. Land and water are the key factors for sustainable agricultural development of a nation with the increasing trend of the population availability of fresh natural resources are under threat (Osama, *et al.,* 2017). Although there have been extensive efforts that had partly succeeded in introducing the concept of water management and led to the formation of different water board organizations at different levels, most of these organizations are not functioning properly and the need for an optimization model is crucial to support planning for water resources development and management (Osama, *et al.*, 2017).

Ethiopia has vast cultivable land of 30 to 70 million ha, but only 15 million ha of land is under cultivation. With current irrigation schemes covering about 640,000 ha out of 5.3 million ha of total potential irrigable land. In Ethiopia, due to a lack of water storage infrastructure and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year (Seleshi Bekele *et al.*, 2010).

Nowadays, water resources management and planning under limited resources (such as water, land area, production cost, and manpower) is one of the classical problems. The cropping pattern of the irrigation project is the planning and allocation of land area for cultivating each crop. Cropping pattern is constructed based on the size of the land area that used to be cultivated in the previous season. Several crop patterns are not considered economical. Therefore, the farmer needs to have the optimum cropping pattern which will maximize the economic return. Normally, Linear Programming (LP) is an optimization technique which widely used to allocate the limited resources because of the proportionate characteristic of the allocation problem. One popular application of the technique in the water resource literature is finding an optimal seasonal crop pattern which subjected to limited available resources (Singh *et al.*, 2001). Often, the maximization benefit was set as the objective function based on the resource constraints. The objective function and constraint functions are formulated as the linear equation for finding optimum cropping pattern. Often, earlier studies assumed homogeneity in crop water requirement and crop yield for all land area of the irrigation scheme. The crop yield is usually affected by crop water requirement and soil type suitable for the cultivation of each crop (Brown, C. and Lall, U., 2006). In addition, earlier studies considered irrigation efficiency as a constant value in calculating available water. Generally, irrigation efficiency is a variable value based on the amount of available water and farmer participation in water resource management (Burke *et al*., 1999).

To determine the right cropping pattern, the planning should consider various agronomy and extension constraints including crop water consumption, nutrition values, disease and pest resistance, market demand, fertilizer input, labour requirement, capital input, post-harvest processing necessity, crop production level, and market prices (Jebelli *et al.,* 2016). Although the selection of an optimum cropping system is a scientific and professional challenge, it is believed that it can be scientifically addressed using optimization techniques such as a linear programming model. Many authors used this simple linear programming model to optimize the allocation of farmers' resources (water and lands) to maximize the profit or minimize the cost (Frizzone *et al.,* 1997; Bertomeu and Gimenez 2006; Aparnathi and Bhatt 2014).

Birhanu *et al.* (2015) successfully used a linear programming model to obtain an optimized cropping pattern for the Koga Irrigation Dam project in Ethiopia. Chacha irrigation scheme is commonly used to produce once a year with mono-cropping (carrot) system at the same season. This production system is highly affecting the marketing system and discouraging the farmer. Therefore, a linear model was used to optimize the cropping system for the Chacha small-scale irrigation scheme currently essential to utilization of dubious land in the main season. The objectives of this study were to develop an appropriate cropping pattern that maximizes annual return from the irrigation scheme and to develop/identify a crop rotation system that maximize farm income and utilization of dubious land in the main season.

Materials and Methods

Description of the Study Area; The experiment was conducted at Chacha irrigation scheme in the Amhara region, North Shewa Zone, Angolelanatara Woreda. The site is located 14 km from Debrebirhan town. The geographic location of the experimental site is 39^0 26' 56" E and 09°32' 22"N with an altitude of 2770 m. a.s.l. The area has two major seasons; the rainy and dry seasons. Mean monthly maximum and minimum temperature of 19.9 and 6.6

5 °C and up to 3.5°C in the coldest month from October to January when frost occurrence is severe. The area is characterized with mean annual rainfall of 935 mm. The land topography is near to flat and the annual rainfall is about 985mm. The whole area is not cultivated at rain fed system, rather they cultivate in irrigation season. The soil textural class of the study site is dominated by clay texture and low permeability. The water source is either from the dam with gravity flow or from the perennial river by pumping system.

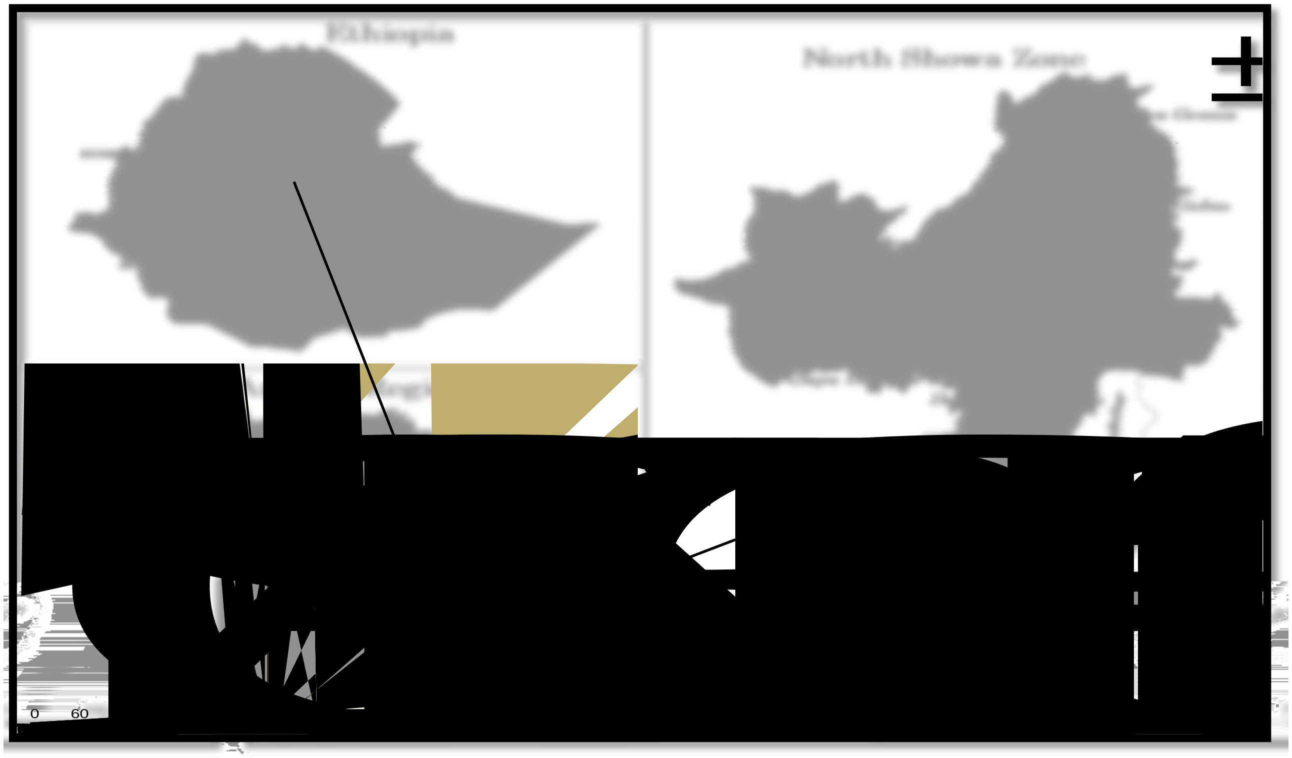

Figure 1.7 Geographical location of the study area

The climatic data was taken from nearby metrological station, at Debrebirhan Agricultural Research Center (DBARC). The maximum evaporative demand of the atmosphere was found in May (4.07mm/day) and the minimum ET_o was found in July and December (3.06mm/day).

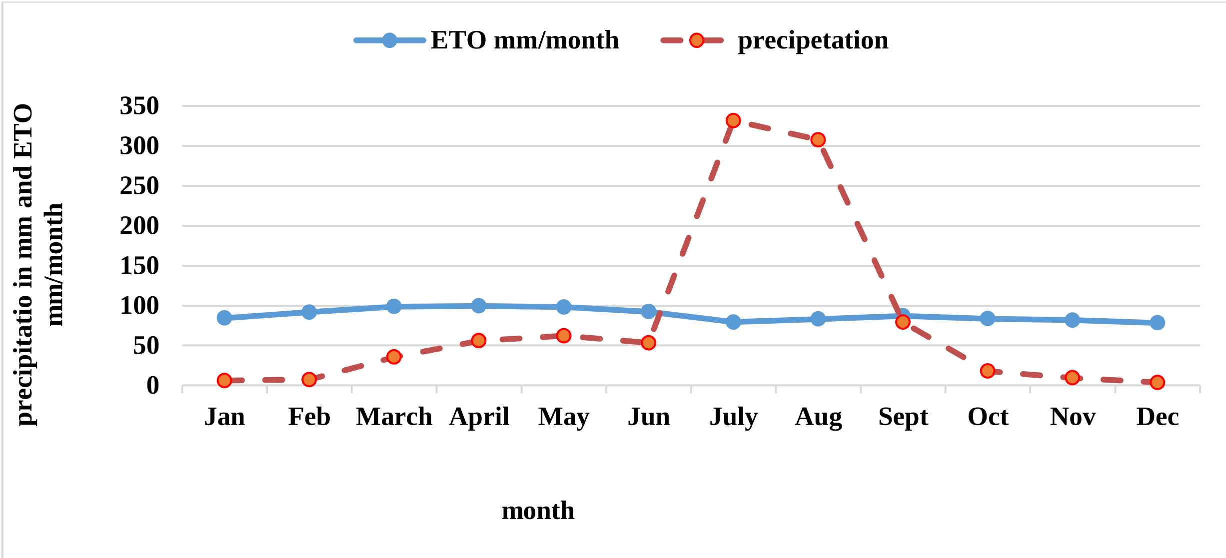

Figure 2. The climate water balance of the study area

Crop Selection and Experiment: With the full participation of farmers, a selection of what crops to grow in winter and summer respectively was identified. Factors to be considered in

soils, water availability, labour requirements, marketing aspects, availability of inputs, rotational considerations, susceptibility to diseases, and total growth period (LGP). Once the crops are selected, a cropping program showing the seasonal cropping patterns and indicating the time and the area for each crop was made. Factors such as the sowing or transplanting dates, the length of the growing season, and the time needed for harvest and land preparation for the next crop were considered during planning. Therefore, it is useful to indicate on the cropping program diagram the time needed for harvesting. To reduce the risk of diseases and pests and the removal of certain nutrients through plant uptake, the cropping program was allowing rotation of the crops in the plots.

The experiment was conducted for four years and it was consisting of double-cropping. The set of experiments was laid out in Randomized Complete Block Design in three replications. Both rain-fed and irrigable crops were receiving recommended fertilizers. UREA and NPS were used as sources of nitrogen and phosphorous, respectively. UREA was applied in split (half at planting and half at some stages of the crops as per the agronomic recommendation) while all the NPS was applied at planting. The plot size was

2.8 x 2.8m^2 and 1.5m b/n plots and 2m between blocks to manage irrigable crops. The experiments were was conducted on fixed plots in the subsequent two years. As presented

Model Development: A standard form of linear programming model has the following components (Anon., 2001). Decision variables to be optimized, an objective function that must be maximized or minimized and will be put subject to constrains. The definition of the above-mentioned components and their adaptation to the Chacha scheme will be discussed as follows.

2.3.1. Decision Variables: Decision Variables are the combination of mathematical expressions in the objective function to be optimized by the model. The goal is to find values for the coefficient of decision variables to provide the best rate of the objective function (Anon., 2001). For the Chacha scheme, the types of crops being planted are the decision variables that the percentage of which is to be optimized. The food security strategy for Ethiopia recommends that specific crops be included in any proposed cropping system to improve the nutrition and fiber values in the farmers' family diet. The twelve decision variables $T_1, T_2, T_3 \ldots T_{12}$, and their coefficients $C_1, C_2, C_3 \ldots C_{12}$, for the scheme, are presented in Table 1.

2.3.2. Objective Function: The Objective Function is a mathematical expression that combines the decision variables and their coefficients to achieve the goal of maximum farm benefits (Anon., 2001), and is expressed as follows.

$$Z = f(T_1, T_2, T_3 \ldots T_{12})$$

The highest farm benefit for the Chacha irrigation scheme means the highest farming income resulting from an optimized combination of crops being grown and subjected to the constraints. The general form of the objective function (Z) could mathematically be expressed as follows (Schulze, 1998).

Where j =1 to 12

Given the twelve decision variables (n=12) in the case of the Chacha scheme, then the objective function could be developed as follows:

$$C_1T_1 + C_2T_2 + C_3T_3 + \ldots + C_{12}T_{12}$$

Where Z is the farm gross income resulting from growing the 12 optimized cropping sequences and C_1, C_2, C_3 ...C12 are the coefficients in the objective function related to an increase in Z (the objective function value).

2.3.3. Constraints: The five constraints are land, labor, seed, fertilizers, and chemical cost. They usually restriction or limitation on the diction variable value. The model assesses and identifies possible solutions that respect these limits to achieve the optimum objective function (Anon., 2001). The constraints are mathematically expressed as follows:

Where a_{ij} are the coefficients for the introduced constraints and b_i are the values for the defined constraints. The expansion of the above expression for n number of decision variables (cropping sequence or treatment) and m number of constraints in Chacha irrigation scheme.

Statistical Analysis: The linear programming model quantifies an optimal way of integrating constraints to satisfy the objective function to optimize crop production and profits for irrigation user farmers. Favourably, the Microsoft Excel program includes a linear programming Solver, which could be utilized for simple optimization scenarios like optimization of cropping patterns in small-scale irrigation projects. This Solver tool could easily be accessed from the Data menu after activating the Add-Ins part of Excel Options.

The objective function (Maximizing farming benefits) which includes decision variables (percentage of crops in the cropping pattern) was subjected to agronomy and extension constraints as well as the minimum required crop levels to comply with the food security strategy. After inputting data in an Excel sheet and running the Solver, the linear programming tool could successfully find a solution while all constraints and optimal conditions were satisfied. A sensitivity analysis was also performed to analyze all other likely development scenarios. This paper will discuss the processes that led to the development of an optimized cropping system for the Chacha small-scale irrigation scheme.

Results and Discussion

Soil Chemical Properties

Table 2. Soil analysis result of Chacha irrigation scheme

Treatme	p	E.C(dS/	AV.	EX.	%O	T.N(	C/
1	6.	0.11	9.26	0.38	2.9	0.33	9.2
2	5.	0.08	9.54	0.34	2.9	0.33	8.9
3	6.	0.09	9.74	0.38	2.8	0.31	9.0
4	5.	0.17	10.3	0.40	2.9	0.34	8.8
5	6.	0.17	10.6	0.42	2.9	0.32	9.1
6	6.	0.17	10.6	0.40	2.9	0.34	8.8
7	6.	0.19	11.7	0.43	2.8	0.33	8.6
8	5.	0.16	12.2	0.45	2.9	0.33	8.7
9	6.	0.20	11.7	0.36	2.9	0.33	8.9
10	5.	0.20	10.4	0.40	3.0	0.36	8.5
11	5.	0.19	10.2	0.38	2.8	0.34	8.5
12	5.	0.17	10.0	0.36	2.9	0.35	8.4

**E.C= Exchangeable Cation, Av. P= Available Phosphorous, Ex. K Exchangeable potassium, OC= Organic Carbon, T. N= Total Nitrogen C/N= Carbon to Nitrogen Ratio*

Experimental land was fallow land so the fertility status was relatively better at initial and slightly declaim season over season due to intensive cultivation for successive three years. During the main season, salt removal and pH decline and vice versa is observed in the irrigation season.

Accounting for all identified constraints, the model maximized the farm income (Objective Function) for the Chacha irrigation scheme, while optimizing the percentage of cropping pattern. The initial total percentage of cropping pattern introduced to the model was equal share for all 12 treatments; however, after running the solver specifying the constraints, the model optimized to 72 % Beat root-Food Barely-Potato-Fababean-Carrot-Wheat-Garlic and 28% Beat root-wheat-Potato-Food barely-carrot-Fababean-Garlic. All the rest 10 treatments were leads to zero percent from the percentage share to maximize the benefit.

The optimal cropping pattern is allocation of land to various crops by making use of limited resources. Traditionally, farmers have relied on experience, intuition, and comparisons with their neighbors to make decisions regarding cropping patterns. This pattern is done proper and maximum utilization of land and water and farmer can get two cropping season in a year. Similarly, loucks et al., (1981) present in irrigated agriculture, where various crops are competing for a limited quantity of land and water resources, linear programming is one of the best tools for optimal allocation of land and water resources. It provides more income and fulfills the nutritional requirement of our family.

Table 3. Optimization result of Chacha irrigation scheme

Treatment	Trt 11	Trt 12	Combined	Upper Limit	Reserved
% cover	72	28	72/28		
Land	1.00	1.00	1.00	1.00	0.00
Seed	15,317.75	15,317.75	15,317.75	17,686.25	2,368.50
Chemical	1,565.00	2,345.00	1,783.96	1,783.96	0.00
Total	28,609.62	31,609.62	29,451.76	32,755.13	3,303.37
Fertilizer	5,449.76	10,449.76	6,853.34	8,783.10	1,929.75
Benefit (Birr/ha)	173,269.41	189,122.03	177,719.49		7,601.62

Trt 11= Beat root-Food Barely-Potato-Fababean-Carrot-Wheat-Garlic

Trt 12 = Beat root-wheat-Potato-Food barely-carrot-Fababean-Garlic

Results show that all the allocated land and capital for chemicals used up the entire available total capital (100%) in the optimal solution. Capital for seed used only 86.61 % of the total available. This implies that the optimal solution saved 13.39 % of the available capital. In the area of capital for labor, used 90 % of available capital implying for the optimal solution made a savings of 10 % from the allocated capital. In the area of capital for fertilizer, 78 % of the available capital is allocated for fertilizer in the optimal solution and it saved 28 % from the allocated capital.

Therefore, covering 72 % of the cultivated area with Beat root-Food Barely-Potato-Fababean-Carrot-Wheat-Garlic and 28 % with Beat root-wheat-Potato-Food barely-carrot-Fababean-Garlic cropping pattern in second irrigation season in the first year, main season, and second irrigation season in the second year respectively shows better farm benefit 177,720 Et. Birr in a year/ha. This result is similar with Joseph, O.*et, al.* (2015) that presents the Model saved 0.2% and 0.6% of available capital and labor requirement respectively and 16.25% of significant increment of the net returns.

Land use efficiency is the effective use of land in a cropping year, which mostly depends on crop duration. The average land-use efficiency indicated that an improved pattern used the land with 60.68% efficiency. Whereas the cropping pattern followed by local farmers in the irrigation scheme used the land for one time in a year. The land-use efficiency is lower than that of the two times in a year.

Food barley is not surviving the waterlogging during the main season, therefore cropping patterns containing food barely are rejected. Rejecting the non-strategic crops and cropping patterns will significantly increase the total net benefit of farmers in the irrigation scheme. On the other hand, keeping cultivation of the crops in the non-strategic cropping patterns with smaller areas is essential for reservation and satisfy the food requirements. It is observed that the farmers of the locality cultivate carrot and garlic in irrigation season as the major crop, however not cultivate in the main season. This result agrees with Sara Osama, *et al.* (2017) that states that there is a significant reduction in the allocated areas for non-strategic crops, and the allocated areas for strategic crops such as wheat, maize, rice and cotton have increased substantially to satisfy their actual food requirements.

Based on this study, cultivating four crops in the cropping pattern, which are important for crop rotation, disease, and insect control, and soil fertility management in the irrigation season. Using this cropping pattern gives one season additional cropping season that is not used by the local farmer in the Chacha irrigation scheme. Like Chacha irrigation scheme, agricultural diversification is the most appropriate strategy that augments growth, stabilizes farm income, generates full employment, and attains the goals of food security. The land is cultivated once a year only in irrigation season, however, cultivating wheat and fababean in the main season is possible with BBF. The finding of this study strongly agree with the result of Singh, A.I. and Singh, J. P. (999) study indicated that crop planning at command area level and better resource sharing at community level has potential to enhance crop production by 60 to 96 percent and net return by 23 to 26 percent.

Conclusion and Recommendation

The model improves the cropping pattern in the Chacha irrigation scheme by favoring crops that achieve high profitability while using a small amount of input and increasing crops that have a comparative advantage while decreasing all crops that are nonprofitable, that use a large amount of input. As a result, the total net revenue is maximized at the end of the term.

Finally we recommend wheat and fababean in the rainy season, while garlic and carrot for irrigation season. Using Beat root-Food Barely-Potato-Fababean-Carrot-Wheat-Garlic with 72 % and Beat root-wheat-Potato-Food barely-carrot-Fababean-Garlic 28 % cropping pattern encourages production two times in a year with the above sequence in the irrigation scheme towards better farm benefit. Producing crops in the main rainy season at the Chacha irrigation scheme is possible except for barley. Barley is not an appropriate crop for the main season at the Chacha irrigation scheme. As we conclude, for water resources planning and management, optimization techniques are used for limited use of resources such as land, production cost, manpower, fertilizers, seeds, and pesticides. For cultivating each crop, the land area needs to be planned properly. Hence the crop pattern has to be decided optimally depending on the available economic basis. Therefore farmer needs to be educated to adopt optimum cropping pattern which maximizes the economic returns.

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