Developing Suitable Cropping Pattern for Irrigated Agriculture at Efratana Gidem Woreda Yimlow Irrigation Schemes in Amhara Region.

Demisew Getu*, Tsegaye Getachew, Belihu Nigatu, and

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 world's readily available freshwater resources are becoming scarce due to higher 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 in the world 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). Increasing momentum in agricultural production with more than 70 percent increase for the developing countries of Asia and Africa in coming decades (FAO, 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 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 and valuable. Hence, today, the agricultural sector around the world is under more pressure for limiting its water use, not only because of the increasing water demand but also because of climatic changes and more frequent droughts (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). Irrigation accounts for more than 40%

(Birhanu *et al.,* 2015).

Ethiopia has vast cultivable land of 30 to 70 M, ha, but only 15 M ha of land is under cultivation, with current irrigation schemes covering about 640,000 ha out of 5.3 M 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 no enough water for most farmers to produce more than one crop per year (Seleshi Bekele *et al.,* 2010).

Based on AGP II assessment report in the Efratana gidem woreda 26 river is mainly used with 2712 ha of land is irrigated, about 60 small springs are used in modern and traditional irrigation canal system around 2658 ha of land is irrigated about four small springs are used in modern irrigation canal system around 518 ha irrigated. About 56 springs are used traditional diversion ways and covers 2140 ha of land. Other water resources like about seven community pond, 445 hand dung wells, and about 76 geo membranes are available for livestock and domestic use. Generally flooding is a major practice but, they practice furrow, drip, basin in small coverage and for perennial trees ring application were used. Therefore in the woreda fallowing the appropriate cropping pattern is better qualitative and quantitative production more than two time in a year.

Nowadays, water resources management and planning under limited resources (such as water, land area, production cost, and manpower, etc.) is one of the classical problems. The crop pattern of the irrigation project is the land area provided for cultivating each crop. Generally, crop 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 intern of economic. 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 to find 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 crop pattern, the portion of treated water from wastewater world Often, most earlier studies assumed homogeneity in crop water requirement and crop yield for all land area of the considering project. The obtained crop yield is usually affected by sufficient crop water requirement and physical 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, consider various agronomy and extension constraints including crop water consumption, nutrition values, disease, and pest resistance, market demand, fertilizer input, labor 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. Accordingly, a linear model was used to optimize the cropping system for the yimllo small-scale irrigation scheme currently being developed in the Amhara region of Ethiopia (Jebelli *et al.*,2016). The objectives of this study were to develop appropriate cropping pattern which maximizes annual return from the irrigation scheme and to develop/identify crop rotation system which improves maximize farm income.

Materials and Methods

Description of the Study Area: The experiment was conducted at Amhara region north Shewa zone, Efratana gidim District a yimllo irrigation scheme. The site is located 154 km from Debrebirhan town and 9 km from Ataye town (Figure 1). The geographic location of the experimental site is 39^{o} e of 1514 m.a.sl. Mean annual rainfall of 822 mm, Mean monthly maximum and minimum temperature of 27.7 and 11. 5°C respectively.

Figure 1. Geographical location of the study area

With full participation of farmers, crops, which grow in winter and summer respectively

financial considerations, climate and soils, water availability, labor requirements, marketing aspects, availability of inputs, rotational considerations, susceptibility to diseases, and total growth period (LGP). Once the crops were selected, a cropping program showing the seasonal cropping patterns and indicating the time and the area for each crop was made. 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 also assessed. To reduce the risk of diseases and pests and to the removal of certain nutrients through plant uptake, the cropping program was allowing rotation of the crops in the plots.

The experiment was conducted with double-cropping systems consisting of triple-cropping systems. 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 (the half at planting and half at some stages of the crops as per the agronomic recommendation) while full doze of the NPS was applied at planting. The plot size was 2.8m x 2.8m (7.84m^2) and 1.5m spacing b/n plots and 2m between blocks to manage irrigable crops. The experiment was conducted on fixed plots in the subsequent two years. Treatments were selected as per the availability of commodities in the respective sites and the best sequences are selected by considering the aforementioned criterion to fit the sequence with little time lags or short fallowing time for the following planting time by selecting suitable crops with short maturity days (Table 1).

Table 13 Treatments (for Efratana Gidim yimllo irrigation scheme)

Treat ment	2009	2010			2011		
	Irr. Sea. II	Main Season	Irr. Sea. I	Irr. Sea. II	Main. Season	Irr. Sea. I	Irr. Sea. II
1	Maize	Sorghum	Cabbage	Maize	Sorghum	Cabbage	Maize
2	Mung Bean	Sorghum	Onion	Mung Bean	Sorghum	Onion	Mung Bean
3	Onion	Sorghum	Pepper	Onion	Sorghum	Pepper	Onion
4	Tomato	Sorghum	Potato	Tomato	Sorghum	Potato	Tomato
5	Pepper	Sorghum	Tomato	Pepper	Sorghum	Tomato	Pepper
6	Pepper	Mung Bean	Cabbage	Pepper	Mung Bean	Cabbage	Pepper
7	Tomato	Mung Bean	Potato	Tomato	Mung Bean	Potato	Tomato
8	Onion	Mung Bean	Pepper	Onion	Mung Bean	Pepper	Onion
9	Mung Bean	Mung Bean	Onion	Mung Bean	Mung Bean	Onion	Mung Bean
10	Maize	Mung Bean	Tomato	Maize	Mung Bean	Tomato	Maize
11	Tomato	Teff	Potato	Tomato	Teff	Potato	Tomato
12	Onion	Teff	Pepper	Onion	Teff	Pepper	Onion
13	Pepper	Teff	Cabbage	Tomato	Teff	Cabbage	Tomato
14	Maize	Teff	Tomato	Maize	Teff	Tomato	Maize
15	Mung Bean	Teff	Onion	Mung Bean	Teff	Onion	Mung Bean

Note: *main season (July, August September and October); Irrigation season I (November, December January and February); Irrigation season II (April, March, May and June)*

Soil data or samples before planting and harvesting were analyzed for pH, E.C, Av. P, Ex. K, OC, OM, T.N C/N ratio of the soil and Soil texture was collected. Crop data like Variety, Length of growing period (LGP), planting date, days to emergence, days to maturity, plant height at maturity, flowering date, fruit weight, harvesting time, grain (fruit) yield ($kgha^{-1}$).

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 farmers. The linear programming model, as a reliable optimization technique, has been known in many engineering fields for years. It has also extensive application as an optimization module in several complex engineering software. However, the complex software usually requires heavy license fees for installation and operation, which in most cases is beyond the financial reach of many small-scale irrigation projects. Favorably, 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 optimality conditions were satisfied. A sensitivity analysis was also performed to analyze all other likely development scenarios.

Model Development: A standard form of linear programming model used has the following components (Anon., 2001). Decision variables to be optimized, an objective function that must be maximized or minimized and subject to constrains and constraints. The details of the above-mentioned components and their adaptation to the Yimllo scheme are discussed below.

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 Yimllo 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 fifteen decision variables T_1, T_2, T_3 ... T_{15}, and their coefficients C_1, C_2, C_3 ... C_{15}, for the Yimllo scheme, are presented in Table 1.

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 $f(T_1, T_2, T_3, \ldots T_{15})$

The highest farm benefit for the Yimllo 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 15

Given the fifteen decision variables (n=15) in the case of the Yimllo scheme, then the objective function could be developed as follows:

$$C_1T_1 + C_2T_2 + C_3T_3 + \ldots + C_{15}T_{15}$$

Where Z is the farm gross income resulting from growing the 15 optimized cropping sequences and C_1, C_2, C_3 ...$C15$ are the coefficients in the objective function related to an increase in Z (the objective function value).

Constraints: The constraints are mathematical expressions to represent Limited recourses like land, water, labor and inputs for production. The model assesses and identifies possible solutions that respect these limits to achieve the optimum objective function (Anon., 2001). Based on this study carried out, 5 constraints were identified for the Yimllo scheme. The constraints are generally expressed as follows:

Where a_{ij} are the coefficients for the introduced constraints and b_i are the values for the defined constraints.

Results and Discussion

Accounting for all identified constraints, the model maximized the farm income (Objective Function) for the Yimllo scheme, while optimizing the percentage of cropping pattern. The initial total percentage of cropping pattern introduced to the model was equal shear for all 15 treatments; however, after running the solver specifying the constraints, the model increased the cropping pattern to 58.40 % and 41.60% for treatments 5 and 15 respectively.

All the rest 13 treatments led to zero percent from the percentage shear to maximize the benefit. Table 2 indicated that 99% usage of land by the optimal solution. In the field of capital for seed/seedling used only 87.68% of the total available. This implies that the optimal solution savings 12.32 % from the available capital. In the area of capital for different chemicals, used 97.87% of the available Capital requirement for chemicals for the optimal solution made a savings of 2.13%. In the area of capital for total labor and fertilizer, used up the entire available total capital (100%) in the optimal solution.

Covering the cultivated area with 58.4 of Sorghum-Tomato-Pepper and 41.6 % Teff-Onion-Mung bean cropping patterns in the main season, first and second irrigation season respectively shows better farm gross benefit of 321,824.96 Et. Birr in a year. This result is verified by Mehri A. *et, al.* (2021) optimum cropping patterns based on the crop yield response, the benefits in the planning horizon increased by 46.7 and 37.8% for the baseline condition and climate-change condition, respectively, compared to the present condition.

Based on this result in Yimllo irrigation scheme, during the main season, Sorghum and Teff, the first irrigation season relatively coldest season, tomato and onion, and in the second irrigation season Pepper and Mungbean are preferable. 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 for 90.68%. Whereas, the cropping pattern followed by local farmers in the irrigation scheme used the land two times a year in which the land-use efficiency is lower than that of the three times in a year. Rejecting the nonstrategic crop and cropping patterns will significantly increase the gross benefit of farmers in the irrigation scheme. On the other hand, keeping cultivation of the crops in the nonstrategic cropping patterns with smaller areas is essential for reservation and satisfy the food requirements. It is observed that the farmers of the locality cultivate Teff and sorghum as the major crop in the main season and onion in the irrigation season. This result agrees with Sara Osama, *et, al.* (2017) stating that there was significant reduction in the allocated areas for non-strategic crops but, 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, cultivate six crops in the cropping pattern which is important for crop rotation, disease, and insect control, and soil fertility management in the irrigation season. Following this cropping pattern allows using the unusable time, land and water at the time of first irrigation season in the irrigation scheme. The finding of this study strongly agrees with the result of Singh, A.I. and Singh, J. P. (999) indicating that crop planning at command area level and better resource sharing at community level have potential to enhance crop production by 60 to 96 per cent and net return by 23 to 26 per cent.

Table 2. Optimal allocation of resources and Benefit

Treatment	Trt 5	Trt 15	Combined	Upper Limit
% Cover	58.40	41.60	58.4/41.6	
Land	1.00	1.00	0.99	1.00
Seed	18,128.00	17,583.00	17,762.09	20,258.20
Chemical	3,770.00	4,875.00	4,200.62	4,292.00
Total Labor	119,222.22	137,203.70	125,785.19	125,785.19
Fertilizer	11,432.00	8,376.50	10,073.38	10,073.38
Gross benefit	320,003.04	324,015.49	321,824.96	

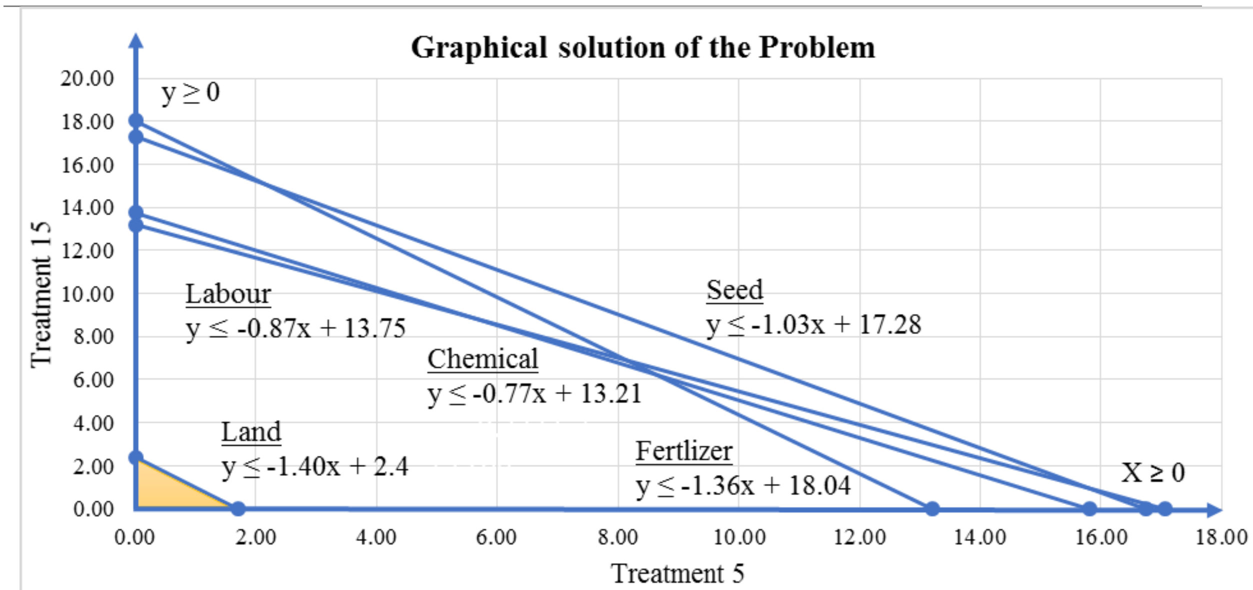

Figure 2. Graphical solution of the optimize problem

As show in the above graph the shaded part is the fissible region of the optimal solution, here the production constraints are land, fertilizer, chemical, labour and seed are represented in the graph and all of the equation are negative slope this implies the percentage shear of the two feasible treatment vice versa.

Conclusion and Recommendation

The model resulted in the optimal cropping pattern in the Yimllo irrigation scheme favoring crops that achieve high profitability 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 maximizing at the end of the term. Covering a cultivated area with 58.4% of Sorghum-Tomato-Pepper and 41.6 % Teff-Onion-Mung-Bean cropping patterns in the main season, first and second irrigation season respectively shows better farm benefit in a year. However, in the first pattern solanaceous crops appear successively, this favored the occurrence of diseases and pests. Following Teff-Onion-Mung bean cropping patterns in the main season, first and second irrigation season pattern for better farm benefit in a year.

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