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Optimal Allocation of Irrigation Water for Rice Production in Ghana, Case Study: Kpong Irrigation Project (KIP)

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Abstract: **We suggest a Linear Programming Model (LP) for optimal allocation of irrigation water for rice production at the Kpong Irrigation Scheme based on a set of fixed constraints and the maximization of the net returns. In this paper, the System of Rice Intensification (SRI) is incorporated into a formulated LP Model. The main crop was rice but was factored into the LP Model as six (6) distinct crop categories on the basis of percentage of irrigation water utilized and the seasons in which they are grown. Comparison of results obtained by using existing farming plan and the LP Model show that results obtained from the LP Model were improvements on the existing farming plan. The LP Model saved 50% of irrigation water in both the major and minor seasons and also chalked an increment of 101.50% of the net returns.**

Keywords: **Linear Programming; System of Rice Intensification; Optimal Solution; Net Returns.**

I. INTRODUCTION

Water in recent times has become a highly valuable commodity due to its multipurpose uses. It has become abundantly clear that there is increasing demand for water for the purpose of irrigation, industrial purposes, power generation, livestock use, and domestic use for urban and rural development.

In Ghana, illegal mining operators whose operations contaminate existing water bodies and in some extreme cases dry up water bodies. These operations of illegal miners coupled with the invasion of livestock at canal area of irrigation schemes threaten the quantum of fresh water for agricultural purposes. According to Kyei-Baffour and Ofori [13], the major drawback of the existing irrigation schemes in Ghana is the management of water.

In Ghana rice production at the various irrigation schemes are done under the practice of continuous flooding, a system that requires large amounts of water. This practice does not only waste water but produces low yields. There is the need to employ systems that will ensure efficient application of irrigation water (saving water) and increment in rice yield.

Mathematical optimization technique like linear programming uses several related mathematical techniques to allocate limited resources among competing demands in an optimal way, Kamarkar [10]. LP Models have been used extensively in areas of irrigation water allocation, optimal selection of crops, optimization of profits of farmlands etc.

In this paper, LP Model is developed to aid in obtaining optimal allocation of irrigation water for rice production at the Kpong Irrigation Scheme. The LP Model incorporates SRI which encompasses applied principles ranging from seed sorting, sowing, transplanting younger seedlings, weeding, and water management, all within the growing period of rice plants, Katambara et al. [11].

II. LITERATURE REVIEW

Heaps of studies have been carried out in the area of application of Linear Programming Models to allocation of limited resources like land and water in the agriculture sector. Keramatzadeh et al [12], used (LP) and multi goal linear programming (MGLP) models to determine solutions that can maximize the net returns of farmers. Hoesein and Limantara [8], optimized water supply for irrigation using linear programming model. Kakhki et al. [9] applied and compared linear programming model and a fuzzy multi-objective fractional programming model in Taybad.

Frizzone et al. [6] optimized water resource using LP Model. Also Qureshi et al. [15], Al-Harkan et al. [2] and Ali and Mahmoud [3] applied LP Models to determine optimal allocation of water and selection of crops. In the field of optimal cropping pattern, Majeke [14] and Hassan et al. [7] applied LP Model to calculate crop acreage, production and income.

This review of literature would be incomplete without considering SRI. This is a new practice of growing rice that has proven to be very effective in saving water, increasing rice yields and it requires less farm inputs than the conventional rice growing practice in many parts of the world, Katambara et al. [11]. A brief description of principles of SRI obtained from the study conducted by Stoop et al. [17] are as follows:

Sorting out of the seeds: In SRI the approach used to remove defective seeds from good seeds so as to ensure that only good seeds are sown is by flotation-sink method in salty solution. Good seeds are the ones that sink in salty water capable of floating a raw egg. Generally the concentration is not substantial to cause an effect on the selected seed.

Raising seedlings in garden like nursery: This ensures a careful management of seedlings and easy uprooting as well as transplanting.

Uprooting and transplanting time: The time between uprooting and transplanting should be between 15 - 30 minutes and the roots should be kept moist during this time.

Early transplanting of 8 to 15 days old seedlings: In addition to the provision of adequate buffer for the seedling from being damaged during transplanting, full tillering and optimal production occurs when the seedling are transplanted before entering the fourth phyllochron of growth.

Single, widely spaced transplants: This ensures that the plants have enough space for tillering as well as to allow a mechanical weeder to pass through without harming the plants.

Early and regular weeding: This ensures that weeds do not compete with the rice plant. In addition, mechanical weeders aerate the soil. The roots need oxygen so as to be strong and healthy for optimal tillering and development of healthy rice grains.

Carefully controlled water management: Makes the rice plant healthy since the roots are supplied with moisture as well as air. This allows the root to uptake adequate nutrients from various soil horizons.

Application of compost: The compost materials are rich with nutrients as well as organisms whose activities favour the growth of rice. Above all it is environmentally friendly to use composite than industrial fertilizers.

No use of herbicides: The non-use of herbicides favours the sustainability of the ecosystem and the micro-organisms whose activities are suitable for the growth of rice plants.

Reports from the studies conducted by Ceesay [5], Satyanarayana et al. [16], Barret et al. [4] and Uphoff [19] indicate that under SRI there is 20% - 40% increase in yield and up to 50% water savings.

In the Proceedings of International Workshop on Water-wise Rice Production in 2002 [1], authors presented studies conducted in areas like Intermittent irrigation, System of Rice Intensification (SRI), Aerobic rice, Rice-wheat, Physiology and breeding, Irrigation systems and Technology transfer for water savings in the Philippines. All these studies reported on methods of rice production that save fresh water which has become increasingly scarce.

III. LINEAR PROGRAMMING MODEL

In this paper, the LP Model formulated was based on irrigation water utilization and the net returns of rice in the Kpong command area. Rice was factored into the LP Model as six (6) distinct crop categories on the bases of percentage of irrigation water utilized and the seasons in which the crops are grown.

The critical key about the formulated LP Model is that, it utilizes one of the gains derived from the application of SRI. This gain according to Ceesay [5], Satyanarayana et al. [16], Barret et al. [4] and Uphoff [19] is that under SRI there is 20% - 40% increase in yield and up to 50% water savings. Factoring this into the model implies that rice production at

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100% irrigation water utilization has a lower yield compared to rice production at 75% irrigation water utilization (see Table I for details).

The Linear Programming Problem was formulated as: Maximize:

$$Z = \sum_{i=1}^{6} \sum_{j=1}^{2} P_{ij} X_{ij}$$

Variable description:

Z= The total net returns from all the crops (GH¢)

Six crop categories: (*i*=1,2,3,4,5,6); where:

$1 = R_{11}$, rice planted at 100% irrigation utilization in the major season.

$2 = R_{12}$, rice planted at 75% irrigation utilization in the major season.

$3 = R_{13}$, rice planted at 50% irrigation utilization in the major season.

$4 = R_{21}$, rice planted at 100% irrigation utilization in the minor season. $5 = R_{22}$, rice planted at 75% irrigation utilization in the minor season. $6 = R_{23}$, rice planted at 50% irrigation utilization in the minor season.

Two seasons: (*j*=1,2); where:

Major season = 1, March/April to August

Minor season = 2, September/October to February

P_{ij}= The net return from *i*th crop (GH¢/ha) in the *j*th season

X_{ij}= The crop area under *i*th crop (ha) in *j*th season.

Constraints:

Subject to:

Land usage:

$$\sum_{i=1}^{6} \sum_{j=1}^{2} X_{ij} \leq TA$$

Where *TA*= Total Land area under cultivation in hectares.

Water:

$$\sum_{i=1}^{6} W_{i1} X_{i1} \leq W_{ma}$$

$\sum_{i=1}^{6} W_{i2} X_{i2} \leq W_{mI}$

Where:

W_{i1} = The water requirement in major season for *i*th crop

W_{i2} = The water requirement in minor season for *i*th crop

W_{ma} = Total available water for irrigation in the major season

W_{mI} = Total available water for irrigation in the minor season

Non-negativity:

$X_{ij} \geq 0$ for *i*=1, 2, 3, 4, 5,6 *j*=1,2

The functional constraints relating to water and land availability for the various seasons mean that the maximum land to be cultivated in each season must be smaller than the total available land and the maximum water used in each season must not exceed the total available water in that season.

IV. MATERIALS AND METHODS

The Kpong Irrigation Scheme is a 3000 ha irrigation scheme owned and operated by the Government of Ghana. It is located about two hours north east of Accra, the capital near the towns of Akuse and Asutsuare. It derives water from Volta River via the Kpong Reservoir which is primarily a relatively low head hydroelectric generation and storage facility, Tinsley [18]. The current water users of Kpong Irrigation Scheme are categorized into four groups, i.e. small scale rice farmers, banana estate, fish pond users and vegetable farmers whose farms are out of the project area.

The solution to the Linear Programming Problem was obtained using the Simplex method with a available computer program. Table I capture the data for this study and was obtained from Kpong Irrigation Scheme. Table I depicts the water demand in cubic meters, the maximum yield per hectare and the respective net returns of the various crop. The first column of Table I represents the crops. The first three (R_{11}, R_{12} and R_{13}) are grown in the major season whilst the last three (R_{21}, R_{22} and R_{23}) are grown in the minor season.

R_{11} represents rice grown at 100 % irrigation level in the major season, R_{12} represents rice grown at 75 % irrigation level in the major season and R_{13} represents rice grown at 50 % irrigation level in the major season. Also R_{21} represents rice grown at 100 % irrigation level in the minor season, R_{22} represents rice grown at 75 % irrigation level in the minor season and R_{23} represents rice grown at 50 % irrigation level in the minor season. These were captured as six (6) distinct crop categories by the Linear Programming model.

TABLE I: Water Demand, Maximum Yield and Net Returns for the Various Crops

Crop	Water Requirement (m^3/ha)	Yield (tons/ha)	Net Returns (GH¢/ha)
R_{11}	12000	5.5	2281
R_{12}	9000	6.6	4026
R_{13}	6000	7.7	4697
R_{21}	13000	5.5	2611
R_{22}	9750	6.6	4422
R_{23}	6500	7.7	5159

Source: Kpong Irrigation Scheme

V. RESULTS AND DISCUSSION

Tables II and III captures the comparison of results on resource utilization of LP Model solution with the existing farming plan practiced by the farmers at the Kpong Irrigation Scheme for major and minor seasons respectively. Results from these tables indicate 100% utilization of land by both LP Model solution and the existing farming plan. In the area of utilization of water LP Model solution saved 50% of the water available in the major and minor seasons whilst the existing farming plan utilized the water available in the two seasons.

TABLE II: Comparison of Resource Utilization under Optimal Solution with Existing Farming Plan

	Major Season			
	Existing Farming Plan		LP Solution	
Resources	Land (ha)	Water m^3	Land (ha)	Water m^3
Available	2300	27600000	2300	27600000
Usage	2300	27600000	2300	13800000
% Usage	100%	100%	100%	50%
Left Over	0	0	0	13800000
% Left Over	0%	0%	0%	50%

TABLE III: Comparison of Resource Utilization under Optimal Solution with Existing Farming Plan

	Minor Season			
	Existing Farming Plan		**LP Solution**	
Resources	**Land (ha)**	**Water m^3**	**Land (ha)**	**Water m^3**
Available	2300	29900000	2300	29900000
Usage	2300	29900000	2300	14950000
% Usage	100%	100%	100%	50%
Left Over	0	0	0	14950000
% Left Over	0%	0%	0%	50%

Table IV captures the comparison of results on total net returns of LP Model solution with the existing total net returns obtained by farmers at the Kpong Irrigation Scheme. Result from Table IV indicates that the total net returns increased by 101.50%, i.e. LP Model solution as a percentage of existing net returns. The increment of net returns from GH¢11251600 to GH¢22668800 shows a massive improvement in the net returns.

TABLE IV: Comparison of Total Net Returns Under Optimal Solution with the Existing Farming Plan

Total Net Returns (GH¢)		
Existing Net Return	**LP Solution**	**% of Existing Net Returns**
11251600	22668800	101.50%

VI. CONCLUSION

This paper presented a formulated LP Model which aided in obtaining optimal allocation of irrigation water for rice production at K pong Irrigation Scheme given a set of fixed constraints and the maximization of the net returns. Comparison of results obtained by using existing farming plan and the LP Model show that results obtained from the LP Model were improvements on the existing farming plan. The LP Model saved 50% of irrigation water in both the major and minor seasons and also chalked an increment of 101.50% of the net returns. These results are feasible based of the reason that the yield (yields after application of SRI) used fall within the yield reported by the study conducted by Tinsley [18]. Also some farmers at the K pong command area have recorded higher yields under the application of SRI.

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