NATURAL RESOURCE MANAGEMENT ISSUES OF PAKISTAN'S AGRICULTURE: THE CASES OF LAND, LABOUR AND IRRIGATION

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With the objective to understand the optimization behavior of farmers in allocating land, labor and irrigation water, Linear Programming (LP) analytic technique was applied to 13 Kharif and 7 Rabi crops, using national level data from 1990-2005. The crops included in the analysis have been occupying 80 - 85 percent of Pakistan's cropped area for the last three to four decades. The optimization analysis resulted in bringing up three major natural resource management issues of the Pakistan's crop sector to the forefront. First, Basmati rice, mung, fodders of millet & sorghum, onion and IRRI rice were found optimal Kharif crops relative to sugarcane, maize, maize fodder, millet, sorghum, cotton and tomato. For Rabi wheat, potato, gram, rapeseed and berseem proved to be optimal relative to barley and sugarcane, for this period. The results imply that to have an efficient agriculture base Pakistan should either replace the sub-optimal crops with the optimal ones, or the resource management side of such crops should be improved with the help sensitivity analysis. Second, cotton and tomato appeared to be relatively sensitive to labor availability than other crops; they seemed to establish a direct correlation between the optimality status and labor availability. And third, irrigation emerged as a critical input for IRRI rice in Kharif and for potato and gram in Rabi season; for these crops the crop optimality was directly correlated to the number of irrigations applied. In contrast, its opportunity cost is higher than the per unit return in cotton, tomato, wheat and berseem. This signified that irrigation needs to be managed efficiently in the latter four crops; whereas in the former three crops use of extra water would help in optimizing.
Keywords: Pakistan crop sector**,** Linear Programming, optimality, NRM

INTRODUCTION

Pakistan's crop sector consists of 13 Kharif (summer) and 7 Rabi (winter) season crops that occupy 80 - 85 percent of the cropped area for the last three decades (Arifullah, 2007). These crops include cotton, Basmati rice, IRRI rice, sugarcane, onion, tomato, mung, maize, sorghum, millet and fodders of maize, sorghum and millet (Kharif crops) and wheat, barley, potato, gram, rapeseed, berseem and sugarcane (Rabi crops). The researchable issue is 'if this standardized cropping schedule is due to profitability or stagnation'? In the face of decreasing contribution of agriculture sector in GDP this leads one to assume that this sector is sub-optimal by and large. So far some researchers (Hassan *et al*., 2003) have sparingly used Linear Programming to arrive at the optimality issues of land resources under certain particular crops or for some particular region. However, no study has been found looking in to the details of the resource allocation and management issues, taking into account, Pakistan's crop sector as a whole.

The situation thus stipulates to study the issues related to agricultural resource allocation and there management in Pakistan's crop sector at national level. With this main objective in mind, this research article attempts to analyze how Pakistani growers allocate land and manage irrigation water and labor resources while optimizing.

MATERIALS AND METHODS

To review the hypothesis that Pakistan's crop sector is economically optimal (i.e. all component crops mentioned in the introduction part are equally profitable), the paper uses Linear Programming (LP) and its sensitivity analysis methodology. The execution of the above mentioned methodology called for estimation of the needed formulas, ratios, functions, LP model and its sensitivity analysis required relevant data on production, costs, revenues, levels of input used and their prices, levels of output and output prices. The data used in this paper are average estimates of 5 years (2001-05) obtained through a detailed survey of cost and revenues of crops production conducted for PhD study of the first author. These estimates include cost of production of 19 major crops grown in Pakistan during Rabi and Kharif. Following the assumption, each of the (13) Kharif and (7) Rabi crops are allocated one hectare of land. There are 11 constraints in the model, one for each input (i.e. land, labor, irrigation water, bullock, tractor, nitrogenous & phosphatic fertilizers, farm yard manure, pesticides, marketing expenditures and cash requirements) in the LP model. However, this paper restricts discussion to the first three constraints and there sensitivity analysis as to concentrate on the subject matter of this paper.

To analyze the economic performance or optimality for this system of crops the Operations Research (OR) or Linear Programming (LP) provides the plausible tool. The analytic technique is generally referred to as Operations Research in Management Sciences (Taha, 2003) and Linear Programming in the discipline of economics (Hillier and Lieberman, 1995). According to Taha (2003) and Hillier and Lieberman (1995), LP can be represented in general form as:

$$\text{Maximize } Z = CX \quad (1a)$$
$$\text{Subject to } AX \leq B \quad (1b)$$
$$Xi \geq 0 \quad (1c)$$

Where Z = net revenues from all productive activities Xi
C = c1, c2, c3 ……cn (profit/net return from each unit of productivity)
X = x1, x2, x3 ……xn (various productive activities)
A = technology matrix (containing technology coefficients aij)
B = constraints bi (maximum values of each constraint)

In the above model, A is an M x N matrix, B is an M x 1 vector and C is an N x 1 vector and the value of their elements are known in the sense that researchers have to provide such values. The elements of vector X are unknown and the LP model uses *Simplex Algorithm* to solve for optimal values.

Optimization by means of the model provided in 1 (a–c) resulted in turning in only 5 of the 13 Kharif and 4 of the 7 Rabi crops in the LP solution and all other dropped due to their sub-optimality relative to other crops. This was due to the non-negativity constraint given in (1c) which relaxes the activity Xi to drop to zero. Conceptually such a solution would be optimal for an individual grower, but could not be recommended as a national solution. Hence, the LP model was modified replacing $Xi \geq 0$ with $0.50x_i \leq X \leq 1.50x_i$. This renewed condition helped LP to optimize on all existing crops; however, relatively sub-optimal crops would drop from its existing 1 hectare area to 0.50 hectare and more optimal would increase from existing 1 hectare to 1.50 hectare, depending on the level and weight of optimality each crop carries.

While maximizing total profit, growers are not free of constraints; they have limited land holdings, which they have to allocate to various crops. Allocation of area to various crops is further limited to the availability of various inputs or factors of production like manual and animal labor, mechanical labor (tractor), inorganic and organic fertilizers, pesticides, irrigation water and funds required for the needed inputs and operations involved. Hence, instead of the general form of LP provided in model 1 (a – c), we used the extended LP model 3(a-n) to see if land, labor and irrigation water have been optimally allocated and managed in Pakistan crop sector during the study period.

RESULTS AND DISCUSSION

The LP results for 13 Kharif and 7 Rabi crops are presented in Tables 1 to 3 whereas the data on matrix a, b and c are provided in Tables 4 to 9. The results in Table 1 comparing the existing situation with the optimal situation differ from the assumption that Pakistan’s crop sector is economically optimal or that all participant crops maintain identical level of yield. There is a net return increase from Rs.316.80 thousands to 350.88 in Kharif and Rs.173.21 to Rs. 185.79 thousands in Rabi.

Although 11 constraints were used in the optimization process including one each for land, labor, irrigation water, bullock, tractor, nitrogenous and phosphatic fertilizers, farm yard manure, pesticides, marketing costs and cash requirements in the estimation of LP model. However, we restrict our discussion to the first three constraints and its sensitivity analysis to serve the main objective of this paper.

Land Resources

The optimality status of each crop was checked by allowing the area to fluctuate between 50%± ranges of the existing ones. Consequently, areas under Basmati rice, mung, fodders of millet & sorghum, onion and IRRI rice increased and that of sugarcane, maize, maize fodder, millet, sorghum, cotton and tomato decreased, suggesting the former as more optimal than the latter among the Kharif crops (‘Optimal LP Solution’ in Table 1). Amongst Rabi crops, wheat, potato, gram, rapeseed, berseem appear optimal and barley and sugarcane (as annual crop) as sub-optimal. This LP solution yields net revenues of Rs.350.88 thousands (against Rs.316.80 thousands of existing situation) and Rs.185.79 thousands (against Rs.173.21 thousands of existing situation), respectively, from Kharif and Rabi crop seasons.

Table 1. Pakistan's Crop Sector: Existing Situation versus Optimal LP Solution

Particulars	Existing Scenario		Optimal (LP) Solution	
	Area (Hectare)	Net Return (Rs.)	Area (Hectare)	Net Return (Rs.)
Kharif Crops				
Seed Cotton	1	15087.42	0.74	11215.46
Rice(Basmati)	1	38991.04	1.50	58486.56
Rice(Irri)	1	34446.65	1.17	40130.59
Sugarcane	1	23740.97	0.50	11870.49
Maize	1	8315.19	0.50	4157.6
Maize Fodder	1	10881.89	0.50	5440.95
Onion	1	74724.92	1.23	92033.12
Millet	1	1943.87	0.50	971.94
Sorghum	1	1559.28	0.50	779.64
Mung	1	6110.56	1.50	9165.84
Millet Fodder	1	19031.63	1.50	28547.45
Sorghum Fodder	1	14087.67	1.50	21131.51
Tomato	1	67874.18	0.99	66946.33
Total Kharif	**13**	**316795.00**	**12.63**	**350877.00**
Rabi Crops				
Wheat	1	13549.41	1.08	14569.29
Potato	1	72451.19	1.12	81247.2
Gram	1	7429.67	1.22	9080.83
Berseem	1	29032.61	1.08	31386.68
Rapeseed	1	24133.67	1.50	36200.51
Barley	1	2869.62	0.50	1434.81
Sugarcane	1	23740.97	0.50	11870.49
Total Rabi	**7**	**173207.00**	**7.00**	**185789.00**

Labor Resources

Table 2 reproduces existing scenario, optimal LP solution and results of sensitivity analysis carried out. Against the total availability of 961.43 man-days (MD) of labor for Kharif crops, LP solution prescribes a range of 955.08 to 967.49 man-days for optimal solution, suggesting that, outside this range, the present optimality status would be affected. In case total availability of labor decreases from lower bound, and drops for instance to a level of 955 man-days (column under 'Sensitivity Analysis' of Table 2), area under cotton crop drops from 0.74 to 0.50 hectare and that of tomato from 0.99 to 0.97 hectare, suggesting that these two crops would become more sub-optimal if labor is constrained. In contrast, if more labor becomes available, areas under these two crops enhance from 0.74 hectare and 0.99 hectare (LP solution) to 0.98 hectare and 1.06 hectare, respectively, suggesting that these two crops are labor sensitive and their optimality status heavily depend on labor availability.

As far as Rabi crops are concerned, against the total availability of 486.27 man-days of labor, LP solution prescribes a lower bound of 470.17 man-days for optimal solution, leaving upper bound open up to infinity. A lower level of 470 man-days brings very small change in area under only one crop–wheat, with no major changes in other crops. A further drop in labor availability to 468 man-days, however, makes wheat sub-optimal, dropping its area to 0.99 hectare and improving that of gram from 1.22 to 1.30 hectare.

Irrigation Water Resources

The total number of irrigation available for Kharif crops were 107.86 (Table 3, col. 2). The LP optimal solution remained optimal for a range of 105.85 to 109.82 numbers of irrigation (Table 3, col. 3). Sensitivity analysis indicated this range to be critical mostly for IRRI rice, cotton and tomato. IRRI rice suffered from shortage of water and improved with greater availability of irrigation water. In contrast, cotton and tomato improved in optimality with a drop in the number of irrigation and deteriorated when the number of irrigation increased. This was due to the relatively high costs of irrigation water and its lower contributions towards the objective function.

In case of Rabi crops, against 58.08 total numbers of irrigation available for Rabi crops, the LP optimal solution remains optimal for a range of 53.34 to infinite

Table 2. Labor Resource Allocation: Sensitivity Analysis

Particulars	Existing Scenario	Optimal (LP) Solution	Sensitivity Analysis (If below or above optimal range)	
	Labor Available 961.43 MD	Labor Range (955.08-967.49)	Lower Limit 955	Upper Limit 968
	Area (Ha.)	Area (Ha.)	Area (Ha.)	Area (Ha.)
Kharif crops				
Seed Cotton	1	0.74	0.50	0.98
Rice(Basmati)	1	1.50	1.50	1.50
Rice(Irri)	1	1.17	1.24	1.09
Sugarcane	1	1.50	0.50	0.50
Maize	1	0.50	0.50	0.50
Maize Fodder	1	0.50	0.50	0.50
Onion	1	1.23	1.25	1.21
Millet	1	0.50	0.50	0.50
Sorghum	1	0.50	0.50	0.50
Mung	1	1.50	1.49	1.50
Millet Fodder	1	1.50	1.50	0.50
Sorghum Fodder	1	1.50	1.50	1.50
Tomato	1	0.99	0.97	1.00
Total area	**13**	**12.63**	**12.45**	**11.78**
Rabi Crops				
Particulars	**Existing Scenario**	**Optimal (LP) Solution**	**Sensitivity Analysis (If below or above optimal range)**	
	Labor Available 486.27 MD	**Labor Range (470.17-infinity)**	**Lower Limit 470**	**Upper Limit**
Crops	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**
Wheat	1	1.08	1.07	Infinity
Potato	1	1.12	1.12	Infinity
Gram	1	1.22	1.23	Infinity
Berseem	1	1.08	1.08	Infinity
Rapeseed	1	1.50	1.50	Infinity
Barley	1	0.50	0.50	Infinity
Sugarcane	1	0.50	0.50	Infinity
Total area	**7**	**7**	**7**	Infinity

(Table 3). Sensitivity analysis indicates that lower bound is critical largely for potato and gram as these two crops affect badly due to shortage of Irrigation water; however, wheat and berseem improve in area due to decrease in total numbers of available irrigation, because of relatively high costs of irrigation water and lower contributions towards objective function.

CONCLUSIONS AND RECOMMENDATIONS

This paper addressed three major natural resource management issues of Pakistan's crop sector using LP analysis. Results show that, in Kharif, Basmati rice, mung, fodders of millet & sorghum, onion and IRRI rice were optimal, whereas sugarcane, maize, maize fodder, millet, sorghum, cotton and tomato remained suboptimal. Similarly in Rabi crops, wheat, potato, gram, rapeseed and berseem were optimal relative to barley and sugarcane. These findings imply that, for the Pakistan's crop sector to be economically efficient, the sub-optimal crops would have to be replaced with optimal ones.

According to the labor sensitivity analysis cotton and tomato were found to be relatively sensitive to labor availability than other crop. The direct relationship between optimality status and labor availability leads to conclude that improved use of precious labor resource would help generate more revenues out of these crops.

Table 3. Water Resource Allocation: Sensitivity Analysis

Particulars	Existing Scenario	Optimal (LP) Solution	Sensitivity Analysis (If below or above optimal range)	
	Irrigations Available 107.86	Irrigation Range (105.85-109.82)	Lower Limit 105	Upper Limit 110
(1)	(2)	(3)	(4)	(5)
Crops	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**
Seed Cotton	1	0.74	1.00	0.50
Rice(Basmati)	1	1.50	1.50	1.50
Rice(Irri)	1	1.17	0.92	1.38
Sugarcane	1	0.50	0.50	0.50
Maize	1	0.50	0.50	0.50
Maize Fodder	1	0.50	0.50	0.50
Onion	1	1.23	1.20	1.26
Millet	1	0.50	0.50	0.50
Sorghum	1	0.50	0.50	0.50
Mung	1	1.50	1.50	1.42
Millet Fodder	1	1.50	1.50	1.50
Sorghum Fodder	1	1.50	1.50	1.50
Tomato	1	0.99	1.02	0.96
Total area	**13**	**12.63**	**12.64**	**12.52**
Rabi Crops				
Particulars	**Existing Scenario**	**Optimal (LP) Solution**	**Sensitivity Analysis (If below or above optimal range)**	
	Available Irrigation 58.08	**Range (53.34-infinity)**	**Lower Limit 53**	**Upper Limit Infinity**
Crops	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**	**Area (Ha.)**
Wheat	1	1.08	1.23	Infinity
Potato	1	1.12	1.10	Infinity
Gram	1	1.22	1.01	Infinity
Berseem	1	1.08	1.10	Infinity
Rapeseed	1	1.50	1.50	Infinity
Barley	1	0.50	0.50	Infinity
Sugarcane	1	0.50	0.50	Infinity
Total area	**7**	**7.00**	**6.94**	**Infinity**

Table 4. Matrix 'A' Showing input use in each crop during Rabi Season

2001-2005	Bull (day)	Man-Days	Tractor (hrs.)	Nitrogen (kgs.)	Phospho. (kgs.)	FYM (kgs.)	Pesticide (lit.)	Irrigation (No.)	Marketing (Rs.)	Invest (Rs.)
Sugarcane	22.23	104.17	18.24	162.93	79.35	3.03	3.65	17.78	5645.19	29991.77
Wheat	15.36	42.07	12.61	107.57	49.93	1.24	1.06	4.18	848.94	11763.23
Gram	0.00	21.63	8.90	4.45	9.20	0.00	0.00	5.08	211.33	4245.64
Potato	4.33	114.92	13.58	157.98	107.99	11.71	5.43	10.44	15940.62	63387.21
Rapeseed	0.00	21.70	12.46	36.99	18.50	0.00	1.82	3.95	287.73	5290.17
Barley	0.00	21.70	4.57	41.21	20.60	0.00	0.00	3.25	212.68	3350.81
Barseem	0.00	160.08	7.39	29.39	14.70	0.00	0.59	13.40	9113.03	12180.75

Table 5. Vector 'B' Showing Input Availability for the Rabi Crops Used in the L P Model

2001-2005	Bull (day)	Man-Days	Tractor (hrs.)	Nitrogen (kgs.)	Phospho. (kgs.)	FYM (kgs.)	Pesticide (lit.)	Irrigation (No.)	Marketing (Rs.)	Invest (Rs.)
	41.91	486.27	77.75	540.52	300.27	15.98	12.55	58.08	32259.52	130209.59

Table 6. Vector 'C' Showing Net Variable Revenues for the Rabi Crops Used in the L P Model

Vector 'C'	Sugarcane	Wheat	Gram	Potato	Rapeseed	Barley	Barseem
2001-2005	23740.97	13549.41	7429.67	72451.19	24133.67	2869.62	29032.61

Table 7. Matrix 'A' for Kharif Crops

2001-2005	Bull (day)	Man-Days	Tractor (hrs.)	Nitrogen (kgs.)	Phospho (kgs.)	FYM (kgs.)	Pesticide (lit.)	Irrigation (No.)	Marketing (Rs.)	Invest (Rs.)
Sugarcane	22.23	104.17	18.24	162.93	79.35	3.03	3.65	17.78	5645.19	29991.77
Basmati	0.79	63.61	15.75	84.77	60.82	0.18	3.98	17.48	1022.07	16799.73
IRRI	8.01	71.13	14.06	83.22	46.77	0.53	2.97	17.65	1604.42	14512.33
Cotton	12.40	55.81	15.73	123.24	51.28	0.94	17.29	5.88	368.50	18577.84
Maize	3.80	48.82	10.65	94.06	43.82	2.88	3.31	5.08	749.82	12093.49
Onion	9.12	188.23	8.05	91.74	58.83	13.54	1.81	8.85	6197.85	34209.77
Millet	0.00	21.53	5.00	37.81	18.91	0.00	0.00	5.62	165.36	3259.17
Sorghum	3.80	21.53	2.82	42.14	21.07	0.00	0.00	3.79	195.30	3286.15
Mung	0.00	18.39	3.55	38.22	11.47	0.00	1.36	3.18	181.33	3369.55
Tomato	0.00	189.32	12.46	91.16	45.58	8.59	5.43	8.65	14390.59	33030.53
Milletf	0.00	48.82	5.00	0.00	0.00	0.00	0.59	5.62	2770.98	5134.42
Sorghumf	3.80	59.23	2.82	2.61	1.30	0.00	0.59	3.79	2805.55	5734.32
Maizef	3.80	70.83	10.65	35.77	0.00	0.00	0.00	4.50	2842.30	8435.84

Table 8. Vector 'B' for Kharif Crops

Vector 'B'	Bull (day)	Man-Days	Tractor (hrs.)	Nitrogen (kgs.)	Phospho (kgs.)	FYM (kgs.)	Pesticide (lit.)	Irrigation (No.)	Marketing (Rs.)	Invest (Rs.)
2001-2004	67.73	961.43	124.78	887.67	439.19	29.69	40.98	107.86	38939.27	188434.89

Table 9. Vector 'C' Showing Net Variable Revenues for the Kharif Crops Used in the L P Model

Vector 'C'	Sugarcane	Basmati	IRRI	Cotton	Maize	Onion	Millet	Sorghum	Mung	Tomato	Milletf	Sorghum	Maizef
2000-2004	23740.97	38991.04	34446.65	15087.42	8315.19	74724.92	1943.87	1559.28	6110.56	67874.18	19031.63	14087.67	10881.89

Third, irrigation water appeared to be a very critical input for IRRI rice in Kharif and for potato and gram in Rabi season; since there was a direct correlation between number of irrigation applied and relative optimality of these crops. In contrast, irrigation water contributed less towards the revenues generation of cotton, tomato, wheat and berseem relative to its characteristics as cost increasing input. This implies that improved water management practices in cotton, tomato, wheat etc. would help release some excess precious water for more revenue generating crops like IRRI rice, potato & gram.

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