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APPLICATION OF LINEAR PROGRAMMING TO ROTATIONAL PLANNING

One of the assumptions of activity analysis is the independence of the activities involved in the programme. This might give the impression that only competitive or supplementary relations could be considered in this type of analysis. This is not all true. The technique can take care of complementary relationships by designing each process accordingly. For example, a rotation could be defined as an activity and this makes it possible to handle the problem of complementarity. The main objective of this paper is to find the most profitable rotational system that will allow for complementary relationships. Different rotations and not the individual enterprises are the alternatives in this situation. Such a study has a special significance because it puts farm planning programme on a continuous basis rather than confining it to short-term annual programme.

In working out the optimal rotational programme, a realistic farm situation of the common run of the farmers was taken into consideration. Not only the common rotations followed by most of the farmers were selected as alternatives, but the irreducible minimum fodder requirements were treated as fixed activities. The resulting farm plan would, thus, include an irreducible minimum requirement of fodder in the rotations. Resources for these activities were subtracted from the total available resources as a part of the complete rotations. Levels of rotations which provided the minimum fodder requirements, thus, became the fixed activities. Rest of the resources were, thus, available to the competing rotation activities. The resource input requirements for individual crop enterprises were pooled over the rotation period and the annual requirements were worked out by applying simple arithmetic average technique.

Returns from different activities were also aggregated over the rotation period and annual average returns to the fixed resources were arrived at. Fixed resources were assessed over a period of one year only. Thus, all the resource requirements and returns to the fixed resources from different rotations and resource levels were put on an annual basis.

Actual farm situation studied related to an 18 acre farm in village Ramgarh Sardaran, Ludhiana district (Punjab). The input requirements were worked out by survey method through a conference with the farmer and are given in Appendix I.

Returns to the fixed resources were worked out and are shown in Appendix II. The inequalities of resource supplies were laid down as under:

$$R_1+R_2+R_3+1.25+R_4+R_5+R_6 \leqslant 10.0 \text{ acres of Rabi land for Wheat}$$

$$0.5\ R_5 \leqslant 2.0 \text{ acres of Rabi land for Gram}$$

$$0.5\ R_1 \leqslant 6.0 \text{ acres of Rabi land for Berseem}$$

$$0.5\ R_1+R_4+R_6 \leqslant 10.0 \text{ acres of Rabi land for Other Fodders}$$

$0.5\ R_1+0.75\ R_4 \leqslant$ 0.8 acres of Rabi land for Sugarcane

$R_1+R_2+0.75R_4+0.5R_5+R_6 \leqslant$ 9.0 acres of Kharif land for Maize and Cotton

$R_1+R_2+R_3+R_4+R_5+R_6 \leqslant$ 10.0 acres of Kharif land for Fodders

$R_4 \leqslant$ 10.0 acres of Kharif land for Sugarcane

$18.0R_1+14.0R_4+21.0R_5 \leqslant$ 434 Man-hours from 15th March-14th April

$17R_1+10R_2+10R_3+21R_4+5R_5 \leqslant$ 190 Man-hours 15th April-30th April

$34R_1+32R_2+28R_3+31R_4+14R_5+24R_6 \leqslant$ 433 Man-hours 15th Oct.-15th Nov.

$94R_1+44R_2+44R_3+227R_4+22R_5+24R_6 \leqslant$ 1886 Man-hours mid.Nov - mid.March.

$R_1+\ .\ .\ .\ R_4+37R_5+R_6 \leqslant$ 2.52 acres of cotton maximum

$12.50R_1+15R_2+11R_4+15R_5+10R_6 \leqslant$ 10 Ton farmyard manure

$26R_1+19R_2+40R_4+12R_5+34R_6 \leqslant$ Rs. 648.00 for Kharif season

$20R_1+35R_2+35R_3+25R_4+20R_5+15R_6 \leqslant$ Rs. 590.00 for Rabi season.

Resource restriction and input-output matrix in Appendix III is composed of input coefficients for different rotational activities and relates the resource restrictions with the activities in the programme.

The solution was obtained through simplex method. The final iteration (Appendix IV) gives the following results.

$R_3 = 9.0$ acres and

$R_6 = 1.0$ acre.

Adding up the activity levels fixed in advance to provide for the minimum fodder requirements, the optimal solution came to :

R_1 (Wheat-Cotton-Fodders-Maize)	=4.0 acres
R_3 (Wheat-Fallow)	=9.0 acres
R_5 (Wheat-Fodders-Gram-Maize)	=4.0 acres
R_6 (Cotton-*Senji*)	=1.0 acre

The break-down of acreage for different crops under these rotations on an annual basis is worked out in Table I.

TABLE I—BREAK-DOWN OF ACREAGE UNDER DIFFERENT ROTATIONS IN THE OPTIMAL PLAN ON YEARLY BASIS

Level (acres)	4	9	4	1	
Crop	R_1	R_3	R_5	R_6	Total
	(Acres)	(Acres)	(Acres)	(Acres)	(Acres)
Wheat after Kharif	2	—	2	—	4
Wheat after Fallow	—	9	—	—	9
Gram	—	—	2	—	2
Berseem	1	—	—	—	1
Other Rabi Fodders	1	—	—	1	2
Cotton after Wheat	2	—	—	—	2
Cotton after *Senji*	—	—	—	1	1
Maize after Rabi Fodders	2	—	—	—	2
Maize after Gram	—	—	2	—	2
Kharif Fodders	—	—	2	—	2

Returns to the fixed resources are worked out in Table II.

TABLE II

Crop	Acreage	Returns per Acre	Total Returns to Fixed Resources
	(Acres)	(Rupees)	(Rupees)
Wheat after Kharif	4	222.00	888.00
Wheat after Fallow	9	319.00	2,871.00
Cotton after Wheat	2	260.00	520.00
Gram	2	226.00	452.00
Cotton after *Senji*	1	470.00	470.00
Maize after Rabi Fodders ..	2	192.50	385.00
Maize after Gram	2	192.50	385.00
Total Returns to Fixed Resources per Year			= 5,971.00

Based on rotational planning, the farmer would earn an income of Rs. 5,971.00 per year continuously over the rotation period, unless the assumptions made in the analysis were falsified by an abnormal situation.

Conclusions

As could be seen from the Z_j—C_j row of the problem matrix (Appendix IV), the net returns to the fixed resources seem to be the highest in case of R_4, which includes sugarcane. If the resource restrictions were ignored, this rotation would be most profitable. Resource restrictions, however, set a limit on the enterprise combinations, as is the case in this farm situation. Sugarcane was a heavy labour consuming crop in the crushing season. Available labour, therefore, resulted in keeping this activity out of the programme, and in increasing acreage under wheat. The optimum solution was found in a combination of rotations rather than a particular rotation. From the practical standpoint, there seems to be no difficulty in following this product mix and the solution is, therefore, feasible.

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APPENDIX I

INPUT COEFFICIENTS OF FIXED RESOURCES OVER ROTATION PERIOD

Rotation I

Land :

Wheat takes one acre from (1)‡
Cotton takes one acre each from (6) and (7)
Berseem takes one acre each from (1), (3), (4) and (5)
Maize takes one acre each from (6) and (7)

Labour (Man-hours) :

	Wheat	+ Cotton	+ Berseem	+ *Senji*	= Total
15th March-14th April	0	0	36	0	36
15th April-30th April	10	0	24	0	34
15th October-15th November	28	0	36	4	68
Mid. November-Mid. March	44	0	144	0	188
Irrigation Maximum (acres)	0	1	1	0	2
Farmyard Manure (ton)	0	10	0	15	25
Cash (rupees) :					
Kharif season	0	34	0	19	53
Rabi season	35	0	5	0	40

Rotation II

Land :

Wheat takes one acre from (1)
Maize takes one acre each from (6) and (7)

Labour (Man-hours) :

	Wheat	+ Maize	= Total
15th March-14th April	0	0	0
15th April-30th April	10	0	10
15th October-15th November	28	4	32
Mid. November-Mid. March	44	0	44
Irrigation Maximum (acres)	0	0	0
Farmyard Manure (ton)	0	15	15
Cash (rupees) :			
Kharif season	0	19	19
Rabi season	35	0	35

Rotation III

Land :

Wheat takes one acre from (1) and (7)

Labour (Man-hours) :

	Wheat	+ Fallow	= Total
15th March-14th April	0	0	0
15th April-30th April	10	0	10
15th October-15th November	28	0	28
Mid. November-Mid. March	44	0	44
Irrigation Maximum (acres)	0	0	0
Farmyard Manure (ton)	0	0	0
Cash (rupees) :			
Kharif season	0	0	0
Rabi season	35	0	35

‡The figures in the pa.entheses refer to resource restrictions given in Appendix III.

Rotation IV

Land :

Wheat takes one acre from (1)
Cotton takes one acre from (6) and (7)
Senji takes one acre each from (1) and (4)
Sugarcane takes one acre each from (1), (4), (5), (6), (7) and (8) for 3 years.

Labour (Man-hours) :

	Wheat +	Cotton +	*Senji* +	Sugarcane I	— II	— III =	Total
15th March-14th April	0	0	0	40	8	8	56
15th April-30th April	10	0	0	24	24	24	82
15th October-15th November	28	0	24	24	24	24	124
Mid. November-Mid. March	44	0	24	312	264	264	908
Irrigation Maximum (acres)	0	1	0	1	1	1	4
Farmyard Manure (ton)	0	10	0	15	10	10	45
Cash (rupees):							
Kharif season	0	34	0	65	30	30	159
Rabi season	35	0	15	20	15	15	100

Rotation V

Land:

Wheat takes one acre from (1)
Kharif Fodders take one acre from (7)
Gram takes one acre each from (1) and (2)
Maize takes one acre each from (6) and (7)

Labour (Man-hours) :

	Wheat +	Kharif Fodder +	Gram +	Maize =	Total
15th March-14th April	0	0	42	0	42
15th April-30th April	10	0	0	0	10
15th October-15th November	28	0	0	0	28
Mid. November-Mid. March	44	0	0	0	44
Irrigation Maximum (acres)	0	.75	0	0	.75
Farmyard Manure (ton)	0	15	0	15	30
Cash (rupees):					
Kharif season	0	5	0	19	24
Rabi season	35	0	5	0	40

Rotation VI

Land :

Cotton takes one acre each from (6) and (7)
Senji takes one acre each from (1) and (4)

Labour (Man-hours):	Cotton +	*Senji* =	Total
15th March-14th April	0	0	0
15th April-30th April	0	0	0
15th October-15th November	0	24	24
Mid. November-Mid. March	0	24	24
Irrigation Maximum (acres)	1	0	1
Farmyard Manure (ton)	10	0	10
Cash (rupees) :			
Kharif season	34	0	34
Rabi season	0	15	15

APPENDIX II

Net Returns to the Fixed Resources from Different Rotations

Rotation No.	Gross Returns over Rotation Period (Rupees)					Variable Costs (Rupees)					Net Returns (Rupees)	
											Rotation Period	Yearly
I.	Wheat 261.00	+ Cotton 315.00	+ Fodders —	+ Maize 250.00	= Total 826.00	Wheat 39.00	+ Cotton 54.90	+ Fodders 50.00	+ Maize 57.50	= Total 201.40	624.60	302.30
II.	Wheat 261.00	+ Maize 200.00			461.00	Wheat 39.00	+ Maize 57.50			96.50	364.50	364.50
III.	Wheat 362.50	+ Fallow —			362.50	Wheat 44.00	+ Fallow —			44.00	318.50	318.50
IV.	Wheat 290.00	+ Cotton 315.00	+ *Senji* —	+ Sugarcane 2100	2705.00	Wheat 41.00	+ Cotton 54.90	+ *Senji* 25.50	+ Sugarcane 507.50	628.90	2076.10	519.07
V.	Wheat 261.00	+ Fodders —	+ Gram 240.00	+ Maize 250.00	751.00	Wheat 39.00	+ Fodders 15.00	+ Gram 13.90	+ Maize 57.50	125.40	625.60	312.80
VI.	*Senji* —	+ Cotton 525.00			525.00	*Senji* 25.50	+ Cotton 54.90			80.40	444.60	444.60

APPENDIX III

Resource Restrictions and Input-Output Coefficients

C	Rs.	0	302	365	319	519	313	445
Resource		B	R_1	R_2	R_3	R_4	R_5	R_6
1. Rabi land for Wheat	.. ..	10.00 acres	1	1	1	1.25	1	1
2. Rabi land for Gram	.. ..	2.00 „	0	0	0	0	.5	0
3. Rabi land for Berseem	.. ..	6.00 „	.5	0	0	0	0	0
4. Rabi land for *Senji* and *Metha*	.. ..	10.00 „	.5	0	0	1.0	0	1
5. Rabi land for Sugarcane	.. ..	8.00 „	.5	0	0	.75	0	0
6. Kharif land for Maize and Cotton	.. .. ..	9.00 „	1	1	0	.75	.5	1
7. Kharif land for Fodders	.. ..	10.00 „	1	1	1	1	1	1
8. Kharif land for Sugarcane	.. ..	10.00 „	0	0	0	1	0	0
9. Permanent Labour from 15th March to 14th April	..	434 Man-hours	18	0	0	14	21	0
10. Permanent Labour from 15th April to 30th April	..	190 „ „	17	10	10	21	5	0
11. Permanent Labour from 15th Oct. to 15th Nov.	..	433 „ „	34	32	28	31	14	24
12. Permanent Labour from Mid. Nov. to Mid. March	..	1886 „ „	94	44	44	227	22	24
13. Irrigation Maximum	.. ..	2.52 acres	1	0	0	1	.37	1
14. Farmyard Manure	.. ..	10.00 ton	12.5	15	0	11	15	10
15. Cash available for Kharif season	.. .. ..	Rs. 648.00	26	19	0	40	12	34
16. Cash Available for Rabi season	.. .. ..	Rs. 590.00	20	35	35	25	20	15

APPENDIX IV

FINAL ITERATION

Z	C Re-sour-ces	B	P	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}	P_{19}	P_{20}	P_{21}	P_{22}
319	P_3	9.00																
0	P_8	2.00																
0	P_9	6.00																
0	P_{10}	9.00																
0	P_{11}	8.00																
0	P_{12}	8.00																
445	P_6	1.00	—4.39995	0	0	0	0	0	4.39995	0	0	0	0	0	0	.099999	0	0
0	P_{14}	10.00																
0	P_{15}	434.00																
0	P_{16}	100.00																
0	P_{17}	156.993611																
0	P_{18}	1466.00																
0	P_{19}	1.52																
519	P_4	0.00																
0	P_{21}	614.00																
0	P_{22}	260.00																
$Z_j - C_j$		3316.00	245 599781	0	0	0	0	0	73.400219	0	0	0	0	0	0	12.60059	0	0