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Research Article

APPLICATION OF LINEAR PROGRAMMING TECHNIQUE ON HILL BASED INDIGENOUS SHIFTING CULTIVATION PRACTICES OF NAGALAND, INDIA

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Abstract: Slash-and-burn farming, also known as shifting cultivation (*Jhum*) is a traditional community farming practice engaged by indigenous people of India since time immemorial. This traditional practice has been an extensive farming where resource utilization was never a primary concern for farmers earlier. But, in the present-day scenario of climate change, depleting natural resources and increasing mouths to feed, it is pertinent to scientifically improve the practice. The current study was to understand the on-going farm practices of *Jhum* paddy growers of Wokha district of Nagaland and assess its improvement.
The research work was conducted as exploratory research on economics, resource constraints and optimization of input resources of *Jhum* farming. It was conducted during the year 2017-18 with 63 respondent farmers from five villages based on random sampling. Three major cropping systems *viz*. Paddy + Sugarcane + Maize (PSuM), Paddy + Maize (PM) and Paddy + Maize + Sesame (PMSe) were identified. From the study, it was observed that medium land holding farmers of PSuM and small farmers of PM and PMSe had highest net return (Rs. ha^{-1}) *i.e*., Rs. 63871.18, Rs. 104887.21 and Rs. 53021.22 respectively in the respective existing set up of cropping system.
After applying LP technique for maximization of gross margin, it was observed that net return for all cropping system gained significantly with minimum gain of 18.4% using existing resources. Also, it was observed that medium and large farmers of PMSe and PSuM were more likely to gain more by application of LP technique.

Keywords: *Shifting cultivation, Copping system, Linear programming, Net return, Gross margin*
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Introduction

Shifting cultivation or 'slash and burn' (also called as *Jhum* cultivation) is a traditional practice in some parts of India. It is practised in forest regions of vast hilly stretches where indigenous farmers grow multiple crops in field on community level [1,2]. In this practice, rotation of cultivable land based on *Jhum* cycle is of importance rather than the crops [3]. Such cultivation practice is the principal and traditional method of agricultural practice among the Naga tribes in the state of Nagaland, India [4]. *Jhum* consists of clearing of plot of forest land by slashing and burning the vegetation and cultivating land for few years and then abandoned for newer fertile stretches. The abandoned land is then left fallow to regain the vegetation cover so that after a *jhum* cycle, usually of 3 to 5 years, can be cultivated again [5]. Such cultivation practice is considered a serious threat to biodiversity and climate of the region [6]. In the view of traditional Naga farming systems, improved fallow management practices can therefore, be an option for improving the livelihood and food security.
The present study focuses on describing the existing agrarian structure of high hill farming of Nagaland and assessing the economics, resource constraints and optimization of limited farm input resources of different cropping systems by applying linear programming technique. As population and its pressure on land is increasing, agricultural planning plays an important role for increasing productivity, reduce cost and maximize returns to farmers [7]. The present research would support better resource utilization in shifting cultivation practices and thereby improve indigenous farmer's income.
Linear Programming (LP) approach is a mathematical procedure for determining optimal allocation of scarce resources, is credited to George B. Dantzigin 1947.For achieving better gross margin and support in agriculture production of food crops, fishery and livestock, application of linear planning has been found effective [8,9]. It is a method of identifying constraints which have a binding or limiting on a multi-product or multi-activity farming system that may result in obtaining the optimum combination of inputs in order to maximize gross margin or minimize the cost within the limits of available resources. In addition, the gross margin associated with the cropping system was found suitable as objective function for application of linear programming [10].

Material and Methods

The study was based on descriptive research design conducted during 2017-18 to understand the economics of upland paddy based *Jhum* farming in Wokha district of Nagaland state. The district extends between 26.1° North latitude and 94.27° East longitude, and is located at high altitude of about 1313m above mean sea level. It is populated with an indigenous Naga tribe '*Lotha*' and agriculture practised is traditional and organic in nature. The current research strives to assess farm economics, resource constraints and optimizing farm resources to achieve maximum gross margin for the paddy farmers with existing resources and farming system.
Out of the five rural development Blocks of the district, two blocks *viz*, Wokha and Chukitong, were selected using simple random sampling. From the blocks, five villages were randomly sampled as second stage unit, namely Phiro, Wokha, Longla, Yanthamo and Yimkha. Then probability proportional to land size sampling scheme was applied to select farmers using auxiliary information on the size of farm landholding. A total of sixty-three (n = 63) paddy farming households were sampled. Farmers were categorised based on cropping systems and operational farm holding size groups for analysis and drawing valid interpretation.

Also, the secondary data on agriculture profile and related information of the villages were collected from Statistical Handbook of Nagaland [11,12].

Formulation of Linear Programming (LP) model

The resource input and economic output of the *Jhum* based farming were assumed to be independent and linearly related given that the farmers were not practising intensive farming. As traditional and subsistence farming and small farmers suffer from inefficiencies like area allocation under crop, working capital allocation and optimal utilization of scarce labour, linear programming helps in arriving at optimum solution. Hence, it is considered a useful tool of farm management analysis even in under developed countries [13].

In the present study, for obtaining optimum land allocation to multiple crops, linear programming was formulated for maximizing gross margin with subject to various constraints [14] assessed for each cropping system. Gross margin was defined as the net realisation on variable costs along with savings accrued from family labour, own working capital and own planting materials. It excludes fixed cost, overhead costs such as rentals, electricity, insurance, living costs and interest on long term loan. Hence, gross margin does not represent measure of profit of an enterprise. The net return of optimal cropping system for a particular year of accounting was considered a measure of profit of the enterprise, obtained by deducting all savings component from optimal gross margin. Constraints considered for the study were operational land area for each farm group, working capital, labour requirement per hectare and combination of agronomy and vegetable crops. The gross margin of a cropping system was calculated in general as

Gross margin = Gross value from all crops (excluding losses at farm level) + Savings from own working capital, planting materials and family labour-Input cost on hired labour, interest on loan working capital and transportation. Mathematically it can be presented as

Gross margin (Z) = $\sum_{i=1}^{c} P_i X_i + \sum_{j=1}^{s} S_j X_j - \sum_{k=1}^{e} Q_k X_k$ --------------------------- (1)

Where,

P_i = Market price of i^{th} crop produced per hectare (Rs. per ha); i= 1,2,...,c crops;

X_i = Area (ha) for i' agronomy crop and average area (ha) of i* vegetable crops produced; $i^* \neq i'$ and $i = i^* \cup i'$ and $x_{i'} \cup x_{i^*} \in X_i$;

X_j = Unit of nominal savings (Rs.) from j^{th} savings component; j = 1,2,...s;

S_j = Savings co-efficient for j^{th} component *viz*., interest rate (%) on own working capital ($s_{j'}$); and savings rate of (Rs. per man day) on family labour (s_{j^*}); j=1,2,...s savings component;

X_k = Unit of k^{th} cost component *viz*, hired labour (man days), loan working capital (Rs.) k = 1,2,..., e cost component;

Q_k= Unit cost co-efficient (Rs per unit) of k^{th} cost component; k = 1,2,...,e;

Objective of the study was to maximize Z

Subject to following constraints ----------------------------------- (2)

$X_{i'} \geq$ Minimum area under each agronomical crop($x_{i'}$);

$X_{i^*} \leq$ Average area under each vegetable crop (x_{i^*});

$X_j \leq$ Average family labour man days(x_{j^*}), average owned working capital ($x_{j'}$), and average own planting material (x_{jp}), $\{x_{j^*}, x_{j'}, x_{jp}\} \in X_j$;

$X_k \geq$ Average number hired labour(x_{k^*}) man days and average loan capital ($x_{k'}$);

$\sum X_{i'} \geq$ Average total land area under agronomy crop;

$\sum X_{i^*} \leq$ Average total area under vegetable crops;

$\sum X_{i'} + \sum X_{i^*} \leq$ Average operational area available;

$x_{k^*} + x_{j^*}$ = Average labour (Man days) requirement;

$x_{j'} + x_{k'} \leq$ Average working capital (Rs.) requirement;

and non-negativity constraints

X_i, X_j and $X_k \geq 0$; P_i, S_j and $Q_k \geq 0$

In this study sixteen types of constraints were identified for each cropping systems for setting up linear programming model as described above. Also, the net return (profit in Rs/ha) of the farmers were obtained as net monetary value realised after deducting losses at field, non-cash savings and cash expenses from of the gross value.

Sensitivity analysis of the model

The analysis of parametric change and their effect on linear programming solutions is referred to as "sensitivity" or "post-optimality" analysis [15]. The sensitivity report of Ms Excel -2007 Solver add-in provides classical sensitivity analysis information for both linear and nonlinear programming problems. The dual values for (non-basic) variables are called Reduced Costs in the case of linear programming problems and the dual values for binding constraints are called Shadow Prices for linear programming problem. The constraint variable with higher value was considered as very sensitive variable towards objective function. Negative shadow prices indicated loss to optimal value of objective function with increase in each unit.

Optimum resource allocation for maximizing gross margin

The study region was observed to have paddy growers following three major cropping system *viz*., Paddy and Maize (PM); Paddy, Maize and Sesame (PMSe); and Paddy, Sugarcane and Maize (PSuM). If Z is gross margin, then general form of objective function (Z) applicable in the study region is

Z = Sum of gross return from different crops (Rs/ha) + Savings from own working capital @23% p.a. + Savings from family labour @ Rs 300/man days + Savings from owned planting material (Rs)-Interest on Loan capital @ 30% p.a.- Hired labour @ Rs 300/man days.

For three cropping system the Z is framed as follows subject to the constraints [Table-3]:

Paddy and Maize (Pm) Growing Farmers

a) For PM farmers (small)

$Z^sPM = 9382.716\ X_1 + 21853.448\ X_2 + 189349.112\ X_3 + 347727.273\ X_4 + 351666.667\ X_5 + 400000.000\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + 1X_{11}$

(b) For PM farmers (medium)

$Z^mPM = 8855.814\ X_1 + 26830.025\ X_2 + 199710.005\ X_3 + 437519.531\ X_4 + 308975.610\ X_5 + 415104.446\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + 1X_{11}$

(c) For PM farmers (large)

$Z^lPM = 9696.113\ X_1 + 28012.048\ X_2 + 190860.786\ X_3 + 453461.538\ X_4 + 294000.000\ X_5 + 396694.215\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + 1X_{11}$

Paddy, Maize and Sesamum (PMSe) Growing Farmers

a) For PMSe farmers (small)

$Z^sPMSe = 8000.000\ X_1 + 30978.261\ X_2 + 36428.571\ X_3 + 100000.000\ X_4 + 197560.976\ X_5 + 450000.000\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + 1X_{11}$

(b) For PMSe farmers (medium)

$Z^mPMSe = 7903.030\ X_1 + 27543.320\ X_2 + 34006.515\ X_3 + 92081.448\ X_4 + 187610.619\ X_5 + 450000.000\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + 1X_{11}$

Paddy, Sugarcane and Maize (PsuM) Growing Farmers

a) For PsuM farmers (small)

$Z^sPsuM = 8355.972\ X_1 + 442046.512\ X_2 + 26983.240\ X_3 + 96275.072\ X_4 + 197494.781\ X_5 + 463524.590\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + X_{11}$

(b) For PsuM farmers (medium)

$Z^mPsuM = 8280.726\ X_1 + 481708.593\ X_2 + 26412.556\ X_3 + 86975.296\ X_4 + 197962.459\ X_5 + 452528.266\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + X_{11}$

(c) For PsuM farmers (large)

$Z^lPsuM = 8293.750\ X_1 + 544925.373\ X_2 + 29276.062\ X_3 + 99557.522\ X_4 + 198576.577\ X_5 + 472734.375\ X_6 + 0.23\ X_7 - 0.30\ X_8 + 300\ X_9 - 300\ X_{10} + X_{11}$

Statistical analysis

The constraints have been assumed to be independent and the total working capital, labour requirement and owned planting material was kept constant as existing cropping system. However, this assumption might not hold practically true for all feasible solution. The analysis of the above LP problem was done through Ms-Excel 2007 Solver Add In tool.

Table-2 *Crop details of PSuM, PM and PMSe farmers*

Crops	Sowing time	Harvesting time	Average area (ha)	Average production ('000 kg)	Gross value (Rs per hectare)		
					Small	Medium	Large
Paddy	March	September	1.24 ± 0.28	1.30± 0.29	8524	8350	8575
Sugarcane	April	Dec - Feb	0.16 + 0.06	0.64±0.26	442047	481709	544926
Maize	March, April	July	0.28 ±0.12	0.51±0.23	26700	26682	29024
Sesame	March	September	0.10 ± 0.04	0.06±0.02	36429	34007	NA
Ginger	March	Nov- Dec	0.07 ±0.05	0.66±0.44	97517	87997	99558
Colocasia	March, April	December	0.20 ± 0.10	1.99±0.94	195475	196741	197034
Chilli	January (June)	May (July)	0.11 ± 0.04	1.10±0.39	431195	448800	468880
Cabbage	October	March	0.26 ± 0.10	2.74±0.98	351667	308976	294000
Cucumber	Feb - March	June	0.14 ± 0.06	1.40±0.63	400000	415105	396695
Others	Seasonal		0.85 ± 0.22				

Note: (+) Standard deviation is considered in area and average production; Source: Sample survey (2017-18)

Table-3 *Constraints for three cropping systems under different landholdings*

Particulars	Label	Type	Limit	PM farmers			PMSe farmers		PSuM farmers		
				Small	Medium	Large	Small	Medium	Small	Medium	Large
Area under paddy (ha)	X_1	≥	Minimum	0.80	1.00	1.41	1.00	0.80	0.90	0.66	0.70
Area under maize (ha)	X_2(X_3**)	≥	Minimum	0.11	0.13	0.41	0.20	0.37	0.11	0.10	0.10
Area under sugarcane (ha)	X_2**	≥	Minimum	-	-	-	-	-	0.13	0.10	0.06
Area under sesamum (ha)	X_3*	≥	Minimum	-	-	-	0.07	0.06	-	-	-
Area under colocasia (ha)	X_3(X_5***)	≤	Maximum	0.09	0.25	0.47	0.08	0.26	0.16	0.36	0.36
Area under chilli (ha)	X_4(X_6***)	≤	Maximum	0.15	0.15	0.10	0.16	0.18	0.13	0.22	0.15
Area under ginger (ha)	X_4***	≤(≥**)	Maximum (Average**)	-	-	-	0.06	0.11	0.04	0.09	0.06
Area under cabbage (ha)	X_5	≤	Maximum	0.24	0.41	0.13	-	-	-	-	-
Area under cucumber (ha)	X_6	≤	Maximum	0.17	0.25	0.06	-	-	-	-	-
Owned working capital (Rs)	X_7	≤	Average	21281.00	27531.61	19639.43	15978.63	21273.11	19045.98	22259.20	27986.32
Loan working capital (Rs)	X_8	≥	Average	11459.00	14824.71	10575.08	8603.88	11454.75	10255.53	11985.73	15069.56
Family labour (man days)	X_9	≤	Maximum	122.38	190.12	195.68	134.73	198.94	171.28	213.41	257.50
Hired labour (man days)	X_{10}	≤	Maximum	28.79	44.82	44.90	31.00	46.50	48.65	64.79	83.13
Planting material (Rs)	X_{11}	=	Average	2559.50	5294.46	9317.83	5898.15	7845.61	15886.60	20463.28	26381.93
Total area available (Ha)	X_{12}	≤	Average	1.45	2.19	2.59	1.59	2.14	1.59	2.02	2.55
Total agronomy area (ha)	X_{13}	≤	Average	0.93	1.40	1.83	1.29	1.80	1.35	1.632	2.09
Total horticulture area (ha)	X_{14}	≥	Average	0.52	0.79	0.75	0.30	0.34	0.24	0.383	0.45
Total labour (man days)	X_{15}	=	Average	141.07	208.74	240.04	163.84	210.72	190.11	222.625	278.38
Total working capital (Rs)	X_{16}	≤(=**)	Maximum Average**	32740.00	42356.32	30214.50	24582.50	32727.86	29301.50	34244.93	43055.88

*Note: The parenthesis having * is for PMSe farmers; ** is for PSuM farmers; and *** is for both the PMSe and PSuM farmers*

Table-4 *Optimal Gross margin of farmers for three cropping systems under different landholdings*

Components	PM farmers			PMSe farmers		PSuM farmers		
	Small	Medium	Large	Small	Medium	Small	Medium	Large
Optimal Z (Rs)	245564.38	417109.02	278189.24	150065.3	236131.6	302496.06	635711.20	937151.10
Area under paddy (ha)	0.80	1.00	1.41	1.00	0.8	0.90	0.66	0.70
Area under maize (ha)	0.11	0.13	0.42	0.20	0.368	0.11	0.10	0.10
Area under Sugarcane (ha)	-	-	-	-	-	0.35	0.88	1.29
Area under sesamum (ha)	-	-	-	0.09	0.421	-	-	-
Area under colocasia (ha)	0.02	0.25	0.47	0.08	0.26	0.07	0.08	0.25
Area under chilli (ha)	0.15	0.15	0.10	0.16	0.18	0.13	0.22	0.15
Area under cabbage (ha)	0.24	0.41	0.13	-	-	-	-	-
Area under ginger (ha)	-	-	-	0.06	0.11	0.04	0.09	0.06
Area under cucumber (ha)	0.17	0.25	0.06	-	-	-	-	-
Own working capital (Rs)	21281.00	27531.61	19639.43	15978.63	21273.11	19045.98	22259.20	27986.32
Loan working capital (Rs)	11459.00	14824.71	10575.08	8603.88	11454.75	10255.53	11985.73	15069.56
Family labour (man days)	122.38	190.12	195.68	134.73	198.938	171.28	213.41	257.50
Hired labour (man days)	18.69	18.62	44.37	29.11	11.782	18.83	9.22	20.88
Own planting material (Rs)	2559.50	5294.46	9317.83	5898.15	7845.611	15886.60	20463.28	26381.93
Total area available (ha)	1.45	2.19	2.59	1.58	2.139	1.59	2.02	2.55
Total agronomy area (ha)	0.91	1.13	1.83	1.29	1.589	1.35	1.63	2.09
Total horticulture area (ha)	0.54	1.06	0.76	0.30	0.55	0.24	0.38	0.45
Total labour (man days)	141.07	208.74	240.04	163.84	210.72	190.11	222.63	278.38
Total working capital (Rs)	32740.00	42356.32	30214.50	24582.50	32727.86	29301.50	34244.93	43055.88
Optimal net return (Rs/ha)	138846.497	158777.017	79463.501	63177.046	76536.608	145185.280	270926.477	324982.994

Table-5 *Comparative analysis for the three cropping systems under different land holdings*

	PM farmers				PMSe farmers			PSuM farmers			
	Small	Medium	Large	Average	Small	Medium	Average	Small	Medium	Large	Average
Current net return (Rs/ha)	104887.2	103477.6	67112.66	91825.81	53021.23	37905.79	45463.51	63006.55	63871.18	61300.05	62725.93
Optimum net return (Rs/ha)	138846.5	158777	79463.5	125695.7	63177.05	76536.61	69856.83	145185.3	270926.5	324983	247031.6
Percentage gain	32.377	53.441	18.403	36.885	19.154	101.913	53.655	130.429	324.176	430.151	293.827

Table-6 *Sensitivity analysis*

Decision variable	Reduced Cost for PM farmers				Reduced Cost for PMSe farmers			Reduced Cost for PSuM farmers		
	Small	Medium	Large		Small	Medium		Small	Medium	Large
X_1	-179966.396	-17974.211	-18315.935	X_1	-28428.571	-26103.485	X_1	-433690.54	-473427.867	-536631.623
X_2	-167495.664	0	0	X_2	-5450.310001	-6463.195	X_3	-415063.272	-455296.037	-515649.311
X_3	0	172879.98	162848.738	X_4	100000	58074.933	X_4	-101219.709	-110987.163	-99019.055
X_4	158378.161	410689.506	425449.49	X_5	197560.976	153604.104	X_6	266029.809	254565.807	274157.798
X_5	162317.555	282145.585	265987.952	X_6	450000	415993.485				
X_6	210650.888	388274.421	368682.167							
Constraint variables & Shadow Prices										
X_{12}	189349.112	26830.025	28012.048	X_{12}	0	34006.515	X_{12}	197494.781	197962.459	544925.373
				X_{13}	36428.571	0	X_{13}	244551.731	283746.134	0
							X_{14}	0	0	-346348.796
							X_{15}	-300	-300	-300

Results

The data collected from the different cropping system of paddy growers were analysed in this study and three cropping systems identified were based on responses of the sample farmers. The findings were similar to findings of [16] who noted that the cropping systems were different in a region because of natural, economic and technological reasons. The three types of cropping systems for *Jhum* cultivation were "Paddy + Sugarcane + Maize + Ginger + Colocasia + Chilli (PSuM)"; "Paddy + Maize + Colocasia + Chilli + Cabbage + Cucumber (PM)" and "Paddy + Maize + Sesamum + Ginger + Colocasia + Chilli (PMSe)". The following table shows farm size-based frequency distribution of respondent farmers (n = 63) as per three different cropping systems.

Table-1 *Frequency distribution of farmers in PSuM, PM and PMSe based on farm size*

Farm size groups	Number of farmers			Total
	PSuM	PM	PMSe	
Large (≥ 2.6 ha)	8	2	0	10
Medium (1.76 to 2.5 ha)	28	10	7	45
Small (≤ 1.75 ha)	4	2	2	8
Total	40	14	9	63

Source: Sample survey (2017-18)

It was observed that maximum paddy based *Jhum* famers (63.5%) of Wokha district were involved in PSuM cropping system and the least (14.25%) were practising PMSe system. The period of sowing to harvesting for the crops identified in all the cropping system for *Jhum* cultivation in the study area is discussed in the [Table-2].

From the [Table-2], the average area (ha) and production ('000 kg) of different crops with gross valuation (Rs/ ha) can be observed. It is noted that among the crops maximum area was under upland paddy, colocasia, cabbage and cucumber, but higher gross value was with sugarcane, chilli and cucumber. The cropping mix of different cropping system adopted by farmers was such that the risk was low and local consumption could be fulfilled. Also, it was observed that all the produce of sugarcane were processed into jaggery for consumption and commercial purpose, but the processing cost for the conversion has not been covered in the economics and linear optimization. The optimal solution on gross margin (Z) of the three-paddy based cropping systems and optimal area under different crops, have been presented in the [Table-4].

Discussion

The small, medium and large farmers of PM growers showed the optimal gross margin at Rs. 245564.38, Rs. 417109.02 and Rs. 278189.24 respectively and the area under different crops have been allocated as presented in [Table-5]. The optimal solution on gross margin for PM farmers reveals that area under cabbage and cucumber plays a pivotal role in improving returns for the farmers [Table-4]. The following [Table-5] shows comparative advantage of linear optimization of crop mix over current cropping system of the PM farmers. It is observed that for medium farmers a maximum advantage of 53% over existing set up can be obtained by linear optimization approach and on an average 37% gain seems possible. Results of sensitivity analysis on PM farmers are presented in Table 6to identify significant binding constraints. It was observed that area under paddy was significantly having negative reduced cost for all farm size groups. For small farm size cultivators of PM system, area under maize was crucial. Also, it was noted that the area under vegetables had high positive reduced cost and total operational area constraint had high positive shadow price.

Regarding PMSe growers, it can be observed that small and medium farmers showed the optimal gross margin at Rs. 150065.3 and Rs. 236131.6 respectively [Table-4]. For improving gross margin of PMSe farmers, the sesame crop for medium farmers and vegetables especially chilli and colocasia was found important. The optimal solution also revealed that family labour and own working capital were very crucial during crunch in external credit and hired labour requirement. The [Table-5] shows comparative advantage of linear optimization of crop mix where medium farmers are slated to gain more than 101% over existing set up through LP. Sensitivity analysis of PMSe farmers was obtained, it is observed that area under paddy and maize were significantly having negative reduced cost while area under sesame was non-binding [Table-6]. Area under vegetables had positive reduced cost. Ironically, area under agronomy crops was binding for small farmers but total operational area was significantly binding for medium farmers of PMSe.

The optimal solution on gross margin for PSuM farmers reveals that area under sugarcane and chilli plays a pivotal role in improving returns. The following [Table-5] shows comparative advantage of linear optimization of crop mix over current cropping system of the PsuM farmers. It is to be noted that processing cost for sugarcane to jaggery was not included in the study owing to non-availability of data. The reduced cost of binding decision variables and shadow cost of constraints [Table-6] shows that area under paddy, maize and ginger were significantly had negative reduced cost, while area under chilli had positive one. Also, total operational area and agronomy crop area was having high positive shadow price for small and medium farmers. For large farmers, the total area under vegetables was crucial with significant negative shadow price [17-20].

Conclusion

From the study on linear optimization of shifting cultivation, it was emphatically observed that the technique would improve gross margin of the traditional farmers. The land was not a binding constraint especially for medium and large farmers similar to findings of [21]. Since high hill cultivation is not much intensive, low productive and indigenous, it is important that such linear programming techniques may be incorporated to identify best mix of existing resources to enhance production, income and livelihood security of local farmers. The Simplex method applied in the study identified inefficiencies in farming enterprises especially with medium size farms of Wokha district. Gain in efficiency ranged from 16% to above 400% similar to findings of [8], and the area allocation for different crops especially vegetables were identified as limiting constraint. However, the limitation of the study was the deterministic model of linear programming as all decision variables and constraints were considered non-random and linearly related. Bearing all limitations in purview, the study showed consonance with findings of [10] that linear optimization might help better resource allocation in *jhum* cultivation.

Application of research: Linear optimization might help better resource allocation in *jhum* cultivation.

Research Category: Modelling of cropping systems

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Study area / Sample Collection: Wokha district, Nagaland

Cultivar / Variety / Breed name: Paddy, Maize, Sugarcane, Sesamum

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