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Minimising Environmental Problems in Hill Agriculture of Nepal through Multiobjective Farm Planning

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I

INTRODUCTION

Agricultural development through modern farm technology is reported to be causing several adverse environmental effects. Wicherek (1993) concludes that water run-off carries fertile soil. To augment soil productivity, chemical fertilisers are used. These fertilisers too are carried off by rain and irrigation, polluting water bodies. The use of pesticides, besides being a health hazard, causes soil degradation through biological impoverishment of the soil micro-fauna, indispensable for proper soil balance. Thus soil erosion, soil degradation and water pollution are reported to be the major environmental problems resulting from modern farming practices. The severity of these environmental problems is much more and widespread in hill agriculture due to the fragile ecosystem and its impact on the plains through downstream sedimentation, flooding and water pollution. Cattle grazing and forest fodder lopping in the hills further accelerate the rate of soil erosion by denuding forests and pastures. It is hypothesised here that the extent of these adverse environmental effects could be considerably reduced through optimal farm planning, while meeting the present levels of subsistence. Agronomic researches have shown that the extent of soil erosion caused significantly differs among various crops, as also the use of agro-chemicals in different crops. However, inclusion of environmental protection objectives along with the traditional production and income objectives in farm planning leads to a multiobjective planning framework. This paper, therefore, attempts to delineate the major environmental protection objectives for the hill agriculture, and to develop a multiobjective farm planning model for minimisation of environmental problems while maintaining the present levels of foodgrains production and farm income. For the purpose, a representative hill district of Dhading in Nepal was selected for obtaining the requisite data and other information.

Farm Planning Perspective in Dhading District

The average size of land holding in Dhading is 0.73 hectare (ha). Over 75 per cent of the cultivated area in the district is rainfed. Irrigation, wherever possible, is done from permanent or seasonal water streams. Small holdings are deficit both in foodgrains production and cash farm income from the view-point of their subsistence needs. Therefore, the production of foodgrains and of milk along with some cash farm income remain the prime economic objectives requiring top priority.

The farm households generally keep one or two cows and buffaloes, but only some possess

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bullocks which are shared by others on exchange with human labour. Due to limited land availability and pressing subsistence needs, there is a heavy dependence on forests and pastures for fodder. Consequently, about 31 per cent of the non-arable mountain terrain in Dhading faces the problem of degraded forests, erosion hazard and over-grazing, and nearly 36 per cent of arable mountainous terrain is badly suffering from soil erosion, low fertility and over-grazing (ICIMOD, 1993). Thus minimisation of soil erosion caused by crop cultivation along with the minimisation of both cattle grazing and dependence on forest fodder appear to be the most important environmental protection objectives. The use of fertilisers and pesticides is presently quite low. But larger use of these agro-chemicals is being emphasised upon, which would lead to run-off losses and the residual chemical effects causing water pollution and bio-chemical soil imbalances. Therefore, minimisation of the use of these agro-chemicals also deserves inclusion in the environmental protection objectives.

II

OPERATIONAL MODEL

There are three broad categories of multiobjective optimisation methods (Cohon and Marks, 1975). One category includes the methods in which prior articulation of the decision-maker's preferences is done and then single objective optimisation is constructed. Goal programming is one such technique in which objectives are converted into preferred goal levels and deviations from these goals are minimised. The second category comprises the generating methods in which the non-inferior solution set is obtained through a sequence of properly constructed single objective optimisations and the best compromise solution is selected by the preference function. The parametric programming or the constraint method is one such technique. The third category consists of the techniques, such as step method, in which the preferences are progressively incorporated through an interactive procedure of generating a sequence of single objective optimum solutions with updated information till no further improvement is possible. In both these latter categories of methods, the computational burden becomes unmanageable in case the problem has higher dimensions of more than four objectives. When the number of objectives is large and these could be stated in terms of desired goal targets, the goal programming offers a more pragmatic approach. However, this method suffers from a limitation that there exists a possibility of an inferior solution turning out to be the optimum when all the goal targets are exactly met. One has to guard against such a possibility when deviations from all the goals become zero.

In the present case, the environmental protection objectives together with the economic objectives makes a large set of nine objectives to be simultaneously optimised. Therefore, the following Lexicographic Goal Programming (LGP) model based on Romero and Rehman (1989) is developed for the multiobjective optimisation situation described here.

1. The achievement function consists of a vector of deviational variables which are to be minimised.

$$\text{Min } Z = [P1\ (w_1 d_f^-,\ w_2 d_m^-,\ w_3 d_c^-),\ P2\ (w_4 d_c^+,\ w_5 d_{ffs}^+,\ w_6 d_{gs}^+),\ P3\ (w_7 d_n^+,\ w_8 d_g^+)]$$

where Z is the achievement function resulting to the multiple objectives; P1, P2 and P3 are respectively first, second and third priority levels assigned to different goals; w_i's represent the weights assigned to goal deviations,[1] d^-/d^+ represent the negative/positive deviations from the targeted goals; and the subscript f stands for foodgrains production goal, m for milk production, c for cash income, e for soil erosion, ffs for forest fodder in season s, gs for grazing in season s, n for nutrients and q for pesticide goal.

This achievement function is minimised subject to the following constraints and goals:

2. Land constraints for year round irrigated, monsoon irrigated and unirrigated lands in summer, rainy and winter seasons. There are nine land types and 31 crop activities.

$$\Sigma A_{li} X_i < = L_l,\ l = 1, 2, ..., 9;\ i = 1, 2, ..., 31;\ A_{li} = \text{unity}.$$

3. Bullock labour constraints for peak ploughing seasons of April, July and November. Bullock power is generated from k-th livestock activity.

$$\Sigma a_{ji}X_i - a_{jk}X_k < = 0,\quad j = 1,2 \text{ and } 3;\ k = 3.$$

4. Green fodder constraints for two livestock seasons (s = 1 for June to November, and s = 2 for December to May).

$$\Sigma a_{Gsk}X_k - \Sigma y_{Gsi}X_i - X_{ffs} - b_1X_{gs} - X_{DGs} + X_{GDs} < = A_s.$$

k = 1, 2, 3, respectively for buffaloes, cows and bullocks.

5. Dry fodder constraints for two livestock seasons.

$$\Sigma a_{Dsk}X_k - \Sigma y_{Dsi}X_i + X_{hs} - tX_{hs-1} + b_2X_{DGs} - b_2X_{GDs} < = 0.$$

6. Human labour constraints for peak months of April, June, July, August, November and December, with labour hiring.

$$\Sigma a_{zi}X_i + \Sigma a_{zk}X_k - X_z < = H_z,\ (z = 1,2, ..., 6, \text{ peak months}).$$

7. Minimum cattle grazing requirement (half an hour per day).

$$\Sigma a_{vsk}X_k - X_{gs} < = 0.$$

8. Cattle herd ratio (to generate bullock supply).

$$0.93\ X_{k3} - X_{k2} < = 0,\ k_2 = \text{cows and } k_3 = \text{bullocks}.$$

9. Coarse-fine cereals ratio (preference for fine cereals).

$$\Sigma y_{ic}X_{ic} - 1.57\ \Sigma y_{if}\ X_{if} < = 0,\ \text{if = fine cereals and ic = coarse cereals}.$$

10. Cereal-pulse ratio (for food balance).

$$\Sigma y_{ce} - X_{ce} - 56.85\ \Sigma y_p\ X_p < = 0,\ \text{ce = cereals and p = pulses}.$$

11. Area ratio for summer and rainy season vegetables (for regular supply).

$$\Sigma X_{v2} - 0.31\ \Sigma X_{v1} < = 0.$$

12. Area ratio for summer-winter season vegetables (for regular supply).

$$\Sigma X_{v2} - 0.79\ \Sigma X_{v3} < = 0.$$

13. Total foodgrains production goal. First, the target (F) is set at the present production levels on respective farm types; subsequently, it is increased for sensitivity testing.

$$\Sigma y_{if}\ X_i - \Sigma a_{kf}\ X_k + d_f^- - d_f^+ = F.$$

14. Milk production goal. The target (M) is set at the present production levels on respective farm types.

$$\Sigma y_{km}\ X_k + d_m^- - d_m^+ = M.$$

15. Returns to the fixed farm resources (RFFR) goal. First, the target (C) is set at the present levels on respective farm types; subsequently, it is increased for sensitivity testing.

$$\Sigma r_iX_i - w\ \Sigma X_z + d_c^- - d_c^+ = C.$$

16. Soil erosion goal. The target for soil erosion from cropped area and cattle grazing also set at zero level.

$$\Sigma e_i X_i + \Sigma e_g X_g + d_c^- - d_c^+ = 0.$$

17. Cattle grazing goals. The target set at zero level.

$$X_{gs} + d_{gs}^- - d_{gs}^+ = 0.$$

18. Forest fodder harvesting goals. The target set at zero level.

$$X_{ffs} + d_{ffs}^- - d_{ffs}^+ = 0.$$

19. Chemical fertilisers use goals. Targets (N_n) for purchase of N and P nutrients set at the existing purchase levels. There is neither any deficiency nor significant use of potash nutrient.

$$\Sigma a_{ni} X_i - \Sigma y_{nk} X_k + d_n^- - d_n^+ = N_n, (n = 1 \text{ for N}, n = 2 \text{ for P}).$$

20. Pesticides use goal. Target (Q) for pesticides use also set at the existing use level.

$$\Sigma a_{qi} X_i + d_q^- - d_q^+ = Q.$$

Where,

X_i = crop production activities (area in ha),
X_{v1} = summer season vegetables,
X_{v2} = rainy season vegetables,
X_{v3} = winter season vegetables,
X_k = livestock activities (number),
X_{ffs} = forest fodder harvesting activities,
X_{gs} = cattle grazing activities,
X_{DGs} = substitution of dry fodder for green fodder,
X_{GDs} = substitution of green fodder for dry fodder,
X_{hs} = dry fodder storage activity across livestock seasons,
X_z = labour hiring activities,
L_l = net sown area for l-th land type in each crop season,
A_s = fodder available through other miscellaneous sources,
H_z = family labour available in peak month z,
a = input-output coefficient,
y = productivity coefficient,
e_i = soil erosion per ha under i-th crop,
e_g = soil erosion per hour of cattle grazing,
w = nominal wage rate,
t = storability ratio of dry fodder to the next season,
b_1 = green fodder required to substitute one hour of grazing, and
b_2 = substitution ratio between dry and green fodder.

The required primary data were collected for the year 1994-95 from a sample of 112 farm households selected from the district through three-stage simple random sampling technique. The holdings with less than one hectare and having less than 40 per cent of the irrigated area are categorised as small unirrigated (Su), those with less than one hectare and 40 per cent or more of the irrigated area as small irrigated (Si), holdings of one hectare or more and having less than 40 per cent of the irrigated area as large unirrigated (Lu), and those of one hectare or more with 40 per cent or more of the irrigated area as large irrigated (Li).

Various coefficients and the targets used in the model were built up from these primary data, except for the soil erosion rates which were obtained from various sources (CSWCRTI Annual Reports; HMG/Nepal, 1978 and 1996; Gupta and Khybri, 1986).

III

OPTIMUM PLANS AND ENVIRONMENTAL TRADE-OFFS

The following three sets of optimum plans (each having four plans for four farm categories) are generated so as to test the hypothesis stated earlier and to examine the effects of further increase in foodgrains production or cash farm income upon the environmetnal impact parameters.

(i) P1 plan indicates the minimum levels of environmetnal problems associated with the present levels of foodgrains production, milk production and cash farm income.

(ii) P2 plan indicates the minimum levels of environmental problems associated with the increased level of foodgrains production and present levels of milk production and cash farm income.

(iii) P3 plan indicates the minimum levels of environmental problems associated with the increased level of cash farm income and the present levels of foodgrains and milk production.

In all these optimal plans, negative deviations from the economic goal levels (i.e., targets for foodgrains production, milk production and cash farm income) and positive deviations from environmental goal levels (i.e., targets for soil erosion, cattle grazing, forest fodder lopping, and use of nitrogen, phosphorus and pesticides) are minimised. The results pertaining to these optimal plans together with the existing farm plan are presented in Table 1. These results indicate some positive deviations in most of the environmental goal targets, which remove the chance of the optimal solutions being inferior solutions. The goal conflicts in these plans are shown in Table 2. These conflicts indicate the trade-offs involved in terms of the amount of increase in environmental impact parameters resulting from one unit further increase in economic goal of foodgrains production or returns to fixed farm resources beyond the optimum solution level shown in each plan.

Existing Plan

The existing plan (P0) shows that more than 81 per cent of the cropped area on all categories of farms in put under cereal crops and among these the most important being maize under unirrigated conditions and paddy under irrigated conditions. These two crops together occupy a little over 61 per cent and 72 per cent of cropped area respectively on small and large farms. The limited area under wheat crop is partly attributable to non-wheat food habit of the people and partly to stray grazing of cattle during winter season. The small farms keep more number of cows, whereas the large farms keep more number of buffaloes and bullocks.

The present levels of total foodgrains production and returns to fixed farm resources are shown in Table 1 under the existing plan. The table shows that the present level of total foodgrains production varies from 0.624 tonne on small unirrigated farms (Su) to 2.052 tonnes on large irrigated farms (Li) and returns to fixed farm resources (in Nepalese rupees, N Rs.) vary from N Rs. 14,518 on Su to N Rs. 34,831 on Li farms. When these figures are

TABLE 1. EXISTING AND OPTIMUM FARM PLANS WITH THEIR ENVIRONMENTAL EFFECTS

Sr. No.	Particulars	Small unirrigated farm (Su)				Small irrigated farm (Si)			
		Existing plan	Optimum plans			Existing plan	Optimum plans		
		(P0)	P1	P2	P3	(P0)	P1	P2	P3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A.	Crop plan (ha)								
	Early paddy	0.017	0.034	0.034	0.034	0.044	0.046	0.046	0.046
	Main paddy	0.096	0.078	0.096	0.072	0.313	0.190	0.274	0.188
	Upland paddy	0.016	0.097	0.206	0.093	0.007	0.176	0.176	0.176
	Maize	0.390	0	0.095	0	0.313	0.114	0.265	0.109
	Millet	0.190	0.318	0.321	0.318	0.156	0.114	0.149	0.114
	Wheat	0.062	0.137	0.379	0.164	0.051	0.061	0.222	0.090
	Pulses	0.004	0.027	0.024	0.027	0	0.032	0.027	0.032
	Oilseeds	0.012	0	0	0	0.007	0	0	0
	Summer vegetables	0.002	0.010	0	0.036	0.002	0.008	0	0.030
	Rainy vegetables	0	0.003	0	0.011	0	0.002	0	0.009
	Winter vegetables	0.035	0.013	0	0.046	0.036	0.010	0	0.038
	Farm fodder	0	0.079	0	0.036	0	0.257	0	0.229
1.	Net sown area (ha)	0.434	0.434	0.434	0.434	0.480	0.480	0.480	0.480
2.	Cropping intensitiy (per cent)	189.9	183.4	266.1	192.9	193.5	216.7	297.1	227.3
B.	Livestock plan (No.)								
1.	Buffaloes	0.83	1.21	1.10	1.22	1.00	1.33	1.24	1.33
2.	Cows	1.13	0.25	0.54	0.23	1.33	0.53	0.76	0.52
3.	Bullocks	0.57	0.27	0.58	0.25	1.19	0.57	0.82	0.56

(Contd.)

TABLE 1 (*Contd.*)

Sr. No.	Particulars	Small unirrigated farm (Su)				Small irrigated farm (Si)			
		Existing plan	Optimum plans			Existing plan	Optimum plans		
		(P0)	P1	P2	P3	(P0)	P1	P2	P3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
C.	Goal achievement levels								
1.	Foodrains production (tonne)	0.624	0.624	0.955	0.624	0.734	0.734	1.056	0.734
2.	Milk production (kilolitre)	0.614	0.614	0.614	0.614	0.720	0.720	0.720	0.720
3.	Returns to fixed farm resources (Nepalese Rs.'000)	14.518	14.518	16.097	17.360	16.465	16.765	17.885	19.200
4.	Annual soil erosion (tonne) on								
	(a) Crop land	6.05	2.90	4.72	3.25	4.92	4.46	6.64	4.75
	(b) Pasture land)	2.04	0.12	0.25	0.11	3.56	0.24	0.35	0.24
5.	Cattle grazing (animal month)	10.60	0.60	1.28	0.56	18.43	1.26	1.80	1.24
6.	Forest fodder (tonne)	4.58	4.41	7.48	5.31	4.06	2.48	3.39	3.26
7.	Nitrogen use (kg)	29.75	17.89	28.80	23.80	32.82	34.56	47.82	40.50
8.	Phosphorus use (kg)	4.41	0	0.44	3.16	7.58	2.77	5.50	6.19
9.	Pesticide use (litre)	0.036	0.040	0.035	0.087	0.058	0.057	0.052	0.098

(*Contd.*)

TABLE 1 *(Contd.)*

Sr. No.	Particulars	Large unirrigated farm (Lu)				Large irrigated farm (Li)			
		Existing plan (P0)	Optimum plans			Existing plan (P0)	Optimum plans		
			P1	P2	P3		P1	P2	P3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A.	Crop plan (ha)								
	Early paddy	0.139	0.186	0.186	0.186	0.235	0.353	0.353	0.353
	Main paddy	0.317	0.213	0.308	0.183	0.889	0.421	0.659	0.411
	Upland paddy	0.097	0.205	0.351	0.160	0.034	0.319	0.445	0.305
	Maize	0.806	0	0.166	0	0.718	0	0.257	0
	Millet	0.226	0.644	0.677	0.680	0.292	0.361	0.327	0.361
	Wheat	0.098	0.048	0.891	0.223	0.158	0.348	0.841	0.438
	Pulses	0.072	0.063	0.097	0.062	0.049	0.084	0.118	0.084
	Oilseeds	0.083	0	0.047	0	0.032	0	0	0
	Summer vegetables	0.026	0.053	0.043	0.187	0.014	0.057	0.088	0.282
	Rainy vegetables	0	0.016	0.013	0.058	0	0.018	0.027	0.087
	Winter vegetables	0.194	0.067	0.054	0.236	0.114	0.072	0.181	0.357
	Farm fodder	0	0.301	0.034	0.116	0	0.476	0.323	0.190
1.	Net sown area (ha)	1.077	1.077	1.077	1.077	1.322	1.322	1.322	1.322
2.	Cropping intensity (per cent)	191.1	166.8	266.2	194.2	191.8	189.8	273.8	216.2
B.	Livestock plan (No.)								
1.	Buffaloes	1.76	1.93	1.73	1.96	1.81	1.82	1.58	1.83
2.	Cows	0.80	0.61	1.10	0.53	1.03	1.04	1.64	1.02
3.	Bullocks	1.60	0.66	1.19	0.57	1.69	1.12	1.76	1.09

(Contd.)

TABLE 1 (*Concld.*)

Sr. No.	Particulars	Large unirrigated farm (Lu)				Large irrigated farm (Li)			
		Existing plan (P0)	Optimum plans			Existing plan (P0)	Optimum plans		
			P1	P2	P3		P1	P2	P3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
C.	Goal achievement levels								
1.	Foodrains production (tonne)	1.507	1.507	2.369	1.507	2.052	2.052	2.908	2.052
2.	Milk production (Kilolitre)	1.015	1.015	1.015	1.015	1.044	1.044	1.044	1.044
3.	Returns to fixed farm resources (Nepalese Rs.'000)	30.103	30.103	30.103	43.080	34.831	34.831	34.831	52.880
4.	Annual soil erosion (tonne) on								
	(a) Crop land	14.28	6.98	10.63	8.85	16.11	8.61	14.32	12.01
	(b) Pasture land)	3.66	0.28	0.50	0.24	4.48	0.48	0.74	0.46
5.	Cattle grazing (animal month)	18.95	1.44	2.62	1.26	23.21	2.46	3.86	2.40
6.	Forest fodder (tonne)	4.51	4.35	15.30	8.84	6.87	4.76	9.14	8.89
7.	Nitrogen use (kg.)	82.64	67.37	93.64	101.54	109.18	110.41	166.90	170.14
8.	Phosphorus use (kg.)	19.01	10.34	15.64	30.60	27.84	22.34	40.86	56.18
9.	Pesticide use (litre)	0.177	0.157	0.168	0.339	0.188	0.217	0.349	0.632

converted on per hectare (ha) basis (by dividing by net sown area) so as to allow inter-farm productivity comparisons, it is found that the foodgrains productivity varies only slightly from 1.40 to 1.55 tonnes per ha and the returns to fixed farm resources vary considerably from N Rs. 26,000 to N Rs. 35,000 per ha across different categories of farms.

Under the existing crop plan, the average amount of soil erosion per farm due to crop cultivation is estimated to be 6.05, 4.92, 14.28 and 16.11 tonnes per year respectively on Su, Si, Lu and Li farms. Cattle grazing varies from 10.60 to 23.21 animal months per year on different categories of farms. The soil erosion on pasture lands is estimated to be 2.04, 3.56, 3.66 and 4.48 tonnes per annum due to cattle grazing activities respectively on Su, Si, Lu and Li farms. The use of inorganic nitrogen per farm is about 29.75, 32.82, 82.64 and 109.18 kg per year respectively on Su, Si, Lu and Li farms. However, the use of phosphorus is quite less, varying from 4.41 to 27.84 kg per year on different categories of farms. The existing use of pesticides, particularly insecticides and fungicides, is found to be 36, 58, 177 and 188 millilitres per year respectively on Su, Si, Lu and Li farms.

Environment-Friendly Plan (P1)

The optimum plan P1 suggests the following modifications in the existing farm plans on different categories of farms. The maize crop is indicated to be altogether abandoned on all categories of farms except the small irrigated farms on which also about 64 per cent reduction in maize area is indicated. Similarly, about 19, 39, 33 and 53 per cent reductions in area under main season paddy over the existing plan are suggested respectively on Su, Si, Lu and Li farms. The maize crop causes a higher rate of soil erosion and the main paddy has lower productivity, hence, not preferred in the optimum plan. However, to maintain the existing level of foodgrains production, an increase in the areas under early paddy, upland paddy, millet and wheat crops is suggested in P1 plan. Early paddy has higher productivity as compared to the main season paddy. Upland paddy is grown in unirrigated land without puddling, and its higher plant density protects soil more than its competing crop of maize. The millet cultivation requires less number of bullock days per ha and, hence, less number of cows to maintain herd ratio[2] and so less feed, fodder and grazing requirements. This reduces the dependence on forest and pastures for fodder. The wheat crop is grown during winter season and the rate of soil erosion under this crop is very low. Millet and wheat straw also provides feed for animals in considerable quantities during lean periods. In this plan, about 10, 25, 17 and 19 per cent of the total cropped areas respectively on Su, Si, Lu and Li farms are allocated to farm fodder production. In the optimal livestock plan, buffaloes substitute cows for milk production on all categories of farms.[3] This plan illustrates that if bullocks are shared with good harmony on community basis by different farms, the number of bullocks actually required in the villages/area declines to about 50 per cent of the existing numbers. Since the low milk yielding cows are mainly kept for bullock reproduction, the number of cows required also decreases.

As a result of these changes in the cropping pattern and livestock composition, the optimum plan P1 indicates substantial reductions in soil erosion on crop lands by 52.07, 9.35, 51.12 and 46.56 per cent respectively on Su, Si, Lu and Li farms as compared to those in the existing plan. This plan also leads to a substantial decrease in cattle grazing and associated soil erosion on pasture lands by more than 90 per cent. Thus as compared to the existing plan, the optimum plan P1 reduces total soil erosion (both on crop lands and pasture lands) by 62.42, 44.58, 59.53 and 55.85 per cent per annum respectively on Su, Si, Lu and Li farms. The forest fodder lopping under this plan is also reduced by about 4 per cent on unirrigated farms and by 31 to 39 per cent on irrigated farms. Use of inorganic nitrogen in crop production decreases by about 40 per cent on small unirrigated farms and by 18 per cent on large unirrigated farms. On irrigated farms, however, the use of nitrogen slightly increases. Inorganic phosphorus use decreased on all categories of farms, but the use of pesticides slightly increases in some cases. Along with these reductions in the environmental problems, the optimal plan P1 fully meets the goal targets set out for foodgrains and milk production and cash farm income (REFR). Therefore, this set of P1 plans (generated for different types of farms) appears to be the most environment-friendly as it significantly reduces the levels of environmental problems as compared to those prevailing in the existing farm plans, while maintaining the present levels of foodgrains and milk production and cash farm income. Thus the hypothesis set out earlier is accepted that the optimum farm planning could considerably reduce the adverse environmental effects from hill agriculture.

It can be seen from Table 2 that in this optimum plan, the foodgrains production goal conflicts with forest fodder lopping goal on all farm categories (except Si farms). The trade-off magnitude varies from 21.22 to 26.25 tonnes of increased forest fodder requirements for every one tonne further increase in foodgrains production beyond the level indicated in P1 plan for these farms. On Si farms, however, foodgrains production goal is found to have a conflict with cattle grazing goal and inorganic nitrogen use goal, the respective trade-off quantities being 36.07 animal months of increased grazing and 35.32 kg of increased nitrogen requirements per tonne of further increase in foodgrains production in this plan. On Li farms, foodgrains production also has a conflict with pesticides use, the trade-off quantity being 1.38 litres of increased pesticides use per tonne of further increase in foodgrains production in this plan. Similarly, the goal of returns to fixed farm resources is found to have a conflict with forest fodder goal on all farms, except on Si farms where it conflicts with cattle grazing and nitrogen use. In addition, the RFFR on Su and Li farms is also found to have a conflict with pesticides use.

Effects of Raising Foodgrains Target

Plan P2 outlines the optimal crop and livestock plans and the associated levels of environmental effects when the target for foodgrains production is increased by about 40 to 60 per cent on different categories of farms so as to achieve a uniform yield of 2.2 tonnes per ha of foodgrains on all categories of farms. This plan envisages substantial increases in the areas under main paddy and maize crops as compared to the environment-friendly P1 plan. Therefore, the levels of soil erosion on crop lands under this plan increases substantially, while those on pasture lands increase only marginally on all categories of farms. The amount of fodder harvesting from forests also increases in most of the cases except on Si farms. The plan also shows that the inorganic nitrogen and phosphorus requirements shoot up in most cases, while pesticides use becomes slightly higher on large farms. All these levels of adverse environmental effects in this plan are quite higher as compared to the P1 plan. Thus further efforts to raise foodgrains production targets on hill farms are expected to cause increased soil erosion, dependence on forests for fodder and use of agro-chemicals.

It can be seen from Table 2 that the foodgrains production conflicts with inorganic nitrogen use on all but Su farms. On Su farms, however, the foodgrains production is found to have a severe conflict with soil erosion. The foodgrains production is also found to have a conflict with cattle grazing on Sri farms and with forest fodder harvesting on Lu and Li farms.

TABLE 2. GOAL CONFLICTS AND TRADE-OFFS BETWEEN ENVIRONMENTAL PROBLEMS AND FOODGRAINS PRODUCTION/INCOME GENERATION

Goal conflicts	Trade-off levels*											
	P1 plan				P2 plan				P3 plan			
	Su	Si	Lu	Li	Su	Si	Lu	Li	Su	Si	Lu	Li
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Foodgrains production and												
Soil erosion	-	-	-	-	12.35	-	-	-	-	-	-	-
Forest fodder	23.19	-	21.22	26.25	-	-	44.80	40.35	-	-	27.33	-
Cattle grazing	-	36.07	-	-	-	55.10	-	-	30.16	36.07	-	44.07
Nitrogen use	-	35.32	-	-	-	31.83	72.10	43.72	-	-	107.85	124.38
Phosphorus use	-	-	-	-	-	-	-	-	-	-	-	-
Pesticide use	-	-	-	1.38	-	-	-	-	-	-	-	-
Returns to fixed farm resources and												
Soil erosion	-	-	-	-	-	-	-	-	-	-	-	-
Forest fodder	0.76	-	0.85	0.86	-	-	1.14	-	0.76	0.79	-	1.03
Cattle grazing	-	0.79	-	-	-	-	-	-	-	-	1.33	-
Nitrogen use	-	2.44	-	-	-	-	3.39	-	-	-	10.28	7.52
Phosphorus use	-	-	-	-	-	-	-	-	-	-	-	-
Pesticide use	0.02	-	-	0.11	-	-	-	-	0.02	0.08	-	-

Notes: * Shows increase in the amount of the concerned environmental impact parameter for every unit further increase in foodgrains production or returns to fixed farm resources.

Units of measurement are: foodgrains production, soil erosion and forest fodder in tonne, cattle grazing in animal months, nitrogen and phosphorus uses in kg pesticides in litres and returns to fixed farm resources (RFFR) in thousand Nepalese rupees.

Dash (-) indicates no goal conflict.

Effects of Raising Farm Income Target

Plan P3 portrays the optimal crop and livestock plans and the associated environmental effects when the target for returns to fixed farm resources (REFR) is increased by about 15 to 50 per cent over the existing level on different farm categories, so as to achieve a uniform rate of return of N Rs. 40,000 per ha on all categories of farms. This plan envisages slight increases in the areas under vegetable crops with some readjustments in the areas under foodgrain crops over those in the earlier plans. The increased cash generation in plan P3 moderately increased soil erosion on crop lands and forest fodder lopping, but drastically increased the use of agro-chemicals as compared to those in plan P1. The rates of soil erosion and forest fodder lopping in plan P3, though higher than those in the optimum plan P1; are found to be lower than those in plan P2. Cattle grazing and the associated soil erosion on pasture lands, however, are observe to be the minimum in this plan among all the plans discussed here. The use of inorganic nitrogen and phosphorus in this plan increases drastically on large farms and marginally on small farms as compared to the existing as well as P1 plans. Also, the use of pesticides under this plan doubles and even triples on some farms as compared to that in P1 plan. However, the levels of environmental problems relating to soil erosion, cattle grazing and forest fodder are relatively less in P3 plan than in P2 plan. But, the use of agro-chemicals, particularly on large farms, are found to be quite higher in P3 plan as compared to P2 plan. Thus raising cash farm incomes through increased vegetable production is relatively more environment-friendly than raising foodgrains production (plan P2), as it would help conserve the natural resource base of land and forests.

Table 2 exhibits the conflicts of RFFR goal with pesticides goal on small farms and with inorganic goal on large farms. The RFFR goal also has a conflict with forest fodder on all farm categories, except Lu farm on which it has a conflict with cattle grazing goal.

IV

CONCLUSIONS AND POLICY IMPLICATIONS

The results presented and discussed earlier emphasise that the adverse environmental effects resulting from hill agriculture can be considerably reduced by multiobjective optimal farm planning, and that raising cash farm income through vegetables production is relatively more environment-friendly than raising foodgrains production on hill farms. In this section, some policy planning implications of effecting the changes in cropping pattern and livestock composition as envisaged in the environment - friendly plans are brought out.

Since most of the farmers in the district are presently away from cash economy and grow mainly foodgrain crops, the general price policy may not initially be practical for effecting farm level changes. The zoning policy for agricultural land use, such as restricting the main season paddy production on low lying areas, maize cultivation in the level terraces and reducing the number of cows in the hills, seems to be technically sound for the hills, though it may have some problems relating to administrative efficacy. The non-price economic incentives along with emphasis on optimal crop planning through extension education would constitute the more promising and pragmatic policy measures at the initial stage to achieve the desirable changes in crop and livestock plans.

Subsidised inputs (especially the seeds and credit) and extension education for improved practices in favour of environmentally better suited crops like wheat and millet can increase the popularity of these crops. In addition, extension education relating to better food quality and nutritional aspects of wheat and millets would also be helpful in bringing a gradual change in the food habits of the otherwise rice eating local people. The unrestricted grazing of cattle in the hills during the winter season is one of the major problems faced in wheat area expansion. Therefore, area-based community efforts could help succeed in expanding wheat acreage. The optimum plan does allocate some land for farm fodder which reduces the extent of cattle grazing needs. Yet, some grazing by cows and bullocks would be required which has to be regulated on the village pastures and other fallow lands. For this purpose, user groups on pocket area basis can be formed to practice regulated and controlled grazing and growing of farm fodder, millets and wheat crops. These groups are to be provided with full extension back up and subsidised input supplies of seeds and credit for millets and wheat crops.

The optimum plan also suggests the substitution of buffaloes for cows for milk production. Compared to the cows, the buffaloes have higher milk productivity, with more percentage of fats in milk. Hence, a premium price on higher milk fat by the Dairy Development Corporation, the largest purchaser of milk from the farmers of Dhading district, can help generate the market forces in favour of buffalo rearing. Further, the lower demand for bullocks in the optimal plan would also help in keeping the low cattle herd ratio. For this purpose, the pool of bullock labour, while maintaining the private ownership, could be managed by the user groups on community basis so that it can be smoothly shared by all the farm households.

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NOTES

1. The deviations at the first and third priority levels are weighted with their respective market prices as these relate to marketable goods. At the second priority level, the weight given to grazing is unity and the deviation in the goal of forest fodder harvesting is weighted with the inverse of green fodder amount required to substitute one hour of grazing. Similarly, deviation in the soil erosion goal is weighted with the inverse of the estimated amount of soil erosion caused per hour of cattle grazing.

2. Buffaloes are preferred in the plan for their higher milk yield, and these require no grazing. While this is quite a desirable feature, certain ratio of cows in the herd is also necessary for supply of bullocks for farm operations. Therefore, the existing district level cow-bullock ratio is maintained in the model.

3. Though, in a single farm plan, usually integer constraints on livestock activities are desirable, it is avoided here as the plan figures represent an area based land use planning. A small rounding off in the number of cows/buffaloes aggregate to a large bias in fodder needs.

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