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AGROECOSYSTEM FUNCTION AROUND A HIMALAYAN BIOSPHERE RESERVE*

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ABSTRACT

Structure and functions of the agroecosystems in the buffer zone of Nanda Devi Biosphere Reserve (Uttaranchal Himalaya) inhabited by Bhotiya communities were studied using ecological and economic currencies to assess the impact of the conservation policies on the traditional agroecosystems of the buffer zone along an elevational gradient over a period of two years. Implementation of conservation policies has tremendously curtailed the availability of natural resources which sustained the agroecosystems of this region since time immemorial. Three representative villages—Lata at lower elevation

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(1900-2400m amsl), Tolma at middle elevation (2400-2800m amsl), and Malari at higher elevation (2800-3600m amsl)—were considered for the study. Rain-fed cultivation on steep terraced slopes is the predominant form of land use and only 8 percent of the total cultivated land is irrigated. Over 31 species of food value comprising cereals, pseudocereals, millets, pulses, oil seeds, vegetables, etc. and eight species of medicinal and aromatic plants are grown in the traditional agroecosystems of the study area. However, recently the acreages of many of these crops, such as *Eleusine coracana, Fagopyrum esculentum,* and *Panicum miliaceum,* have declined by 25 percent to 50 percent within the last three decades (1970-75 to 1990-95) due to various reasons. Grain/tuber and crop by-product yield (kg/ha) of the crops found common in the area was recorded maximum at higher elevation region of the NDBR as compared to lower and middle elevation regions except for *Hordeum himalayens* and *Triticum aestivum.* Energy output to input ratio of different crops grown under rain-fed conditions ranged between 0.97 and 4.3 at lower elevation, 0.95 and 4.25 at middle elevation, and 1.5 and 4.9 at higher elevation. However, under irrigated conditions, which exist only in the higher elevation zone in the study area, the energy efficiency ratio of crops grown was recorded between 1.8 and 6.3.

In general, the energy efficiency (considering all the outputs—grain or tuber yield, crop by-product, fruits, fuel, and herbaceous fodder from the agroecosystems) was observed to be higher for the summer and winter season crops of the lower and middle elevation regions of the buffer zone than for the summer season crops of higher elevation. However, the monetary output-to-input ratio was found to be higher for medicinal plants cultivation at all the elevation regions (output-to-input ratio ranging between 10 and 13) than for the kitchen garden (output-to-input ratio ranging from 4.7 to 5.6) and crops grown in agricultural land at higher, middle, and lower elevation regions (output-to-input ratio ranging between 2.3 and 5.19). Among the agricultural crops cultivated in the buffer zone, monetary output-to-input ratio was obtained maximum for the mixed cropping of *Solanum tuberosum* (potato) and *Phaseolus vulgaris* (kidney bean) among the crop combinations at all the elevations. This ratio was 7.6 under irrigated conditions and 7.2 in rain-fed condition at higher elevation. The ratio was observed least for *Hordeum himalayens* (0.59) at lower elevation. The yield potential and energy efficiency of some of the crops of the NDBR buffer zone have been compared with crops of different agroecosystems of the Himalayan region. It has been found the crops of the study area are giving lower returns in terms of yield and showing lower efficiency in terms of energy compared to crops of the other agroecosystems of the Himalayan region.

INTRODUCTION

The agroecosystems in the buffer zone area of Nanda Devi Biosphere Reserve, India (NDBR) are largely dependent on the surrounding forests for natural resources. Farming systems have evolved through the process of trial and error over centuries. Similar to many other parts of the Central Himalaya, the agro-ecosystem of the buffer zone of NDBR, due to variations in climatic conditions, unavailability of reliable markets, and small and fragmented landholdings on small terraces, has led the farmers to adopt subsistence farming systems which are characterized by substantial diversity and a high degree of self-reliance [1-5]. The people living in the buffer zone of the Chamoli part of the Biosphere Reserve are called Tolchhas, a sub-community of the Bhotiya tribe. These people still practice transhumance and before 1962 their main occupation was trade with the Tibet. But due to the Indo-China war in 1962, the trade links were completely stopped and then the residents started concentrating on agriculture and related activities for their livelihood. However, the creation of the Biosphere Reserve and the imposition of conservation policies reduced the availability of natural resources to support agriculture. The change from traditional subsistence agriculture to cash-crop-based agriculture has been advancing in the last few years. Many traditional crops thus totally vanished; some others are at the brink of extinction. Consequently, the ecological and economic security of the traditional agro-ecosystems of this area appears to be in jeopardy, as in other parts of the Central Himalaya [3]. The present study aims to understand the structure and functioning of the traditional agroecosystems of the buffer zone after the implementation of conservation policies in terms of: a) cropping patterns and yield potentials of various crops at different elevation zones of NDBR; b) energy and economic efficiencies of these agroecosystem types; and c) aims to suggest an appropriate strategy for conservation and re-development of traditional agroecosystems with the overall goal of biodiversity conservation in the Biosphere Reserve.

STUDY AREA AND CLIMATE

The Nanda Devi Biosphere Reserve (NDBR) is one of the 14 Biosphere Reserves in representative ecosystems of India. It is located in the Himalayan highlands bio-geographic province of India, spread into three districts of Uttar-anchal, namely, Chamoli, Bageshwar, and Pithoragarh. It is named after the tenth highest mountain peak (Nanda Devi, 7817m) in the world (and second highest in India), which carries the name of the famous Goddess of the region, "Nanda Devi." The region was declared a Biosphere Reserve on January 18, 1988 under UNESCO's Man and Biosphere (MAB) program. The reserve covers a total area of 2236.74 km^2 with a core zone of 624.62 km^2 and a buffer zone of 1612.12 km^2 (Figure 1).

In the Chamoli part of the NDBR's buffer zone, the rural settlements are spread within the altitudinal limits of 2200 and 3600m amsl. The climatic year consists of three distinct seasons—summer (April-June), rainy (July-September), and winter (October-March). Average rainfall is about 900mm. About 48 percent of the annual rainfall occurs in a short period (July-August) featuring a strong monsoonic influence. Monthly maximum and minimum temperatures range

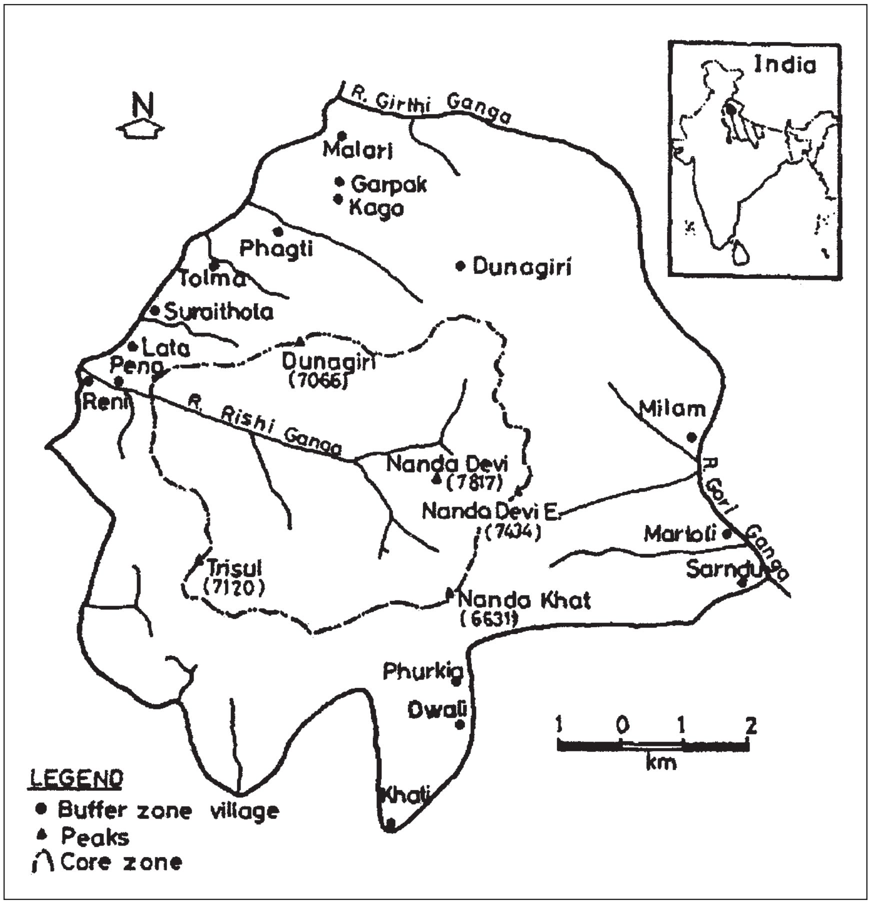

Figure 1. Location map of Nanda Devi Biosphere Reserve (NDBR).

between 24°C and 14°C and 7.5°C and 3.0°C, respectively (Figure 2). Parent material is crystalline rock, including garniferous mica schists, garnet schists, and mica quarzite. The soils in general are deep in agricultural land, black in color, loam to sandy loam, and excessively drained.

DESCRIPTION OF THE RURAL SETUP

A total of 17 villages are situated in the buffer zone of NDBR, of which 10 fall in the Garhwal division (Chamoli district) and 7 in the Kumaon (districts Bageshwar and Pithoragarh) division of Uttaranchal Himalaya. The present study was carried

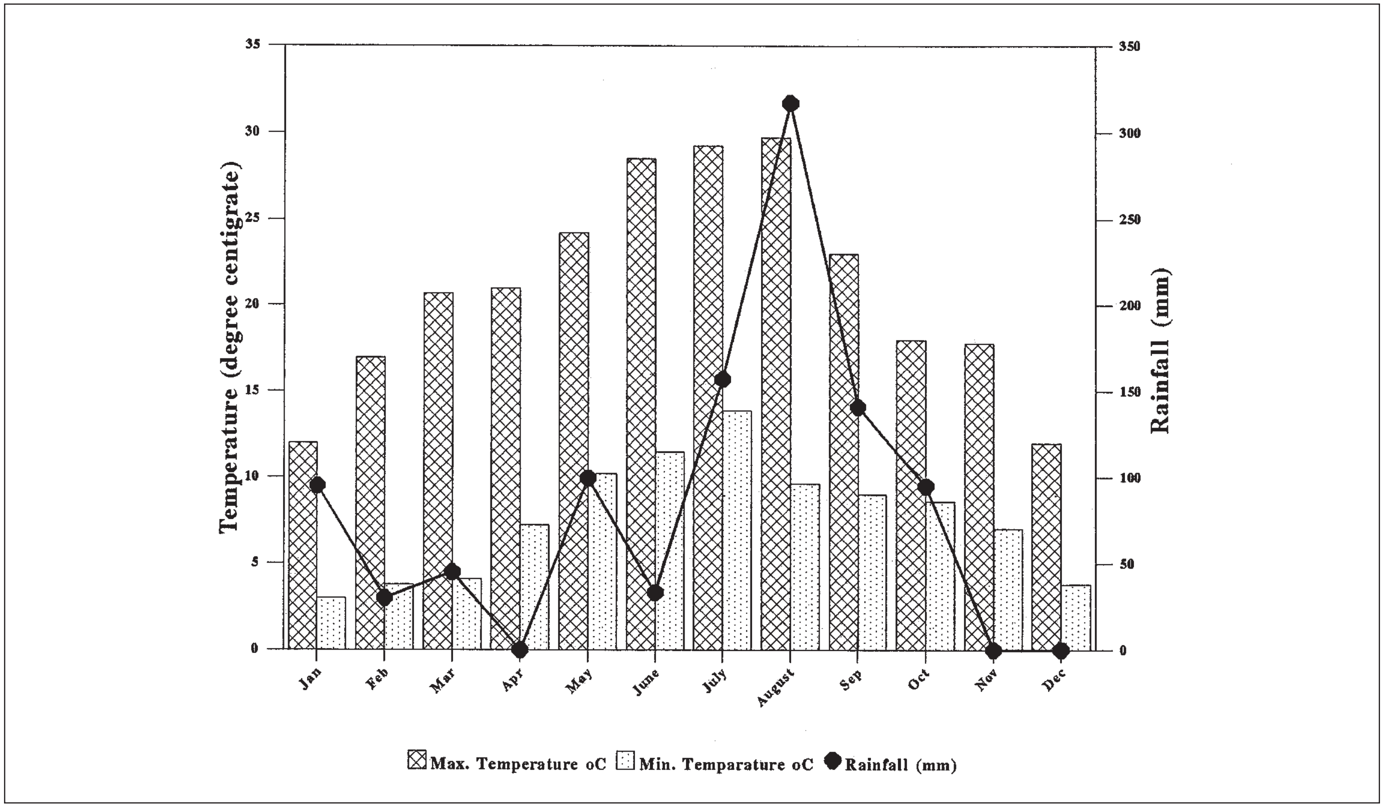

Figure 2. Climatic data (rainfall, mean monthly maximum and minimum temperatures) for the study area (buffer zone of NDBR).

out in the 10 buffer zone villages located in the Chamoli District of Garhwal division of Central Himalaya. The total population of the villages was 2253 (782 male adults, 781 female adults, and 750 children below 15 years of age). The people of the study area belong to the Tolchha sub-community of the Bhotiya tribe. They belong to Indo-Mongoloid ethnic groups and practice trans-humant patterns of life. Except for the residents of Reni, Peng, Lata, Phagti, Laung, and Tolma villages, the villagers have two permanent dwellings: one at high altitude (summer dwelling) between 2800-3600m amsl, and the other (winter dwelling) in the lower valleys (outside of the NDBR buffer zone) between 800-1500m amsl. This community has its own traditions, culture, and religious beliefs. The people of the region were principally traders. Rearing livestock (particularly sheep and goat) was their subsidiary occupation. Their trade relationship with Tibetans was strong before the Indo-China war. At that time, they would carry wheat, rice, and buckwheat to Tibet through different passes and border routes, in exchange for salt and wool. As noted, the trade links were stopped after the 1962 war.

The medicinal and aromatic plants, for which the Tolchha had already established the market in the lower valleys of the region long ago, began to be collected in large quantity for commercial purposes. These species also began to be cultivated on a smaller scale as low-volume, high-value crops for exchange or barter with local food commodities in other areas of the region. Besides, one or two members of each family were engaged in mountaineering expeditions as a laborer or porter, or as a tour guide. This practice has been prevalent in the region since 1939.

Due to its unique ecological and cultural importance, the area was declared Nanda Devi National Park in 1982 and a biosphere reserve in 1988. With the imposition of the attendant conservation policies, the rights of local people to use natural resources were curtailed, which created the conflicts among the locals and Biosphere Reserve authorities. However, to resolve the conflicts, various developmental activities were initiated by government agencies in the region. Since the developmental package or planning was not done in accordance with local demands, most of these activities were not implemented. The local community has been facing a series of problems during the recent past that stem from these conservation policies. When further restrictions were imposed on the collection of wild resources, the area under cultivation, and number of species of medicinal and aromatic plants, which initially were brought under cultivation after the Indo-China war, were increased.

Livestock reared by the inhabitants are cows, bullock, sheep, goats, horses, and mules. All households depend entirely on the forest for fuel, timber, fodder, and leaf litter for organic manure. Wild resources make a significant contribution to food security.

METHODOLOGY

The buffer zone villages of Nanda Devi Biosphere Reserve (NDBR) in the Chamoli district were studied during 1995-1998. All households in all villages were surveyed with a questionnaire to note land-holding size, the area under different crops, crop compositions, cropping patterns, and crop rotations. The information was collected through informal discussions with knowledgeable members of the families. Each household was visited at least 5-6 times during each cropping period. Based on altitudinal variation and its corresponding effects on crop compositions, cropping patterns, crop rotations, and availability of natural resources, the entire buffer zone had been divided into three elevation regions: 1) lower (1900-2400m amsl); 2) middle (2400-2800m amsl; and 3) higher (2800-3600m amsl). Out of the 10 villages, three representative villages (one from each region) were selected for in-depth agroecosystem analysis. The main characteristic features of selected villages are given in Table 1. Traditional crops of the region are cultivated in pure and mixed forms in rain-fed (at all elevations) and irrigated conditions (at higher elevation) in the study area. Three replicate plots were identified in each studied village for detailed ecological analysis of the agroecosystems. At the higher elevation where irrigation was used, three replicate plots for each crop/crop mixture were selected. Care was taken to ensure similar aspect and topographic conditions to minimize the errors in the analysis. The yield (grain and crop by-product) was calculated based on 50 quadrats (50 × 50 cm) in each marked replicate plot at the harvesting time. The average yield of the 50 quadrates was further extrapolated per hectare (kg/ha). Assessment of declining crop diversity was based on the methodology given by Maikhuri et al. [1].

The input of energy through seed was calculated on the basis of the total energy expended to produce that fraction of the crop yield. Energy input through animal power (1 bullock/hour = 3.03 MJ) was based on Mitchell [6]. Labor inputs in worker hours were calculated for different cropping systems. Total food energy consumed was apportioned to each activity, according to the relative duration, on the basis of grouping involving either sedentary, moderate, or heavy work. An energy expenditure per hour of 0.418 MJ for sedentary, 0.488 MJ for moderate, and 0.879 MJ for heavy work for an adult male, and 0.331 MJ for sedentary, 0.383 MJ for moderate, and 0.523 MJ for heavy work for an adult female, was used to calculate the labor energy input into the system [7]. The input of organic manure into the agriculture was converted into energy by multiplying the quantities with the standard replacement cost values in terms of commercial fertilizer.

For calculating the output of energy under different crops (for mixed and mono cropping), the total economic yield of various crops was converted into megajoules of energy by multiplying them by standard values given for various edible parts of crops (Table 2). The energy values of medicinal plants were estimated after burning the samples in a bomb calorimeter on the basis of oven-dry

Table 1. Characteristic Features of the Buffer Zone Villages Situated Along an Elevational Gradient in NDBR, Uttaranchal Himalaya

Parameters	Lower altitude	Middle altitude	Higher altitude
Altitude	1900-2400m amsl	2400-2800m amsl	2800-3600m amsl
Transhumance	Not practiced	Practiced (short migration)	Practiced
Cropping patterns	3 crops per 2 year	3 crops per 2 year	1 crop per year
Distance from NDBR core zone	5-8 km	3-4 km	>12 km
Main occupation	Agriculture	Agriculture	Agriculture
Subsidiary occupation	Animal husbandry	Animal husbandry	Animal husbandry
Horticultural trees	Present	Present	Absent
Number of cultivated agricultural crops	14	12	10
Number of cultivated medicinal plant species	3	4	8
Land under traditional crops (ha)	105	61	107
Land under medicinal plants (ha)	2.12	3.49	5.79
Total arable land (ha)	107.12	64.49	112.79
Villages	Lata, Reni, Peng	Tolma, Phagti, and Laung	Malari, Dronagiri, Kaga, and Garpak

(80°C) weight of samples. The values of energy thus obtained (nutritive value) were then corrected to the heat of combustion by applying the following formula:

$$\text{Energy value} = \frac{\text{W} \times \text{temperature difference} - (\text{t} + \text{w})}{\text{Wt. of the sample}},$$

where t and w = calorific value of thread and wire respectively.

The energy efficiency of each system was calculated as the output/input ratio. Fruit trees are planted on the raised field margins of the agricultural terraces

Table 2. Energy Values for Different Crops and Other Items Used in the Villages (Values Expresed as Dry Weight MJ Equivalent) Based on [6]

Category	MJ/kg
Grain	16.2
Millets	13.8
Pseudocereals	14.2
Pulses (various beans)	17.1
Leafy vegetables	15.8
Root and tubers	15.3
Mustard	22.7
Straw	14.0
Fruit	9.1
Milk	2.9
Farmyard manure (compost)	7.3

observed in the lower and middle altitudinal region of the buffer zone; their density was measured in 20 randomly laid 10m × 10m quadrats. The fruit trees were further classified as less than 10 years old, from 10 to 15 years old, and more than 15 years old. Five representative trees of each class of each species were selected to determine the production of fruits, fuelwood, and other products per tree.

For the cost-benefit analysis, labor for male and female workers and animal labor costs were calculated on the basis of prevailing daily wages or charges. The monetary returns in terms of crops (grain and by-products), fruits, edible oil, feed, and fuelwood were calculated based on the prevailing market price for each commodity. Export of the traditional crops from the villages was assessed through questionnaires for the elderly and knowledgeable persons of each household of each study village. The information collected was further cross-checked by making direct measurements when the villagers sold their produce in nearby markets after harvesting the crops.

RESULTS

General Description of the Agroecosystem of the Buffer Zone of NDBR

In the entire buffer zone, the rain-fed agriculture on steep terraces is the predominant form of land use, while only about 22.4 ha (8 percent of the total cultivated land) of land is irrigated. Irrigation is practiced only in one village, Malari, which lies at 3200m amsl in the buffer zone. All households of the region were involved in agriculture. The average landholding is about 0.67ha/household (0.12ha per capita). The rain-fed agriculture in the villages of the lower and middle regions is practiced on two nearly halves of agricultural land locally called "sari" with different crop compositions. A summer (April to October) and a winter crop (October to June) is harvested, the tradition being to let a sari lie fallow during one winter season every period of two years. In villages of the higher zone, the crops are cultivated only during the summer or "kharif" season and lies fallow in the winter or "rabi" season for 5-6 months due to the harsh climatic conditions. The crop rotations, cropping patterns, and crop composition practiced in buffer zone villages are depicted in Figure 3. The major crops cultivated in the lower and middle regions of the buffer zone are *Amaranthus* spp (amaranth), *Phaseolus vulgaris* (kidney bean), *P. lunetus* (a kidney bean locally known as chhimi), *Fagopyrum* spp (buckwheat), *Eleusine coracana* (finger millet), *Panicum miliaceum* (hog millet), *Solanum tuberosum* (potato), *Triticum aestivum* (wheat), *Hordeum vulgare* (jau), and *H. himalayens* (naked-barley). The higher regions grow *Phaseolus vulgaris* (kidney bean), *Fagopyrum* spp (buckwheat), *Panicum miliaceum* (hog millet), *Solanum tuberosum* (potato), and *Hordeum himalayens* (naked barley). Eight species of medicinal and aromatic plants (*Allium humile, A. Stracheyi, Angelica glauca, Pleurospermum angelicoides, Saussurea costus, Carum carvi, Megacarpaea polyandra* and *Dactylorhiza hatagirea*) are cultivated by the villagers of the higher region. Four (*Allium humile, A. stracheyi, Saussurea costus,* and *Carum carvi*) and three species (*Allium humile, A. stracheyi,* and *Carum carvi*) are cultivated in the middle and lower regions, respectively. *Allium* species covered 86 percent, 83 percent, and 60 percent of the total land under medicinal plant cultivation in lower, middle, and higher elevation zones, respectively. The smallest portions are devoted to *P. angelicoides* and *M. polyandra* in the higher region. As noted, a variety of horticultural trees (apple, apricot, and walnut) that provide fruits and fuel are grown on the raised margins of the rain-fed terraces in the lower and middle elevational zones. Seasonal and off-seasonal vegetables such as cucurbits, ginger, cabbage, and green vegetables are grown in kitchen gardens (estimated at from 0.003ha to 0.015ha/household).

Of the 67 predominant food crop species of the Central Himalaya, about 31 species of food crops—cereals (3), pseudocereals (5), millet (2), and pulses (6), and oil-yielding crop (1), vegetables (14), and medicinal and aromatic plants (8)—are grown in the traditional agroecosystems of the NDBR buffer zone.

Crop Diversity

Crops such as *Echinochloa frumentacea, Glycine max, Fagopyrum* spp, *Setaria italica,* and *Pennisetum typhoides,* which were grown in 1970-75, have completely vanished from the area. The area under cultivation of *Eleusine coracana,*

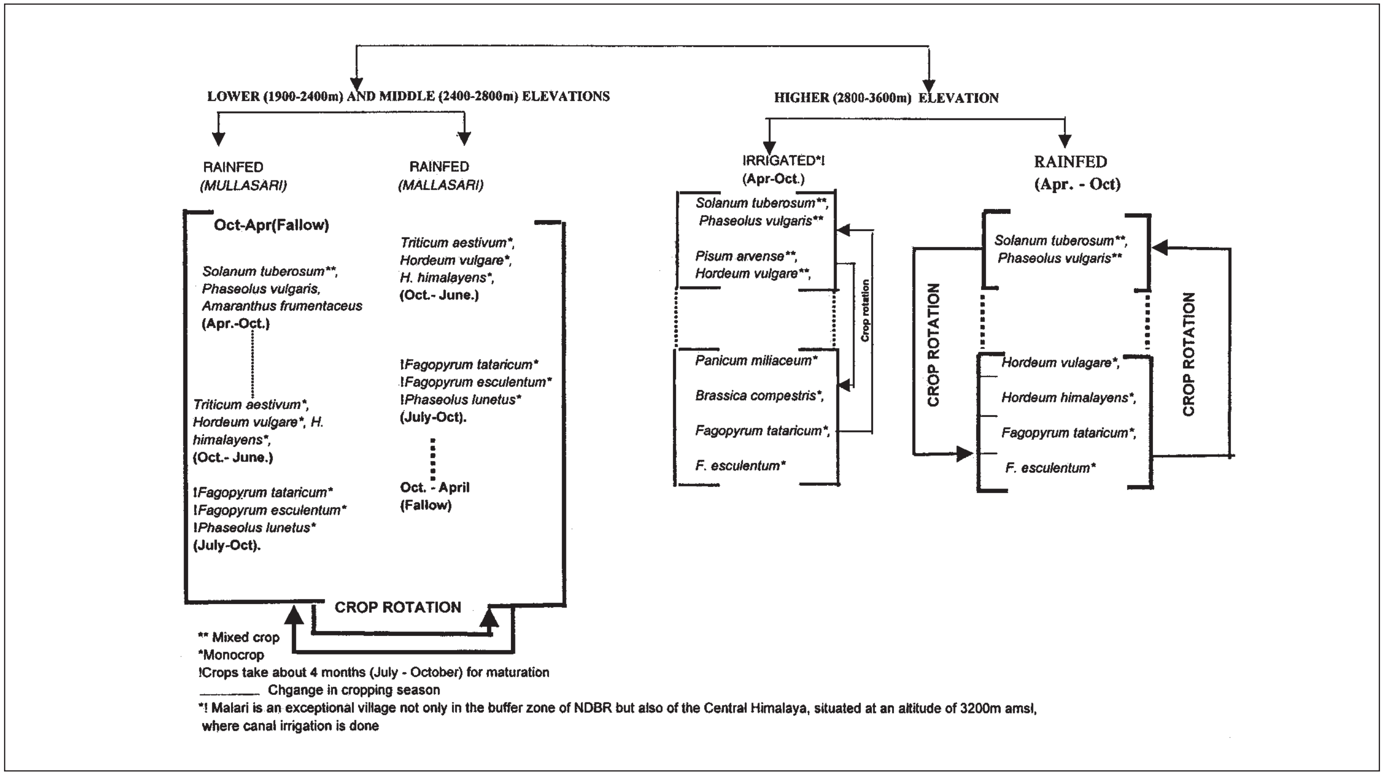

Figure 3. General cropping patterns, crop compositions, and crop rotations in the villages along an elevational zone in the buffer zone of NDBR.

Fagopyrum esculentum, Hordeum himalayens, Panicum miliaceum, Pisum arvense, and *Triticum aestivum* has been reduced by 25 percent to 50 percent during the last three decades (Figure 4). However, the area under cultivation of several traditional crops such as *Amaranthus, Fagopyrum tataricum, Hordeum vulgare, Phaseolus* spp. (kidney bean), and *Solanum tuberosum* has increased during the same period because of increasing market demand. Cultivation of six medicinal plant species (*Angelica glauca, Pleurospermum angelicoides, Saussurea costus, Carum carvi, Megacarpaea polyandra,* and *Dactylorhiza hatagirea*) has emerged during the 1980s in the villages of the high region of the NDBR.

Yield Potential

The yield (grain/tuber) of all crops and by-products was generally higher in the high region than in the lower and middle ones. For crops, mixed cropping of *Solanum tuberosum* and *Phaseolus vulgaris* provided maximum yield in the higher region and mixed *Amaranthus* and *Phaseolus* gave the smallest yield in the rain-fed conditions of the lower region of the buffer zone. *Solanum tuberosum* alone provide six to seven times the yield of the other crops in the lower and higher zones. Other crops, cultivated as a monocrop, varied little in yield with the highest yield exhibited by *Phaseolus vulgaris* and the lowest by *Brassica compestris* in the middle region (Figure 5a). Crop by-product yield was greatest for mixed cropping of *H. himalayens* and *P. arvense* (followed by *P. milliaceum*) in the higher region, and *Amaranthus* sp. and mixed cropping of *Solanum tuberosum* and *Phaseolus vulgaris* and *Amaranthus* sp. in the lower and middle region.

Among the crops cultivated in irrigated land, potato in pure form exhibited the highest yield followed by *Solanum tuberosum* and *Phaseolus vulgaris* (combined) and *Fagopyrum esculentum* (pure). *B. compestris* gave the smallest yield. However, crop by-product yield was highest for *P. milliaceum* and lowest for *S. tuberosum* (Figure 5b).

Energy and Economic Efficiency

Total energy input was greatest for *Eleusine coracana* in monocropping in the lower region, followed by *Amaranthus* and *Fagopyrum esculentum* in the middle region, and was lowest for *H. hemalayense* in the higher region. *F. tataricum* (in pure form) required more energy input than the other crops of the higher region. Among the mixed crops, *S. tuberosum* with *P. vulgaris* used the most energy in all regions.

Common crops and crop combinations showed greater energy and monetary outputs in the higher zone than in the middle and lower zones, except in the case of *T. aestivum, H. himalayense, H. vulgare,* and *B. campestris.* These four crops exhibited the highest energy and monetary outputs in the lower region. When only tuber is counted as an output among the crops cultivated at all elevations,

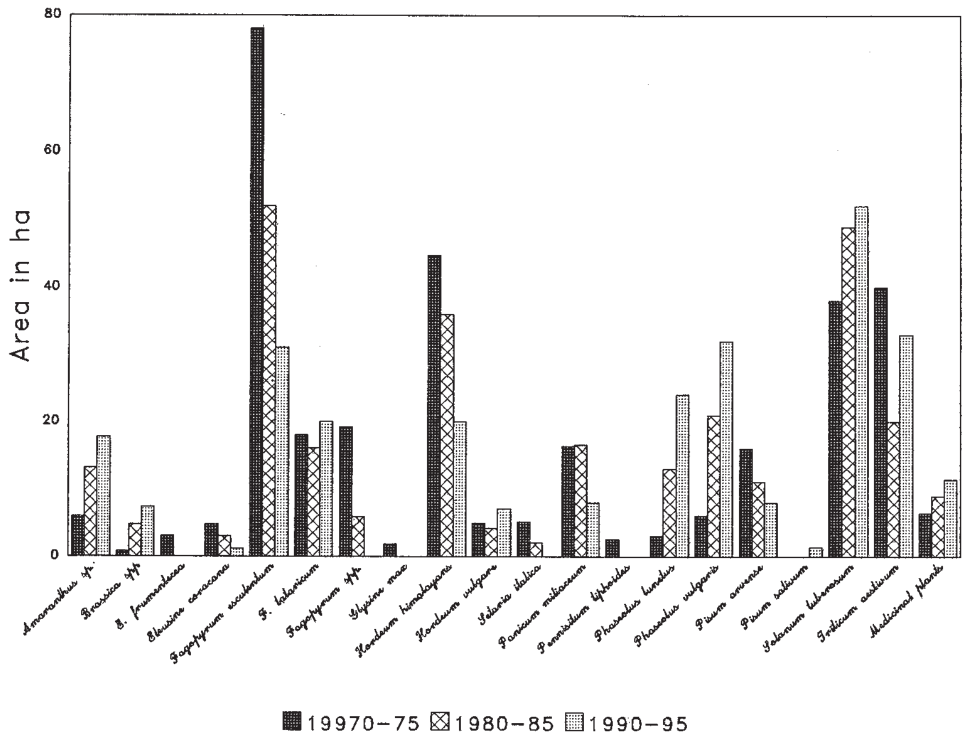

Figure 4. Change in area (ha) under different crops at three points of time.

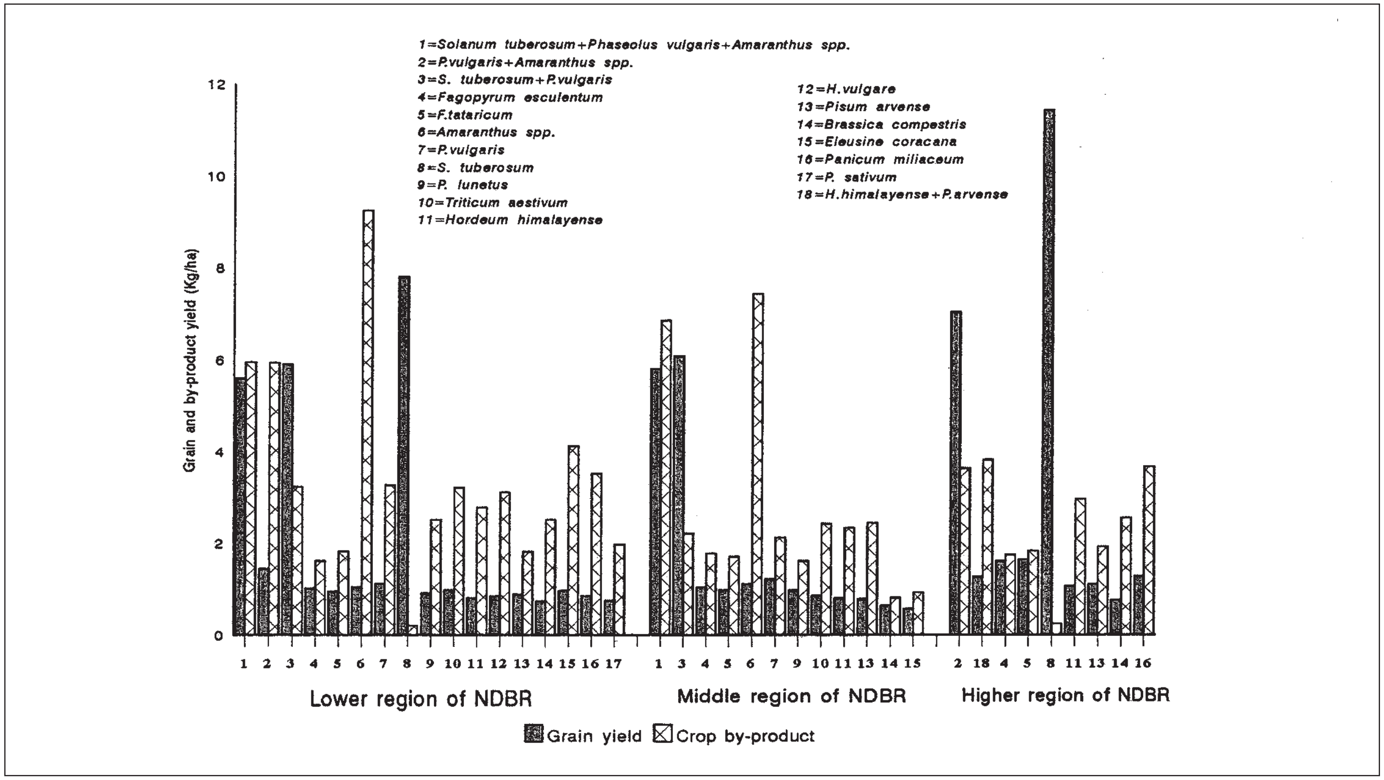

Figure 5a. Grain and crop by-product yield (kg/ha) for different crops in the studied villages situated along an elevational zone of the buffer zone of NDBR.

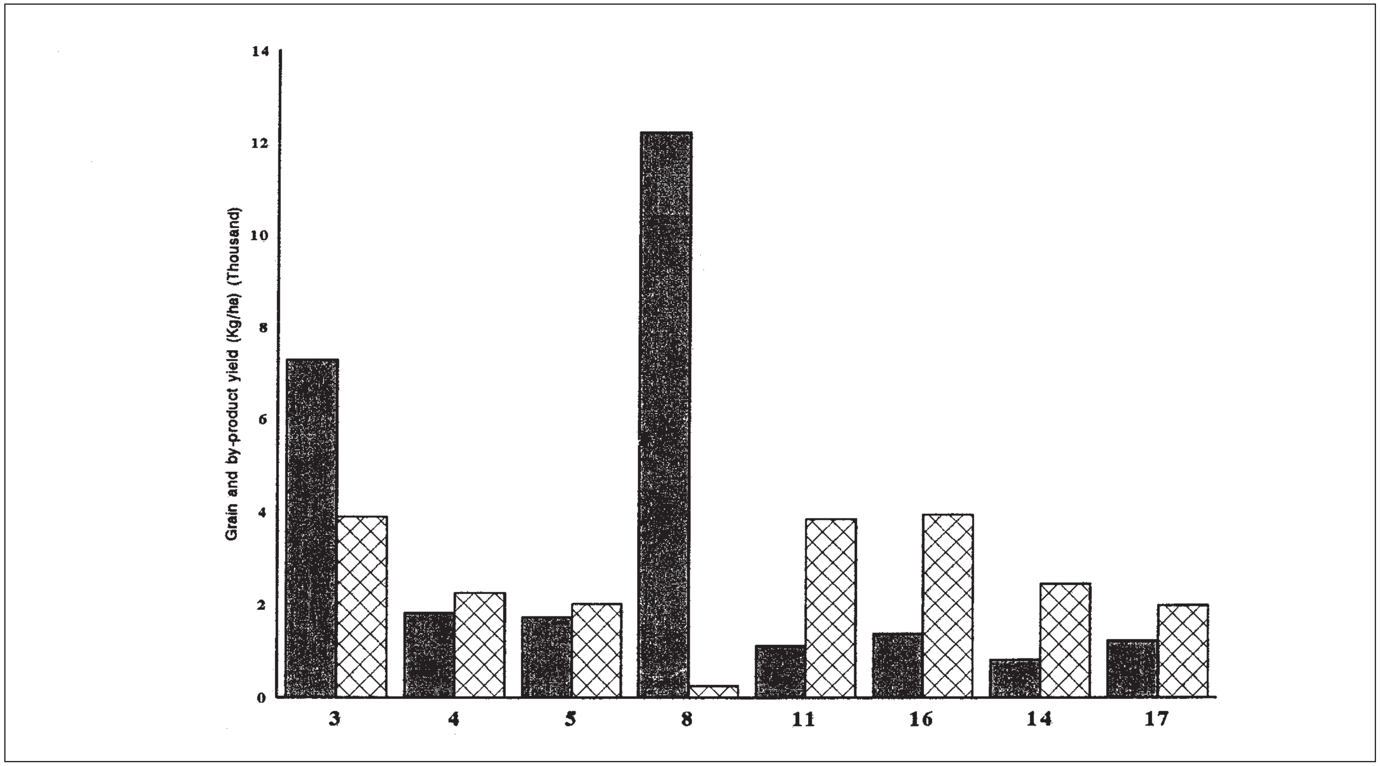

Figure 5b. Grain and crop by-product yield (kg/ha) for different crops grown under irrigated condition in the studied village located in the higher elevation zone.

S. tuberosum in pure form in the higher region exhibited the maximum energy output-to-input ratio (4.6). *E. coracana* in the lower region had the smallest (0.36). When the grain and by-product yield were combined, the energy efficiency ratio was higher for *P. miliaceum* and *H. himalayense* (4.9) followed by *S. tuberosum* (4.7), grown in the higher region in pure form, than for mixed cropping of *S. tuberosum* and *P. vulgaris* and *Amaranthus* and *S. tuberosum* and *P. vulgaris* in the middle and lower regions, respectively. Energy efficiency was higher for medicinal plants than for traditional crops, the former ranged between 1.03MJ/ha (*D. hatageria*) and 6.7MJ/ha (*P. angelicoides*).

The highest monetary efficiency was obtained in all three zones by mixed cropping of *S. tuberosum* and *P. vulgaris:* 7.2, 5.1, and 4.8 in the high, middle, and lower regions, respectively. Yet, cultivated medicinal and aromatic plants exhibited two to three times the monetary benefits overall as compared to traditional crops, as seen in Table 3.

However, among the crops cultivated in irrigated land, in pure or mixed form, *S. tuberosum* exhibited the highest energy and monetary efficiency of all crops when grain/tuber yield was considered alone. If both grain/tuber and crop by-product yield are considered, *P. miliaceum* gave the lowest energy efficiency. The monetary efficiency was highest for mixed cropping of *S. tuberosum* and *P. vulgaris* and lowest for *P. miliaceum. S. tuberosum* and *Pisum arvense* in pure form (Table 4).

The average annual energy (MJ) and monetary (Rs) inputs per hectare in all systems, estimated in terms of seed, labor (human and animal), and organic manure used, are shown in Table 5. However, energy and monetary outputs were measured in terms of yield of crops, by-products, fruits, edible oil, and fuel wood from agri-horticultural trees and from green grasses from the bunds and weeds growing in and around the agricultural crop fields. Kharif season crops at all elevations recorded the highest annual energy input as well as output, with those for the middle region being highest of all. Kitchen gardening at all elevations required more energy than rabi season crops grown at middle and lower elevations.

The energy output-to-input ratio was highest for medicinal plants cultivation, followed by kitchen gardening, in all regions, when only economic yield was considered. However, when all system outputs were combined, crops cultivated during kharif season in the middle and lower regions were found to be energetically efficient.

The yield and energy efficiency of some crops of the present study site were compared with the same crops grown in monoculture in other agroecosystems of the region (Table 6) (for mixed cropping the combinations differ). As in the NDBR, the yield potential and energy efficiency of all monoculture crops were lower than those for the same crops in each agroecosystem under multiple cropping. However, most of the multiple croppings practiced in these agroecosystems had higher energy efficiency than did the NDBR multiple croppings. Nonetheless, the NDBR cases had higher yield potential in most crop combinations.

Due to lack of adequate markets and village cooperatives, all agricultural produce (particularly those of best market value, such as kidney bean, amaranth, buckwheat, potato, and certain medicinal plants) were sold at very cheap prices in the local market (Table 7). The local people are exploited by middle-men traders who earn from 35 percent to 75 percent of the revenue.

The area under kitchen gardening was very small in all of the buffer zone villages. In Lata (lower region) and Tolma (middle region), village households produced an average of 6.7 kg garlic, 25 kg cabbage, and about 250 kg seasonable vegetables (cucurbits, radish, spinach, mustard leaves, faba bean, and colocassia) annually. By way of contrast, Malari households (higher region) averaged 4.5 kg garlic, 1-2 kg chillies, 30-35 kg cabbage, and approximately 125 kg of seasonable vegetables.

DISCUSSION

Agriculture, practiced on 0.7 percent of the total geographical area of the Nanda Devi Biosphere Reserve, must provide a livelihood to the inhabitants. As elsewhere in the Central Himalaya, agriculture in the buffer zone is a very complex interlinked production system involving crop and animal husbandry and forests [2, 4, 8, 9]. Inaccessibility, environmental heterogeneity, and ecological fragility have favored the evolution of subsistence production systems sustained with organic matter and nutrients derived from the forests. The 419 families of the buffer zone villages in the Chamoli district of the NDBR practice subsistence agriculture. Land holdings are small and fragmented. Per capita cultivated land is 0.12 ha, as compared to 0.19 ha per capita in the other parts of the Central Himalaya. Agriculture in this region is characterized by settled agriculture on terraced slopes, covering 92.2 percent of the total agricultural land, while only 7.8 percent of the area is irrigated. More than 31 crop species and numerous land races are cultivated. The majority of the crops are grown in the middle and lower parts of the buffer zone, particularly during kharif (rainy) season; just two to three crops are grown in winter season. The mixed cropping of this region differ from that in other parts of the Central and Eastern Himalaya where a regular arrangement of crops in mixed cropping is common practice [2, 5, 10-13]. Crop diversity in the settled terraced agriculture of this region is much higher than in other mountainous regions of the world [14-16]. This huge diversity has been maintained through a variety of crop compositions, cropping patterns, and crop rotations, and also on account of the wide range of variation in edaphic, topographic, and climatic conditions, and of selection pressure over centuries of cultivation [1-3, 10]. The present study revealed declining traditional crop diversity over a short period (1970-1995). Crops have mostly been replaced by traditional crops that have high market demand (potatoes, kidney bean, amaranth, buckwheat). Parallel information about the genetic erosion of crop plants has been reported from the Central Himalaya and several other mountain lands [17-22].

Table 3. Energy Input/Output Pattern (MJ/ha/yr) and Output/Input Ratios for Different Crops in the Lower, Middle, and Higher Elevation Zones of the Buffer Zone of NDBR Values in Parentheses are Monetary Equivalents (Rs/ha/hr)

	Lower altitudinal region				Middle altitudinal region				Higher altitudinal region			
			Output/input ratio				Output/input ratio				Output/input ratio	
Crops	Total energy input	Total energy output	Grain yield	Grain + crops by-product	Total energy input	Total energy output	Grain yield	Grain + crops by-product	Total energy input	Total energy output	Grain yield	Grain + crops by-product
Solanum tuberosum + phaseolus vulgaris + amaranthus spp.	40339 (8259)	169559 (44898)	2.1 (4.6)	4.2	40160 (8032)	170758 (49080)	2.3 (5.0)	4.25	—	—	—	—
Amaranthus + Phaseolus vulgaris	38581 (7536)	110107 (30590)	0.58 (3.6)	2.8	—	—	—		—	—	—	—
Solanum tuberosum + Phaseouls vulgaris	41449 (7977)	131029 (44180)	2.2 (4.8)	3.1	39765 (7647)	137443 (46122)	2.4 (5.1)	3.4	34397 (7300)	153871 (58680)	3.0 (7.2)	4.2
Hordeum himalayens + Pisum spp.	—	—	—	—	—	—	—	—	32381 (7252)	74315 (19936)	0.69 (1.6)	2.3
Fagopyrum tataricum	40237 (7882)	39053 (13380)	0.40 (1.2)	0.97	40955 (7876)	39121 (13490)	0.43 (1.28)	0.95	41340 (7974)	48052 (18470)	0.59 (1.9)	2.5
Fagopyrum esculentum	41192 (7942)	40940 (13150)	0.37 (1.8)	0.99	42286 (8025)	41075 (13290)	0.39 (1.4)	0.97	33032 (6745)	50184 (19620)	0.79	1.5
Amaranthus spp.	54140 (10772)	143990 (10500)	0.26 (0.97)	2.6	55176 (11035)	144980 (10450)	0.29 (0.92)	2.6	—	—	—	—

Phaseolus vulgaris	33893 (8862)	73386 (35323)	0.56 (3.1)	2.1	34990 (8986)	74780 (36340)	0.58 (3.2)	2.1	—	—	—	—
Solanum tuberosum	43910 (9281)	127533 (31400)	2.7 (3.1)	3.0	—	—	—	—	33908 (7757)	157456 (40885)	4.6 (5.2)	4.7
Phaseolus lunetus	15806 (4702)	50770 (21410)	0.98 (3.4)	3.1	15076 (4906)	51985 (22608)	1.10 (3.2)	3.4	—	—	—	—
Triticum aestivum	18648 (5910)	60886 (10350)	0.84 (0.66)	3.2	17186 (5780)	51558 (10800)	0.91 (0.65)	3.2	—	—	—	—
Hordeum himalayens	17342 (5442)	54702 (9180)	0.75 (0.59)	3.1	16460 (5200)	54063 (9076)	0.73 (0.55)	3.2	10800 (5018)	53104 (9006)	1.5 (0.89)	4.9
Hordeum vulgare	17460 (5500)	57708 (9634)	0.78 (0.61)	3.3	16460 (5200)	55680 (9280)	0.80 (0.59)	3.3	—	—	—	—
Pisum arvense	—	—	—	—	13564 (3907)	40543 (21330)	1.1 (4.5)	2.9	27616 (3817)	44088 (25260)	0.66 (5.6)	1.5
Brassica compestris	—	—	—	—	14227 (3412)	54808 (20230)	1.2 (4.3)	3.8	14039 (3132)	50364 (19260)	3.5 (6.1)	3.7
Eleusine coracana	64688 (10490)	71066 (12120)	0.28 (0.36)	1.2	—	—	—	—	—	—	—	—
Panicum miliaceum	14479 (3733)	63050 (10440)	0.95 (0.91)	4.3	—	—	—	—	13432 (3550)	66040 (12400)	1.29 (1.7)	4.9
Pisum sativum	13649 (3907)	40475 (18950)	0.93 (3.8)	2.9	—	—	—	—	—	—	—	—

Table 3. (Cont'd.)

Crops	Lower altitudinal region				Middle altitudinal region				Higher altitudinal region			
			Output/input ratio				Output/input ratio				Output/input ratio	
	Total energy input	Total energy output	Grain yield	Grain + crops by-product	Total energy input	Total energy output	Grain yield	Grain + crops by-product	Total energy input	Total energy output	Grain yield	Grain + crops by-product
Medicinal Plants												
Allium humile	3265 (3025)	10026 (30250)	3.0 (10.0)	—	3545 (3550)	12944 (39050)	3.6 (11.0)	—	3332 (3520)	11667 (35200)	3.5 (10.0)	—
Allium stracheyi	2760 (2636)	7110 (25050)	2.5 (9.5)	—	3015 (2154)	7337 (25850)	2.4 (12.0)	—	2936 (2566)	6556 (23100)	2.2 (9.0)	—
Saussurea costus	—	—	—	—	3410 (3250)	18837 (29250)	5.5 (9.0)	—	3210 (2900)	20608 (32000)	6.4 (11.0)	—
Angelica glauca	—	—	—	—	—	—	—	—	3250 (3078)	14060 (24625)	4.4 (8.0)	—
Pleurospermum angelicoides	—	—	—	—	—	—	—	—	3050 (3083)	20435 (27750)	6.7 (9.0)	—
Megacarpaea polyandra	—	—	—	—	—	—	—	—	2200 (2125)	7165 (12750)	3.25 (6.0)	—
Carum carvi	2422 (1560)	7803 (31200)	3.2 (20.0)	—	2840 (1573)	11805 (47200)	4.1 (30.0)	—	2640 (1664)	10404 (41600)	3.94 (25.0)	—
Dactylorhiza hatagirea	—	—	—	—	—	—	—	—	3475 (2760)	3543 (33750)	1.03 (12.5)	—

Table 4. Energy Pattern (MJ/ha/yr) and Output/Input Ratio for Different Crops in the Irrigated Agriculture of the Higher Elevation Zone of the Buffer Zone Area of NDBR. Values within Parentheses Represent Monetary Equivalents (Rs/ha/yr)

			Energy output/input ratio	
Crops	Energy input (total)	Energy output (total)	Grain	Grain + crop by-product
Solanum tuberosum + Phaseolus vulgaris	2837 (6200)	165178 (53748)	3.9 (7.6)	5.8
Fagopyrum tataricum	34813 (6727)	53274 (20830)	0.80 (2.5)	1.53
Fagopyrum esculentum	31411 (6330)	56423 (22010)	0.79 (3.4)	1.8
Solanum tuberosum	29760 (6872)	188135 (48940)	6.2 (7.1)	6.3
Hordeum himalayens	9504 (4510)	58907 (10290)	1.8 (2.28)	6.1
Pisum arvense	10310 (3424)	58512 (28350)	2.0 (7.1)	5.6
Brassica compestris	12833 (2917)	53007 (21060)	1.2 (5.5)	4.13
Panicum miliaceum	12299 (3310)	78006 (13470)	1.8 (1.6)	6.3

Several factors are directly or indirectly responsible for the decline in crop diversity. Yet the broad genetic base plays a crucial role in maintaining the long-term stability of a traditional agricultural system in a number of ways: it increases productivity; improves soil fertility when legumes are incorporated; reduces the chances of pests, pathogens, and weed infestations; conserves soil nutrients; checks soil erosion; and produces a rich and balanced nutritional diet [1, 3, 23]. On the other hand, a narrow genetic base and uniformity of varieties increase vulnerability to insects, pests, and diseases [24-25].

Villages located in the higher region of the buffer zone practice agriculture mainly in the summer season (kharif). Lower and middle region farmers make effective use of land by taking two crops a year. Crop yield data suggest that

Table 5. Comparative Energy and Monetary Budgeting (MJ/ha/yr) of Different Traditional Crops in Elevation Zones in the Buffer Zone of NDBR. Values Within Parentheses are Monetary Equivalents (Rs)

	Lower areas			
	Kharif season	Rabi season	Kitchen garden	Medicinal plants
Input				
Seed	2448 (1048)	904 (224)	62.1 (287)	81 (275)
Human labor	645.95 (1934)	1029 (3125)	591 (1770)	587 (1761)
Animal labor	1043 (255)	2803 (500)	—	—
Farmyard manure	34443 (5200)	13140 (1825)	21680 (3011)	3060 (425)
Total input	38579 (8437)	17876 (5674)	22333 (5068)	3728 (2461)
Output				
A. Grain yield	30865 (18583)	14145 (8652)	39500 (26680)	9029 (30470)
B. Crop by-product	64890 (4350)	42541 (4558)	—	—
C. Fruits	5098 (4350)	—	—	—
D. Edible oil	270 (468.5)	—	—	—
E. Fuel wood	—	2995 (300)	—	—
F. Green grasses	20860 (2235)	8082 (866)	—	—
Total output	121983 (43848.5)	67763 (14409)	39500 (26680)	9029 (30470)
Output/input ratio				
Grain yield only	0.80 (2.2)	0.79 (1.52)	1.76 (5.3)	2.4 (12.0)
All produce	3.16 (3.55)	3.7 (2.5)	—	—

Middle areas				Higher areas		
Kharif season	Rabi season	Kitchen garden	Medicinal plants	Kharif season	Kitchen garden	Medicinal plants
2486 (1140)	1000 (250)	60.0 (270)	95 (333)	2506 (1145)	46.8 (180.0)	115 (387)
655 (1980)	1090 (3175)	600 (1825)	490 (1855)	696 (1977)	208 (623)	592 (1915)
1105 (270)	2870 (525)	—	—	1712 (295)	—	—
35786 (5600)	12920 (1745)	22460 (3210)	3041 (440)	21789 (3026)	17995 (2499)	3265 (550)
40032 (8990)	17880 (6595)	23120 (5305)	3626 (2628)	26653 (6443)	18249 (3302)	3972 (2852)
31410 (19150)	13168 (6080)	38510 (25440)	10695 (33647)	44975 (19562)	40658 (18492)	8536 (28805)
65785 (4410)	40222 (4325)	—	—	34846 (3733)	—	—
5198 (19250)	—	—	—	—	—	—
270 (470)	—	—	—	—	—	—
—	3144 (315)	—	—	—	—	—
22213 (2380)	7092 (760)	—	—	1013 (388)	—	—
124876 (42660)	63626 (11480)	38510 (25440)	10695 (33647)	80834 (23683)	40658 (18492)	8536 (28805)
0.78 (2.1)	0.73 (0.92)	1.66 (4.7)	2.9 (13.0)	1.68 (3.0)	2.2 (5.6)	2.1 (10.0)
3.1 (4.74)	3.5 (1.74)	—	—	3.0 (3.6)	—	—

Table 6. Comparative Analysis of Yield (kg/ha) and Energy Output/Input Ratio, MJ/ha (Values Within Parentheses) of Different Crops/Crop Combinations of the Buffer Zone of NDBR With the Crops/Crop Combinations of the Other Part of Central and North Western Himalaya

Crops	In NDBR buffer zone	After Semwal and Maikhuri (1996)	After Nautiyal et al. (1998)	After Singh et al. (1997)	After Maikhuri et al. (1997)	After Ralhan et al. (1991)	After Sharma (1991)
Mixed cropping	5810 (2.2)[a1] 7111 (2.3)[a2] 1910 (0.58)[a3]	5900 (2.42)[b1] 7288 (1.68)[b2]	2167 (1.89)[c1] 1680 (1.18)[c2]	1846 (4.23)[d]	1200 (7.8)[e1] 1850 (12.5)[e2] 8100 (16.3)[e3] 2150 (13.1)[e4]	—	2247 (4.4)[f1] 1960 (1.8)[f2] 2320 (3.8)[f3]
Triticum aestivum	950 (0.87)	3765 (4.17)	1250 (1.41)	2110 (1.15)	1350 (4.3)	3880 (0.31)	1763 (4.14)
Hordeum vulgare	810 (0.57)	—	1075 (1.02)	1289 (1.8)	1465 (4.6)	2407 (0.27)	—
Eleusine coracana	1371 (0.28)	—	1450 (0.63)	1026 (5.77)	—	3580 (0.40)	990 (2.0)
Brassica compestris	750 (1.2)	—	725 (1.12)	720 (1.96)	950 (8.2)	825 (0.33)	—
Panicum miliaceum	1082 (1.12)	2302 (2.80)	—	—	2150 (20.8)	—	—
Hordeum himalayens	890 (1.1)	—	—	—	1750 (6.0)	—	—
Solanum tuberosum	8970 (3.65)	—	—	21620 (6.75)	8000 (5.1)	20000 (0.92)	—
Fagopyrum esculentum	1050 (0.51)	—	—	—	1810 (7.2)	—	—
Fagopyrum tataricum	980 (0.59)	—	—	—	1680 (9.7)	—	—

The crop mixtures in mixed cropping are:
[a1] = *Solanum tuberosum, Amarnathus spp., Phaseolus vulgaris;* [a2] = *P. vulgaris, S. tuberosum;* [a3] = *Phaseolus vulgaris, Amaranthus* spp.
[b1] = *Echinochloa coracana, Vigna mungo, Macrotyloma uniflorum, Vigna angularis, Amaranthus spp.,* and *Glysine max;* [b2] = *Oryza sativa, Echinochloa frumentosea,* and *Setaria italica*
[c1] =*Echinochloa frumentacea, Zea mays,* and *Lens esculentum;* [c2] = *Eleusine coracana, Lens esculentum*
[d] = *Vigna mungo, Vigna sinensis, Dolichus uniflorus, Phaseolus vulgaris, Fagopyrum esculentum, Fagopyrum tataricum, Glysine max*
[e1] = *Solanum tuberosum, Amaranthus spp., Eleusine coracana;* [e2] = *Eleusine coracana, Macrotyloma uniflorum;* [e3] = *Fagopyrum esculentum, Solanum tuberosum;* [e4] = *Amaranthus spp., Phaseolus vulgaris*
[f1] = *Triticum aestivum, Brassica spp.,* [f2] = *Eleusine coracana, Glysine max;* [f3] = *Oryza sativa, Glysine max*

Table 7. Monetary Rates (Rs) of Different Agricultural Produce at Different Market Centers

Agricultural produce	Selling price in local market	Selling price in semi-urban centers	Selling price at urban centers
Agricultural produce			
Solanum tuberosum	4	6	8
Phaseolus vulgaris	22	30	40
Amaranthus spp.	10	15	25
Fagopyrum tataricum	10	20	30
Fagopyrum esculentum	10	15	25
Phaseolus lunetus	16	20	30
Pisum arvense	10	20	30
Medicinal plant produce			
Allium humile	55	110	150
Allium stracheyi	55	110	150
Angelica glauca	25	85	110
Pleurospermum angelicoides	25	85	110
Saussurea costus	25	85	110
Carum carvi	80	200	350
Dactylorhiza hatagirea	150	450	800
Megacarpaea polyandra	15	25	35
Horticultural produce			
Apple	7	15	25
Apricot	10	25	30
Walnut	30	65	90

potatoes provide higher yield when cultivated as a monocrop in rain-fed and valley land in the higher region than do the other crops grown in mixed or monocrop stands at the other two regions. The expansion of cash crop monocropping of potatoes, the by-product of which does not have any fodder value, implies less production of fodder from private farms, and thereby increases pressure on forests for fodder [3]. Furthermore, the soil erosion rates from potato farms on steep, terraced fields could be six to eight times higher than those from traditional staple food crops, despite the two to four times higher usage of organic manure in the former than in the latter [26]. In such protected areas, potato cultivation as a monocrop may not be viable ecologically and economically in near future. However, the potential economic returns from mixed cropping of *Solanum tuberosum* and *Phaseolus vulgaris* and *Amaranthus; Solanum tuberosum* and *Phaseolus vulgaris; Pisum arvense, Fagopyrum* are over three to five times the returns from wheat and barley. Since these crops are energy efficient, profitable, and climatically suitable not only for the buffer zone, but also for other parts of higher Himalayan region, research and policy aimed at improving yield and marketing facilities are the most promising ways to bring better economic futures to the residents.

Crops grown in the higher region in rain-fed land are energetically most efficient (followed by those of the middle and lower regions). Crops cultivated in irrigated land were found to be more efficient than the rain-fed crops. This point may be argued by the fact that the crop fields of higher regions remain fallow for five to six months each year. Therefore, the soil becomes more fertile than in lower and middle areas, where two crops are harvested annually.

In the present study, the total yield (kg/ha) and energy efficiency was lower for the majority of the traditional crops than other workers have reported [2, 3, 5, 11, 27, 28] in certain agroecosystems of the central and northwestern Himalaya where common food crops (wheat, rice, and maize) were given more emphasis. Depleting natural resources and forest wealth, on one hand, and the scarcity of forest resources due to reduced accessibility in the wake of the imposition of conservation policies, on the other, have a direct bearing on agro-ecosystem productivity and sustainability, and run the risk of the loss of agro-biodiversity in the buffer zone areas.

This can also be attributed to the fact that herbaceous vegetation growing on the bunds of agricultural land, fruits, edible oil, and fuelwood obtained from agro-horticultural trees, together with weeds biomass, are also considered as auxiliary outputs [2], which consequently enhance the energy and monetary efficiencies of the agriculture. It was observed that when all auxiliary outputs are considered together, the traditional crops grown in "mono" and mixed conditions in the NDBR buffer zone exhibited higher energy and monetary efficiencies than those grown in other parts of the central Himalaya [1]. Kitchen gardens of the study area in particular, and elsewhere in the central Himalaya in general, are smaller in size than those in the northeastern Himalaya and other mountain areas [2, 5, 29-31]. The addition of organic wastes and ash, the saving in travel and transport labor due to the proximity of the home, and the maintenance of a high crop diversity, including medicinal plants, make the kitchen gardens economically highly efficient than agriculture.

Due to limited opportunities for income generation, farmers export surplus agricultural produce at low prices to market traders against cash payments or barter of rice, sugar, salt, and similar basic food commodities. Farmers are not conscious of the big profit margins that the middlemen or terminal traders obtain.

Nevertheless, the traditional agriculture of the buffer zone has adapted to a wide variety of local environments, producing diversity and reliability of food supply, reducing the incidence of diseases and insect/pest problems, using labor efficiently, intensifying production with limited local resources, and earning maximum returns with low levels of technology. The agroecosystem utilizes a very wide range of crops and provides sustainable yields by drawing on centuries of accumulated experience by farmers who did not depend on external inputs.

However, growing human population, imposition of conservation policies, and other socio-economic and cultural changes have not only weakened the sustainability of the traditional agriculture of the area, but also increased the pressure on already-dwindling existing natural resources, thereby reducing the agro-biodiversity in particular, and biodiversity in general, of the reserve. Therefore, to achieve the conservation objectives with better management of the biosphere reserve, several options exist for improving the productivity and sustainability of the agricultural system of the region. These include: 1) improving the traditional technologies of soil fertility maintenance (i.e., mulching and composting of bio-resources while mixing with organic manure) and other agronomic practices to enhance yield of the traditional crops in their natural habitat; 2) encouraging mixed croppings of *S. tuberosum* and *Phaseolus vulgaris* and *Amaranthus* or *S. tuberosum* and *Phaseolus* since legumes improve soil fertility while providing high economic returns; 3) strengthening agriculture, particularly in the lower region, through agri-horticultural inputs which are more remunerative and for which the region has climatic advantages; 4) empowering women since the agroecosystems of this region are mainly managed and operated by them; 5) adding value in traditional crops as an indirect but viable and appropriate strategy for their conservation in their natural habitats; 6) opening small cooperatives either at village or community levels to take over marketing responsibilities, so that the more benefits could reach the local farmers, thereby increasing the interest of the farmers in cultivating these crops; 7) strengthening the kitchen garden, a highly organized production system through the cultivation of spices/condiments and medicinal plant species; 8) compensating farmers for crop damage caused by wildlife; and 9) growing crops that are least damaged by wildlife (e.g., *Amaranthus, Hordeum,* and medicinal plants) in areas where chances of damage from wildlife are highest.

These measures are viable options for reducing conflicts between local people and Biosphere Reserve authorities. The nine strategies suggested above stand to improve the agricultural productivity and socio-economic conditions, and to help conserve biodiversity in the reserve.

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