Chapter 5:
Making a Living Out of Agriculture: Some Reflections on Vegetable Production Systems in the Manupali Watershed

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Introduction

Sustainability of agricultural production systems must come at little or no cost to the primary producer. Such a maxim is particularly pertinent to farmers in the developing world, especially those close to subsistence, for whom the seasonal harvests determine marginal profit or loss.

Efforts to enhance sustainability of tropical upland agricultural systems, plagued by steep and unstable slopes, highly erosive rainfall, and precarious transport systems, must appreciate the non-separability of long-term development prospects of lowlands and highlands (Jodha, 1997), yet recognize the valuable contributions of uplands to biodiversity conservation, to clean water supply, to recreation and the like.

A trivial approach to the sustainability issue of tropical uplands would be to convert them into extensive national parks, but this does not recognize the rights of indigenous and migrant populations already in situ. Other government approaches to promote sustainability could include legislation that restricts cultivation of erosive species; whether directly through policy, or indirectly by removal of import barriers for lucrative temperate crops grown in tropical highlands.

Faced with dilemmas akin to the above, and with a brief to minimize the environmental impacts attributed to vegetable production systems in the northern uplands of Mindanao, Philippines, we implemented a research program under the umbrella of the USAID-SANREM over the period 1994-1998. The study area lies between 124° 47' to 125° 9' east and 7° 57' to 8° 8' north, and is characterized by steep lands in the upper foot slopes above 800 m (our particular study area) over thick deposits of siliceous volcanic ejecta. Average annual rainfall is about 2300 mm, concentrated during May to November.

Some of the salient and comparative features from our research are presented herein, with full experimental details and discussions presented elsewhere (Midmore *et al.* 1997a, 1997b; Poudel *et al.* 1997, 1998, 1999a, 1999b, 1999c; Nissen and Midmore 1997a, 1997b, 1997c; 1999). In essence, we assessed the current vegetable production systems in terms of their financial integrity, their resource use and their perceived future, leading to a classification of farming types. Following this we, cooperatively with vegetable farmers, chose production technologies aimed at reducing environmental impact and enhancing income generation, and quantified their benefits and detractions.

Farm and Crop Level Analyses in Relation to Sustainability

Fifteen percent of vegetable farms were surveyed with a full previous-year recall, following extensive discussions with local *barangay* officials based upon local knowledge and with reference to a digitized 1986 land use map. Composite soil samples were collected from the main parcel of vegetable land on each surveyed farm, following quantification of natural and cultivation-imposed slope. Full details on data analyses are presented in Poudel *et al.* (1998).

Data collected illustrate the precarious nature of current production systems. One-half of farms were cultivated up-and-down the slope, for ease of operation and to enhance drainage. One third were farmed on slopes greater than 18%. This predisposed much of the land to soil erosion and runoff. Pesticides were applied on 26 occasions average during the tomato season, with only slightly lower figures for other vegetable crops (Table 5.1). Such prevalent spraying could lead to build-up in pesticide resistance, and almost one-half of producers recently changed

Table 5.1. Pesticide application frequency and rates, by crop per season.

	Tomato	Cabbage	Potato	Chinese Cabbage
Insecticides (kg/ha)	13.5	9.0	4.4	6.8
Fungicides (kg/ha)	20.5	9.8	14.6	3.7
Number applications	26.0	26.0	19.0	15.0

products to achieve more effective control. In spite of such copious applications, insect and disease reportedly led to close to 50% production losses. The control of late blight in potato with fungicides was essential for production, for potato yields were positively related to increased expenditure on fungicides (r=0.630 P = 0.01). There was a fair degree of correspondence between crop yields and fertilizer application rates across farms (*e.g.* between nitrogen rate and tomato (r=0.752 P = 0.01) or cabbage (r = 0.630 P = 0.01) yields), indicative of scope for yield improvement through fertilizer application on some farms. Possible spin-off benefits such as canopy-cover-induced reductions in soil erosion, could be had through objective use of nitrogenous fertilizer.

Taking the annual farm level data, it was apparent that intensification (*i.e.* expressed as number of crops grown per year, or as the inverse of proportionate area under the major vegetable crop) was associated with higher total rates of pesticide application per unit vegetable area. High fertilizer application rates were associated with a lowering of soil pH, a decrease in the Ca saturation of exchange sites, and a potential reduction in stable aggregates. Dolomitic limestone (for magnesium in the soil is also in short supply, as discussed later) must, therefore, accompany fertilizer application if soil acidification is not to become more prevalent in this watershed.

Classification of farming types among the sampled farms was undertaken using Principal Components and Factor Analyses and led to identification of seven factors (Table 5.2) from which two major distinct groups of farmers were identified. The factors reflected the following, in decreasing order of importance: 1 - the annual amounts of N, P, K applied per farm, 2 - the degree of non-dependence on vegetable crops, 3 - minimization of reliance on one or a few crops, 4 - a measure of soil acidity, 5 - opportunity costs for all farm family labor and rent, 6 - total input expenses per hectare arable land, and 7- an agro-ecological factor representing land use intensity and altitude.

The two major groups of farmers differed notably, and the major factor differentiating the groups was the quantity of N, P and K applied per hectare per year to vegetable crops (Table 5.3). Greater external nutrient applications offset the scope for fallowing, (which was limited by holding size, in the high external nutrient (HEN) group (Table 5.3). While the HEN system appears to commercialize vegetable production more than does the LEN (0.7 ha vegetable production per HEN farm per year vs. 0.4 ha per LEN farm), and yields were greater, the annual net returns from vegetable production were less under HEN (Table 5.3). The HEN system was also likely to achieve a net loss on the vegetable enterprise. Net return calculated this way can be interpreted as returns

Table 5.2. Factor loadings of maximum likelihood methods with varimax rotation with variables selected for farm level analysis.

	F1	F2	F3	F4	F5	F6	F7
NEVEGHA	0.9504						
PVEGHA	0.9654						
KVEGHA	0.8941						
ARANVEG		0.9721					
VEGCR			0.9426				
PH				0.9641			
SFUCULT1					0.9650		
INPUTEXP						0.8044	
CI							0.6596
ALTD							-0.4440
Proportion of standardized variance	0.15	0.26	0.35	0.4	0.49	0.56	0.62

Table 5.3. Some characteristics of the two types of vegetable production systems.

	Higher External Nutrient		Lower External Nutrient
Total land holding (ha)	3.2	<	3.7
Annual vegetable (ha)	0.7	>	0.4
Annual non-vegetable (ha)	0.5	<	2.8
Number of vegetable crops/yr	2.7	>	1.7
Vegetable fertilizer N:P:K (kg/ha)	231:68:155	>	142:43:105
Pesticide cost/ha (Peso)	6673	>	4476
Average tomato yield (t/ha)	16.9	>	11.0
Gross vegetable output	36,866 (±7,848)	>	19,452 (±5,141)
Vegetable net return	4,000 (±5,546)	<	6,850 (±3,840)
Gross non-vegetable output	6,513 (±1,422)	<	18,475 (±6,526)
Non-vegetable return	2,917 (±1,266)	<	9,152 (±4,045)

to labour (including management) and money left for payment for fixed costs including land improvement (Midmore *et al.* 1996). Optimizing input use through better management practices should be the primary strategy to improve the sustainability of the HEN system. This would also maximize financial returns over the short- and long-terms. Conservation of nutrients and soil fertility, and cost-effect integrated pest management are obvious options, as is objective rotation avoiding sequences of crops from the same botanical family.

Responses between both groups of farmers to questions relating to their perceptions of soil erosion rates, declining fertility status, declining crop yields and living standards did not vary. Deforestation and current farming practices were identified as responsible for soil erosion, and contour farming and cover cropping were believed to be the most suitable practices to stem soil erosion. Contour hedgerows utilizing leguminous shrubs/trees were not considered suitable for implementation, largely due to their labor requirements, encroachment into already limited space for vegetable crops, and the perceived lack of need for biologically-fixed N, since nitrogenous fertilizers are widely used and P is probably the limiting nutrient.

Digressions Into Fallowing

One-fifth of farmers had land in fallow of one or more years' duration when surveyed in 1994. This was less than the proportion of fallowed to cultivated land (16.7% vs. 50% of total Manupali watershed area in 1994 (Kanemasu *et al.* 1997)) estimated through satellite imagery. Setting aside land for fallow within production systems may lead to some restoration of soil fertility. The opportunity arose to quantify possible benefits of fallowing to vegetable farmers in the Manupali watershed, for extrapolation elsewhere.

In addition to the formal survey in 1994, one-day voluntary hands-on visits were made by one member of our team to farms identified as having fallow during the survey. These visits were made to understand fallow systems. Using soil collected during the survey, compared to cultivated land, fallow lands were more acidic (pH 4.4 vs 4.9) poor in organic matter (1.4 vs. 3.8%) and inexchangeable K and Ca (2.8 vs 5.9, and 0.12 vs 0.58 meq/100 g respectively for Ca and K) and high in aluminum (1.21 vs 0.58 meq/100 g). Profitable short-term conversion of these lands into crop production would require ample fertilizers and soil amendments. Most commonly corn preceded land fallowing, itself following tomato or potato once bacterial wilt (*Pseudomonas solanacearum*) rendered land unsuitable for those species. Corn received low fertilizer input and utilizes residual nutrient resources after vegetable cultivation, but a downward spiral of productivity and fertility ensues as ground cover in successive crops was constrained.

Following an average period of 3.7 years, fallowed lands were recultivated. Land intended for recultivation often had wild sunflower (*Tithonia diversifolia*) stems and seeds spread over it, on the assumption that it would restore fertility (Van Noordwijk *et al.* 1997). Sunflower might enable mobilization of Ca, P and K from the soil, and might promote non-associative nitrogen fixation, but these possible benefits remain to be proven. Some land was fallowed not only due to poor fertility, but also due to lack of labor and/or lack of capital for cultivation. Higher levels of disposable farm income, favorable government policies, changes in farmer attitudes and appropriate market infrastructure might lead to a loosening up in use and improvement of fallow land. Potential systems involving timber trees are outlined later in this paper.

Notwithstanding these, farms with fallow on aggregate showed a higher annual net return compared to farms without fallow (22,246 ± 11836 pesos vs. 7066 ± 3639 pesos) but to some extent this might reflect the less intensive nature (*i.e.* the LEN group) of production if land on larger holdings were available for fallow. However, cluster analysis separated fallow farms into two groups (Table 5.4), both of which fell into the HEN grouping (*i.e.* well above the 242:43:105 kg ha-1 average for LEN). Marked differences between the two groups were evident for annual net returns; the group with larger more-capitalized holdings achieved greater net returns. Among the group with smaller holdings, two-thirds planted potato in 1993 and achieved yields of only 3.5 t ha^{-1}, thus, was largely responsible for break-even or negative returns to vegetables in that year (Table 5.4).

When the idea of planting trees on fallow land (more specifically just prior to fallowing) was suggested to farmers, their acceptance depended upon the ability to generate income, and not necessarily because of perceived improvements to their degraded fallow. If fallow lands truly are the least fertile, and our soil data suggest so, and they are on steep slopes, then land fallowing may be considered as an important step towards environmental sustainability, especially if land is permanently taken out of production. If the ratio of aggrading to degrading land area is greater than unity in the watershed, progress is being made towards a sustainable system. Planting of trees, on holdings with land in excess of that manageable with current labor or capital limitations to vegetable production, may over the medium-term raise income and reduce pressure on, and indeed the financial attractiveness of, vegetable production. Such scenarios as may raise the aggrading: degrading ratio are explored later

Table 5.4. Some characteristics of the two groups of farms with fallow land.

	Group 1 (n=4)		Group 2 (n=17)
Total land holding (ha)	16.3	>	5.6
Annual vegetable (ha)	2.1	>	0.44
Annual non-vegetable (ha)	12.0	>	1.2
Vegetable fertilizer N:P:K (kg/ha)	529:201:400	>	278:88:215
Gross vegetable output	130,256 (±67,575)	>	18,821 (±3,385)
Vegetable net return	79,071 (±43,595)	>	-2,861 (±2,542)
Gross non-vegetable output	120,280 (±74,957)	<	6,640 (±1,216)
Non-vegetable net return	42,363 (±53,209)	<	3,674 (±1,226)

in this paper. For smaller farms with no opportunity for tree planting, conservation technologies that stem soil degradation are the only options to enhance sustainability. Outcomes from experimental approaches to test these two options are now discussed.

Conservation Practices Acceptable to Farmers

Field trials on a purpose-rented research site, and on 12 farmers' fields throughout the vegetable production zone, were set up in 1995. Conservation technologies and cropping sequences were established on replicated erosion plots (19 m x 8 m), on an average 42% slope, and managed for seven cropping seasons. All technologies trialed were endorsed by 30 of the one hundred plus farmers surveyed, following feed-back to the farmers of the key highlights from analyses of survey data. In essence, the technologies comprised: 1) the current practice of planting up and down the slope 2) planting on the contour, 3) planting vegetables up and down the slope but with 5 m strips of bean across the slope at 5 m intervals and 4) as with number 1, but with four two-row strips at 4 m in intervals of high value hedgerow crops planted on the contour. The high value crops were (from top to bottom of the plots): asparagus, pineapple, pigeon peas and lemon grass (replacing tea after the first season). On each technology plot was super-imposed a sequence of three vegetable crops, such that each technology x vegetables species was represented during each growing season. Close to three crops were planted per year on each plot, the trial with a sequence of seven crops lasting 2.5 years. Eroded soil, runoff and nitrate were measured after each erosion event, and soil chemical and physical characteristics were determined throughout the experiment, as were inputs, and crop yields. Sampling of soil and crop yields within plots was undertaken systematically to reflect spatial trends within each set of measurements. Full experimental details are presented by Poudel *et al.* (1999b).

Average soil loss with the farmers' up-and-down cultivation (Table 5.5) was 50% greater than in the conservation practices. Our values are similar to those reported by Presbitero *et al.* (1995) for Leyte, Philippines. As contour hedgerows became established, they were more effective in controlling erosion. Indeed, within the contour hedgerows 71% of total soil lost over the entire experiment was lost in the first three seasons and only 24% in the last three seasons compared to values of 46% and 47%, respectively, in the farmer's treatment. Among crops, tomato led to more soil erosion than any other species tested (Table 5.6). This difference between species in their propensity for erosion was related to differences between their canopy cover and tillage operations. Similar differences between treatments and crops, were evident for runoff, but for nitrate in runoff water no treatment/species effects were apparent (Tables 5.5 and 5.6).

Most soil loss through erosion occurred during only a few erosive rainfall events. Of all the rainfall events (> 1.0 mm) only 6.5% resulted in measurable soil erosion, and three events were responsible for almost 50% of total soil erosion over the seven seasons. Such losses were evident at planting time when bare, or almost bare, soil was exposed to rainfall. In Laguna, Philippines 25% of annual soil loss was due to one rainfall event (Paningbatan 1994) and similar dependency of soil erosion on one or a few rainfall events, even measured over decades (*e.g.* in the Cameron Highlands of Malaysia - Midmore *et al.* 1996), is not uncommon.

Table 5.5. Effects of erosion control measures on cumulative soil loss, runoff and nitrate loss through runoff, averages per cropping season.

	Soil loss t/ha	Runoff 1000 l/ha	Nitrate kg/ha
Up-and-down	23.3 a	254 a	4.6 a
Contouring	13.5 b	147 b	3.3 a
Strip cropping	15.6 b	205 ab	3.5 a
Hedgerows	16.2 b	171 b	2.5 a

Values with same letter within a column not statistically different at $P < 0.05$.

Table 5.6. Effects of crops on cumulative soil loss, runoff and nitrate loss through runoff, averages per cropping season.

	Soil loss t/ha	Runoff 1000 l/ha	Nitrate kg/ha
Tomato	21.3 a	245 a	4.8 a
Corn	15.1 b	161 b	2.8 a
Cabbage	15.0 b	177 b	2.8 a

Values with same letter within a column not statistically different at $P < 0.05$.

Average enrichment ratios (ER - ratio of nutrient content of eroded soil to that of the source soil) for organic matter, P, Ca, S, and N were 1.2, 4.7, 1.7 and 1.3, respectively, while for other nutrients, *e.g.* K and Mg, they were both 0.8. The high value for extractable P prompts particular concern both for its possible adverse effects on downstream aquatic habitats and due to the inherently low P availability in all but the fertilizer-rich Ap horizon. ERs for P increased over time, while those for K and Mg progressively declined. The former was most likely due to addition of phosphate fertilizer, while the latter reflected the much lower concentrations of K and Mg in soil eroded from deeper down the soil profile. Total amounts of nutrients per hectare removed in eroded soil over seven seasons totalled 320-637 kg N, 1.4-2.9 kg P, 23-39 kg K, 71-139 kg Ca, 14-31 kg Mg and 8000 to 13500 kg organic matter. *In situ* soil at the end of the experiment was particularly deficient in organic matter, Ca, Mg, K (*e.g.* Table 5.7) and had a lower pH, declining from pH 5.8 (± 0.05) to pH 3.8 (± 0.04) throughout the experiment. Application of dolomitic lime and potash can remedy this loss except for loss of organic matter, yet it is the loss of organic matter that contributes much to the exchangeable K, Mg and Ca. The close correlations between yields of some crops and Mg levels across treatments (*e.g.* tomato, $r = 0.63$ $P < 0.01$) although involving self correlation with other soil variables, strengthens the argument for application of dolomite.

Marked spatial trends in soil fertility and crop yields within plots were noted. Scouring of upper reaches, and depositions lower down, were responsible for much of this. An example of differences between tomato yields on upper and lower halves of each plot is presented in Table 5.8. On average over the experiment, yields on the lower half of plots were 36% greater for corn, 40% for tomato and 78% for cabbage compared to those of the upper half. The lower upper yields were associated with less organic matter, P, total N, Ca and Mg, four-fold reduction in infiltration, and

Table 5.7. Some soil quality parameters compared across original soil (0-15 cm), eroded soil (during 7th season), and remaining soil after the 7th season (0-15 cm).

Parameter	Treatment	Original	Eroded	Remaining
Organic Matter (%)	Up-and-down	7.35	7.02	6.06 ns[1]
	Contouring	8.16	7.61	6.06 ns
	Strip cropping	7.32	7.16	5.79 ns
	Hedgerows	7.00	7.28	5.58 ns
P (meq/100g)	Up-and-down	2.98	26.63	10.21 ***
	Contouring	4.09	29.95	14.51 ***
	Strip cropping	3.74	23.31	8.99 **
	Hedgerows	3.86	22.74	8.42 *
K Cmol$_c$/kg)	Up-and-down	1.04	0.29	0.26 ***
	Contouring	0.87	0.28	0.27 ***
	Strip cropping	1.01	0.29	0.27 **
	Hedgerows	0.97	0.31	0.25 ***

[1] Difference between original and remaining soil.

Table 5.8. Tomato yields (t/ha ± SE) according to slope position over five cropping seasons (1-5).

	1	2	3	4	5
Upslope	20.8 (5.1)	7.7 (1.4)	9.9 (2.3)	3.7 (1.8)	13.3 (3.3)
Downslope	25.9 (5.1)	11.1 (1.7)	14.2 (2.9)	4.3 (1.4)	23.3 (4.1)

greater soil acidity and exchangeable A1. These data suggest that the overall impacts of erosion could be large even if soil per se is not removed by erosion from the fields and landscape.

The movement of nutrients and organic matter down the slope on contour plantings was less than in other treatments, with little differential deposition down the slope in the former. A scouring effect, *i.e.* digging into the slope near the lower side of hedgerows, was observed after a couple of seasons of hedgerow contour planting. Data illustrating the scouring effect across the natural terraces formed between the high value hedgerows are presented in Table 5.9. The greatest loss of organic matter occurred in the upper portion of the upper mid-terrace of each plot, with maximum accumulation in the lower portion of the lower mid-terrace. These differences were matched by differences in yields (Table 5.9) and have been shown to occur on similar soils planted on the contour with perennial leguminous hedgerows species (Angus *et al.* 1997). Clearly the poorer upper sections of each terrace require nutrient replenishment.

Most importantly, yields per unit planted area for vegetable and corn were greatest in the contour and strip treatments; reasons for this are currently being investigated.

Table 5.9. Scouring effect on soil and yield in terraces formed naturally between high-value hedgerows, four hedgerows in each plot.

	Organic Matter (%)		Calcium (Cmol kg^{-1})		Corn (t ha^{-1})	
	Upper-side	Lower-side	Upper-side	Lower-side	Upper-side	Lower-side
Top terrace[1]	7.4		1.5		-	
Upper mid	4.4	10.3	0.82	0.93	0.94	1.50
Middle terrace	4.9	10.6	1.01	1.85	0.80	1.40
Lower mid	7.7	10.9	1.30	1.03	1.20	1.60
Bottom terrace[1]	9.9		1.97			-

[1] Top and bottom terraces only half-sized terraces.

Some Exercises with EPIC Modelling

The Erosion-Productivity Impact Calculator (EPIC) Model (Williams *et al.* 1984), as a process-based model, and the Modified Universal Soil Loss Equation, were calibrated to Manupali watershed conditions to compare crop sequence scenarios in relation to soil erosion. In the near future, the model will also be modified to simulate all of the conservation treatments. The model was initialized with data from research plots and validated for farmers' plots (Table 5.10). Under-estimations (*e.g.* on the 23% slope) were due to the model's inability to estimate gully or ephemeral gully erosion, but otherwise the model provided reasonably accurate prediction of erosion, suitable for estimation of watershed

Table 5.10. EPIC model validation of annual soil loss (t/ha) for contour hedgerow system.

	Crop Sequence	Slope %	Annual Soil Loss Measured	Annual Soil Loss Simulated
Researcher-managed	Tomato-corn-cabbage	42	44.1	42.1
	Corn-cabbage-tomato	42	53.5	54.9
Farmer-managed	Sweet pepper-fallow-cabbage	20	13.4	11.8
	Fallow-corn-cabbage	23	18.2	14.5
	Fallow-cabbage-potato	33	34.0	45.3
	Cabbage-corn-potato	40	26.6	33.9
	Fallow-fallow-potato	62	19.1	23.6
	Fallow-fallow-fallow	20	23.7	22.9

erosion (and runoff - data not presented). Model simulations highlighted both the need to carefully manage tomato if planted in September, and the soil conservation benefits of planting corn at that time. Annual actual and predicted soil losses for identical cropping sequences on slopes of 44% were from four to six times greater than on 20% slopes, indicative of the proportionally greater attention that must be turned to conservation practices as slope increases.

Based on EPIC simulation results, the cropping sequence of tomato-cabbage-tomato resulted (98.3 t/ha) in nearly three times more soil loss than that of cabbage-tomato-cabbage (28.1 t/ha), indicating that consideration must be given to the crops and planting seasons when designing a multiple cropping pattern to minimize erosion on steeplands. The reason for low annual soil loss from the cabbage-tomato-cabbage cropping sequence is attributed to a greater canopy cover by cabbage than tomato during erosive rainfall events. Erosion from the system where corn followed cabbage in the autumn was nearly double than that where corn followed tomato. Corn responded through better growth to the greater residual nutrients following tomato than cabbage, hence canopy cover by corn was greater with consequent reduction in soil erosion.

Compatibility of Trees with Vegetables

Financial rewards are attracting interest in planting fast-growing timber species among vegetable (and other) farmers. On larger farms, with land in long fallow, trees provide the ideal opportunity to gain financial returns, especially since fallowing alone is unlikely to markedly enhance soil fertility. Intercropping small trees and high-input annuals save on management costs and make the association even more attractive. A shift of a vegetable enterprise towards trees also alleviates current and anticipated labor shortages, for the management of trees after the first year's growth is not labor intensive. From an environmental perspective the ability of trees to ensure constant canopy cover over (at least part of) the soil, and a possible safety net effect to reduce nutrient loss through leaching, add to the attractiveness of associating a high-input system (vegetables) with an otherwise poorly resourced commodity (timber). Our research aimed to quantify the benefits of vegetables on trees, of trees on erosion, of different tree-management options, and the overall financial attractiveness of agroforestry. Set on three major sites, two directly in cooperation with farmers and one on rented land, our experiments addressed local farmers' concerns with agroforestry and vegetables. We compared the performance of various tree species alone and intercropped with vegetables, their population and pruning practices, and supplementary fertilization to trees. These were conducted over a number of seasons. Growth and yield of trees and vegetables, spatially referenced, were quantified, as was N use by way of 15N.

Tree growth over the two years of data collection was considerably greater when intercropped (*e.g. c.* 58 m^3/ha vs. *c.* 27 m^3/ha for non-intercropped trees) and, as side-dressing of trees made no appreciable difference to current tree performance, it is believed that the extra growth represented nutrient uptake in excess of that for vegetables. The degree to which intercrop yield decline was due to above- or below-ground competition from nearby trees was investigated. Applications of 15N fertilizer to sole vegetables, and vegetables at varying distances from *Eucalyptus torreliana*, showed no differential uptake of 15N (all between 18-21% of applied 15N). Intercropped trees however, intercepted N that had leached, or would soon leach, past the vegetable root zone (Table 5.11). This most likely happens quickly in a 200 mm monthly average rainfall regime. Although there was apparently no competition for N, or any other nutrient based on foliar sampling, vegetable yields were

Table 5.11. Analysis of harvested tree parts (± SE) of *Eucalyptus torelliana* intercropped with cabbage.

	Dry Weight (kg)	N (%)	NDFF* (%)
Leaves	0.86 (0.24)	1.99 (0.09)	10.05 (3.23)
Green branches	0.35 (0.76)	0.66 (0.11)	8.37 (1.94)
Woody branches	0.08 (0.04)	0.42 (0.07)	7.84 (2.27
Stem	0.57 (0.14)	0.36 (0.06)	8.72 (1.65)

*Nitrogen derived from fertilizer.

reduced in the rows closer to the tree (by 25%). In part this was due to competition for light, for the canopy of *E. torreliana* is dense around the trunk. In addition, since rainfall was well-distributed over the sampling period, and competition for soil moisture was unlikely, it is possible that allelopathic compounds from eucalyptus root exudates were present. This possibility requires further investigation because of its potential impact on site quality.

Intercropped with the sparse shading tree species *Paraserianthes falcataria*, crop yields were constant across the 5-m wide alley, adding weight to the thesis that below-ground competition was minimal. That unfertilized trees did not reduce yield more than did fertilized trees further supports this viewpoint. In this system, intercropped yields did not differ from monocropped yields until the third season, when they were reduced by 18%. This coincided with the onset of enhanced growth in the intercropped trees. Until intercrop yields began to decline, the intensive nutrient and weeding management of the intercrops significantly reduced the costs of managing trees.

Data on intercrop performance from the various tree population trials all conform to the pattern illustrated in Fig. 5.1, for *E. deglupta*. Intercrop yields declined as stand basal area increased. The stand basal area (*i.e.* II/4000 * mean diameter breast height * No trees ha-1) is commonly used to describe forest stand growth, and is easy to measure, correlating well before complete tree canopy closure with crown area and shading. Such data provide information on the anticipated loss in terms of vegetable yield as the tree grows, a set of values that can be compared with the percent of control yield that is still economic based on returns to vegetable production over the short-term. While we as researchers struggle with this, farmers may have an instinctive feeling for the balance. However, once the balance involves prediction of net profit over the duration of the tree rotation, farmers would be unlikely to correctly

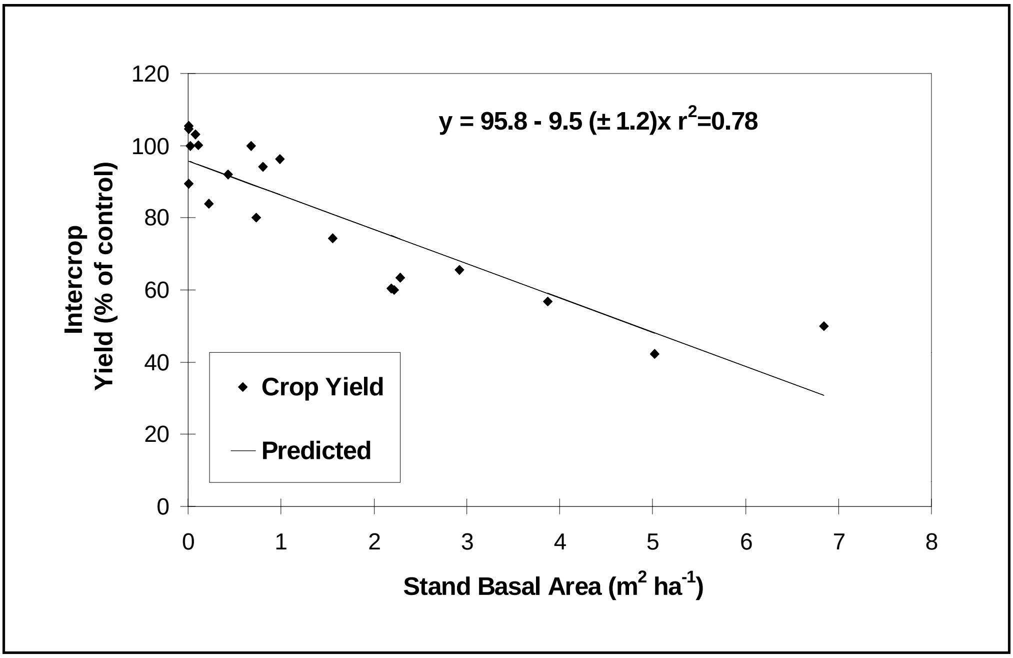

Fig. 5.1. Intercrop yields decline as stand basal area of *Eucalyptus deglupta* increases.

predict outcomes. Indeed, our data suggest that timber intercropping is not as profitable on a per area basis as high-yielding vegetables if one assumes that vegetable yields with continuous cropping do not decline (Table 5.12). As our data show that vegetable productivity does decline, and if labor availability follows current trends, then timber intercropping becomes increasingly attractive (Table 5.12). Added advantages of carbon sequestration and sale of carbon credits, conservation of soil resources and risk diversification to offset the possible opening of markets to import vegetables, also weigh in favor of timber intercropping.

Farmers interested in minimizing competition between trees and vegetables will need to confront both the above- and below-ground sources. Periodic pruning and increased fertilization (for P) near the tree are options. However, our data show that intensive pruning will slow growth of the tree, which is unacceptable for farmers with a priority to grow trees quickly. Similarly, moving the first intercrop row away from the tree limits the tree in accessing non-limiting nutrients, especially if the nutrient is leached before tree roots reach that far. These trade-offs are real, and need to be addressed experimentally to enhance efficient, and reduce competitive, use of resources.

Table 5.12. Projected effects of a four year rotation of (a) food crops only, (b) *Paraserianthes falcataria* (leguminous timber tree) only, and (c) intercropping of both for the first two years, on net present value of agricultural revenue (in Philippine Pesos), when unconstrained or constrained by fertility.

Rotation	Unconstrained	Constrained
Food crops alone	156356	80982
Forestry alone	17176	17176
Agroforestry	91766	81776

Conclusions

The magnitude of soil and nutrient losses, and their relationships with conservation practices, have been quantified in this study. Smaller, more intensively-farmed operations do not result in higher net profit for farmers, although they may, due to higher nutrient use, have better canopy cover and, therefore, less erosion per unit cultivated area. Higher input use may, however, be in response to soil degradation and cumulative losses of nutrients through erosion. Conservation practices reduced soil erosion by approximately one-half, and, though effective during the major erosion events, the level of soil conservation was less than hoped for. Scouring effects down the slope, even across naturally formed terraces behind the contour hedgerows, still require attention. Our data suggest that differential applications of dolomite and chicken dung (as a proxy for organic matter) may be called for. Crop yields were not disadvantaged by adoption of soil conservation practices, but full economic comparisons await final scrutiny.

For tree-vegetable intercrops we have quantified some of the interspecific interactions. Trees did not out-compete vegetables for below-ground resources in the first year. Indeed, they benefited from excess nutrients in the vegetable systems. The degree of competition for light can be managed by the farmer through varying planting density of trees, their planting geometry, and pruning. These results are of direct relevance to farmer cooperators, for the research upon which they were based focused on farmer needs.

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