AGRO-FORESTRY IN TROPICAL ASIA

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ABSTRACT - Traditionally the forest supplied tropical man's requirements of food, of fuel, and of fodder for his livestock. Increasing - largely immigrant - populations upon limited tropical land area, practiced in the open agriculture of a more tolerant environment, reduced fallowing periods and the time for natural regeneration of the forest soils. The resulting decline in yields and productivity was further aggravated through erosion caused by tropical rainfall upon soils bare-tilled to control weeds.

The panacea of the high-inputs technology using (mainly) externally sourced inputs could not be maintained; particularly in the context of rapidly increasing prices for the petroleum feedstock upon which most of these inputs and their transportation was based. Moreover, they failed to provide vital rural needs of fuel and fodder.

The logical alternative, - now belatedly being researched, - is an accelleration of the time-proven practice of 'forest-fallow', through the creation of a simulated forest systematically and integrally linked into a sustainable (arable) farming system. The technique involves the planting in rows of rapid-growing (ideally NF) coppicing trees, with avenues two to five metres wide between the rows into which arable crops are seasonally planted with minimal tillage. The avenues are continually manured by the loppings from the rows of trees (hedges) which thus re-cycle leached fertility and nutrients stored in the sub-soil regions.

The technique optimizes the alternating dry and wet seasons of the tropics for the rapid production of weed-shading and soil-cooling foliage during the dry season (otherwise unproductive in the temperate farming model) from the deeper reserves of moisture and nutrients available to the hedges. The wet season is then utilized for the growing of arable food crops in the fertile, leaf-mulched avenues between the lopped hedges.

That at least one arable crop can continuously be grown in the avenues each year, with adequate yields and minimal external inputs, is now known. Research continues towards increasing productivity to two crops a year where a bimodal rainfall pattern might permit this.

The technique is now also being researched in the populous regions, denuded of valuable forest, along the base of the Himalayas, with appropriate (NF) trees planted in hedge-rows along the ridges of the terraced fields. These provide the farmer with a continuous supply of fuelwood as well as foliage for fodder and mulch-fertility while also stabilizing bunds against erosion. Thus, the hitherto dry or winter seasons of this region are productively harnessed for the growing of produce vital to the economy of the farmer and his habitat, and complementary to the production of arable food corps in the terraced avenues between the bunds during the rainy summer months.

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The goal of a sustainable and productively integrated agro-forestry system for fuel and fodder as well as for food, with minimal (if any) involvement of externally sourced inputs, is now within sight. Its management for optimal resource efficiency is now being researched.

Index terms: leguminous trees, N_2 fixation.

SISTEMAS AGROFLORESTAIS NA ÁSIA TROPICAL

RESUMO - Tradicionalmente, as florestas supriram o homem das regiões tropicais com o alimento, o combustível e a forragem para os animais. Com o aumento das populações, entretanto, aumentaram as áreas sob agricultura aberta, e houve importação de um modelo agrícola desenvolvido para áreas de clima mais ameno. Isto reduziu os períodos de pousio e o tempo para a recuperação natural dos solos. O decréscimo resultante na produtividade foi agravado através da erosão causada pelas chuvas tropicais sobre os solos desnudos.

A panacéia da tecnologia de altos insumos usando, principalmente, produtos importados não pode ser mantida, particularmente devido ao rápido aumento dos preços do petróleo e seus derivados, dos quais tanto os insumos quanto o seu transporte dependem. Para agravar, esta tecnologia falhou no que diz respeito ao suprimento das necessidades rurais de combustível e forragem.

A alternativa lógica, agora tardiamente sendo pesquisada, é a aceleração da prática secular do sistema de pousio, através de reflorestamento sistemático e integralmente ligado a um sistema agrícola produtivo. A técnica envolve o plantio de linhas de árvores de crescimento rápido e habilidade de rebrota (preferencialmente fixadoras de N_2), com faixas intercalares de 2 a 5 metros de largura, nas quais as culturas são plantadas após cultivo mínimo. As faixas são continuamente adubadas com podas das árvores que, então, reciclam os nutrientes lixiviados para o subsolo.

A técnica permite aliviar os efeitos da alternância de estações secas e chuvosas dos trópicos, através do rápido crescimento da cobertura vegetal que resfria o solo. A estação chuvosa é usada para o crescimento da cultura sobre o solo fértil e protegido das faixas intercalares.

É sabido que, pelo menos, uma cultura pode ser continuamente crescida a cada ano, nas faixas intercalares, mantendo produtividade adequada com um mínimo insumo externo. A pesquisa agora se direciona em aumentar a produtividade para duas culturas anuais, onde uma distribuição de chuva bimodal permitir.

A aplicação desta técnica está também sendo estudada nas regiões populosas e deflorestadas ao redor dos Himalaias, onde árvores fixadoras de N_2 apropriadas estão sendo plantadas em linhas ao longo dos terraços. Isto fornece ao fazendeiro um suprimento contínuo de lenha, bem como folhagem para forragem e cobertura morta, enquanto protege os terraços da erosão.

Os objetivos para conseguir um sistema agroflorestal integrado e produtivo, tanto para lenha e forragem como para alimento, estão sendo alcançados. Seu manejo para máxima eficiência está agora sendo pesquisado.

Termos para indexação: leguminosas arbóreas, fixação de N_2.

INTRODUCTION

Traditionally, the forest supplied (tropical) man's requirements of food, of fuel for his hearth, fodder for his livestock and timber for his dwellings. The forest provided the base for a stable and self--sustaining system which protected its structure, limited development of noxious weeds and pathogens, guarded its soils from the extremes of rain and sunshine and continuously re-cycled its sustaining nutrients from sub-soil reserves provided that adequate time was allowed for the processes of natural regeneration.

But pressures of population and their herds reduced the time for natural forest fallow through increasing demands upon limited area for arable cropping. This was a farming system adopted from the temperate regions from where many of the subsequent populations of the tropics originated (Aryans into Southern Asia, Mongols into S.E. Asia, etc). With them came the practice of range-feeding for herds of livestock in place of browse feeding off fodder trees by domestic livestock. With them also came the annual crops, adapted to the Spring-Summer seasons of the temperate regions. But arable crop yields in the tropics were invariably lower than in the temperate lands of their origin. Various factors contributed to this: besides temperature and humidity extremes, lower insolation during the crop-maturing period than is usually experienced during the longer days of the temperate climate summer are examples.

The largely immigrant population then endeavoured to compensate for reduced yields by the cultivation of two crops a year under the year-round availability of tropical sunshine, although of an intensity reduced by day-length and cloud-cover during the growing seasons. And so fallow periods were further reduced and this resulted in greater reductions in yield until the lands were eventually abandoned. Soil recovery under grasses and rough weeds was more slowly than under forest cover with its ability to tap deeper, sub-surface reserves of nutrients.

By the middle of the twentieth century the pressures of population upon limited tropical land area had become acute. Open arable farmland with reducing organic content produced only very low yields without generous inputs of applied fertilizer which usually had to be imported. Scant area was available for grazing herds of livestock. Forests were severely denuded, and the lack of kindling for cooking resulted in dung being used more for fuel than for fertility, thus depleting the soil even further. Desertification occurred in much of India and was spreading southwards into Sri-Lanka and eastwards into S.E. Asia.

Early Research

Earlier research endeavours to combat the problem continued blind to the fact that a sustained and productive tree-crop agriculture prevailed on the plantations of the tropics; rubber, cacao, coffee, coconut, oil-palm, etc. Research towards a sustainable arable system continued along the open-field pattern of the 'western' temperate regions, with increasing requirement for imported inputs of fertilizers and of mechanization the latter aggravating erosion even further. That soils under the tropical environment required very different management from temperate soils was not appreciated even though the intensity of the tropical rainfall was shown to be about eight-times as erosive as in the temperate regions and the depletion of soil organic content about five times higher under the tropical sunshine (Lundgren 1982).

One of the earliest researchers into the problem, Abeyratne (1962), wrote "Experiments with different tillage implements at Maha-Illupallama (in Sri-Lanka) have led to the conclusion that under the rainfall and temperature conditions, and with the soil types of the dry-zone, the use of conventional tillage implements developed in a different environment in other countries are both ineffective as far as weed-control is concerned and dangerous in terms of damage to soil structure and in increasing the erosion hazard".

"Soil aggregates break down if soils are cultivated too wet or too dry; soil moisture characteristics are such that optimum conditions last for so short a duration that tillage is invariably done at the wrong time".

"A non-inverting tillage implement and minimum tillage raise problems of weed control and it is becoming increasingly clear that the final technique of weed control and seed-bed preparation will be one that combines the use of non-inversion tillage implements, leaving crop residues on the surface for seed-bed preparation, with the use of herbicides for weed control".

Abeyratne's (1958, 1962) pioneer research had identified loss of fertility through erosion, tillage, and weed-control as the prime problems of upland, rainfed, farming in the tropics. In 1975, Lal, working in Nigeria, but with an experience and background of agriculture in India quantified the erosion which occurred under the intensity of tropical rinfall, and showed that the erosion consequent upon tillage could be reduced 95% by adoption of the 'zero-tillage' technique tehen being researche (Table 1). This author also emphasized the need for mulch (Table 2) to reduce over 90% of the run-off from the undulating lands under tropical rainfall, and thus to greatly increase infiltration of this water into the ground where it could better be stored.

Tillage, practiced almost entirely for weed-control, was also the most laborious and expensive of all the farmers operations. Wijewardene and Weerakoon & Seneviratne (1982) explained how tillage just ten centimeters deep involved the cutting, lifting and turning of about 1,300 tonnes of soil per hectare with each pass. Further, that even with animal draft, the farmer still had to walk about 100 kilometers each time he ploughed an hectare of land.

Trials in Nigeria with mechanized 'zero-tillage' as used in the temperate regions showed that draft energy requirements could be reduced over 80%, and man-power inputs halved (Table 3). The technique showed promise for adaptation to the capacities of the small-scale farmer on just a few hectares, using only hand tools, provided that two special tools could be developed for him. One was a "Very-Low--Volume" sprayer to apply herbicide solutions in logistically reasonable quantities of around 40 litres per hectare as against the 400 to 500 litre-per-hectare requirement of conventional napsack sprayers. The other was a hand operated planter capable of injecting metered quantities of seed through mulch into untilled soil, a planter very different from the high-draft needs of tractor-drawn no-till planters.

TABLE 1. Effect of zero-tillage on soil and water loss during 4 months under maize. Lal (1976).

Slope %	Soil loss (t/ha)		Run-off (mm)	
	Zero-tilled	Plowed	Zero-tilled	Plowed
1%	0.03	1.2	11.4	55.0
10%	0.08	4.4	20.3	52.4
15%	0.14	23.6	21.0	89.0

TABLE 2. Effect of ground cover (mulch) on run-off and soil loss for a 10% slope (Lal 1976).

Mean annual values	Bare-ground	Mulched
Soil loss (t/ha/yr)	252.6	0.2
Run-off (mm/ha/yr)	504.1	29.3
Run-off (% of rainfall)	42.1	2.4

TABLE 3. Effect of tillage systems on energy and time needs for establishing a crop of maize (Wijewardene 1980).

Treatment	Number of passes	Energy (MJ/ha)	Labour (h/ha)
Conventional tillage			
plow-disc (2) - plant	4	235	5.4
Zero-tillage			
Spray-mow-plant	3	52	2.3

The development of these tools enabled a 90% reduction in the time for establishing a crop (Table 4) thus providing the facility for a ten-times increase in area productivity without need for tractorization. It also permitted the zero-tillage technique at small-scale, hand-tool level. Yields were also maintained at least at conventional tillage levels provided there was adequate mulch (about four to five tonnes per hectare, dry weight, being adequate) and compactation from machinery was avoided (IITA 1980).

More Recent Research

The energy crisis of the mid-'70s forced a re-evaluation of the zero-tillage technique and its validity, under circumstances of the rapidly escalating prices for imported inputs, primarily of fertilizers and herbicides. The technique, further, more ignored the rural population's need for fuel-wood and fodder, which had traditionally been essential components of the rural ecosystem. The total energy inputs into the system were then studied (Table 5) and further identified as imported-inputs or locally--sourced inputs. The need for fertilizer as an energy-dependent component was critical particularly as it had to be imported. The need for fuel-wood and fodder also became critical, although of lesser importance.

TABLE 4. Effect on man-power requirements of conventional and zero-tilled systems for establishing two successive crops using hand tools only (Wijewardene 1980).

Field operation	1st season Man/h/ha		2nd season Man/h/ha	
	Conv.	Zero	Conv.	Zero
A. Field preparation				
a. Burning	4	4		
b. Clearing/slashing	132		76	
c. Man.tillage & ridge	127		85	
d. Spray CDA (herb.)		8		8
B. Seeding (maize & cowpea)				
a. Hand planting	35		35	
b. Injection-planter (RIP)		13		9
C. Pest control				
a. Hand weeding	190	4	150	3
b. Spray CDA (pre-em.herb.)		9		5
c. Spray CDA (3) (insect'de)		2		2
D. Fertilizer application				
a. Hand dibbling	25		25	
b. Band-applicator	8			8
Man/h/ha	513	48	371	33
Yields kg/ha				
maize	600	1,773	500	1,112
cowpea	500	2,020	400	1,820

TABLE 5. Comparative fuel energy inputs into an hectare of crop production (Wijewardene & Weerakoon 1982).

1. Mechanized tillage (tractor till, cultivate)	300 MJ/ha (I)
2. 'No-till' (mechanized)	50 MJ/ha (I)
3. Manual tillage systems	100 MJ/ha (L)
4. Manual 'no-till' systems	10 MJ/ha (L)
5. Fertilizer (200 kg 30-15-15)	5,000 MJ/ha (I)
6. Herbicide (1 kg/ha)	100 MJ/ha (I)
7. Fuel-wood (farm family living off 1 hectare farm for ½ year.10 cu.ft wood)	3,000 MJ/ha (L)
8. Draft animal fodder (for tillage, transport and manure for ½ year)	6,000 MJ/ha (L)

Note: I = Imported energy
L = Local energy

Realizing that 'live-mulch' systems played an important part in maintaining fertility levels and minimizing erosion on tropical plantations, as well as for restoring worn out and depleted soils experiments were commenced by Wijewardene (1980) at IITA in Nigeria in 1976 towards the objective of sustainability with minimal imported inputs. This research was further developed by Okigbo & Akobundu (IITA 1980) and showed convincingly that while crop yields inevitably declined in conventional tillage systems (even at high rates of fertilizer inputs), and declined still but at a substantially lower rate under zero-tillage systems, yields could be sustained at high levels without added fertilizer in live-mulch systems. Here, the fertility levels were being maintained on a continuous basis by the live mulch, which also controlled most of the weeds which would otherwise have developed. The practical management of such live-mulch systems has however proven elusive at the small-farmer level in the techniques for control of the live-mulch during the development of the arable crop. Sophisticated 'growth-regulator' techniques became necessary, and this was an undesirable complication.

The alternative, therefore, of a 'high' source of permanent and living mulch was then evolved by Wilson & Kang (1980) for easier management at ground level. It developed as a permanent blend of arable farming and forestry, perhaps an ideal 'agro-forestry'. The technique involved growing arable crops in the avenues between hedges or rows of vigorous, fast-growing and coppicing, leguminous trees. At crop establishment the trees are lopped and the leaves and twigs laid on the soil to form a rough mulch in the avenues. Woody matter is laid aside and stacked for kindling. The need of the arable crops is then drilled through the mulch using an injection-planter, or even just dibbled into holes punched by a forked stick! The loppings added to the soil not only provide mulch but also much needed nutrients raised by the trees from sub-soil-surface levels to which their roots penetrate. Wilson & Akupu (1982) have quantified in Table 6 the quantum of nutrient thus raised per cropping season and the corresponding crop yields obtained when fertilized by the leaf mulch of four different species of legumes trees. Table 7 shows similar results from parallel research at Sri-Lanka's Maha-Illupallama station for rows of *Leucaena*. Several loppings are necessary after planting of the arable crop to ensure no competition for light by the hedges. These loppings, usually three or four at two to three weekly intervals, provide useful 'top-dressing' fertility when laid between the rows of emerging crops. About six tonnes of woody biomass is thus also produced throughout the year in ideal size for the hearth.

The research by Weerakoon & Seneviratne (1982) (Table 8) also shows the very considerable (80 to 86 percent) suppression in weed-growth within the avenues by the dense shade of the over-hanging trees of the hedges which rapidly regrow during the non arable cropping dry-seasons. The alternating pattern of dry and wet seasons in the tropics (both sunny) thus provides for alternating development of fuel-wood and foliage (with shade-control of weeds in the avenues) and reduces soil temperatures which preserve moisture and microbial activity during the dry season, and arable food crops during the rainy seasons. In contrast the open-field model of temperate-style arable farming, the fields deteriorated considerably during the dry season. The soils baked dry and weed development was considerable. The advantage of year-round productivity of the 'avenue-cropping' system for the benefit of the farmer becomes evident. It gives food, fuel-wood and fodder.

TABLE 6. Mulch yields and nutrients from tree-legume loppings (Wilson & Akupu 1982).

Species	Mulch dry wt kg/ha	Nutrient content (kg/ha)			Maize yield kg/ha
		N	P	K	
Cajanus cajan	4,100	151(3.6)	9(0.2)	68(1.6)	3,173
Tephrosia candida	3,067	118(3.8)	7(0.2)	49(1.4)	1,912
Leucaena leucocephala	2,467	105(4.2)	4(0.2)	51(2.0)	2,606
Gliricidia sepium	2,300	84(3.7)	4(0.2)	55(2.5)	2,587
Control	-	-	-	-	2,030
LSD (0.05)	-	19	2	8	NS

Note: Values in parenthesis show nutrient %.

TABLE 7. Biomass and nutrient yields from three-loppings of Leucaena avenues during one cropping season (Weerakoon & Seneviratne 1982).

	kg/ha
Biomass yields of woody dry matter	3,066
Biomass yields of leafy dry matter	2,838
Nutrient yields of leafy matter	N 90
	P 9
	K 73

TABLE 8. Dry weight (g/m^2) of weeds growing between maize and cowpea planted in Leucaena avenues or open field (Weerakoon & Seneviratne 1982).

Treatment	Maize	Cowpea
Grown in Leucaena avenues	19	17
Grown in open (control)	96	123
LSD (0.05)	20	35
Percentage suppression	80	86

While much of the research in 'avenue-cropping' has used Leucaena as the hedge-grown tree, *Gliricidia* deserves more attention in the future for its great adaptability to a range of tropical soils and temperatures, besides also growing easily from cuttings. In fact, the very small quantity of seed shed by the *Gliricidia* ensures it does not become a weed as could happen due to the profuse production of seed by *Leucaena.* Mulch production and fertility levels are similar in *Gliricidia* as in *Leucaena* (Table 6) although *Gliricidia* is known to take longer, initially, to develop. Doubtless other species will be found which have quicker initial growth as interest in this trees develops for its potential in 'avenue-cropping'. Research currently being undertaken by Handawela (1983) shows that even in the second year after establishment of the *Gliricidia* hedges and avenues (Table 9) yields for maize growing in the avenues without added fertilizer (1,561 kg/ha) exceeded control yields (grown on conventionally tilled, open fields without mulch) of 1,350 kg/ha despite of added NPK fertilizer (60 - 60 - 60 kg/ha). Research continues, towards examining the sustainability of the system even under increased cropping intensities, i.e. two seasons a year of arable cropping where a bi-modal rainfall enables this. The growing of crops other than maize is also being researched and alternative widths of avenues may be necessary.

While the productivity of the leguminous trees in this agro-forestry role is naturally less than its potential as a pure stand for wood (over 20 t/ha per year, Patel 1983) or for fodder (over 20 t/ha per year, Wong & Devendra 1982), the total productivity of the system for the benefit of the farmer and his habitat needs special appreciation.

Higher Altitude Applicability

In the higher altitudes such as at the base of the Himalayan range (1,500 to 3,000 m) maize is grown as the summer crop and wheat as the winter crop on the narrow terraced fields right up the sides

TABLE 9. Effect of 'simulated forest' and fertilizer on maize yields over two years (1980 and 1981) in Sri-Lanka (Handawela 1983).

Treatment	Loppings added	Grain yield	Loppings added	Grain yield
		kg/ha		
A. Simulated forest (#)				
1. No added fert'er	561	1,373	2,811	1,561
2.+ 60N	-	-	3,129	1,921
3.+ 60N, 60P, 60K	579	3,002	2,963	2,728
B. Without simulated forest				
1. No added fert'er	-	1,163	-	680
2.+ 60N	-	-	-	1,385
3.+ 60N, 60P, 60K	-	-	-	1,354

(#) = Gliricidia planted 5 m x 3 m, and maize grown in avenues between.

of the mountain range. A traditional appreciation was common for trees along the bunds forming the terraces, which stabilized and secured the bunds besides providing browse fodder for the farmers livestock. However, this very desirable practice has declined over the past century with an increasing tendency towards the open type of arable farming introduced from the temperate countries, and by staff trained in these agricultures. The sad result has been a severe denudation of the once-tree-covered hill-sides which today show severe erosion. This is particularly acute in Nepal.

A new program based at the Indian hill-station, Palampur in Himachal-Pradesh, is currently researching a return to the planting of trees on the bunds with the introduction of rapid-growing leguminous trees specially adapted to these altitudes, and planted densely along the terrace bunds for mulch, fodder and fuel-wood. Among the several species being studied in this role are:

Robinia pseudoacacia (a very promising introduction from Europe)
Leucaena diversifolia
Prosopis juliflora
and *Albizzia lebbeck*.

Appreciation for the system by the farmers has been particularly enthusiastic. It is becoming ever more clear in the tropics that 'agriculture can not develop without forestry, and forestry can not develop without the support of agriculture'. Together they thrive.

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