Article

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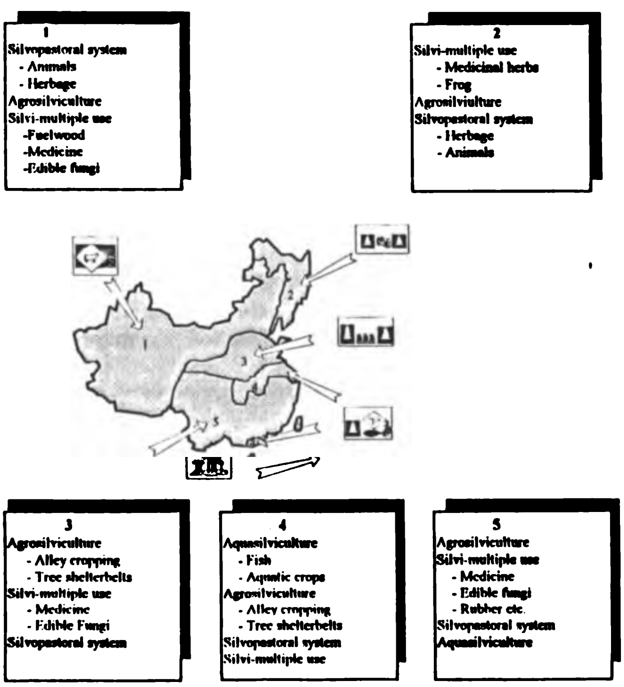
Agroforestry in China: Present State and Future Potential

In China, major agroforestry systems are estimated to cover 45 million ha. Agrosilviculture is a dominant practice. Aquasilvicultures, e.g. tree-fish-arable crop and tree-fish-livestock systems, are alternatives for land use in the wetlands. Silvopastoral systems are popular in the northern and western regions. Compared to a monoculture, well-managed systems have many benefits. The recycling of residues is expected to increase the efficient use of natural resources. The C sink in the vegetation of major agroforestry systems in China was 179 Tg yr^{-1}, and agroforestry is reported to have a positive effect on soil conservation and biodiversity. The major constraint on agroforestry is that most of the systems are on a low level of management, primarily resulting from a shortage of technical support. However, there is a great potential for the development of agroforestry in China. This paper presents recommendations concerning policy options, technical support, extension, and marketing in agroforestry.

INTRODUCTION

China's current forest areas cover only 14% of the country's total territory. Annual deforestation is 0.44 million ha (1). Heavy pollution and other environmental degradation are caused by rapid economic development. Since 1980s, increases in food production in China have barely kept up with the annual population growth, and there is little unoccupied space to fill with productive agriculture. The food that will be required to feed a population of 1.6 billion or more in the next century will have to come almost entirely from today's farmland.

Figure 1. Distribution of main agroforestry systems in China. No. 1 is the agricultural and pastoral regions of the Three-North and Qin-Tibet Plateaus; No. 2 is the northeastern forest region; No. 3 the central plains; No. 4 the wetlands or lowlands; No. 5 the southern hilly and mountain regions.



Agroforestry is a land-use system in which woody perennials are intentionally grown in association with agricultural crops and pastures as well as with livestock, and in which there is both ecological and economic interaction between trees and other components (2–5). This definition implies that agroforestry is expected to be an alternative for the increase of the forest cover and food production, to slow the environmental degradation and to contribute to our natural heritage of plants and animals. Agroforestry has been practised for several thousand years in China (6, 7). In recent decades, agroforestry has been rapidly developed in order to increase overall production by harnessing the potential of the various resources involved. Thus, a reasonable assessment of the current state and the potential of agroforestry is necessary for better management in the future.

AGROFORESTRY SYSTEMS AND MANAGEMENT

Agroforestry is widely practised in the wetlands, the hilly-land of southern China, the plain, the Three-North agricultural-pastoral area, and the northeastern forest area (Fig. 1) (Table 1). Most of the agroforestry systems in these areas have been developed from old or traditional practices.

Agrosilviculture

Agrosilviculture denotes the combination of arable crops and trees, including alley cropping/intercropping, shelterbelts, and home gardening (3, 4). This system is the most extensively practised in China (Fig. 1).

Alley Cropping

In alley cropping, arable crops are intentionally grown between the rows of trees; i.e. intensive management under trees. Alley cropping is dominant in the hilly and mountainous areas in southern China, which are situated in tropical and subtropical zones. Alley cropping is also popular in the central and northern plains. The traditional practice is to intercrop arable crops between tree rows for 1–3 years. The major improvement in alley cropping in recent decades has been a widening of the distance between tree rows and a reduction in tree plantation density in order to extend the intercropping period or to intercrop permanently, and to make the systems compatible with machine-based methods. One example is the alley cropping of Paolownia imperials (*Paulownia tomentosa*) in the Henan and Shandong provinces, in which the distance between tree rows is 18–80 m. Similar designs can be found in the alley croppings of poplar trees, Maidenhair tree (*Gingko biloba*), and Common jujube (*Zizyphus jujuba*).

Home gardening

Home gardening is the multi-species, multi-storey association of trees with herbaceous crops or livestock. Home gardening in the rural areas of China covers 3.44 million ha, i.e. 3.6% of the arable land (8). What distinguishes home-gardening systems from other land use is the intensive utilization of aboveground and the belowground resources with high species diversity. Usually, the upper-storey consists of trees that produce timber, fuelwood, fruit and fodder. The middle-storey consists of shrubs. The under-storey includes vegetables, other annual crops or animals. However, most home gardens are randomly or haphazardly arranged and the individual components are not very productive. The introduction of highly productive species and the use of efficient management patterns are a positive means of improving

Table 1. Area and distribution of major agroforestry systems in China.

Agroforestry systems	Area * (mil. ha.)	References
Agrosilviculture:		
Alley cropping	4.96	Estimated from 1, 10, 42–44
Windbreaks	35.00	25, 43
Home gardening	3.44	8, 38
Silvopastoral system	0.39	25, 44
Aquasilviculture	0.13	10, 12, 13
Orchard intercropping	1.32	21, 32, 43
Total	45.24	

* Taiwan not included.

Cultivating mushroom under the closed forests in Liuyang, the lower reaches of the Yangtze River, China. Photo: Wending Huang.

home-garden production. One example is the use of recycled residues in Jiangsu Province (8). The excrement of chickens and pigs, and the leaves of trees and crops are placed in a biogas pool to produce biogas. The residues of the biogas pool are used to produce mushrooms. The residues of the mushrooms are used to grow earthworms, which in turn are fed to chickens. Organic matter is also used as fertilizer for tree and crop growth.

Shelterbelts

A shelterbelt is made up of strips of trees planted in fields to reduce soil erosion, wind and sand encroachment, and drought stress. This includes a windbreak that is useful in checking drifting sands in desert areas and along the coasts.

Shelterbelts are especially effective in protecting farmland from severe wind and sand encroachment, and for producing high-quality timber in the central and northern plains. Farmland protected by tree shelterbelts covers 10.7 million ha and takes up 45.7% of all arable land (9). The most well-known type of agroforestry is an intercropping of Paolownia imperials (*P. tomentosa*) with arable crops.

In the northern parts of China, a windbreak is a major alternative for the control of desertification and protection of pasture and farmland. Shelterbelts have been established recently to enhance soil and water conservation in the upper-middle reaches of the Yangtze River and other hilly areas. For maximum efficiency, the upper to middle part of the hill should be forested, the lower slope should be bench-terraced horticulture, and the bottom should be farmland (10, 11).

Aquasilviculture

Aquasilviculture is a land-use system linking trees with fish or aquatic crops. The major aquasilviculture systems are managed in the middle and lower reaches of the Yangtze River, the Huihe River, the Zhujiang River and the coasts. Virgin swamp, abandoned arable, coastal wasteland, and forest lands constitute the major land resources utilized for aquasilviculture (10–13). Aquasilviculture is practised in areas with a high watertable. Ditching and terracing are employed for lowering the water level. The ponds are made on one side and the terraces on the other by removing the soil from the moist lands. Fish are grown in the ponds, while trees are planted on terraces and intercropped with arable crops. A successful example is the fish-pond-mulberry systems widely used in the wetlands. Mulberry trees and arable crops are interplanted on the dikes. Fish are bred in the ponds. The mulberry leaves are fed to silkworms, whose excreta are used as fish food. The pond-mud fertilized by organic matter and fish excreta is put up on the dikes as manure for the mulberry trees and the arable crops. Other similar examples are the tree-fish-arable crop and tree-fish-animal systems in the middle and lower reaches of the Yangtze River. The tree species are *Taxodium ascendens*, *T. distichum* and *Metasequoia glyptostroboides*. Aquatic species includes the silver carp, crab, turtle and shrimp. The animals include geese, ducks, sheep. The various species in the system can satisfy their growth requirements in their different niches and realize their functional potential to produce by-products and benefit the environment. In the tree-aquatic crop systems, the combination of rice and *Taxodium ascendens* is practised in the wetlands of the lower reaches of the Yangtze River. Trees are planted in the rice fields or on the dikes with a row distance of 5–12 m. Other types include lotus-trees, arrowhead-trees and wildrice-trees.

However, the shade from the trees reduces the temperature, light, and wind velocities. Exposure to wind is important for the system because the resulting waves help to produce oxygen for the fish. A high oxygen level is critical in summer in ponds with a high-density fish population. Thus, wind direction and a sparse structure of tree stands or belts must be taken into account in the design of aquasilviculture.

Silvopastoral System

The silvopastoral system is a form of land use in which forest and pasture are simultaneously managed for wood production and domesticated animals (5, 14). The silvopastoral system is dominant in the Three-North region. This region covers 1.49 million km^2 of desert and vast drought areas in the northern, northeastern and northwestern parts of China. The silvopastoral system is noted for its spatial arrangement of multi-storeyed vegetation. The upper storey consists of arbor species, the middle of shrubs, and the under storey of forage or grazing land.

The primary use of trees for pasture and livestock is to produce fodder, provide shade, and to serve as a windbreak. One widely used practice is to give priority to forage production using widened tree spacing. Forage production usually can be maintained through tree harvesting. The variations in silvopastoral systems range from planting trees in widely spaced rows in existing pastures, to thinning of existing tree stands. Another alternative takes wood production as the primary objective. Grazing is not permitted until newly planted trees are high enough to prevent damage by animals.

Silvi-Multiple Use

Silvi-multiple use is popular in the northeastern forest areas. This region includes the provinces of Helongjiang, Jilin, Liaoling and parts of the Inner Mongolian Autonomous Region. One of most noted examples of silvi-multiple use is the tree-ginseng (*Pnanax schinseng*) system. The ginseng is widely used as a valuable medicinal product, with a large market in China (10, 15, 16). Another example of integration is the silvi-frog system. Forest frogs can produce a frog oil, which is a kind of crude drug used widely in the Helongjiang and Jilin provinces. Agrosilviculture and silvi-edible fungus cultures are also popular.

In southern China, the silvi-medicinal herb culture and silvi-edible fungus management are notable for their high profit. Rubber, tea, coffee and coconut trees intercropped with arable crops are very popular for increasing the production of multiple products.

The silvi-medicinal herbage culture is widely practiced in the Henan, Anhui and Shantong provinces. The major species are the tuber of elevated gastradia (*Gastrodia eleta*), the root of balloonflower (*Platycodon grandiflorum*), the rhizome of large-headed atractylodes (*Atractylodes macrocephala*), and tree peony (*Paeonia suffruticosa*). The Maidenhair, mulberry, persimmon, apricot, Chinese chestnut, hawthorn, walnut, and Chinese pepper trees associated with arable crops make up the main parts of the intercropping systems in the northern parts of China.

AGROFORESTRY FOR SPECIES DIVERSITY

Tree species are very diversified in agroforestry systems, especially in the tropical and subtropical areas. Nearly 75% of major plantation species, investigated according to Silviculture Techniques of China Main Plantation Species and Huang and Wang (10), are involved in the practice of agroforestry.

Most arable crop, livestock and aquacultural species are integrated with tree species. Over half of the cultivated Chinese medicinal herb species have been intercropped into the forest stands. According to our investigation at the Zhaoguan Agroforestry Experimental Farm in October 1993, birds increased eight species and bird numbers expanded fifteenfold compared with that of un-exploited swamp land. In the tests on intercropping Chinese fir (*Cunninghamia lanceolata*) with corn, millet, soybean, buckwheat, sweet potato, hot pepper, and tung oil tree (*Aleurites fordii*), the microorganisms in the soil, except for millet, increase 1–3 times compared with a monoculture of *Cunninghamia lanceolata*, and the azotobacters on the roots are over 9–28 times larger (17).

AGROFORESTRY FOR INCREASED PRODUCTIVITY

The measurement most frequently used to judge the land-use efficiency of intercropping is the land equivalent ratio (LER) (18). We calculated the LER of *T. ascendens* crop systems under experimentation in Lixiahe wetlands in China (Fig. 2). Calculations showed the LER to be between 1.51–2.53, implying that the products which could be obtained from one ha of agroforestry management would need a total of 1.51–2.53 ha of monocultures.

In most intercropping systems, intercrop yields are smaller, because of the shade and competition from trees. But there is an increase in the total yields of trees and intercrops combined. Compared with tree plantations without intercropping, the total yield of trees and arable crops in intercropping systems can increase 0.4–1.5 times (12, 19–21). In the northern plains, the tree biomass, compared with pure tree plantation, increased by 1.81 to 2.5 tons ha^{-1} for 10-year old *Paulownia fortunei* in alley cropping fields (22). A study of the agroforestry in wetlands showed that the benefit-cost ratios of all 24 intercropping types were from 1.0 to 6.7 (23).

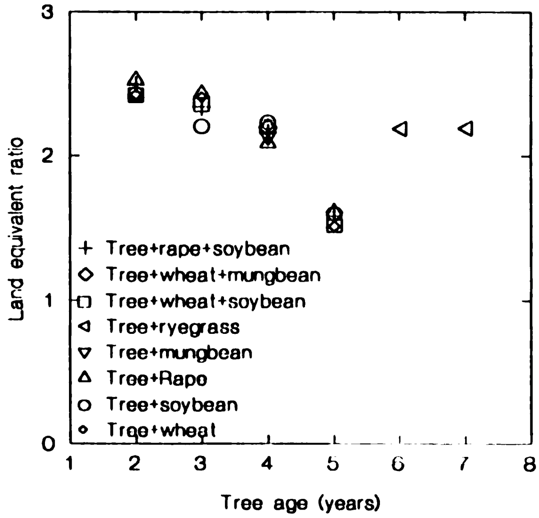


Figure 2. Illustration of the land equivalent ratio (LER) of agroforestry systems in the wetlands of eastern China. The tree species is *Taxodium ascendens*. LER = $P_1M_1^{-1} + P_2M_2^{-1}$, P_1 is production of tree species in intercropping systems, P_2 that of crops, M_1 production of tree species in a monoculture, snd M_2 that of crops. The critical value of LER is 1.0. If it is above 1.0, the intercropping system is said to be advantageous, if below 1.0, the monoculture holds the edvantage. Agroforestry experiments were set up at Zhaoguan Forestry Farm, Jiansu Province in 1984. Before that, the area was composed of reed marshes. In order to identify the best composition of tree stands for intercropping, the test of tree planting spacings was set up, with the same planting density (1667 trees ha^{-1}). The four planting spaces of trees were 2 x 3 m, 1.5 x 4 m, 1.2 x 5 m, 1.5 x 2 x 6 m (1.5 m is the distance of interplants, 2 m is the distance of narrow interrows, and 6 m is that of wide interrows). There were three repetitions for each specing. A total of 12 plots were designed with an equal area (0.5 ha per plot). Wheat and rape were intercropped in winter (the seeds were sown in November) and soybean was intercropped in summer for tha first 5 years; then ryegrass (*Lolium perenne*) was intercropped for the following 2 years. In addition, 5 densities of soybean with three replications, in which the sowing densities of soybean seeds were 67.5 kg ha^{-1}, 75 kg ha^{-1}, 82.5 kg ha^{-1}, 90 kg ha^{-1}, 97.5 kg ha^{-1}, were intercropped in the above four spacing plantations in 1987. Five densities of mung bean (*Vigna radiata*) with three replications, in which the sowing densities of mung bean sseds were 30 kg ha^{-1}, 33.75 kg ha^{-1}, 37.5 kg ha^{-1}, 41.25 kg ha^{-1}, 45 kg ha^{-1}, were intercropped in tha four above-mentioned stands in 1987. The mean biomass of trees and intercrops was used to calculate LER. Monocultures of trees and crops were measured in the same field formerly composed of reed marshes. We did not find a significant difference in the LERs between legume and nonlegume crop intercropping. The LER decreseed from 2-year-old to 5-year-old tree stands in all intercropping types involved. When tree stands were 5 years old, the LER decreased significantly because of tree canopy closure. The transfer of the intercropping of high-light requiring crops (wheat, rape, soybean and munghean) to low-light requiring ryegrass (*L. perenne*) increased the LER.

AGROFORESTRY FOR SOIL CONSERVATION

Maintenance of Soil Fertility and Improvement of Nutrient Cycling

One of the most significant hypotheses of agroforestry is the potential for maintenance of soil fertility and productivity. Agroforestry can be considered as a means of maintaining fertility through symbiotic fixation and efficient use of fertilizers. There is a need for more data, but it is at least a plausible hypothesis that trees and shrubs can be identified which, grown in agroforestry systems, will be capable of fixing about 50–100 kg N ha^{-1} yr^{-1} (24). If nutrient reserves are present in weathering rock but only at depth, tree roots may be able to tap sources unavailable to crops through recycling them as litter and root residues. The measurement of litters in *Taxodium ascendens* arable crop systems (the *T. ascendens* stands are 5 years old) in the wetlands of eastern China gives annual returns to the soil of: 89.5 kg N ha^{-1} yr^{-1} of which 66.2 kg from *T. ascendens*, 5.8 kg P ha^{-1} yr^{-1} of which 3.2 kg from trees, and 32.8 kg K ha^{-1} yr^{-1} of which 12.1 kg from trees (23). In the mulberry tree-fish systems, after nitrogen was absorbed by trees, 45% of the remaining nitrogen flowed into the pond, fertilizing soil and water for the benefit of aquatic microorganisms and plant growth. After harvesting fish, the mud and water were brought up on the land to improve the soil (25).

Maintenance of organic matter levels in the soil through the supply of litter and root residues is the major source of soil fertility improvement, because organic matter can maintain the good physical condition of the soil, protect against leaching, and lead to more efficient use of fertilizers through improved ion-exchange capacity (24). According to our measurements in the *T. ascendens* wheat-soybean system at the Zhaoguan Farm of Jiangsu Province, the return of litter to soil was 5.9 tons ha^{-1} in 5-year-old tree stands, of which 4.0 tons came from trees. In the same experiment, on the less ventilated and permeated marshlands, the noncapillary porosity increased from 0.4% to 1.8%. This is of significance in keeping the soil more aerated and increasing the drainage capacity in marshlands. The pH of

Tree-fish-rape system in Susong, Yangzhou city. Photo: Wending Huang.

soil decreased from 6.85 to 6 after 7 years of inter-cropping management (23). High pH often causes yellow leaves on young trees and on some crops.

Control of Soil Erosion and Desert Encroachment

Agroforestry has a potential for controlling erosion through the multistorey cover and litter. Even though a high tree canopy can not reduce erosion, many agroforestry systems for improving soil organic matter do help to check erosion. Maintenance of a ground-surface cover of 60% or more may be helpful in reducing erosion (23). In the northern parts of China, windbreaks or shelterbelts combined with herbaceous plants are among the most efficient alternatives for halting desert encroachment and controlling soil erosion (19). The introduction of agroforestry may provide a solution to the erosion on slopes caused by conventional arable farming. Barrier hedges are combined with trees on grass or arable crop strips, as reported by some researchers (10, 15, 19, 26).

CARBON BUDGET IN AGROFORESTRY SYSTEMS

The carbon sink in China's agroforestry systems, including tropical, subtropical, temperate, and boreal forests, was 179 Tg yr^{-1} (Table 2). If agroforestry is practised in a cycle of 15 years, the C pool of trees would amount to 620 Tg and the C sequestration of vegetation (trees, intercrops and grass) would reach 2683.8 Tg. The whole C budget of crops and forage grass is difficult to estimate because most of these crops are consumed by humans, or animals, or used as fuel after harvesting. The other components (fish, livestock, etc) of agroforestry were not included in this study. Compared with a monoculture of trees or crops, the vegetation C sink of agroforestry was increased 0.5–3 times in the wetlands (15), 0.3–3 times in the plains (estimated from 10, 15, 22, 27), 0.5–2 times in the southern hilly areas (estimated from 17, 21, 28–30). One estimate claims that for each ha of agroforestry established on deforested land in the tropics, perhaps as much as 2200 t C could be prevented from escaping into the atmosphere (31).

DISCUSSION

Constraints

Arid and semiarid regions in China cover 53% of the land area (32). This is the primary obstacle to increasing the production of forestry and agriculture in China.

Most agroforestry practices are on a low management level. Many old or conventional activities are unproductive and have improved very little over the years, and technical support is inadequate. Present agroforestry systems are usually unsuitable for the operation of machinery. Farmers are sometimes unwilling to intercrop in tree plantations, the major reason being that it is more complicated to manage agroforestry than a mono-culture. Forestry sectors are often based on strict rules for protecting trees from the damage that would result from arbitrarily pruning or thinning. A conflict between local residents and forestry agencies would occur if more emphasis were on the increase of forest cover. Foresters are in favor of forest protection while farmers are in favor of their intercrop or cash income.

When the production of agroforestry raises yields above local consumption levels, the problem of disposing of the surplus output arises, especially in inaccessible areas.

Potential and Recommendation

There are three main possibilities for using potential resources to increase production in a given land-use system: expansion of the cultivated area, increasing the frequency of cropping, and increasing the yield per unit of permanently cultivated land (33). A good example of expanding the cultivated area is the establishment of a windbreak, which is used as a reclamation technique to halt desertification. Biological controls and improved land-management practices have increased woodland by 22.7% at Yanchi, reducing severely desertified land by 10% (34). Research shows (3, 4, 12, 22, 35–38) that because of the advantage of agroforestry in resource sharing and environmental facilitation, agroforestry can raise productivity if the systems are properly managed. In the northern parts and along the coasts, large areas are available for shelterbelts or windbreaks. Another natural resource is the forest land which could provide opportunities for increasing the frequency of cropping through intercropping and multiple-product production.

Productivity in agroforestry can be improved not only by raising yields, but also by reducing the cost of production. Increased space utilization and the substitution of green manure from nitrogen-fixing trees for costly industrial fertilizer have positive roles to play, both in the protection of land from degradation and in indirectly reducing production costs. Recycling of organic materials in agroforestry is a promising way to convert waste materials into useful products. This has been practised extensively in southern and eastern China (8, 15, 19, 25, 39). However, the use of machinery, fertilizer, pesticides and irrigation are more difficult to manage in agroforestry than in a monoculture. A good alternative seems to be the system of using widely spaced alley cropping that makes the use of tractors and power tillers possible. At present, most agroforestry systems are operating at a fairly low level of management. Plant arrangement in home gardens is usually haphazard and excessively dense, with inadequate attention to growth requirements and species interaction. This leads to reduced yields and product quality. Efficient management can be improved considerably through more research back-up and extension efforts. In addition, the introduction of sophisticated techniques should be clearly demonstrated to farmers and explained in an understandable way.

In order to achieve long-term sustainability in landuse, a consistent and attainable policy for agroforestry development is needed, because farmers presently worry about the frequent

Table 2. C sink and C density of vegetation per year in the agroforestry systems of China.

Systems	Tree biomass (ton ha^{-1} yr^{-1})	C sink (Tg yr^{-1}) Tree	Crop	Grass	Total	C density of vegetation (Mg ha^{-1} yr^{-1})
Alley cropping	6.96	17.23	13.99	1.23	32.45	6.54
Shelterbelt	0.72	12.57	98.68	8.71	119.96	3.43
Home gardening	5.34	9.19	9.70	0.86	19.75	5.74
Silvopastoral system	1.66	0.32	0.33	0.65	1.67	
Aquasilviculture	2.61	0.17	0.03	0.20	1.54	
Orchard intercropping	2.80	1.85	3.73	0.33	5.91	4.48
Total		41.33	126.10	11.49	178.92	3.95

* The biomass of alley cropping was calculated according to research findings (10, 15, 27–29, 46–52); correspondingly biomass of shelterbelt (10, 27, 45, 50, etc.); of home gardening (8, 39, 53, 54); of the silvopastoral system (10, 27, 45, 55); of aquasilviculture (10, 25, 56); of orchard intercropping (21, 32).
** C density of vegetation is, in this table, defined as the quotient of total C sink (calculated from the aboveground and underground biomass of tree, crop and grass) divided by the areas of corresponding agroforestry systems (Table 1).
*** Taiwan not included.

policy changes. The sharing of benefits and obligations must be well defined. This will encourage farmers' activities in agroforestry management. Multiple solutions to the problem of marketing for surplus output are required through the development of cooperative marketing organizations and the establishment of local processing industries.

As a means of recovering forests as well as controlling desertification and soil erosion through integrated management, the recently developed Three-North Shelterbelt Program, the Coastal Shelterbelt Program, the Huang-Hui Plains Afforestation Program, and the Soil-Water Conservation Forest Development of the Upper-Middle Reaches of the Yiangtze River, all seem to be steps in the right direction. However, a technical bias and excessive bureaucracy, which exclude active local participation, should be avoided because they easily result in misunderstanding and mistrust between the farmers and the forestry agencies. The participation of local communities and farmers is so important that it will decisively influence the completion and maintenance of the programs.

Because of the complexities and component interaction in agroforestry, technical support is critical for efficient management. Most research so far has been highly descriptive or empirical (40). There is still insufficient experimental field evidence to answer the many important questions concerning why there are certain results (not only what the results are) (41). The mechanisms which contribute to the economic and environmental benefits are inadequately understood. Substantial research should be well supported. This research includes both management techniques and theoretical mechanisms. Most management patterns suggested still need wider demonstration and field trials to test their adaptability, economic viability and social acceptability.

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