SHRUBS AND TREE FODDERS FOR FARM ANIMALS

PROCEEDINGS OF A WORKSHOP IN DENPASAR, INDONESIA, 24 – 29 JULY 1989

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Abstract

This publication presents the results of an international meeting held in Denpasar, Bali, Indonesia, 24–29 July 1989, that focused on the use of shrubs and tree fodders by farm animals. Through 26 papers, the workshop addressed feed-resource availability, use by ruminants and nonruminants, processing methodology, economics, and development issues. These aspects and the current knowledge on shrubs and tree fodders were further highlighted by country case studies detailing prevailing situations and policy matters. A special session was held to discuss the successful development and results achieved in the three-strata forage system in Indonesia. The workshop concluded with important working group discussions on the priorities for further research and development, and on the potential for the wider use of shrubs and tree fodders in the developing world.

Résumé

Cette publication présente les résultats d'une rencontre internationale tenue à Denpasar, Bali, Indonésie, du 24 au 29 juillet 1989 et qui a porté sur l'utilisation des arbustes et fourrages végétaux par les animaux d'élevage. Les 26 communications qui y ont été présentées traitaient de la disponibilité des ressources alimentaires pour les animaux, de leur utilisation par les ruminants et les non-ruminants, des méthodes de transformation, des aspects économiques et des questions du développement. Ces sujets et les connaissances actuelles sur les arbustes et les fourrages végétaux ont ensuite été étudiés plus à fond dans le cadre d'études de cas de divers pays exposant les circonstances particulières de chacun et les questions liées aux politiques. Une séance spéciale a porté sur la mise en place et les résultats des systèmes de production de fourrages végétaux en trois strates en Indonésie. L'atelier s'est terminé par d'importantes discussions des groupes de travail sur les priorités de recherche et de développement pour l'avenir et sur les possibilités d'utilisation élargie des arbustes et des fourrages végétaux dans les pays en développement.

Resumen

Esta publicación presenta los resultados de una reunión internacional celebrada en Denpasar, Bali, Indonesia, del 24 al 29 de julio de 1989, y la cual centró su atención en la utilización de forrajes elaborados a partir de arbustos y árboles para alimentar a animales de granjas. En 26 trabajos presentados al seminario, los participantes abordaron temas tales como la disponibilidad de recursos alimentarios y la utilización de los mismos por rumiantes y no rumiantes, metodologías de procesamiento y cuestiones de economía y desarrollo. Estos aspectos y el conocimiento que se tiene actualmente sobre los forrajes de arbustos y árboles se vieron subrayados aún más por estudios de casos por países en los que se detallaron situaciones existentes y cuestiones de políticas. Se celebró una sesión especial para discutir el desarrollo y resultados exitosos alcanzados en Indonesia con el sistema de forraje de tres niveles. El taller concluyó con importantes discusiones de los grupos de trabajo sobre las prioridades existentes en el campo de la investigación y el desarrollo y sobre el potencial que encierra la amplia utilización de arbustos y árboles en el mundo en desarrollo.

Contents

Agrosilvipasture systems in India

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Abstract — *Agrosilvipasture systems have evolved in response to pressures of both animal and human populations coupled with changing climatic regimes. The systems, integrating trees or woody perennials and grasses with crop farming, ensure stability in land productivity, achieve high productivity and diverse produce, improve soil fertility, and enhance the supply of nutritious fodder to livestock in varied agroecological conditions. Agrosilvipasture systems, when compared with traditional land-use systems, have much higher yields and year-round forage availability. Potential fodder trees, grass species, and production systems have been identified for specific situations. The systems, besides being economical, result in ecological improvement and show great promise for enhancing biomass production and meeting the increasing demand for forage and fuel wood. Each of these aspects, including the use of trees and shrubs and research and extension needs, are discussed in this paper.*

Résumé — *Les systèmes agrosylvipâturaux ont évolué en réponse aux pressions exercées par les populations animales et humaines combinées aux changements dans les régimes climatiques. Les systèmes, qui intègrent les arbres ou plantes ligneuses et les graminées aux cultures, garantissent la stabilité de la productivité des sols, permettent une productivité élevée et diversifiée, augmentent la fertilité des sols et améliorent l'approvisionnement en fourrages nutritifs pour le bétail dans diverses conditions agroécologiques. Les systèmes agrosylvipâturaux, comparés aux systèmes conventionnels d'exploitation des terres, ont un rendement beaucoup plus élevé et assurent une disponibilité plus grande de fourrage sur toute l'année. On a déterminé quels arbres fourragers, espèces de graminées et systèmes de production conviendraient sans doute dans certaines situations. Les systèmes, outre qu'ils soient économiques, entraînent une amélioration de l'écologie et offrent de grandes promesses d'amélioration de la production de la biomasse et de réponse à la demande toujours plus grande de fourrages et de bois de chauffe. L'auteur aborde chacun de ces aspects, y compris l'utilisation des arbres et des arbustes et les besoins au plan de la recherche et de la vulgarisation.*

Resumen — *Los sistemas de agrosilvipastizales se han desarrollado en respuesta a presiones de poblaciones humanas y animales junto con cambios de condiciones climáticas. Dichos sistemas, que integran los árboles o plantas leñosas y gramíneas con el cultivo del campo, garantizan la estabilidad de la productividad del suelo, logran una alta producción y variado rendimiento, mejoran la fertilidad del suelo y aumentan la provisión de forraje nutritivo a la ganadería en diversas condiciones agroecológicas. Comparados con los sistemas tradicionales de uso de la tierra, los sistemas de agrosilvipastizales tienen mucho mayor rendimiento y disponibilidad forrajera durante todo el año. Se han identificado, para situaciones específicas, los árboles forrajeros, especies de hierbas y sistemas de producción potenciales. Además de ser económicos, los sistemas dan por resultado mejoras ecológicas y se presentan como una gran promesa de acrecentamiento de la producción biomasiva y de*

satisfacción de la creciente demanda de forraje y leña. Este estudio trata cada uno de estos aspectos, inclusive el uso de árboles y arbustos y las necesidades de extensión e investigación.

Introduction

India has a long history of shortages of animal feeds and fodders. The current gap between demand and supply is more than 50% (Singh 1987a). The problem has been the result of low productivity, ruthless exploitation of available grazing resources, preference by farmers of growing nonforage crops, and increasing animal population. To overcome this shortage, growing food and fodder crops on the same unit of land in rain-fed situations and integrating trees and grasses with crop farming on marginal and submarginal land with improved technology deserve high priority (Singh 1988a).

The concept

The concept of integrating farming and forestry originates from the realization that trees play a vital role in safeguarding the long-range interests of agriculture, including animal husbandry. Such integration, known as agroforestry, makes agricultural economy more viable. It involves more or less intimate and interacting associations of agricultural crops, horticultural crops, and woody perennials on the same unit of land. This form of land use has two main objectives:

- productivity, involving a multiplicity of outputs, and
- sustainability, which implies the conservation, or even improvement, of soils, broadening future land use options.

Generally, it is believed that such a system should not only integrate various crops for their complimentarity but should also conserve and improve productivity. Agroforestry embraces many production systems, such as agrosilviculture (crops, including tree and shrub crops), silvipastoral (pasture animals and trees) and agrosilvipastoral systems (crops, pasture animals, and trees) (Nair 1985), coppice farming, and horti–forage–food (fruit, forage, and food crops).

In India, where small land holdings, abundance of labour, and low input supply are characteristic, land sustainability should get priority over productivity and economical viability. However, because of the large number of the land owners, the low level of capital available, the inadequate research base, the lack of support service, and the complexity of knowledge required from the individual land owner, improvement in the system is comparatively slow. Elsewhere in the tropics, agroforestry systems also operate on small farms and barely within the cash economy (Briscoe 1983).

Tree leaves as livestock feed

Planting fodder trees to enhance livestock production and minimize seasonal nutritional deficits is becoming increasingly widespread in India. In hilly areas, feeding tree leaves to ruminant livestock is a traditional practice (Balraman 1980; Gupta 1981). In some parts of India, more animals feed on shrubs and tree fodders than on grasses and pasture.

Many tree leaves are used as ruminant feed in both the plains and the hills (Sen et al. 1978; Thakur et al. 1987). The comprehensive work of Gupta (1981) and others has indicated that several hundred varieties of tree fodder are commonly and traditionally fed to livestock in different parts of India; the feed value of many of these species needs to be studied properly. So far, only about 160 fodder tree leaves have been analyzed chemically; 40 of these are important in the livestock industry because of their wide distribution. Most tree leaves are rich in crude protein and calcium, and low in phosphorus and crude fibre.

Over 60% of the fodder requirements of goats are normally met with shrubs and tree fodders. Tree leaves and shrubs preferred by goats include peepal (*Ficus religiosa*), bargad (*Ficus benghalensis*), gular (*Ficus recemosa* or *Ficus glomerata*), neem (*Azadirachta indica*), jamun (*Engenia jambolans*), mahua (*Bassia latifolia*), jackfruit (*Artocarpus heterophylus*), bhimal (*Grewia oppositifolia*), kachnar (*Bauhinia variegata*), ber (*Zizyphus jujuba*), jherberi (*Zizyphus numularia*), mulberry (*Morus alba*), cassava (*Manihot esculenta*), gliricidia (*Gliricidia maculata*, *Gliricidia sepium*), babul (*Acacia arabica*), and khejri (*Prosopis cineraria*). Trees and shrubs such as *Acacia nilotica*, *Acacia tortilis*, *Albizia lebbek*, *Alianthus excelsa*, *Clerodendron phlomidis*, *Capparis zeylanica*, *Dichrostachys nutens*, *Gymnosporia spinosa*, *Leucaena leucocephala*, *Sesbania sesban*, and *Sesbania grandiflora* are also highly palatable and nutritious.

Trees can be grown on steep, rocky mountain slopes, in arid, saline, or water-logged soils, and in areas with severe climatic conditions. Also, trees do not need heavy inputs of fertilizer, irrigation, labour, pesticides, etc., as are generally needed to grow conventional fodder crops. Trees use and recycle nutrients that are beyond the reach of grasses and other herbaceous plants. Trees that accumulate nitrogen enhance forage quality. Their relative deep root system can exploit deep moisture resources and, using this and other strategies, trees are more tolerant to dry periods than pastures.

Research and extension is now being directed toward persistent, versatile trees and shrubs to ensure that conservative grazing management maintains a productive ecosystem and does not allow woody, unpalatable species to replace desirable fodders. Eradicating trees in humid and semi-arid areas enhances grass yields and animal production; however, in many situations, killing native trees is not necessary to improve animal production. In the arid zone, grass is often of better quality, stays green for much longer, and is more abundant under the shade of fodder trees, where potential evaporation is reduced by more than 50%. This has been observed with *Pennisetum pedicellatum* in the Sahel region of West Africa, *Panicum maximum* in Botswana and Queensland, *Cenchrus ciliaris* in Queensland (Wildin 1989), and *C. ciliaris* and *Cenchrus setigerus* in India (Gupta 1975). In such situations, unpalatable native trees of limited value should be replaced with others of greater intrinsic worth (e.g., species with palatable foliage or the capacity to fix nitrogen or produce timber).

Agrosilvipasture systems

In age-old "taungya" plantations, forest labourers grow agricultural crops with forest tree crops to meet daily requirements. This approach to production aims at obtaining food, fodder, and fuel from the same unit of land. Under rain-fed conditions, this can be achieved in a production system including the crop–grass–tree combination. Production increased threefold after legumes were introduced into the system (Table 1). Range legumes (*Stylosanthes hamata*) improved the cereal grass yield by 6–26% and contributed 6–16% toward total forage production (Singh 1988b). In addition to improving the nutritive value of grass, legumes provided an excellent ground cover, eliminating weeds and improving soil fertility.

Pasture production in silvipastoral systems is directly influenced by its establishment and management. Long-term studies on pasture production in association with fodder–fuel trees at the Indian Grassland and Fodder Research Institute, Jhansi, have revealed that, if properly established and managed, a pasture could be reasonably productive for 8 or 9 years. However, during the establishment year, pasture production is normally low, varying from 1.5 to 2.5 t/ha.

Deb Roy et al. (1978) studied the forage production of *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* and *Sehima nervosum*, and the effect of different spacings of *Hardwickia binata* and *Albizia amara* on this production on typical red Bundelkhand soils. Forage production (4.23 t/ha) from the mixture of *C. fulvus* and *S. nervosum* was higher than that of *C. ciliaris* (3.74 t/ha). Forage production of *C. ciliaris* was affected by tree density, both under *H. binata* and *A. amara*; the mixture of *C. fulvus* and *S. nervosum* was relatively unaffected by tree density. In

Table 1. Production potential and energetics of restructured forage production systems.

Subecosystem	Maximum harvest (g/m^2)	Annual energetics (kcal/m^2)
Local situation		
Heteropogon contortus + *Faveolatus*	240	1 100.0
Reconstructed adaptable ecosystem		
Cenchrus ciliaris + *Chrysopogon* + *Leucaena leucocephala* + cowpea	670	3 697.5
C. ciliaris + *Chrysopogon fulvus* + *Albizia lebbek* + wild pigeon pea	790	3 357.5
Sehima nervosum + *C. ciliaris* + *A. lebbek* + *Clitoria ternates*	735	3 123.8
Setaria anceps + *Brachiaria mutica* + *Sesbania grandiflora* + *Phaseolus calcaratus*	590	2 507.5
C. ciliaris + *A. procera* + *Phaseolus* spp.	760	3 230.0
C. ciliaris + *Prosopis juliflora* + *Dolichos lablab*	710	3 017.5
C. fulvus + *A. tortilis* + *D. lablab*	515	2 188.8
A. lebbek + *Heteropogon contortus*	410	1 742.5

Source: Deb Roy et al. (1978).

the 5th year, with the development of a canopy, forage production was significantly reduced under both tree species. This was especially so in the case of *A. amara*, probably because of its inherent low branching and spreading crown. These results show the importance of opening the tree canopy through lopping or side pruning. In fact, *A. amara* has a high lopping potential for leaf fodder and firewood production.

Deb Roy et al. (1980) also studied the forage production of two grass species, (*C. ciliaris* and *C. setigerus*) and the effect of different spacings of *L. leucocephala* and *A. tortilis* on this production on typical red Bundelkhand soils. *Cenchrus ciliaris* had a higher forage production than *C. setigerus* (Table 2). *Cenchrus ciliaris* gave a peak forage production of 5.3 t/ha in closely spaced *L. leucocephala* and an overall annual mean forage production for 5 years of 4.3 t/ha.

Roy et al. (1984) reported a dry forage yield of 4.73 t/ha for *C. ciliaris*, 2.21 t/ha for *C. fulvus*, 3.92 t/ha for *Stylosanthes hamata*, and 1.57 t/ha for *Macroptilium artropurpureum* in association with *Dichrostachys cinerea* in a highly calcareous Bundelkhand wasteland. Deb Roy (1986a) reported higher pasture productions for *S. nervosum* (7.8 t/ha) and *C. fulvus* (7.4 t/ha) than for *C. ciliaris* (5.7 t/ha) in the 3rd year of establishment in association with *Albizia lebbek* on a typical Bundelkhand wasteland with a semirocky substratum. On the same site, in association with *Albizia procera*, a mixture of *C. ciliaris* and *Dolichos axillaris* gave peak forage production of 7.9 t/ha. Higher forage production from these systems was attributed to the better establishment and management of grasses. On similar sites, *C. ciliaris* in association with *Prosopis juliflora* (Israeli variety) gave a forage production of 6.0 t/ha, thereby disproving the notion that nothing grows under *P. juliflora*.

In association with *L. leucocephala*, *C. ciliaris* gave a forage production of 7.9 t/ha; *C. fulvus* produced 7.4 t/ha. In later years, *C. fulvus* outyielded *C. ciliaris*. On such sites, even after 7 or 8 years of establishment, *C. fulvus* and *C. ciliaris* produced forage at rates of 5.2 and 4.3 t/ha, respectively, in association with *D. cinerea* (introduced at year 4 with a density of 600 plants/ha). However, under the canopy of *A. lebbek*, these grasses gave lower forage productions: 4.1 and 3.2 t/ha, respectively.

The silvipastoral system, when compared with the traditional land-use system, yields seven times with year-round forage availability; forage that is both nutritious and high in protein (Singh 1988a) (Table 3). Promising shrub and tree species were

Table 2. Forage production (t dry matter/ha) in silvipastural systems.

Treatment[a]	1972	1973	1974	1975	1976	Mean
Ll, S_1, Cc	4.29	3.10	5.34	5.89	2.73	4.27
Ll, S_1, Cs	2.50	2.15	2.15	5.01	2.45	2.85
Ll, S_2, Cc	4.02	2.15	4.02	5.47	3.40	3.88
Ll, S_2, Cs	2.07	2.53	3.22	5.21	3.91	3.39
At, S_1, Cc	3.32	3.11	4.02	4.09	2.99	3.39
At, S_1, Cs	2.96	2.80	2.63	5.43	2.69	3.30
At, S_2, Cc	4.19	2.33	2.95	5.04	3.00	3.50
At, S_2, Cs	1.36	1.37	2.63	5.00	3.00	2.67
Mean	3.09	2.49	3.37	5.14	3.02	

Source: Deb Roy et al. (1980).
[a] Cc, *Cenchrus ciliaris*; Cs, *Cenchrus setigerus*; Ll, *Leucaena leucocephala*; At, *Acacia tortilis*; S_1, 4 × 4 m spacing; S_2, 4 × 6 m spacing.

Table 3. Production potential of some fodder trees in the Bundelkhand region of India.

Species	Age (years)	Trees/ha	Leaf fodder production (kg/tree)	Firewood (kg/tree)
Acacia tortilis	7	440	3.2	51.6
Albizia amara	7	440	13.5	86.6
Albizia lebbek	6	440	5.3	155.0
Albizia procera	6	440	11.3	85.5
Dichrostachys cinerea	6	440	0.8	13.6
Leucaena leucocephala	3	5 000	0.8	5.5
	4	5 000	1.9	11.9
Hawaiian Giant	1.5	5 000	1.5	4.2
Sesbania grandiflora	3.5	5 000	0.9	16.6
Sesbania sesban	3.5	5 000	0.3	12.1

Source: Singh (1984).

tested on marginal and submarginal land sites with recommended plant densities for fodder and fuel. *Albizia* and *Acacia* species gave high firewood production; *Leucaena* and *Sesbania* produced the highest fodder yields per unit land. Because the growth habits of species differ markedly, a new avenue for combining different species on the same piece of land using appropriate planting geometry can enhance total firewood and fodder yields. Production under different silvipasture systems in the rocky conditions of the hill regions and in saline situations have also shown promise (Singh 1988c).

Prosopis cineraria, an unexploited resource of the Thar desert, India, is a tree of worship. Every plant part of this tree is used, providing fodder, fruit, firewood, timber, and construction and fencing materials. The canopy provides excellent shade, enhancing herbage yield, growth, and botanical composition of natural pastures. The highest herbage yields were observed with *Albizia lebbek* (113 t/ha) and *Tecomella undulata* (106 t/ha), followed by *Prosopis cineraria* (2.3 t/ha), *Prosopis juliflora* (0.8 t/ha), and *Acacia senegal* (0.8 t/ha) (Muthana et al. 1976; Ahuja et al. 1978). Sown pastures of *Cenchrus ciliaris* showed a gradual but significant decrease in plant height, tussock diameter, and herbage yield as the distance from the *Prosopis* trees increased.

Lopping management

Excessive, indiscriminate lopping of fodder trees has depleted valuable fodder resources, destroyed forest lands, and initiated soil erosion (Singh 1984). Long-term studies on lopping management of fodder trees at the Indian Grassland and Fodder Research Institute, Jhansi, have revealed that, if properly managed, considerable fodder and firewood may be obtained during lean periods without negatively affecting tree growth.

Deb Roy (1986b), while working on leaf fodder production of two *Albizia* species (*A. lebbek* and *A. procera*) grown in association with *Cenchrus–Stylosanthes* pasture, reported a higher leaf fodder yield in *A. procera*. The data was based on 2 years of lopping studies on 8- and 9-year-old plants. In *A. lebbek*, mean green and dry leaf fodder productions of 9.6 and 5.3 t/ha, respectively, were realized by lopping annually at one-third intensity; corresponding values were 6.2 and 2.8 t/ha with biennial lopping at two-thirds intensity. Roy and Deb Roy (1986) tried to standardize the lopping cycle of some tropical fodder trees between 5 and 10 years old, (*Acacia tortilis, Albizia amara, A. lebbek, A. procera, D. cinerea,* and *H. binata*). Based on 5-year data on various tree growth parameters as affected by lopping, fodder, and firewood yields and the response of trees to different lopping intensities and intervals, lopping treatments producing optimum, sustained yields have been identified (Table 4).

Except for *D. cinerea*, all species tolerated annual lopping. Five-year-old *D. cinerea* tolerated moderate loppings every 6-months, with an annual dry leaf fodder production of 2.1 kg/tree. This is equivalent to 1.3 t/ha with 640 trees/ha in a *Cenchrus–Chrysopogon* pasture. However, Roy et al. (1984) recorded a much lower leaf fodder yield (0.74 kg/tree) with similar age-group trees. This signifies the importance of lopping or browsing by animals to increase leaf fodder availability. *Albizia amara* and *A. procera* tolerated intense lopping; *A. lebbek*, however, could tolerate only moderate lopping. A fodder yield of 12.9 kg/tree (4.13 t/ha) was realized from 10-year-old *A. amara* trees with annual lopping at two-thirds intensity. With 7- to 8-year-old trees grown on a single-row plantation (5 m apart), a leaf fodder production of 5.96 t/ha was obtained. A much lower leaf fodder production of 3.62 kg/tree (1.81 t/ha) from a 14-year-old silvipastoral plantation was obtained by thinning the trees during the summer. In *A. amara*, more leaf fodder is available if lopping is done in the winters. An annual leaf fodder yield of 16.6 kg/tree was realized with *A. procera* with two-thirds lopping; *A. lebbek* yielded 4.0 kg/tree with one-third lopping.

Annual lopping of 8- to 10-year-old *A. tortilis* plantations resulted in 1.12 t/ha of dry leaf fodder; 7-year-old trees yielded 1.40 t/ha of dry fodder (Deb Roy et al. 1979). However, Roy and Deb Roy (1986), based on a long-term lopping trial of this species, recommended only one-third annual loppings for *A. tortilis*. This results in a lower fodder yield of 0.51 kg/tree. In the case of *H. binata*, an annual fodder yield of 3.67 kg/tree (1.17 t/ha) with one-third annual lopping was recorded. A similar production of 3.74 kg/tree (1.87 t/ha) of dry leaf fodder in silvipastoral plantations in association with *Sehima–Chrysopogon* pasture was also recorded. Roy and Deb Roy (1986) recorded a leaf fodder production of 10.2 kg/tree with biennial lopping of moderate-sized roadside plantations of *Bauhinia purpurea* grown 5 m apart.

Table 5 compares initial and lopped fodder yields, firewood yields, and crude

Table 4. Average annual fodder and fuel productions (kg/tree) of some tropical fodder trees under lopping management.

Species	Initial age (years)	Lopping treatment	Leaf fodder	Fuel
Acacia tortilis	10	1/3, annual	1.1 (0.5)	18.6 (11.2)
Albizia amara	10	2/3, annual	25.3 (12.9)	41.2 (23.6)
Albizia lebbek	6	1/3, annual	8.5 (4.0)	9.6 (5.1)
Albizia procera	6	2/3, annual	30.8 (16.6)	24.6 (14.6)
Dichrostachys cinerea	5	1/2, biannual	3.4 (2.1)	8.3 (5.1)
Hardwickia binata	10	1/3, annual	6.7 (3.7)	8.5 (5.5)

Note: Values in parentheses are dry weights (kg).
Source: Deb Roy (1986b).

protein contents of the leaf fodder. Except for *D. cinerea* and *H. binata*, average lopped yield is less than initial yield. Similarly, except for *A. tortilis* and *A. procera*, there is slight increase in the crude protein content of lopped leaves. Therefore, the fodder and firewood yields obtainable during lean periods, without negatively affecting tree growth, suggest that judicious lopping could be a profitable proposition.

Alley farming

In alley farming, fast-growing and coppicing trees are planted in hedgerows and the alleys are used for food, grain or forage production. Tree rows are lopped periodically and the loppings are used as forage or mulch under dryland conditions. Studies on *L. leucocephala* alleys (2 × 0.5 m) lopped at 1.5 m showed increased crop yields compared with the control. Besides regular crop production, such a system yields 6 t/ha per year of leaf fodder from leucaena and 7–9 t/ha of firewood at the end of a 3-year rotation. In *Acacia albida* alleys, Guinea grass yielded a maximum of 8 t/ha of dry forage; this was followed by nandi (*Setaria anceps*) and *C. ciliaris*. Row orientation of alleys has a very important role in the production of associated crops. "Angular" directions (northeast–southwest or southeast–northwest) are more beneficial to crop yields. Using leucaena leaves as manure increases the nitrogen content of the soil compared with basal or top-dressed chemical fertilizer. At 40 kg N/ha, leaf manure resulted in a yield 10% higher than that obtained using urea. In addition to these benefits, leucaena cultivation enriches the soil. The yield of the following cereal crop was 54% higher after the removal of 6-month-old leucaena compared with the control. For 1- and 2-year-old leucaena plantations, yield improvements were consistent for three crops.

Soil improvement

A chemical analysis of surface soil revealed that the organic carbon content and total phosphorus were highest under khejri (*P. cineraria*); nitrate nitrogen was also high (Aggrawal and Saxena 1975). Gupta (1975) found that soil moisture in a 120-cm soil profile was highest under khejri, followed by kumut, rohida, siras, and vilayti babul. Increased soil fertility is consistent with the nodulation in khejri (Basak and Goyal 1975). Singh and Lal (1969) also reported that the soil under khejri had higher contents of organic matter, total nitrogen, available phosphorus, and soluble calcium compared with the soil under babul (*Acacia nilotica* var. *indica*). Also, the pH value of the soil under khejri was near neutral (pH 7.3).

Recent investigations by Shankar and Saxena (1976) and Shankar et al. (1976) revealed that there was a gradual decrease in the percentage nitrogen and organic matter content of the surface soil (0–10 cm) as the distance from the khejri tree increased. This trend closely paralleled that observed for growth and production. High organic matter content in the soil under khejri may be due to leaf fall and its faster mineralization, perhaps because of the favourable moisture condition that exists under the khejri canopy (Gupta 1975). Potential species of trees, shrubs, and grasses and legumes for different agroecological and land situations have been identified (Singh 1988d).

Table 5. Average annual fodder and firewood yields (kg/tree) and crude protein (CP) contents (%) of some fodder trees with lopping management on wastelands.

Species	Initial age (years)	Initial			Lopped		
		Fodder	Firewood	CP	Fodder	Firewood	CP
Acacia tortilis	9	0.8	12.7	13.6	0.5	11.2	12.1
Albizia amara	9	18.3	37.7	18.6	12.9	23.9	19.1
Hardwickia binata	9	3.8	6.6	8.9	3.7	5.5	9.5
Albizia lebbek	6	4.6	8.0	27.1	4.2	5.1	26.0
Albizia procera	6	17.9	17.4	18.7	16.6	14.6	16.7
Dichrostachys cinerea	6	2.8	8.6	12.9	3.9	9.3	13.9

Source: Roy and Deb Roy (1986).

Precautions

The quality of any green fodder mainly depends on the voluntary intake and availability of protein, energy, minerals, and vitamins. Although information on the palatability of fodder tree leaves is scanty, it is known that dry matter intake varies from 1.0 to 2.5 kg/100 kg body weight. This low dry matter intake thus appears to be a limiting factor in energy supply from tree leaves. About 60% of fodder tree leaves evaluated contain less than 50% total digestible nutrients (TDN) on a dry matter basis; 40% of tree leaves contained more than 50% TDN. Thus, the available energy (TDN) in tree leaves is low. Tree fodders like *Adina cordifolia, Aegle marmelos, Alianthus excelsa, Bauhinia variegata, Ethretia laevis, Ficus hookerii, Grewia optiva, Helisteres isora, Holoptelia integrifolia, Lanrea coromandalica, Leucaena leucocephala, Moringa oleifera,* and *Morus alba* contain more than 55% TDN and are, thus, a better energy source.

The low digestibility of many tree leaves is possibly due to their high lignin and tannin contents. Tannins also bind proteins and thereby lower their digestibility. In addition, tannins adversely affect calcium use. The structure of crude fibre, which in tree species is complex and considerably lignified, negatively affects the digestibility of other nutrients (Patnayak 1982). Some tree leaves also contain toxic constituents. For example, the high mimosine content of *L. leucocephala* is toxic to both ruminants and nonruminants. *Stranvaesia nussia* leaves contain HCN. *Taxus baccata* leaves can be deadly if consumed in large enough quantities. *Ficus nemoralis* leaves cause haematuria when they are fed to cattle.

Economics

An economic evaluation of the silvipastoral system needs to analyze the system's efficiency compared with that of a rain-fed farming system. Whereas rain-fed farming in most of the semi-arid and arid tropics embraces only seasonal grain, oilseed, and pulse crops, silvipastoral systems are based on perennial plants. A study conducted at the Indian Grassland and Fodder Research Institute, Jhansi, showed that, at the peak production of rain-fed cropping, the net gain is 86.5% of that obtained in the natural grass and tree system (trees lopped twice a year). However, in poor-rainfall years, the crops suffer, and production could be halved. The efficiency of an improved silvipastoral system is expected to be 5.3 times that of natural grazing lands or 1.8 times that of the best rain-fed system (Singh 1987b). In terms of input and output, efficiency would still be higher because rain-fed farming involves expenditures for cultivation, seed, fertilizers, and labour every year; in the silvipastoral system these inputs are experienced only once, in the 1st year. Productivity enhancement is mainly due to the trapping of solar energy at two tiers: the canopies of both woody and herbaceous plants.

Prajapati (1979) calculated the yields of various components in a fuel–fodder plantation under ravine conditions. Dutta (1979) studied the economic aspects of a three-tier system incorporating the concepts of silvi- and horti-pastoral production in the northeastern region of India and concluded it to be an economically viable and socially acceptable alternative to "jhuming." The economics of silvipastoral systems have been studied in detail in the hot, arid regions of Rajasthan (Gupta 1983). He estimated net annual returns from silvipastoral systems at 360 to

3 270 INR/ha, depending on the species and felling cycles and using a discount rate of 11% (in July 1989, 15 Indian rupees [INR] = 1 United States dollar [USD]). Compared with this system, the returns from annual crops were 180 INR, 20 INR, including the cost of family labour, and 6.5 INR, including the return from existing trees and bushes. Gupta (1983) concluded that multiple-use silvipastoral systems are economically attractive and ecologically beneficial.

Singh and Pathak (1986) observed a net profit of 1 830 INR/ha over 3 years from intensive pasture development under tree plantations. These benefits are optimized under controlled grazing after the 3rd year. In a cut-and-carry system, however, net returns are lower. Singh and Pathak (1986) also observed that cost could be minimized with a relatively larger land area, legume introduction, and farming system approach. Considering the problems of wastelands, this approach includes development, land conservation, and soil amelioration.

Research and extension needs

Research on fodder and fuel trees beneficial to an agrosilvipastoral system should emphasize the following areas:

- introduction, testing, improvement, and multiplication of multipurpose tree species under different agroecological situations;
- selection of seeds of trees and grasses from natural forests and rural areas;
- soil productivity status with respect to various species and management and its impact on soil structure and nutrient supply;
- secondary productivity involving grazing, stall feeding, and feed supplementation, transforming the forage production data into animal production data per unit land;
- physiological studies, such as tolerance to salt and drought, transpiration rate and photosynthetic activities;
- lopping, harvesting, and coppicing management;
- postharvest management studies, such as transporting, drying, storage, and processing of forestry products;
- economic environment and its impact on system components and other farming systems; and
- socioeconomic aspects, including marketability of the product and its impact on rural prosperity.

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