AN INTRODUCTION TO NEEM, ITS USE AND GENETIC IMPROVEMENT

Improvement of neem (*Azadirachta indica*) and its potential benefits to poor farmers in developing countries. R7348. 01.04.99 - 31.12.99.

for

Forestry Research Programme of the Renewable Natural Resources Knowledge Strategy
Department for International Development (DFID)

February 2000

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1.0 BOTANY

Azadirachta indica A. Juss.

Neem (*Azadirachta indica* A. Juss. *Meliaceae*) is an attractive, evergreen tree that can grow up to 20 m tall. Its spreading branches form rounded crowns up to 10 m in diameter. The short, usually straight trunk has a moderately thick, strongly furrowed bark that has a garlic-like odour and a bitter, astringent taste. Its leaves are imparipinate, 20-38 cm long, crowded near the branch end, oblique, lanceolate and deeply and sharply serrate. Neem is rarely leafless and is usually in full foliage even during months of prolonged drought. Its small, white bisexual and staminate (functionally male) flowers are borne in axillary clusters. They have a honey-like scent and attract many bees which act as pollinators. The fruit is a smooth, ellipsoidal drupe, 1-2 cm long that is yellow when mature and comprises a sweet pulp enclosing a seed. The seed is composed of a shell and a kernel (sometimes two or three kernels), the latter having a high oil content. Neem will begin bearing fruit after 3-5 years, becomes fully productive in 10 years and can produce up to 50 kg of fruits annually (NRC, 1992; Tewari, 1992; Chandra, 1997; Ketkar and Ketkar, 1997; Gunasena and Marambe, 1998).

There are acknowledged to be two varieties of neem: *A. indica* ('Indian neem') and *A. indica* var. *siamensis* ('Thai neem') (Lauridsen, 1991). *A. indica* var. *siamensis* has a wide natural distribution in Thailand at altitudes below 200 m (Willan *et al*., 1990). It extends south on the Thai peninsula where the variety is reported to hybridise with Indian neem to give progeny of intermediate characteristics. *A indica* var. *siamensis* has leaves which are larger, less bitter and darker in colour than the Indian neem, and is also reported to grow faster, typically with a single, straight stem (Read, 1993). The two varieties can also be distinguished by differences in their pollen morphology and isozyme patterns (Lauridsen, 1991).

2.0 REPRODUCTIVE BIOLOGY

2.1 FLORAL AND FRUCTAL PHENOLOGY

Floral initiation occurs in neem during a short period of leaf shedding (Ketkar and Ketkar, 1997), after which flowering will last for about five weeks, with the flowers opening in succession. Neem will normally begin flowering and producing seed after 3-5 years of age, but flowering and fruiting can be extremely variable within the species (Kandaswamy and Raveendaran, 1988; Mahadevan, 1991; Gogate and Gujar, 1993; Gupta *et al*., 1995). For example, Gogate and Gujar (1993) found flowering and fruiting in a 50-year old plantation of neem in Maharashtra, India, to be highly variable. Out of 331 trees under study, a total of 292 flowered and fruited in the 1992 season, and fruit production varied from 7.5 to 17.3 kg (dry weight) per tree. Studies on the fructal phenology of neem in a three-year-old provenance trial at Jodhpur, India revealed that 25.52% of the plants in the trial were fruiting in the third year, although this varied between provenances from 0 to 65% (Gupta *et al*., 1995). The majority of the trees were fruiting synchronously, with a small percentage (3.72%) flowering whilst other trees were fruiting.

The timing of flowering and fruiting varies from site to site, but in India, neem flowers in April and the fruits are ready for harvesting in July. Late flowering genotypes have, however, been identified from Tirupur, Tamil Nadu, India (Shanti *et al*., 1996). The genotype flowered and fruited at the normal time and from September to December. Seed germination was reduced in the late-flowering type, and a higher proportion of abnormal seedlings was produced. These abnormalities may be due to an increased level of selfing in the late-flowering type.

2.2 SEXUAL AND BREEDING SYSTEMS

Neem is andromonoecious, i.e. bisexual and staminate (functionally male) flowers occur on the same tree (Singh *et al*., 1996). The anthers start to dehisce around 08.00 hrs in the closed flower, and the pollen is mature before the stigma becomes receptive (protandry) (Gupta *et al*., 1996). Pollination is performed by bees and other small insects, and the ovary is triocular, i.e. it has three chambers each with two ovules. Generally, the endocarp encloses one seed, sometimes two and rarely three, a phenomenon termed polycarpy (Singh *et al*., 1995). The seeds are dispersed mainly by birds and mammals. Neem is thought to be outcrossing, and Kundu (in press) confirmed this by estimating the outcrossing rate in a natural population from Bangladesh using three isozyme loci ($t_m = 0.90$ and $t_s = 0.92$). Selfing has, however, been reported in the species (Gupta *et al*., 1996) and viable seed is produced on self-pollination (Solanki, 1998).

The Arid Forest Research Institute, Jodhpur, India is currently conducting research on the production of hybrids between *A. indica* and *A. indica* var. *siamensis* (U.K. Tomar, pers. comm.[1]). The varieties flower at different times, therefore pollen has to be stored to allow cross-pollination between the two species. This has been problematic, hence, they have not yet produced any seeds or plants.

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3.0 ECOLOGY

3.1 DISTRIBUTION

Neem is thought to have originated in Assam and Myanmar where it is common throughout the central dry zone and the Siwalik hills (NRC, 1992). However, the exact origin is uncertain and some authors suggest it is native to the dry forest of south and south-east Asia, including Pakistan, Sri Lanka, Thailand, Malaysia and Indonesia (Ahmed and Grainge, 1985). In the 19th century, neem was introduced by Indian immigrants to the Caribbean (i.e. Trinidad and Tobago, Jamaica and Barbados), South America and the South Pacific (NRC, 1992). The cultivation of neem spread to Africa in the 1920's when it was introduced to Ghana, Nigeria and the Sudan, and the species is now well established in more than 30 countries.

3.2 HABITAT

Neem can grow in tropical and subtropical regions with semi-arid to humid climates. Neem will typically experience a mean annual rainfall of 450-1200 mm, mean temperatures of 25-35ºC and grow at altitudes up to 800 m.a.s.l. (see Table 1 and references therein). The species is drought-tolerant, and thrives in many of the drier areas of the world. There is, therefore, considerable interest in neem as a means to prevent the spread of deserts and ameliorate desert environments, e.g. in Saudi Arabia (Ahmed *et al*, 1989), sub-Saharan Africa (NRC, 1992) and western India (Gupta, 1994). In Saudi Arabia, several thousand neem trees have been planted on the Plains of Arafat near Mecca to provide shade and relief from the intense desert heat for Muslim pilgrims (Ahmed *et al*., 1989). Two-year-old neem seedlings were transplanted into 1 m^3 pits containing sand mixed with river silt to improve water retention, and the trees irrigated until the plants were well established. In western India, low and erratic rainfall, high potential evapotranspiration, high temperatures and high wind speeds prompted research into water harvesting and conservation techniques for the establishment of neem (Gupta, 1994; 1995). The establishment of neem in troughs (ridge and furrow method) and in 1.5 m diameter pits covered with surface mulch were the most effective techniques of harvesting and maintaining water, and corresponding increases in plant biomass were observed. Both techniques were found to be cost-effective, but the ridge and furrow method was more labour intensive.

Neem grows on all types of soils, including clay, saline and alkaline soils, but does well on black cotton soils (NRC, 1992). It can tolerate dry, stony, shallow soil with a waterless sub-soil, or places where there is a hard calcareous or clay pan near the surface. In Niger, neem was found to utilise groundwater at depths of 6-8 m, whereas an adjacent crop of millet extracted water from the top two metres of soil (Smith *et al*., 1997). The species is also thought to be an efficient water user in comparison to some other tree species. A pot experiment with different irrigation regimes and leaf mulching resulted in no improvement in the growth of neem with high levels of irrigation, but the application of mulch improved water retention and growth at low irrigation levels (Singh *et al*., 1991). Neem does not tolerate water-logging, is fire-resistant and has a unique property of calcium mining which neutralises acidic soils (Gunasena and Marambe, 1998). The species is a light demander and when juvenile, neem will push up vigorously through scrubby vegetation. It is hardy, but frost tender and does not withstand excessive cold, especially in the seedling and sapling stages (NRC, 1992; Chaturvedi, 1993). It coppices and pollards well, and also produces root suckers.

3.3 INVASIVENESS

The NRC (1992) notes that despite the introduction of neem to many exotic locations worldwide, the species has not become an invasive pest. There is a growing awareness, however, that neem can be a competitive and aggressive coloniser of fallow agricultural land (Childs, 1999; D. Faye, pers comm.[2]; S. Rietbergen, pers. comm.[3]). When mature, neem can produce large quantities of seed. The seed will fall to the ground, or be dropped by birds or mammals during the rainy season and under favourable conditions, e.g. in open, undisturbed environments, will germinate with a week or two. The ability of neem to spread and grow quickly and aggressively has produced negative local attitudes towards the tree. In Senegal, some NGOs are finding it difficult to promote the beneficial qualities of neem because of its colonising ability (D. Faye, pers comm), and in Ghana, a women's group reported that they are unable to cultivate cleared land for more than one year (Childs, 1999). As a consequence, the fallow period is decreasing and more land is being encroached upon. Also in Ghana, neem is invading the dry forests on the coastal zone inselbergs, threatening already critically endangered species such as *Talbotiella gentii*. In the Shai Hills Game Production Reserve, the vectors for invasion are baboons, who eat the copious seed produced by neem and thus spread it around (S. Rietbergen, pers. comm.). In 1992, the abundance of shrews and rodents was studied on the Accra Plains of Ghana to measure the impact of invading neem on small mammal communities (Decher and Bahian, 1999). The study was inconclusive, although trapping success was low in areas with dense stands of neem.

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Table 1: Summary of the ecological requirements of neem as reported by various authors.

Factor	Circumstances	Reference
Temperature	Frost sensitive, especially seedlings.	Chaturvedi (1993)
	Shade temperature - 30-35ºC in Sri Lanka;	Gunasena & Marambe (1998)
	21-32ºC up to shade temperatures of 50ºC.	Schmutterer (1995), Benge (1988)
Rainfall	450-1200 mm/yr; as low as 250 mm/yr.	Chaturvedi (1993)
	500-1150 mm/yr.	Gill & Roy (1993)
	400-1200 mm/yr.	Schmutterer (1995)
	<400 mm/yr, if much groundwater e.g. Madagascar.	Schmutterer (1995)
	130 mm/yr to survive, but 450 mm/yr to grow well.	Benge (1988)
Altitude	0-800 m.a.s.l.; occasionally to 1000 m.	Schmutterer (1995)
	1500 m.a.s.l.	Hegde (1993)
Soil Type	Well drained, deep sandy soils.	Schmutterer (1995), Benge (1988)
	Black cotton in India and Sudan	
	Lateritic in Benin	
	Calcareous in Haiti	
	High % fine sand, silt, mica, but does not grow well.	Benge (1988)
Soil pH	6.2-7.0, but 5.9-10.0 tolerated	Schmutterer (1995)
Light	Needs sunlight for productivity.	Benge (1988)
	Seedlings need some protection from sun.	

4.0 ECO-GEOGRAPHIC AND GENETIC VARIATION

Neem is a highly variable species within its native and introduced ranges. The species shows variation across different agro-climatic zones, in its seedling and adult tree growth characteristics, in its products and in the species' genetic make-up (Kumaran *et al*., 1993; Rengasamy *et al*., 1993; Rengasamy *et al*., 1995; Veerendra, 1995; Kundu, 1998; Kundu and Tigerstedt, 1998; Kundu *et al*., 1998; Rathore *et al*., 1998; Sridharan *et al*., 1998; Jindal *et al*., 1999). There appears to be a strong environmental effect on the growth of neem and production of azadirachtin, lower rainfall areas showing slower growth but higher concentrations of azadirachtin in the seeds. Various studies on the environmental and genetic variation in neem are summarised below.

4.1 VARIATION IN GROWTH CHARACTERISTICS

Variation in the seedling growth characteristics of ten provenances of neem from Myanmar, Bangladesh, India, Pakistan and the Sudan were studied under growth chamber conditions (Kundu and Tigerstadt, 1997). Principal component and cluster analysis revealed three distinct groups of populations with provenances from the high rainfall regions being separated from those from the low rainfall areas. Shoot:root ratio and leaf number were proportional to mean annual rainfall, and suggested neem employs an adaptive strategy in response to water deficit at the initial phase of seedling growth. Significant provenance variation was also established for net photosynthesis, stomatal conductance, stomatal density and total guard cell length (Kundu and Tigerstedt, 1998), seedling characters which were also positively correlated with provenance mean annual rainfall.

Variation in plant height, collar diameter and survival rate of six neem provenances (three from Thailand, one from Myanmar, one from Nepal and one from Ghana) were measured at three test sites in Bangladesh and India that were classed as optimum, intermediate and stress environments for neem (Kundu *et al*., 1998). There were significant differences between provenances for height and collar diameter, and a significant genotype x environment effect for height. The authors suggest that rainfall and temperature may be the environmental factors affecting variation in growth characteristics and note the importance of provenance testing for a given site.

The tree height, collar diameter, dbh, clear bole length and canopy diameter of 13-year-old trees grown at CAZRI, Jodhpur, India were also assessed for variation in growth characteristics (Jindal *et al*., 1999). All characters were found to be highly variable, and tree height was positively and significantly correlated with collar diameter, dbh, canopy diameter and fruit yield per tree.

4.2 VARIATION IN SEED CHARACTERISTICS

Fruit and seed characteristics, e.g. weight, length, width, diameter, yield and azadirachtin and oil content are highly variable both within and between provenances of neem (Kumaran *et al*., 1993; Rengasamy *et al*., 1993; Rengasamy *et al*., 1995; Veerendra, 1995; Kundu, 1998; Rathore *et al*., 1998; Sridharan *et al*., 1998; Jindal *et al*., 1999). The weight, length, diameter and form (diameter/length) of neem seeds from four populations (two from Bangladesh, one from Thailand and one from Kenya) were measured and analysed (Kundu, 1998). There were significant differences between populations for all seed parameters, and the populations from Thailand and Kenya were differentiated both from one another and the material from Bangladesh. This study had similar results to that carried out by Kumaran *et al*. (1993) who also found significant differences between populations of neem from Tamil Nadu, India. The authors also found seed length and seed oil content to be highly heritable and the weight of 100 seeds to be robust selection index by virtue of its high genotypic coefficient of variance, high genetic advance and moderate heritability.

The variation in fruit yield per tree, 100-fruit weight, 100-seed weight and 100-kernel weight and oil content in 13-year-old neem trees from Jodhpur, India was measured and analysed (Jindal *et al*., 1999). Fruit yield per tree was highly variable and positively correlated with tree height, collar diameter, dbh, and canopy diameter. 100-fruit weight was positively correlated with 100-seed weight and 100-kernel weight, but there were no correlations between kernel oil content and other fruit characteristics.

Variation in oil and protein content of neem seeds from Laos, Nepal, Ghana, Bangladesh, Myanmar and three areas of India was found to be highly significant (Rathore *et al*., 1998). Neem seeds were collected from 12 different locations in Tamil Nadu and their azadirachtin and oil contents determined (Sridharan *et al*., 1998). Both seed characters were highly variable, but showed some correlation with climatic factors. There was a significant positive correlation between oil content and the number of sunshine hours from September to March, and a negative correlation between azadirachtin content and the total number of rainy days during the fruiting season (April to August).

Neem seeds were collected from 21 agro-ecological zones of India and the content of azadirachtin in the seeds was estimated and compared with the physiochemical properties of the oil (Rengasamy *et al*., 1993). Azadirachtin content within-samples, and within- and between-regions varied substantially from 0.14 to 1.66%. The results suggested that the environment had a strong effect on seed azadirachtin content with trees grown in regions with red and black soils at altitudes above 500 m.a.s.l. being rich in azadirachtin. The physiochemical properties of the oil were also highly variable, but the results suggested that there was a positive correlation between azadirachtin content and the saponification and acid values of the oil. A later study on seeds from the same 21 zones (Rengasamy *et al*., 1995) suggested that trees growing in coastal, arid or semi-arid regions had a high azadirachtin content (>0.72%), and that those from sub-humid regions showed low (mean 0.27%) azadirachtin content. Neem fruits collected from nine agro-ecological zones of Rajasthan, India were also analysed for azadirachtin content and were found to vary from 0.19 to 0.67% azadirachtin by seed kernel weight (Gupta and Prabhu, 1997).

The insect anti-feedant activity of neem seed from nine Indian ecotypes on the acridid, *Schistocerca gregaria*, were compared by Singh *et al*. (1987). There was significant variation for anti-feedant activity between extracts derived from the different ecotypes. Anti-feedant activity, extract yield and oil content could not be correlated with environmental conditions, although kernels from more humid areas yielded more oil, and trees from desert regions possessed higher anti-feedant activity than those growing in humid coastal zones.

4.3 MOLECULAR VARIATION

RAPD profiles of 17 accessions of neem from India were generated using 49 random DNA primers (Farooqui *et al*., 1998). The dendrogram of similarities amongst the RAPD profiles suggested that there was less variation than expected within neem from India. In addition, the pattern of RAPD similarities obtained did not correspond with the pattern of geographical variation in neem, i.e. accessions from a particular region were not always grouped together in the dendrogram of similarities. This result is not unusual when assessing provenance variation using molecular methods, and the use of additional genetic analyses would have assisted the interpretation of the results. In contrast, a study on isozyme variation in four provenances of neem (two from Bangladesh, one from Thailand and one from Kenya) found substantial variation both within- and between-provenances of neem as expected for a widely distributed and outcrossing tree species (Kundu, 1999). The provenance from Thailand was shown to be distinctly different from the provenances from Bangladesh and Kenya, a result that supports the status of the material from Thailand as a distinct variety of neem. Wickramasinghe and Simons (1994) also described the similarities between neem from India, Sri Lanka and Nepal on the basis of isozyme variation, and their differentiation from *A.. indica* var. *siamensis* from Thailand.

5.0 PROPAGATION

Mature neem trees produce large quantities of seed during the fruiting season, and natural regeneration is promoted by high annual rainfall and seed dispersal by birds and bats, who remove the fruit pulp and distribute the clean seed. Neem can, therefore, be propagated readily in the nursery by sexual means. In the last 20 years, however, considerable research on the vegetative propagation of neem has been conducted, largely as a result of the recalcitrant nature of the seed, and the search for elite neem genotypes and their propagation.

5.1 SEXUAL PROPAGATION

5.1.1 Seed harvesting

Nagaveni *et al*. (1987) noted that the fruits of neem are normally collected from the ground, de-pulped and sown immediately because of the risk of low seed viability. Several authors therefore recommend that seeds should be collected from the tree when they are greenish-yellow, rather than when they have fallen to the ground, are de-pulped and dried under shade for two days (Nagaveni *et al*., 1987; Chaturevedi, 1993; Gunasena and Marambe, 1998). In this way, the risk from fermentation of the unopened cotyledons can be reduced, viability can be improved and high germination percentages can be obtained for up to several months after harvest.

Azadirachtin and oil content in neem seeds is reported to vary with seed maturity, hence time of seed harvesting. The fresh flowers and fruits of a 10-year-old neem tree in India were analysed for their azadirachtin concentration by Rengasamy and Parmar (1994). The compound was not detectable in the flowers and in green fruits collected at 20, 30 and 40 days after anthesis (DAA). Green fruits analysed at 50 DAA and yellow fruits analysed at 60 DAA contained 0.051 and 0.112 % azadirachtin respectively. Johnson *et al.* (1996), however, found the concentration of five major limonoids in neem to vary only slightly with maturity, but the azadirachtin concentration was highest (10 mg/g seed kernels) in green newly ripening fruits.

5.1.2 Seed storage

Neem seeds have been variously documented as orthodox, intermediate or recalcitrant (Berjak *et al*., 1995; Bhardwaj and Chand, 1995). However, the species is generally regarded as intermediate and viability can be extended through drying (Mohan *et al*., 1995) and ambient to low temperature storage conditions (Singh *et al*., 1997). A 5-6 day drying period in shade conditions caused a drop in seed moisture content to 11% (Singh *et al*., 1997). Drying was found not to adversely affect germination rates, and seeds could be stored under ambient or refrigerated conditions for up to six months. The storage behaviour of neem from Burkina Faso, West Africa, was studied by varying both seed moisture content and temperature during storage (Gamene *et al*., 1996). During nine weeks of storage, the germination capacity remained highest (≥ 70%) at relative humidities of 55% and 75%, and was markedly lower at either lower (32 and 20-25%), or higher (95%) relative humidities. Seeds with 8.9% moisture content were stored at 3, 20, 30 or 50°C for two weeks. The germination capacity of these seeds was lowered at the highest and lowest temperatures. Similar results were obtained by Eeswara *et al.* (1998) and Sacandé *et al.* (1998) who found viability was best preserved at 10-15°C with seeds having moisture contents ≥ 10%. Sacandé *et al.* concluded that the difficult storage behaviour of neem seeds stemmed from the fact that:

- Neem is sensitive to low temperatures (< 10°C) at moisture contents ≥ 10%.
- Neem's extreme sensitivity to imbibitional stress after storage at moisture contents ≤ 8%.
- Water activity in neem seeds causing metabolic stress in the higher moisture content and temperature range.

Recent research, however, has shown a large variation in the lowest safe moisture content for different neem seed sources (C. Hansen, pers. comm.[4]). The minimum seed moisture content for two seed sources, one from Kenya and one from Myanmar was 20%, whereas that for a second seed source from Kenya was 10%. *A. indica* var. *siamensis* from Thailand and Malaysia was also found to have a minimum seed moisture content of 24 %. These results suggest that there is considerable variation within neem for seed moisture content under storage conditions, and may explain why neem seed has been variously documented as orthodox, intermediate and recalcitrant in the past.

Surendran *et al* (1992) reported that by storing de-pulped and shade dried seeds in earthen pots that contained wet sand (30% moisture content) a viability of 62% could be achieved after three months. Jindal and Vir (1994) report that storing seeds in airtight containers can enhance viability, as respiration rates are decreased thereby allowing the seeds to maintain their storage resources for longer periods. Dod *et al*. (1997) stored neem seeds (9% moisture content) in cloth, polylined jute, paper or

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polyethylene bags for 60 days under ambient conditions. Seeds stored in cloth bags maintained significantly higher viability (37.9% germination after 60 days of storage) compared with the others.

Variation of azadirachtin content during the growth and storage of neem seeds was studied using high-performance liquid chromatography (HPLC) by Yakkundi *et al*. (1995). Seed samples were stored under ambient temperature and humidity, and samples collected and analysed over a period of four weeks. Azadirachtin content was unstable and reduced to 68% of the original level in the dark, and to 55% in daylight. Johnson *et al.* (1996) found losses in both azadirachtin and salannin under similar storage conditions over a period of six months.

5.1.3 Seed germination

Fresh neem seed germinates seven days after sowing and germination is complete after 25 days (Singh *et al*., 1995). Bharathi *et al.* (1996) found that greenish-yellow drupes had the highest viability and germination percentage when compared to both younger (green) and more mature (yellow) seeds. The seeds germinate readily without pre-treatment, although Kumaran *et al*. (1996) found that soaking in 2% KH_2PO_4 gave maximum germination, shoot length and leaf number, and 1% KH_2PO_4 gave maximum root length. Pre-soaking de-pulped seeds for 30 minutes (Hegde, 1993) to three days (Fagoonee, 1984) has also been found to improve germination, and Radwanski and Wickens (1981) suggest that germination is improved when the inner shell is removed to expose the embryo. Recommendations on the optimal storage and germination of neem seeds on farm are shown in Box 1.

Box 1: The optimal harvesting of neem seed to improve viability on farms (after Gunasena and Marambe, 1998)

Optimal harvesting of neem seed to improve viability on farms

Harvesting:
- Fruit should be collected ripe from the tree.
- A tarpaulin can be spread underneath the tree, and the tree shaken so drupes of optimum maturity fall.
- Grade fruits to remove undeveloped, immature and damaged fruits.
- Store fruit in thin layers to avoid damage and the risk of fermentation.
- De-pulp the fruit within 24 hrs after harvesting.
- Remove the kernels from the seed if they are to be used immediately.

Storage:
- Dry the seed under shade for 3-5 days.
- Store the seeds in clean, cloth bags or airtight containers at low temperature ~10°C.

Germination:
- Soak the seed for 24 hrs in cold water if the seeds have been previously dried.
- If the seed is fresh, sow the seed within two weeks of fruit collection.
- Fresh seed should have a germination rate of 85%.

Constraints:
- Hand picking of fruits may ensure better quality seeds, however, it is often too laborious and expensive.
- Lack of water for de-pulping fruits.
- Lack of shelter or space in which to spread and dry neem seed.
- Drying of neem seed is done during rainy season when the relative humidity may be in excess of 75%.

5.1.4 Seedling management

Neem seeds are commonly germinated in plastic bags in the nursery, although direct sowing is said to be successful where there is adequate rainfall (Benge, 1988). For example, a group of Indian villagers have been successfully direct sowing neem seed for about 30 years (Vivekanandan, 1998). Seeds should be planted at a depth of 2.5 cm to avoid predation by rodents and birds (Bahuguna, 1997). Research by Habte *et al.* (1993) concluded that neem could be a highly VAM-dependent species.

The dry matter yield of neem grown in association with mycorhizza at a soil P concentration of 0.02mg/l was shown to be comparable to neem grown with mycorhizza at a soil P concentration of 0.2mg/l. It would therefore seem that improved growth of seedlings in the nursery could be achieved through sowing in inoculated soils.

Opinions differ as to when to transplant neem seedlings to the field. Some authors suggest 12 weeks after sowing in the nursery (De Joussieu, 1963; Radwanski, 1977), but others suggest more than one year's growth in the nursery is required for good survival in the field (Singh, 1982). Bahuguna (1997) recommends that where neem seedlings are to be planted out in dry areas, a strong tap root is required and therefore it is necessary to transplant once the seedlings are more than a year old. As for any tree species, however, good land preparation is imperative when transplanting seedlings.

Once sown, it is important that neem seedlings receive adequate care. Seedlings are sensitive, like mature trees, to waterlogged and very dry soils (Gunasena and Marambe, 1998). Young neem trees cannot tolerate frost or excessive cold conditions (Chaturevedi, 1993; Hegde, 1993), but Bahuguna (1997) reported that neem seedlings are tolerant of shade. Kundu and Tigerstedt (1998) demonstrated that the biomass of neem seedlings was positively correlated to net photosynthesis, stomatal characteristics and light intensity during the early stages of growth. Seedlings are not, however, tolerant of very high light intensities, hence the provision of light shade is recommended. Vivekanandan (1998) reported that in India, *Prosopis juliflora* is used to protect seedlings from both browsing animals and excessive sunlight.

Experiments at Dehra Dun, India have shown that weed growth retards the development of neem seedlings and regular weeding stimulates both height and vigour (Chaturvedi, 1993). An application of mulch around the seedlings will help to ensure water is conserved and reduce weed build up. Young neem seedlings may need watering and in Saudi Arabia trees have been watered up to an age of 10-12 years (Ahmed *et al*., 1989). Alternatively, soil water conservation methods, i.e. planting in pits or trenches with an application of mulch, can be used in water deficient areas (Gupta, 1994; 1995). Hegde (1993) suggests, however, that soil fertility is more important for tree growth than soil moisture. The establishment and management of neem seedlings is reviewed in detail by Bahuguna (1997).

5.2 VEGETATIVE PROPAGATION

Vegetative propagation of neem allows for the mass production of genetically identical individuals (clones). Traditional methods of vegetatively propagating neem include grafting, root cuttings, stem cuttings and stump cuttings. In recent years, however, methods involving the micropropagation of neem through tissue culture have been successfully developed.

5.2.1 Macropropagation

Stump cuttings generally consist of a stem cutting (2.5 cm in length) and a root mass (approx. 23 cm in length). They are planted at the onset of rains, and stumps prepared from two year-old plants have a better survival rate than younger plants. Farmers in Winneba, Ghana, report that they propagate neem by breaking large twigs or small branches from mature trees and stick them in the ground (Childs, 1999).

Sivagnanam *et al*. (1989) reported that stem cuttings of neem dipped into IAA and IBA rooted effectively in a mist propagator in 135 days. Tomar (1998) also found stem cuttings rooted effectively with IBA, but coppice shoots gave better results than the cuttings from the main woody stem. Palanisamy *et al.* (1998) found that maximum rhizogenesis in stem cuttings coincided with the emergence of new shoots, this being February in Jabalpur, India. The use of IBA at 1000ppm increased the rooting percentage, number of roots and root biomass. Kamaluddin and Ali (1996) investigated the effect of both leaf area and auxin on the rooting and growth of green stem cuttings from a two-year-old tree. They concluded that IBA and leaf area did not significantly affect rooting percentages, but that treatment with 0.2% and 0.4% IBA solution had a significant affect on root development and the subsequent growth of the cuttings. Palanisamy and Kumar (1997) investigated the influence of endogenous auxin on rooting. They concluded that rooting was dependent on the endogenous auxin levels of the shoot, and that longer cuttings (25 cm long) rooted more readily than shorter cuttings (5cm).

Gupta *et al.* (1998) investigated the potential for air layering neem. They found that using IBA, branches readily formed roots where the bark had been scraped away. The rooted branches, when cut away from the tree, established in polythene bags giving a 100% survival rate. They concluded that an IBA treatment of 800ppm for air-layering neem is effective in enhancing the rooting of air-layered cuttings.

5.2.2 Micropropagation

Substantial research on the micropropagation of neem was conducted during the 1980's and 90's (Puri, 1999). Callus initiation from young leaves and cotyledons has been achieved (Narayan and Jasiwal, 1985), and tissue cultured seedlings have been obtained from cotyledons, young leaves and stem segments (Rao *et al.*, 1988).

Joshi and Thangane (1996) described a procedure for the clonal propagation of neem from woody explants, generating between two and three shoots per explant. Drew (1993) reported on clonal propagation from stem nodal sections. The tissue cultured shoots successfully developed roots and the regenerated plants established well in a soil medium. Plantlets regenerated from embryos (Thiagarajan and Murali, 1993), and through axillary bud culture (Joarder *et al.*, 1993) have also been successfully established under field conditions. Venkateswarlu (1999) described a procedure for the selection of plus trees and their mass micropropagation. Micropropagated plants were observed to flower 25 months after being transferred to the field and exhibited expected azadirachtin contents and other seed related traits. They concluded that mass production of neem seedlings through micropropagation could produce trees with known azadirachtin content in their seeds. In spite of the seeming success of tissue cultured plants once established under field conditions, it is important to bear in mind that the long term field performance of micropropagated plants has yet to be ascertained (Bahuguna, 1997).

Substantial tissue culture research has explored the possibility of isolating limonoids from neem cultures (Sarkar and Datta, 1986; Ramesh Kumar and Padhya, 1988; Stephen *et al*., 1998). Allan *et al.* (1994) showed that tissue cultures could produce azadirachtin, and an EU-funded project investigated the ability of tissue cultures to produce azadirachtin on a commercial basis (van der Esch, 1999). Their research concluded, however, that to date, the technology is not advanced enough for tissue cultured production of azadirachtin to be economically feasible.

Possible benefits of tissue cultured clonally propagated plants are listed in Table 2, but it seems unlikely that these benefits will reach the poor until further research and selection of the most reliable and economically viable techniques has occurred.

Table 2: The possible advantages and disadvantages of the tissue culture of neem for the rural poor in developing countries.

Advantages of tissue culture	**Disadvantages of tissue culture**
• Overcomes seed viability/germination problems • Allows the selection and multiplication of genetically superior material. • Could increase seed yields per tree.	• Expensive. • Reduces genetic variability. • May increase vulnerability to pests and diseases. • More research needed.

6.0 SILVICULTURE

The interest in neem as a source of botanical pesticides has prompted discussion on the need for plantations of the species. There are thought to be more than 17 million neem trees in India (Ketkar, 1976), which occur along roadsides, in field boundaries, around houses and temples, or in village centres. Pure stands, or plantations, of neem have been established recently in parts of India (R. Senrayan, pers. comm.[5]) and Brazil (P. Foerster, pers. comm.[6]), and can be found in West Africa, Australia, Saudi Arabia and Mexico (Radwanski, 1977; Ahmed *et al.*, 1989; Bosselmann, 1993; I. Moreno, pers. comm.[7]). In India, CAZRI are planning to conduct research on the development of plantation models for neem, based on the need to develop degraded areas and wasteland in Rajasthan (S. Vir, pers. comm.[8]). To date, however, relatively little is known about the silviculture of neem in plantation or agroforestry systems, or its optimal management for fruit production.

6.1 NEEM AS A PLANTATION CROP AND ITS MANAGEMENT

Gorse (1986, cited in Benge, 1988) has commented that neem does not grow well in pure stands and is very competitive for water and soil nutrients. However, Radwanski (1977) noted that neem has been planted on a plantation scale in Nigeria since 1936, and that the introduction of neem to Sokoto, Nigeria was described as the boon of the century, as the trees grew quickly meeting the local demand for firewood and timber. Ahmed *et al.* (1989) have described the development and management of pure stands of neem grown in Saudi Arabia, and Bosselmann (1993) assessed the site adaptation of neem plantations in Australia. Neem could also be planted in mixed stands with leguminous trees like *Leucaena leucocephala, Albizzia lebbeck* and *Acacia nilotica* (Benge, 1988). Under such a system, neem would benefit from the nitrogen fixing abilities of the legume trees, and the risk from pests may be reduced.

Ultimately, the management of neem under a particular silvicultural system depends upon the objective of raising the plantations (Bahuguna, 1997). The uses of neem are varied and it is likely that different management systems will suit different products. Rotations will vary according to whether fuel, timber or seeds are the desired end-product. Parmar and Ketkar (1993) recommended that where neem plantations are required for several products, care is needed to ensure that meeting one requirement does not jeopardise others. For example, if firewood and pesticidal compounds are required from neem, only trees that are more than 10 years old should be used to provide firewood, and younger trees can be used a source of seeds. If the branches of neem are regularly pruned, then it takes some time for the tree to produce fruit again as they re-establish vegetative growth. Bahuguna (1997) suggests that further research is needed to develop suitable silvicultural practices for a range of uses. Table 3 illustrates a range of uses with current recommended management practices.

Table 3: Neem use and management for a range of products.

Use/Desired Product	Management Practice	Reference
Timber	Felling at 35-40 years after planting. Felling at 20 years after planting.	Hegde (1993) Vivekanandan (1998)
Firewood	Simple coppicing after 8 years. Clear felling at 8-10 years.	Benge (1988) Benge (1988)
Seeds	Improved varieties. Adequate moisture supply at fruit formation.	Hegde (1991)
Poles	Coppicing on an 8 year rotation	Radwanski (1977)

Improving the growth of trees

The annual production of biomass in neem plantations is reported to be between 3 and 10 m^3 per ha (Hedge, 1991). This classifies it as a medium fast growing species, slightly slower than fast growing species such as *Casuarina*, *Leucena*, *Acacia* and *Eucalyptus*. Yield of biomass per year has also been reported to vary between 10 and 100 tons of dried material per

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[6] Dr Peter Foerster, Pesticide Service Project, GTZ, Germany
[7] I. Moreno, Eco System del Noroeste, S.P.R. de R.I., Mexico
[8] S. Vir, CAZRI, Jodhpur, India.

hectare per year (Michel-Kim and Brandt, 1981). These authors estimated that 40 tons of solid wood could be harvested per hectare per year under appropriate site conditions. The rate of growth of neem is moderate, however, showing a mean annual girth increment of 3.2 cm. A study in Western Rajasthan showed that growth is fast in the first ten years, after which it slows (Tewari *et al.,* 1996). Radwanski (1977) reported that 66% of the total growth of neem trees occurred within the first three years following planting. A height of approximately 4-7 m is reached after three years and heights of between five and 11 m are obtained after five years, the rate of growth being affected by site conditions. Various yield estimates for both coppicing and felling after different rotation lengths have been described by Benge (1988), and more recently, yield and volume tables for neem have been prepared based on plantations found in Gujarat (Jain *et al*., 1998), and plantations found in northern Ghana (Nanang, 1998).

AFRI (Jodhpur, India) have been researching different methods of water harvesting and moisture conservation on the growth, biomass accumulation and nutrient uptake by neem (Gupta, 1994; 1995). The ridge and furrow method of water harvesting had a 58%, 73%, 11% improvement in height, collar circumference and crown diameter, respectively. Biomass accumulation increased by 3.8%. Neem has also been shown to benefit from both mulching and weeding, but plantation costs increased by up to 50% with the use of soil moisture conservation techniques. The growth of trees is also affected by planting density. Boa (1995) reported on the poor performance of trees planted at 4 x 4 m spacing (approximately 625 trees per hectare). Hegde (1993) recommended a spacing of 6 x 6 or 8 x 8 m for neem plantations (280 and 160 trees per hectare respectively), and suggests that as it will take 8-10 years for trees to attain a good size, they should be intercropped with leguminous trees on a short rotation. A density of 160 trees per hectare has also been recommended by IFGTB (Coimbatore, India). Benge (1988) recommended that wider spacings should be used on poorer quality sites.

Lopping trees for fodder or to reduce shade on crops is common in India (Hegde, 1993). However, repeated lopping can cause damage, retarding growth and leading to a cessation of seed production. The indiscriminate cutting of roadside trees has been recognised as a serious problem for the establishment and subsequent growth of trees (Chaturvedi, 1993).

The growth and productivity of neem could also be increased through the application of biofertilisers, i.e. *Azospirillum*, phosphobacteria and VAM fungi (Krishnan, pers. comm.[9]). It is known that these organisms are effective in increasing the growth and nutrient uptake of neem trees which leads to increases in seed quantity and oil quality. Since neem is often planted on poor, marginal land, the use of biofertilisers could lead to greater productivity on such sites. Tree vigour could be improved and the transplanting age of seedlings reduced by one month. Bacterial inoculum is usually readily available and only small quantities are required for application in the nursery or field.

6.2 THE ROLE OF NEEM IN AGROFORESTRY SYSTEMS

Neem has considerable potential within agroforestry systems as recognised by Tilander (1996), however, the species is thought to be under-utilised in many areas. The good coppicing ability of the tree, as well as low mortality following coppicing, make neem favourable for use in agroforestry systems (Chaturvedi, 1993). Gill and Roy (1993) provide an excellent account of the agroforestry potential of neem which include its use in intercropping and silvipastoral systems. The potential, constraints and opportunities for neem in agroforestry are summarised in Table 4.

6.2.1 Intercropping with neem

The use of neem leaves as a mulch is among one of the species most important potential uses. Tilander and Bonzi (1997) studied the effects of neem leaf mulches and compost on sorghum yield, and found that neem was highly effective in reducing water loss and high soil temperatures, but that yield was increased when compost and neem leaf mulches were combined. Neem compared favourably to other agroforestry species such as *Leucaena leucocephala, Albizzia lebbeck* and *Acacia holocericea* due to the high nutrient content of the leaves and the appropriate decomposition rates. The use of mulches to conserve soil moisture and increase nutrient status of the soils is thought to be especially pertinent to semi-arid areas where growth is often limited (Tilander and Bonzi, 1997). The fact that neem keeps its leaves during drought periods increases its significance as a source of biomass for mulching.

There appears to be some controversy as to the usefulness of neem within an intercropping system. Troup (1921) reported that neem suffers during establishment in an intercropping system as seedlings are suppressed by weeds and eventually die. Radwanski and Wickens (1981) reported that neem has a tendency to become weedy and may invade neighbouring crops. A women's group in Ghana have also faced problems with neem becoming invasive in their fields (Childs, 1999). Planting densities with an intercropping system have been reported to vary between 150-200 trees per hectare (Chaturvedi, 1993; Hegde, 1993; Vivekanandan, 1998).

[9] Prof P. Santhan Krishnan, Tamil Nadu Agricultural University, Coimbatore, India

IFGTB (Coimbatore, India) concluded that neem could be economically cultivated as an agroforestry species. Neem was compared to *Albizzia amara*, *Gliricidia maculata* and *Eucalyptus tereticornus*. Three month-old seedlings of all species were planted at a spacing of 5 m within rows and 12 m between rows to give an average of 160 trees per hectare. Agricultural crops such as sorghum, black gram and groundnut were grown in the field as per traditional practices. After three years there was no significant reduction in yield due to the introduction of trees and the biomass of neem was greater than for other tree species. After five years, the groundnut yield was reduced, but the smallest reduction occurred under neem.

The Forest College and Agriculture Research Institute of TNAU (Coimbatore, India) studied the interactions of three and four year-old neem trees and four agricultural crops: cowpea, sesame, horsegram and sorghum. Their research determined that cowpea was the most suitable crop for a neem-based agroforestry system, showing the least reduction in yield (15% and 16% under three and four year-old trees respectively) compared to pure agricultural crops. The studies also revealed that under neem-based cropping systems available soil nutrients (N, P, K, Ca and Mg) were higher than with pure agricultural crops (Palani, 1997).

Vivekanandan (1998) described a successful agroforestry system from a village in southern Tamil Nadu, India, whereby crops such as sorghum, cotton, millet, black gram, green gram, coriander and sunflower are sown between the neem trees that feature prominently in all farmers fields. Trees are randomly sown or naturally regenerate, hence spacing is irregular. Farmers generally aim for about 86 trees per hectare as if the density is greater than this, not only is ploughing affected, but there is also a risk of too much shade which reduces crop yields. To facilitate farming and encourage growth, trees are pruned so that there are no branches or leaves up to a height of about 3.5 m. Previously tamarind was a favoured tree in this region, but has been largely replaced by neem over the last 30 years as neem competes less with annual crops. Vivikanandan (1998) also reported that peerkai grows up neem trees with approximately 20-30 pods per plant being harvested annually. In spite of the many benefits derived from this agroforestry system and the widespread adoption of the practice by villagers in the area, Vivikanandan lists some drawbacks:

- *Competition for water* - neem competes for soil moisture, therefore, if the monsoon brings less rain than average the crops suffer.
- *Time and labour requirements increased* - there is a high labour cost as the trees are not in straight lines and ploughing takes 1.5 hours per hectare longer. Recently farmers have been experimenting with row sowing to overcome this problem.
- *Competition for light* - coriander is reported to grow well under the shade of the neem tree, however cotton can only be grown under neem while the tree is less than three years old. Competition for light therefore reduces crop choice.

6.2.2 Silvipastoral

In a silvipastoral system, neem can have beneficial effects on the soil (moisture and nutrients status), and provides shade, fodder in the dry season and also animal medicines. Gill and Roy (1993) reported that neem, along with other tree species, improved the fodder productivity of a semi-arid silvipastoral system in India by up to 8.5 tons per hectare. Harsh *et al.* (1992) also studied silvipastoral systems in arid regions. They reported that forage production can be increased to 3.6 tons per hectare from only 0.05 tons per hectare by growing suitable grasses, legumes and trees, including neem.

6.2.3 Neem and afforestation of degraded lands

Chaturvedi (1993) gives an extensive overview of use of neem in plantations and for afforestation in India. The ability of the tree to tolerate drought and saline conditions makes the neem tree a good candidate for land restoration. The tree has been shown to improve the fertility of soil and conserve moisture (Tilander and Bonzi, 1997). In addition, provision of shade all year round reduces water loss through evaporation and protects the soil from becoming baked dry. The fact that the leaves may be used as fodder and that from five years onwards seeds can be gathered from the tree for income generation and pesticidal products also makes this tree a good candidate for restoring degraded lands, where people are often marginalised.

Table 4: The advantages and disadvantages of using neem in agroforestry systems.

Advantages of neem in agroforestry	**Disadvantages of neem in agroforestry**
Coppices well with low mortality.	May become invasive on fallow agricultural land.
Provides a variety of products including mulch, fodder, shade, medicines, pesticides, fertiliser, firewood, and timber.	May reduce the yield of companion crops through increased competition for light and water.
Mulch – favourable decomposition rate, conserves soil moisture, improves soil nutrient status, neem retains its leaves during dry periods.	Competition for light and water greater in arid areas.
Fodder – fodder availability increased.	Competition for light and water greater if neem is densely planted.
Firewood – good source of fuel although somewhat smoky.	Time and labour requirement for tree and crop management is increased
Timber – comparable in quality and durability to teak.	
Suitable for the afforestation of degraded land.	
Provides a source of income generation.	

7.0 PESTS AND DISEASES

Despite the fact that the fruits, seeds and leaves of neem contain several compounds that repel or kill insects, inhibit the growth and development of fungi, and limit the infectivity of viruses, the plant itself is subject to number of pests and diseases. These have been documented in detail elsewhere (Schmutterer, 1990; NRC, 1992; Tewari, 1992; Ciesla, 1993; Boa, 1995), but will be summarised here and discussed in the context of neem genetic improvement.

7.1 INSECTS

More than eight order and 32 families of insects have been recorded feeding on neem (Schmutterer, 1990; Tewari, 1992; Ciesla, 1993; Boa, 1995). Every part of the tree is subject to attack by insects, but the following are regarded as some of the most serious:

Leaf defoliators:

Fire ants (*Solenopsis* spp.) caused severe defoliation of 3-6 year-old neem trees in Andra Pradesh, India (Raghunath *et al*., 1982), and leaf cutting ants are common neem defoliators in Central and South America (Schmutterer, 1990). Several species of moth and butterfly, e.g., *Ascotis selenaria* (*Lepidoptera: Geometridae*) defoliate neem, especially in nurseries (Tewari, 1992). Caterpillars of the genus *Eurema* (*Lepidoptera: Pieridae*) have also been reported as leaf defoliators (Tewari, 1992).

Stem and wood borers:

Adult powder post beetles (*Apate monachus* and *A. terebrans*) (*Coleoptera: Bostrychidae*) attack young trees and bore into small stems and branches (Ciesla, 1993). *Cydia* spp. (*Lepidoptera: Olethreutidae*) are both shoot borers and leaf feeders of neem in India, and up to 55% of shoots have been reported to be infested by *C. aurantiana* (Madhavan and Gopi, 1990). A pyralid, *Hypsipyla* sp., was found damaging neem in Haryana, India and affecting 97.75% of all shoots (Chaudhary, 1997). Several species of termites (*Isoptera*) have been reported on neem (Browne, 1968; Tewari, 1992). They are sometimes locally damaging but do not kill living trees.

Sucking insects:

Sucking insects (*Hemiptera* and *Homoptera*) are the largest group of insects that utilise neem as a host plant (Ciesla, 1993). At least 20 species representing nine families have been recorded to feed on the leaves, branches and stems of neem. This causes desiccation of plant tissue and results in the drying of foliage, defoliation, stem and branch dieback and occasional tree mortality. The production of flowers and fruits may also be affected. In India, the most serious sucking insect is the tea mosquito (*Helopteris antonii*) (*Hemiptera: Miridae*). It attacks the terminal shoots of neem causing the drying of foliage and shoots, and is thought to be due to a phytotoxic reaction to the saliva of the feeding insects (Madhavan and Gopi, 1990). Damage is often widespread in southern India, although large trees will usually recover. The Oriental yellow scale or cochineal (*Aonidiella orientalis*) (*Homoptera: Diaspididae*) has caused widespread damage to neem in parts of Africa and India. This insect attacks the foliage and young stems and often gives the plant a burnt appearance (Boa, 1992; Schmutterer, 1998). The neem scale (*Pulvinaria maxima*) (*Homoptera: Coccididae*) is a pest of neem in India, and both adults and nymphs feed on the sap of tender shoots and leaves (Tewari, 1992). A heavily infested tree will be coated with thick white patches, will lower tree vigour, promote premature leaf fall and the dieback of infested shoots.

7.2 MITES

An eriophyid mite (*Calipitrimerus azadirachtae*) has been recorded on neem foliage in India (Madhavan and Gopi,, 1990; Tewari, 1992). It has been found feeding on both tender shoots and foliage, and causes yellowing, deformity and desiccation.

7.3 MOLLUSCS

Two species of mollusc (*Laevicaulis alte* and *Macrochlamys indica*) caused 10-65% mortality to neem seedlings in India (Tewari, 1992; Ahmed, 1998; Kumar *et al*. 1998). The molluscs are abundant during the monsoon season and feed voraciously on the tender stem above the root collar that results in girdling.

7.4 MAMMALS

In Nigeria, damage to neem by several species of mammals has been reported (Browne, 1968). Browsing by domestic goats damaged neem, and the red flanked duiker (*Cephalophus rufilatus*) occasionally causes bark damage. The Nigerian hare (*Lepus crawshayi*) is suspected of eating the tops of neem seedlings in nurseries.

7.5 DISEASES

Many diseases of neem are caused by fungi that affect its leaves, stems or roots, and are a particular problem for seedlings in plant nurseries. Damping off, a disease that affects germinating seedlings, also affects neem. In India, up to 20% seedling mortality has been reported in the forest nurseries at Dehra Dun (Ciesla, 1993), and is thought to be responsible for the loss of transplanted micro-propagules (Chamberlain, 1999). Other nursery diseases include rhyzoctonia leaf web blight (*Rhyzoctonia solani*), characterised by grey-brown spots on neem foliage and fungal hyphae that join infected leaves together, and colletotrichium leaf spot and blight (*Colletotrichium gloeosporide*) (Ciesla, 1993). The fungus *Odium azadirachtae* causes powdery mildew of neem foliage, and several bacteria, including *Pseudomonas viticola, P. azadirachtae* and *Xanthomonas azadirachtii*, cause leaf spot diseases. The fungus *Corticium salmonicolor* causes pink disease, which is characterised by a pink fungal mycelium that spreads over the tree, destroying the bark and outer layers of wood (Browne, 1968; Tewari, 1992). Branches are killed, which quickly causes the foliage to wilt and turn black. Root rot in neem is caused by the fungus *Ganoderma lucidum* (Ciesla, 1993). The fungus attacks the sapwood and causes a white, spongy rot, the symptoms being pale, thin foliage and branch dieback.

7.6 PARASITIC PLANTS

Neem is one of many hosts of the mistletoe *Dendropthoe falcata* that is widely distributed on the Indian subcontinent and the Solomon Islands (Ciesla, 1993), and a mistletoe of the genus *Tapinanthus* infests neem in Nigeria (Browne, 1968). Schmutterer (1998) also reported that a semi-parasitic plant, *Cassytha filiformis*, had the potential to kill neem in Kenya.

7.7 NEEM DECLINE AND GENETIC IMPROVEMENT

A disorder in neem, resulting from unknown causes, has been reported from several countries in West Africa (Batra, 1991; Ciesla, 1993; Boa, 1995). Symptoms associated with this disorder included the yellowing and loss of older leaves, and open crowns with clumps of leaves concentrated at the branch tips, a phenomenon often referred to as ‘tufting’ or ‘giraffe necks’. It is thought that the decline might be due to site-related stresses such as low soil moisture, competition and low genetic variability (Boa, 1992; Ciesla, 1993; Thomsen and Souvannavong, 1994). Cultural techniques, e.g. matching provenances to sites, the maintenance of optimum stocking levels, good nursery hygiene and the elimination of alternative hosts may be effective means of preventing losses due to pests (Ciesla, 1993). The causes of neem decline are not, however, fully understood and further research is needed in this area.

There is currently no genetic improvement programme for resistance to pests or diseases affecting neem, although some micro-propagated clones have been selected for resistance to fungal diseases in the nursery (Chamberlain, 1999). The establishment of provenance trials does, however, provide a means of monitoring resistance to pests. For example, the tea mosquito has affected some neem provenance trials in India, although some accessions (notably those from Thailand) appear to show resistance to this pest. It is also acknowledged that broadening the genetic base of neem in cultivation, both in natural and exotic environments, may increase the resilience of neem to pest damage, or the stresses that predispose trees to a build-up of pest populations.

8.0 USES OF NEEM

Products of the neem tree have a wide variety of uses including the provision of medicines, pesticides, fuelwood, timber and food (Table 5). Global research on the species has, however, focused heavily on neem's role in crop protection, either in the field or in storage with over 1 500 papers published in the literature in the last 25 years. Research by Moser (1996) indicated that globally the most important use of neem was as an insecticide. However, knowledge on the use of neem as a medicine is also great both where the species is native and introduced (Childs *et al.*, 1999). For example, the main use of neem by people in the Bura Irrigation Scheme, Kenya, was for medicinal purposes (Eskonheimo, 1993).

The availability of neem products varies across the season. The species is generally in leaf all year round and thus leaves can be collected throughout the year. The bark, branches and boles can also be collected as and when required. For example, the production of charcoal in the Winneba district of Ghana is a year-round activity. The fruits and seeds can only be collected on a seasonal basis, however, and these are felt to be the most economically important part of the tree (Stzrok, 1992). The average length of the seed harvesting season is up to 100 days, and seeds are generally collected when they have fallen to the ground (Ahmed, 1995).

Table 5:The products of neem and their different uses.

Product	Seeds	Leaves	Bark	Branches	Fruits
Medicine (animal)		4			
Medicine (human)		4	4		
Crop Protection (field)	4	4			
Crop Protection (storage)	4	4			
Timber				4	
Fuel				4	
Religious festivals		4			
Food					4
Soil amendment/fertiliser	4	4			

8.1 CROP PROTECTION IN THE FIELD

Neem can help control more than 200 pest species through the possession of a complex group of compounds called limonoids (Ahmed, 1995). Many of these limonoids have been isolated and extracted from neem and have demonstrated the ability to block insect growth. The most well known and intensively studied of these limonoids are azadirachtin, meliantriol, salannin and nimbin (NRC, 1992). Azadirachtin is found in the highest concentration in the seeds of neem, and has been the main focus of research on neem and the development of commercial pesticide formulations. The other limonoids found in neem have also received substantial research attention and their modes of action are sometimes known. It is thought that there is a synergistic effect between the various limonoids in neem that gives the species its potent pesticidal effect. However, this synergy is not currently understood, and may be of interest both from a research perspective and the development of new commercial products.

Neem has been used for medicinal purposes for many centuries, but its pesticidal properties were not reported until the early part of this century. It was not until 1962 when Indian scientists ground up the seeds of neem in water and sprayed the resulting suspension over different crops that the potential of neem as a pesticide was envisaged (Pradhan *et al.*, 1962). The research that followed this initial investigation went in two directions. The potential for safe, cheap, environmentally benign pesticides that could be produced on-farm using existing farm, or home utensils was recognised, and has been the focus of research in many developing countries (Moser, 1996). Simultaneously, the potential for pesticides that could break the resistance of pests to synthetic pesticides and reduce negative impacts on the environment was of great interest to commercial pesticide companies, especially those in developed countries.

Efficacy of neem products

Neem extracts, i.e. NSKS (neem seed kernel solution), neem oil, powdered neem seed, NSC (neem seed cake) and commercial neem pesticide formulations are effective control agents for a wide range of plant pests and diseases. The extracts, and their target organisms and the crops they affect have been reviewed in a variety of publications (NRC, 1992; Suri and

Mehrotra, 1994; Schmutterer, 1995; Dales, 1996; Narwal *et al*., 1997; Gunasena and Marambe, 1998). Target organisms include moths, caterpillars, cockroaches, nematodes, beetles, aphids, mosquitos, midges, locusts, leafhoppers, bollworms, scales, weevils, fruit borers, grain borers, mites, fungi, viruses and bacteria. Neem extracts are effective against the pests of many major crops including rice, wheat, cotton, tobacco, legumes, vegetables, and fruits, either during cultivation or in post-harvest storage. Neem products have different modes of action against different pests:

Mode of action

Antifeedant

The antifeedant effect of neem products was first demonstrated in 1962 against the desert locust, *Schistocerca gregaria* (Pradhan *et al.*, 1962), and the compound responsible for anti-feedancy, azadirachtin, was subsequently isolated (Butterworth and Morgan, 1971). The desert locust will not touch plants sprayed with even trace amounts of azadirachtin, feeding is inhibited, and the insects may eventually starve. A number of other triterpenoids extracted from neem, e.g. salannin, also have anti-feedant properties (Gunasena and Marambe, 1998), and feeding inhibition has been reported for a wide range of pests (e.g., Bomford and Isman, 1996; Govindachari *et al*., 1996; Williams and Mansingh, 1996; Deka and Hazarika, 1997; Dhawan and Dhaliwal, 1997; Morallo and Punzalan, 1997).

Repellent

Neem contains several aromatic compounds that can be used to repel insects from biting humans and animals. Neem oil mixed with coconut oil gave up to 98.03% protection against the mosquito, *Anopheles culicifacies*, in all-night biting tests conducted in Gujarat, India (Kant and Bhatt, 1994). Neem oil also provided more than 75% protection against *A. fluviatilis*, *Aedes taeniorhynchoides* and *Mansonia uniformis*. Burning neem oil in a room is also said to repel mosquitos and other biting insects (Saxena, 1999).

Growth disrupter

The treatment of insects, or the plants on which they feed, causes insect growth inhibition, malformation and mortality (NRC, 1992; Dhawan and Dhaliwal, 1997). Azadirachtin, salannin, nimbin and 6-desacetylnimbin disrupt the metamorphosis of insect larvae by inhibiting the activity of ecdysone 20-monooxygenase, a steroid hormone responsible for moulting (Mitchell *et al*., 1997). The larvae do not develop into pupae, and the insects die without reproducing. The larvae of mosquitoes, diamond back moths, cabbage caterpillar and army worm have been found to be affected significantly by various concentrations of neem extract.

Ovicidal effect

Neem products have also been shown to affect sexual reproduction in female insects by reducing fecundity and fertility. Treatment of the migratory locust (*Locusta migratoria*) with azadirachtin resulted in locusts with smaller ovaries and reduced numbers of matured oocytes (Rembold and Sieber, 1981). Azadirachtin has also been shown to block the development of motile male gametes of the malaria parasites, *Plasmodium falciparum* and *P. berghei* (Jones *et al*., 1994). The motility of fully formed male gametes was, however, unaffected by azadirachtin.

Systemic activity

Neem products can show a systemic effect on plant pests, although this mode of action varies from plant to plant and with formulation to formulation (NRC, 1992). Systemic activity also varies from insect to insect, and according to the mode of application. For example, aphids feed on phloem tissues, the part of the plant responsible for the transport of organic material, and are unaffected by neem products applied systemically. However, leafhoppers and plant hoppers feed on the xylem tissues which are responsible for the transport of water. When neem is applied as a soil drench, uptake of the azadirachtin occurs and these types of insects are knocked down (NRC, 1992; Koul and Shankar, 1995; Weintraub and Horowitz, 1997). Neem products have also been shown to be effective against budworms and webworms of spruce and pine species when injected systemically into the trunks of these forest trees (Lyons *et al*., 1996; Wanner *et al*., 1997).

Instability of neem products

When exposed to ultraviolet light, azadirachtin degrades through a process known as photo-oxidation (NRC, 1992; Raguraman and Jayaraj, 1994; Mohapatra *et al*., 1995; Jarvis *et al*., 1997). This means that neem products have reduced efficacy as pest control agents over time. Nimbin and salannin, the major triterpenoids accompanying azadirachtin in extracts of neem seeds, are also photo-oxidised by ultraviolet light (Jarvis *et al*., 1997), although the products of this reaction do show some biological activity against a range of insect pests. As a result, NSKS produced by farmers should be used immediately after preparation, and many commercial formulations contain sunscreens to prolong the potency of the pesticide after spraying on the crop. Neem products are also sensitive to high temperatures and should be stored in cool, dark conditions (NRC, 1992; Stark and Walter, 1995).

Effects on non-target organisms

There is considerable interest in the effects on neem pesticides on non-target organisms and this is of particular importance when registration is being sought for commercial neem formulations (Larson, 1988; Immaraju *et al*., 1993; Rembold, 1993). The effects of neem products on beneficial insects is thought to be relatively minor (Schmutterer, 1997). A field study in Kenya investigated the effect of using NSKS for controlling insect pests on cowpea, and the effect on beneficial (honey bees) and non-target (spiders and ants) organisms (Sithanantham *et al*., 1997). Plots sprayed with NSKS received less visits from bees than the ‘no spray’ plots, but more visits than the plots sprayed with cypermethrin. Spiders and ants were not significantly affected by NSKS sprays. Reddy (1992) found neem leaf litter to harbour numerous taxa of microarthropods during decomposition. Higher rainfall and litter moisture was correlated with a higher density of microarthropods.

There is evidence that neem formulations affect aquatic invertebrates. For example, Margosan-O may not be suitable for mosquito control because the concentrations required to control larval emergence affected three non-target aquatic organisms (Scott and Kaushik, 1998). Another study on six species of aquatic invertebrate in south-west Montana, USA, indicated that mortality from a commercial neem formulation was similar to that from the herbicides 2,4-D and picloram (Dunkel and Richards, 1998). However, in this case mortality could be accounted for by action of the petroleum-based inert carrier in the neem formulation. Yet another study to determine the lethal effects of two commercial neem-based pesticides on eight species of aquatic invertebrates found significant mortality in only one species, and no significant mortality or anti-feedant effects to three detritivores after a 28-day exposure (Kreutzweiser, 1997). Clearly, different neem formulations may have different effects on non-target organisms that could be due not only to the active ingredients, but also inert compounds in these formulations. The effects of neem formulations also have to balanced against the effects and environmental persistence of other more potent pesticides.

On-farm use of neem products in developing countries

Several neem products are used on farms in developing countries. They include neem seed kernel solution (NSKS), neem oil, powdered neem seed, neem leaves and neem seed cake (NSC). All these products have been used for pest control, but the most well-known are the incorporation of neem leaves into stored grain, or the coating of stored grain with neem oil, to protect against storage pests post-harvest, and the use of NSC as a fertiliser and pesticide against soil nematodes (NRC, 1992). Aqueous neem leaf extracts have been traditionally prepared by soaking chopped or ground leaves, which are reported to contain limonoids but not azadirachtin, in water (Hellpap and Dreyer, 1995). The aqueous neem extract can then be sprayed onto crops (IRRI, 1989). However, the production and use of aqueous NSKS has gained significance in many developing countries in recent years, and is a simple, effective means of producing neem pesticides for application on crops in cultivation (see Box 2).

Moser (1996) reported that neem based pesticides are used by a wide range of farmers and are suitable for not just the more marginalised farmers (Marz, 1989). Highly commercial cardamom farmers in southern India use neem seed cake to control nematodes. Commercial tobacco growers in Andhra Pradesh, India, used an aqueous NSKS to control tobacco leaf worm and transmission of the tobacco mosaic virus (Ahmed, 1988). Research from Tamil Nadu, India concluded that farmers with larger holdings used more neem per hectare than farmers with smaller holdings (Palanisami, 1992). However, the same study also showed that farmers with larger holdings also used more synthetic pesticides. In Ghana, the use of neem was also found to be related to the intensity of farming (Childs, 1999). A group of farmers stated that in their village neem was used to control pests of cowpea, but that other villages in the area used no method of pest and disease control as lower cropping intensities resulted in fewer pest problems.

A wide range of farmers appear to use neem, however the frequency of use and type of application will differ according to the magnitude of the various benefits and constraints derived from pesticides produced on-farm or commercially, and the range of alternatives available to the farmer.

Box 2: How to make neem seed kernel solutions on-farm.

Preparing neem seed kernel solution on-farm

You will need:

10 litres water
200–400 g dry neem seed kernels
A bucket
Grinding stone
Muslin cloth
Detergent

To make the NSKS:

1. Grind the neem seed into a powder using a grinding stone or pestle and mortar.
2. Add the powder to the water in the bucket and stir well.
3. Leave the mixture to stand for a minimum of five hours.
4. Filter the mixture with the muslin cloth the remove the particles of seed.
5. Add to the resulting solution a small quantity of household detergent to emulsify the oil in the solution.
6. Place the solution in a knapsack sprayer or hand held sprayer and apply evenly to the affected plants.
7. Alternatively, coat a brush with the solution, and apply by flicking the brush over the affected plants.
8. GTZ recommends that NSKS should be produced during day and sprayed in the evening to avoid degradation by UV light and target pests when they are often most active, i.e. at night. However, in regions where there is frequent rainfall or storms in the evening, then it is better to spray NSKS when it has a chance to dry on the plant.

Constraints to the use of neem pesticides produced on-farm

There is a range of constraints to the use of home-produced neem pesticides in developing countries. For the purpose of this review, these have been categorised as resource-, information- and technical-based constraints. Of these three, resource based constraints are likely to show the most variation between and within countries.

Resource based constraints

Lack of raw materials: Moser (1996) reported that lack of neem trees was cited as a barrier to the widespread acceptance of neem as a pesticide. Childs *et al.* (1999) reported that access to trees and material were regarded as constraints by 41 % and 58 % of organisations contacted during a postal survey. This figure was significantly higher where responses came from regions where neem is introduced. Gomez *et al.* (1993) cited accessibility to trees as a factor determining the use of neem by farmers in Nicaragua. Limonoids have a low solubility in water, hence relatively large quantities of water are required to manufacture NSKS. This may restrict the use of NSK solutions in countries where water is limiting. For example, Radcliffe *et al.* (1999) reported that there was currently both a lack of seed and available water to produce enough aqueous NSKS to use in crop protection on areas planted with grain crops. However, there was an adequate supply of both of these raw materials for use on the smaller areas of land planted with vegetable crops. The seasonality of neem fruit production has also been cited as a constraint to the use of neem as a pesticide (Childs, 1999).

Labour: One of the main constraints for using neem insecticides produced on-farm is that their preparation is time consuming and requires more labour than the use of chemical insecticides (Hoddy, 1991; Ahmed, 1995; P.S. Sohdi, pers. comm.[10]). Farmers in Gujarat, India, found NSKS to be effective, but the preparation was thought to be time-consuming and created more work for women who collect the water needed on-farm and in the home (P.S. Sohdi, pers. comm.). Moser (1996)

[10] P.S. Sodhi, Kribhco Indo-British Rainfed Farming Project, Chakaliya Road, Dahod-389151, Gujarat, India.

reported that just over 65% of organisations contacted during a postal survey regarded labour requirements as a constraint to the use of home-produced neem pesticides. Childs *et al.* (1999) reported that 51% of organisations responding to a postal questionnaire regarded labour as a constraint. In a study on the potential for neem as a crop protectant in Niger, Radcliffe *et al.* (1999) asked villagers who would do what in the process of making an aqueous neem seed kernel extract. Table 6 summarises how villagers perceived the division of labour to be. It can be seen that women play an important role in the labour demanding activities of grinding seeds, carrying water and transporting the solution. Although villagers in Niger did not identify women as being a source of labour for gathering seeds, Ostermann (1993) concluded in her study that seed gathering was an activity predominantly confined to women and children. Several researchers in India also felt that seed harvesting was an activity confined to children, women and old people (Chamberlain, 1999). Where neem-based pesticides are produced on-farm there is an additional constraint in that neem trees generally fruit at the busiest time in the farm calendar, i.e. the onset of the rains. However, it can be assumed that the farmer is a rational decision maker and if benefits from diverting labour from other activities to neem seed harvesting and processing are deemed worthwhile, will be prepared to do so.

Table 6:Division of labour when making a neem-based pesticide on-farm in Niger. Adapted from Radcliffe *et al.* (1999).

	Section of the community		
Task	**Women**	**Men**	**Children**
Gathering fruits			4
De-pulping seeds	4	4	4
Drying seed		4	4
Grinding and milling	4		
Carrying water	4		4
Mixing			
Filtering	4	4	
Transporting Solution	4	4	4
Application			

Note: Shaded areas represent activities for which no answer was obtained.

Equipment: Saxena and Kidiavi (1997) reported that most households in Kenya, like many other African countries, own traditional pestles and mortars which can be used for pounding neem seed. Zehrer (1983) reported that the use of neem oil for post-harvest crop protection was suitable for Togo due to the quantity of neem trees available and the fact that no addition equipment was required. However, Radcliffe *et al.* (1999) perceived that the inadequate supply of such implements was a potential constraint in Niger. They concluded that, as with raw materials, aqueous extracts based on neem seed had potential for vegetables in garden plots, but that this form of pest control may not be viable on larger fields. Women in Ghana were observed to be using equipment for the extraction of neem oil used traditionally for Shea nut processing (Childs, 1999).

Information-based constraints

Moser (1996) concluded that lack of information was the primary constraint to the use of neem pesticides produced on-farm. Leopoltz (1991b), working on a GTZ-funded neem project in Nicaragua, concluded that a higher level of knowledge and understanding is required for innovative plant protection measures than compared to that required for chemical insecticides. Neem differs in its mode of action to synthetic pesticides and therefore where this technology is introduced to farmers familiar with chemical pesticides, it is important to explain that they will not see a rapid reduction in insect numbers or the cessation of crop predation. Rather, insects will continue to feed, albeit with reduced voracity, and after a while a reduction in pest numbers will be observed (Schmutterer, 1990). Childs *et al.* (1999) report that 57% of organisations contacted during a postal survey felt that the fact that neem was slow to have effect was a constraint to the increased use of pesticides derived from it. The number of organisations categorising this as a major/medium constraint was significantly higher in introduced areas than where neem is native (89% and 69% respectively), perhaps reflecting a higher degree of understanding about neem pesticides in native ranges.

Technical-based constraints

A number of constraints surround the harvesting and processing of neem seed which may affect the efficacy of neem pesticides produced on-farm thereby reducing their acceptability to farmers. Table 7 lists some of the technical constraints to the use of neem reported in the literature. A brief explanation is provided and where applicable, a solution suggested to avoid or minimise the constraint.

Table 7: Technical constraints to the use of neem pesticides produced on-farm and their possible solutions.

Technical constraint	Problem	Solution	Reference
Seed processing	Risk of contamination with aflatoxin if seeds picked from the ground.	Pick seeds from the tree, or sweep regularly under the tree.	Nagaveni *et al*. (1987) Chaturevedi (1993) Gunasena & Marambe (1998)
Seed storage	Risk of reduction in efficacy. Loss of material during storage.	Efficient drying. Appropriate storage vessels.	Hellpap & Dreyer (1999)
Quality of material	Variable quality of seeds in terms of amount of oil and azadirachtin	Picking seeds when greenish yellow in colour ensures higher quantities of azadirachtin.	Rengasamy & Parmar (1994) Johnson *et al*. (1996)
UV light	Azadirachtin and other related compounds degrade in UV light	Keep preparations away from sunlight. Where possible apply formulations at dusk when sun is weak.	NRC (1992) Raguraman & Jayaraj (1994) Mohapatra *et al*. (1995) Jarvis *et al*. (1997)
Phytotoxicity	High concentrations of both oil and azadirachtin may cause phytotoxicity.	Don’t make pesticides to strong.	
Effects on non-target organisms	Affects aquatic invertebrates. May have variable effects on different organisms and with different neem formulations.	Effects should be balanced against the effects and environmental persistence of synthetic pesticides.	Scott & Kaushik (1998) Kreutzweiser (1997)

Commercial neem products

Commercial neem products are considerably more sophisticated than the crude NSK solutions. A variety of solvents can be used to extract limonoids from neem seed, e.g. hexane, pentane, methanol and ether, either on their own or in a mixture of more than one solvent (Feuerhake, 1984). One of the most effective is methanol, due to the high solubility of limonoids in alcohol. Johnson and Morgan (1997) describe the selective extraction of nimbin, salannin, azadirachtin and oil from neem seeds using supercritical carbon dioxide and methanol. High pressures (34.4 MPa) and percentages of methanol (20%) removed the majority of the azadirachtin, whilst lower pressures and percentage methanol removed the nimbin and salannin (20.6 MPa and 6% methanol). Once azadirachtin has been extracted and purified, it will be added to a variety of inert compounds at varying concentrations to produce a product with a known, stable, azadirachtin concentration (Table 8). In many countries, a standard quantity of active ingredient is required for the registration of commercial pesticides and their subsequent use on a commercial scale (Zubkoff, 1999). Neem formulations will also contain a number of additives to increase shelf-life, ease of handling and scaling up of the manufacturing process. Sunscreens, such as para-aminobenzoic acid (PABA), are added to reduce the photo-oxidation of azadirachtin by ultraviolet light.

Table 8: Some commercial formulations of neem extracts (Suri and Mehrota, 1994; Moser, 1996; Gunasena and Marambe, 1998; World Neem Conference, 1999).

Country	Product	Active ingredients
India	Azadi	Azadirachtin (concn. of 3.0, 0.15 and 0.03%)
	Fortune Aza	Azadirachtin (concn. of 3.0, 0.15 and 0.03%)
	Godrej Achook	Azadirachtin and other limonoids
	Margocide	Azadirachtin and other limonoids
	Neemarin	Azadirachtin (concn. of 3.0, 0.15 and 0.03%)
	NeemAzal Technical	Azadirachtin (25% w/w; other limonoids 30-50% w/w)
	NeemAzal T/S	Azadirachtin (1.2% w/w; other limonoids 2.8% w/w)
	Nimbecidine	Azadirachtin
	Nimorich	Azadirachtin (concn. of 1.0, 0.3, 0.15 and 0.03%)
	Repelin	Neem, karanja, custard apple and castor products
	Vijay Neem	Azadirachtin (concn. of 3.0, 0.15 and 0.03%)
	Wellgro	Powder formulation
Thailand	Advantage	Thai neem
	A-one	Thai neem, citronella, galanga
	Instar	Thai neem, citronella, galanga
	Jarvan	Neem oil
	Neemix	Thai neem and other medicinal plants
USA	Azadirachtin Technical	Azadirachtin (concn. of 3.0, 0.15 and 0.03%)
	Azatin EC	Azadirachtin
	Azatin XL Plus	Azadirachtin
	Margosan-O	Azadirachtin (concn. of 0.3%)
	Neemix 4.5	Azadirachtin
	Trilogy 70	Neem oil
Germany	Bioneem	
	NeemAzal Technical	Azadirachtin (25% w/w; other limonoids 30-50% w/w)
	NeemAzal T/S	Azadirachtin (1.2% w/w; other limonoids 2.8% w/w)
Ghana	Garden Bloom	Neem powder for horticultural use
	NeemAzal T/S	Azadirachtin (1.2% w/w; other limonoids 2.8% w/w)
	Neemol	Azadirachtin (0.15% w/w)
	Neemol Granulated	Powdered form for soil amendment
	Sidco	Neem powder for seed treatment
Kenya	Neem Ros Pdr	Neem seed cake powder containing azadirachtin (0.5%)
	Nemroc	Neem oil (32%)
	Neemroc combi	Neem oil (32%)and azadirachtin (0.5%)
	Saroneem	Azadirachtin (1%) as an alcoholic extract from neem seed cake
Israel	Neemguard	Neem oil
Australia	GreenGold	
	Liceguard	

Constraints to the use of commercial neem formulations

Moser (1996) reported on the availability of neem-based formulations from 11 developing countries. Jeloise Company Limited (Ghana) began importing neem formulations from India in 1998 in response to demand from a farmer's co-operative, Kuapa Kokoo (Childs, 1999). They now import preparations suitable for vegetable growers and have promoted these formulations through workshops organised by the Ghana Organic Agriculture Network. Jeloise Company Ltd found, however, difficulties in meeting the demand for neem pesticides. When an order is sent to India, there may be a lag of over six months before the order is received and processed. The reason for this appears to be that the manufacturers make in response to demand and do not have stock sitting on shelves due to the short viability of the formulations (M. Ansare-Ansah, pers.

comm.[11]). Economic studies in Thailand, Kenya and Dominican Republic have also confirmed that manufacturers are producing on demand to avoid problems caused by a low shelf-life (P. Foerster, pers. comm.[12]). Other major constraints to the use of commercial neem pesticides include a variety of policy and legislation issues:

Registration of commercial pesticides: Commercial neem-based pesticides were first registered for use in 1992 (Gruber, 1992), and are now registered in at least 14 countries world-wide, either without restrictions or limited to use with certain crops (Moser, 1996). Problems with registering neem products for pesticide use have been greater in industrialised countries where the registration procedure is more complex and demanding. Despite this, however, formulated pesticides are registered for use in the U.S.A and in certain countries within the E.U. The registration requirements for different products can often be unclear, and this is highlighted by the regulations surrounding the use of biopesticides for organic agriculture (Hellpap, 1999). In the U.S.A, there are no federal regulations surrounding the use of biopesticides on organically produced crops. In the E.U., biopesticides can be used for organic agriculture if they have been produced on the farm, and azadirachtin can be used on mother plants or ornamental crops. Clearly, the legislation is unclear, sometimes contradictory and variable between different countries.

Patents on neem products: In India, neem products such as toothpastes, soaps, shampoos and cosmetics have been manufactured using extracts of neem for many years. In recent years, modern packaging techniques and technology have been used to manufacture pesticides and medicinal products based on neem, and over 30 patents have been granted for different processes and products in India, the USA and Japan. Immaraju (1998), like many other neem researchers, feel that neem is uniquely positioned to become a key insecticide in the global bio-pesticide market. In the USA, the actual or impending cancellation of some organophosphate and carbamate insecticides that have either lost patent protection, or are not being re-registered in many markets because of the Food Quality Protection Act of 1996, has opened new opportunities for bio-pesticides and reduced-risk pesticides in general. However, private sector efforts in patenting neem tree-related processes and products began to raise controversy in the mid-1990’s (Kocken and van Roozendaal, 1997; Balasubramanian, 1995; Hoyle and Rifkin, 1995). The focus of the debate was a 1992 US-patent on a process for extracting and stabilising azadirachtin (aza A), granted to the US company W.R. Grace. A coalition of non-governmental organisations opposed this patent on political and legal grounds. The coalition's underlying arguments were: (1) biological resources are common heritage and should not be patented; (2) the patent would restrict the availability of living material to local people, whose ancestors have spent centuries developing the material; and (3) the patent may block economic growth in developing countries. The legal challenged failed, however, on the grounds that there was no prior knowledge of the process within US borders, and the use of traditional extractions of neem would not be prohibited. This patent might have been rejected if USA patent law recognised certain forms of prior inventive activity (Kadidal, 1998). The USA only recognises prior 'knowledge, use or invention' as blocking a claim to a patent when those activities take place within US borders, or are evidenced by publications accessible in the USA, or, more commonly, by foreign patents. However, in 1997, the European Patent Office opposed the granting of a patent on the fungicidal effects of neem oil submitted by W.R. Grace on the same grounds, i.e. that of prior knowledge or ‘prior art’ (Neem Foundation, 1997). W.R. Grace were asked for more details on the extraction process in order to proceed to the next stage of the patent application.

Many authors have argued that USA patent laws are archaic, counter to stated policy directives and are disproportionately influencing the developing world's stance towards GATT and its intellectual property rights provisions (Kadidal, 1998; Balasubramanian, 1995; Hoyle and Rifkin, 1995). They also argue that patents on neem may lead to large-scale purchase of seeds, reduce their availability and price them beyond the reach of local farmers (Kocken and van Roozendaal, 1997; Balasubramanian, 1995).

Adverse government policies: Many countries, such as Thailand and the Dominican Republic, have no import tax on agrochemicals despite having taxes on all other industrial inputs (P. Foerster, pers. comm.[11]). This means that synthetic pesticides are relatively cheap and their use is favoured when compared to neem pesticides produced domestically. In addition, such a policy does not take into account the adverse effects of synthetic pesticide application, i.e. environmental damage, health hazards and reduction of biodiversity. A ban on all hazardous pesticides and taxes levied on synthetic pesticides according to their adverse, secondary effects might be more appropriate policies for many governments.

The benefits and constraints of both home-produced and commercial neem formulations for crop pest control in the field are numerous, but some of the advantages and disadvantages of a range of products are summarised in Table 9. For many farmers, the cost of commercial formulations makes their use prohibitive and therefore it would seem that for farmers isolated from a retail outlet, or capital limited farmers, home made preparations are a more suitable option.

[11] M. Ansare-Ansah, Jeloise Company Ltd., P.O. Box 8568, Kumasi, Ghana.
[12] Dr Peter Foerster, Pesticide Service Project, GTZ, Germany.

Table 9: The advantages and disadvantages of a range of neem products for crop pest control in the field.

Product	Advantages	Disadvantages
Commercial Formulations	Minimum labour requirements Can be formulated for stability under UV	Poor distribution Restricted availability Poor quality Standardisation necessary Registration necessary May be expensive Risk of resistance developing when formulations based on a single compound
Aqueous Neem Leaf Extracts	Leaves available all year round Minimum labour requirements Simple to prepare Cheap	Less effective than neem seed extracts (does not contain azadirachtin) Active ingredients degrade quickly
Aqueous Neem Seed Extracts	Seed can be stored ready for use Simple to prepare Cheap	Active ingredients degrade quickly Quality may be variable Seed not available all year round
Neem Oil	Seed can be stored ready for use Cheap	Active ingredients degrade quickly High labour requirement Seed not available all year round
Neem Seed Cake	Effective both as manure and for nematode control By-product of neem oil extraction, therefore can be produced or bought cheaply	High labour requirement Seed not available all year round

8.2 POST-HARVEST CROP PROTECTION

Post-harvest losses of stored grain were highlighted by the World Food Summit as a serious constraint to the alleviation of poverty in developing countries (Belmain, 1999). Research in Ghana has shown that whilst some farmers use botanicals and synthetics to protect stored grains, most farmers do nothing as they are unaware of botanicals and cannot afford synthetics (Belmain, 1999). In addition, food grains are often stored within the confines of the home rendering chemical fumigation unsuitable (Saxena, 1995). This situation serves to reinforce the belief that alternative forms of controlling post-harvest losses from insect pests must be identified (Saxena, in Schmutterer, 1995).

Prior to the discovery of insecticides, it was common practice in rural India for farmers to mix grains meant for storage with dried neem leaves (Saxena, 1995), and even today, this is the most common form of using neem to protect grains in storage (Pruthi and Singh, 1944). Neem oil (0.5 %) has been shown to be a suitable post-harvest treatment for the storage of cowpeas (Zehrer, 1983), and many other crops (Khaire *et al.*, 1992; Jood *et al.*, 1993; Belmain, 1999). Cardet *et al.* (1998) studied the efficiency of both neem oil and groundnut oil (5-20 ml per kg seed) for protecting tree seed stocks of *Acacia nilotica*, *A. raddiana* and *Tamarindus indica.* Their results showed that neem oil was more effective than groundnut oil in protecting tree seeds from predation. In addition, neem oil affected only the viability of *Acacia nilotica*, whereas groundnut oil affected the viability of all three species. They concluded that neem oil could be used to protect tree seed stocks efficiently in the Sahel.

Table 10 shows the various ways in which neem can be used for post-harvest pest and disease control. For a review of literature relating to the ability of neem extracts to control storage pest see either Dales (1996), Rees *et al.* (1993) or Golob (1980).

Table 10: The use of neem products for post-harvest crop pest and disease control.

Application	**Crop**	**Pest**	**Country**	**Reference**
Layered neem leaves	Mangoes	Various	Ghana	Childs (1999)
Neem leaves (4-10% wt/wt)	Wheat, rice, sorghum, millet	Various	India	Ahmed & Koppel (1987)
Crushed neem fruits on inner surfaces of grain containers	Wheat, sorghum	Various	India	Pruthi & Singh (1944)
Burning neem leaves	Rice, pulses	Various	Sri Lanka	Ganelsingam (1987)
Neem oil	Grains	Various	Benin	Baumgart (1991)
Neem leaf powder/ neem kernel powder, neem oil	Groundnuts	*Corycra cephalonica*	India	Senguttuvan (1995)
Neem leaf powder	Tomatoes	Fungal diseases	India	Sharma (1995)
Neem oil, neem leaf powder	Maize	*Trogoderma granarium*	India	Jood *et al.*, (1993)
Neem oil	Pigeon pea	*Callosobruchus chinenesis*	India	Khaire *et al.*, (1992)
Neem oil, powder, paste or water extract	Various	Various	Ghana	Belmain (1999)
Fresh or dried whole leaves	Various	Various	Ghana	Belmain (1999)
Leaf powder, paste or water extract	Various	Various	Ghana	Belmain (1999)
Neem oil (0.5 %)	Cowpeas	*Callosobruchus maculatus*	Togo	Zehrer (1983)

Most research on neem as a means of controlling storage pests has examined the efficacy of neem products. However, other considerations can be taken into account, for example, does the use of neem have any affect on the taste of the grains being stored? Childs *et al.* (1999) reported that 50% of organisations responding to a postal questionnaire said that taste was a constraint to the further development of neem as a pesticide, although only 12% of organisations categorised this as a medium/major constraint. There was a significant difference in the extent to which taste was seen as a medium/major constraint between organisations from the native range and from where neem was exotic (7 and 40 % respectively). This perhaps reflects the longer use of neem products for storage in the native range. Jood *et al.* (1996) tested the efficacy of neem powders and neem oil, along with other botanical powders in protecting sorghum grains against the larvae of *Trogoderma granarium*. Although neem oil and neem powder at 1% and 2% offered protection, when chapatis were made with milled flours from grains stored for six months, it was discovered that their aroma and overall acceptability had been adversely affected. This was attributed to slight insect infestation, plant pesticidal products or a combination of both.

The fact that in India and Pakistan, and more recently where neem is planted as an exotic, many people have been using neem extracts for post-harvest crop storage would suggest that farmers feel that this is a method appropriate to them. Whilst in some cases the use of neem may not give the degree of control shown by synthetic insecticides, it should be remembered that farmers will use a method of control that is appropriate to the financial resources they have available.

8.3 NEEM IN INTEGRATED PEST MANAGEMENT (IPM)

All pest control methods and practices can be considered for inclusion in an IPM programme, for example the use of pest-resistant crop varieties, biological control agents, cultural techniques, good water management and appropriate fertiliser applications (Lim and Bottrell, 1994). In IPM, pesticides are only used when their benefits are known to exceed economic, environmental and social costs, i.e. when monitoring shows that pests are approaching threatening numbers and natural controls and preventative measures will not stop them – the 'economic injury level'.

Neem experts have stressed the importance of using neem pesticides according to IPM principles (e.g. Schmutterer, 1990). However, a survey conducted by Lim and Bottrell (1991) showed that neem pesticides were being promoted as a preventative measure, and not on the basis of need determined by monitoring and the net returns to farmers. Hence, in 1991, the IRRI-ADB botanical pest control project assessed the value of neem in IPM systems in farmers rice fields in Tamil Nadu, India (IRRI, 1991; 1992). Neem pesticides were compared to the use of synthetic pesticides in IPM, and these treatments were also compared to the farmers' practice of treating rice prophylactically with insecticides. IPM treatments using neem showed that several major insect pests did not exceed economic injury levels. Two species of leaffolder did exceed the economic injury level 53 days after transplanting and did require one application of neem or synthetic insecticide. By comparison, the farmers' practice using no IPM required three applications of insecticide. Yields and income were greater under the IPM treatments than under the farmers' practice treatment, and yields and increased incomes were only slightly less under IPM treatment using neem than under IPM treatment using synthetic pesticides.

8.4 LIVESTOCK AND THE USE OF NEEM

Neem leaves are available throughout the year, and are therefore a potentially valuable source of fodder for livestock during dry periods (Gunasena and Marambe, 1998). The leaves are reported to contain 6.2% crude protein and 52.5% total digestible nutrients (Patel *et al*., 1962), and a minimum of 3.5 kg of neem leaves per day in the diet of livestock can provide and adequate source of vitamin A.

Neem products can also provides a source of veterinary products for livestock. The leaves and neem leaf powder are said to be useful against intestinal worms (R. Saxena, pers. comm.[13]), and have been incorporated into the diet of goats in India for this purpose (S.R. Sabnais, pers. comm.[14]). Indians have traditionally crushed neem leaves and rubbed them into open wounds on cattle to eliminate maggots (NRC, 1992). Neem oil and neem seed extract deter the female blowfly, *Lucilia sericata* from laying its eggs on sheep (NRC, 1992), and in Sri Lanka neem oil is rubbed on cattle as a fly repellent (Ganesalingham, 1987). Azadirachtin also exerts an ovicidal effect on the eggs of the blood-sucking fly, *Stomoxys calcitrans* (Gill, 1972).

8.5 NEEM AS A SOURCE OF FUELWOOD AND TIMBER

Neem is reported to have a calorific value of 4322.81cal/g (Shaheen and Harode, 1987). Parmar and Ketkar (1993) reported that a full-grown tree in India is capable of providing between 400 and 500 kg of fuelwood. Farmers in Winneba District, Ghana, highly value neem as a fuelwood, and generate considerable income through the sale of neem charcoal (Childs, 1999). The tree responds well to coppicing, but Ketkar and Parmar recommend that where neem is used for a number of purposes it should not be harvested for fuelwood until 10 years after planting.

The neem tree can be harvested for timber 35-40 years after planting and has a moderately heavy reddish brown heartwood (Hedge, 1993; Gunasena and Marambe, 1998). The wood is durable and not easily attacked by insects. It is easy to work and compares very well to teak timber. Neem can therefore be used for posts, beams, window and door frames, furniture, agricultural implements, boat building and wood carvings. Despite its numerous good qualities, in India neem wood has been sold at Rs. 7000 per cubic metre against Rs. 24 000 per cubic metre for teak (Hedge, 1993).

8.6 HEALTH AND MEDICINE AND THE USE OF NEEM

Neem has been used for thousands of years to cure disease in humans. A survey conducted in Niger found that the predominant use of neem was for medicinal purposes (Van der Burg and Haasane, 1990). Similarly, a recent study by GTZ (Moser, 1996) showed that a population's knowledge about the use of neem for medicine ranged from 63% in Caribbean/ Latin America to 86% in Africa and 93% in Asia. The same survey indicated that leaves were the most commonly used part of the tree for medicine. Childs *et al.* (1999) report that 87% of organisations responding to a postal questionnaire said that neem was used as a medicine by at least some farmers in the areas in which they worked. This figure was 93% where neem is native and 84% where it is grown as an exotic. A common use of neem is to control fevers, in particular malaria, where a tea made with the leaves is drunk. However, Ketkar and Ketkar (1995) report that extracts of neem are not active against malaria in late stages of infection.

Neem is reported to have anti-fertility, anti-bacterial, anti-fungal, anti-inflammatory and anti-diabetic effects (Ketkar and Ketkar (1995). In recent years, research into the potential of neem as a medicine has increased. A polyherbal formulation containing neem, Praneem, has been developed in India for contraceptive use (Talwar *et al*., 1999). The formulation has a potent spermicidal effect and inhibits the growth of *Candida* spp., *Chlamydia trachomatis* and urinary *E. coli*. Clinical trials have been conducted in India, Brazil, Egypt and the Dominican Republic, although the product is not yet licensed for use. There are also claims that neem has anti-veridical properties and can be effective against diseases such as HIV-1. Anti-cancer

[13] R. C. Saxena, ICIPE, PO Box 30772, Nairobi, Kenya.
[14] S.R. Sabnais, Rural Agricultural Institute, Narayangaon, Pune, Maharashtra, India.

properties have also been demonstrated *in vitro*, however, there is other evidence to suggest that neem can be carcinogenic (Rosenkranz and Klopman, 1995).

The commercial market for neem-based health and beauty products is better developed than that for neem-based medicines. In India, Khadi Village Industries has been responsible for the development of village cottage industries that include soap making. Soap made with neem oil currently represents main use of neem oil in India. Manufacturing neem oil soaps may be an appropriate income generating activity for women's groups. A community group in northern Ghana recently visited a women's group in Burkina Faso where they were exposed to several income generating activities, but chose to adopt neem oil and soap manufacture (Childs, 1999).

Many researchers have commented on the potential of neem as an ingredient for pharmaceutical and household products. For example, to kill or repel dust mites, roaches, ants, fleas, ticks and moths which cause human allergies, disease and destroy textiles (P. Foerster, pers. comm.[15]; D. Faye, pers. comm.[16]; S. Moorty, pers. comm.[17]). The consumer appears to be prepared to pay high prices for such products because of the adverse effect of some existing products and neem's biodegradable nature. As research into neem compounds continues it is likely that consolidation of data will occur and it is quite possible that neem may be identified as a source of cost-effective compounds capable for use in Western medicine or health products. However, the medicinal value that people attribute to neem all over the world and the fact that neem is used repeatedly from generation to generation, suggests that the tree has an important role to play in local medicine and is of great benefit to the disenfranchised and poor who often can not afford the cost of Western medicines.

[15] Dr Peter Foerster, Pesticide Service Project, GTZ, Germany.
[16] Dr Doudou Faye, Senegal.
[17] Dr S. Moorty, Fortune BioTech, Hyderabad, India.

9.0 SOCIO-ECONOMICS OF NEEM USE

Studies on the economics of using neem products have not always been wide ranging. They have tended to compare the direct cost-benefit ratio of using neem pesticides against the use of often, subsidised synthetic pesticides. The value of other products provided by neem, e.g. fuelwood, timber, etc., have not been taken into account, nor have the potential benefits to the environment that could result from reduced chemical pesticide use. As a result, the use of neem products has often been perceived as uneconomical to the rural poor. Marz (1992) stressed the need for on-farm research to investigate the substitution of synthetic insecticides with neem seed extracts, both from an entomological and an economic point of view, but considerable research is still needed in the latter area.

9.1 THE ECONOMICS OF USING NEEM PESTICIDES PRODUCED ON-FARM

In a survey of neem use, Moser (1996) found that 50% of respondents felt that neem was not economical to use, or was partially uneconomical to use. Ostermann (1993), studying the use of neem products (NSKS and neem oil) in vegetable production in Niger, concluded that only when subsidies for synthetic insecticides were removed and more labour saving seed collection techniques developed would the use of neem insecticides become economically viable for farmers. Ahmed (1995) also suggested that neem will appear more economical to use when subsidies for chemical pesticides are removed.

In trials to establish an economic and effective insecticide for controlling a number of pests of pigeon pea in India, neem was found to be less effective and less economical than several synthetic chemicals (Patel *et al*, 1997). Conversely, Wendt (1993) concluded that without the application of home produced neem extracts, the production of tomatoes and cabbages in home gardens in Ecuador would not be possible on an economic basis. Marz (1989) concluded that, at higher concentrations, neem seed extracts could economically replace Deltamethrine in the treatment of cabbages against diamondback moth (*Plutella xylostella)*. The same study in Burkina Faso also concluded that neem seed extracts could economically replace Fentin in the treatment of tobacco seedlings. Hellpap (1993), writing about the use of neem in the Dominican Republic where farmers purchase neem seed powder from a GTZ project, concluded that the cost of using neem is comparable with that of using synthetic pesticides. Marz (1989) also investigated the economics of utilising neem oil for the protection of cowpeas in storage. He concluded that for storage up to six months, it was economically advantageous to use neem over traditional storage methods, but thereafter the use of ash was economically superior.

It can be noted, however, that these studies do not take into account the other benefits that can be derived from the neem tree, e.g. medicines, fuel, timber, etc. Clearly an economic study at the farm level involving all these aspects would be complex. Marz (1992) examined the economics of using neem seed based insecticides together with the value derived from wood when neem was grown in an alley cropping system. He concluded that the economic benefits derived from utilising the tree for both insecticide and wood appeared very promising. Ahmed and Grainge (1986) identified the need for alternative pest-control strategies that are socially and ecologically compatible with local needs and constraints, and simultaneously provide for rural development. They concluded that neem has the potential to meet this need.

In addition to recording the other benefits derived from the neem tree, attempts should be made to incorporate the hidden costs to the environment and human health that result from the use of synthetic pesticides when comparing the economic efficacy of neem with that of synthetics. In many instances, comparisons between the economic efficacy of using neem and synthetic pesticides bear little resemblance to the situation faced by many of the poorest farmers, in that the use of synthetics is not a viable option due to their high cost.

9.2 THE VALUE OF NEEM SEED AS A CASH CROP

Neem products (both unprocessed and processed) can provide a means of generating household income. Most trade appears to be in seeds with the collector being able to add little value to the products. Reports vary as to the prices received for the products, but Table 11 provides an indication of prices received by collectors for seeds. It should be noted that only the most recent references have been used.

Neem seed prices will vary across the season. In 1998, the neem seed harvest in Andra Pradesh, India, was relatively poor, hence the price for seed was low at the beginning of the season (US $0.05 per kg), but increased to US $0.12 per kg towards the end (Chamberlain, 1999). Higher prices will be paid for neem seed kernels (e.g. US $0.25 per kg in Uttar Pradesh, India), but seed processing is labour intensive and does not compare favourably to the salary paid for unskilled labour. Labour costs also have bearing on the commercial production of neem pesticides. In the Dominican Republic, the relatively high cost of labour means that a neem oil processing plant imports seeds from Haiti where labour costs are cheaper (B. Cooper, pers. comm.[18]). Jelosie Company Limited (Ghana) who are considering setting up a manufacturing plant feel that they would have

[18] B. Cooper, Ministry of Agriculture, Antigua.

to import seed from Nigeria, rather than buy internally, because of both labour costs and quantity of material available in Ghana (M. Ansare-Ansah, pers. comm.[19]).

Table 11: The prices paid for various neem products in different countries.

Part traded	**Price per kg (US$)**	**Location**	**Date recorded**	**Reference**
Seeds	0.10	India	1991	Strzok (1992)
Seeds	0.05-0.12	India	1999	Chamberlain (1999)
Seeds	0.09-0.2	India	1999	BAIF (1999)
Seeds	0.50	Kenya	1997	Saxena & Kidiavi (1997)
Seeds	0.20	Haiti	1991	Strzok (1992)
Seeds	0.22	Kenya	1996	Moser (1996)
Seeds	0.22	Sri Lanka	1996	Moser (1996)
Seeds	0.50-1.00	Tanzania	1996	Moser (1996)
Seeds	1.00-1.20	Thailand	1996	Moser (1996)
Seeds	0.12	Ghana	1999	Childs (1999)
Seeds	0.6-1.0	Latin America	1999	Hellpap & Leupolz (1999) Childs *et al.* (1999)
Neem seed cake	0.10	India	1986	Ahmed (1988)

Hegde (1993) reported that in India the price realised by most seed collectors ranges between Rs. 500-2500 per tonne of seed, whilst mill owners will pay up to Rs. 4000 per tonne. During a recent survey in India, a number of interviewees felt that commercial companies and mill owners would be prepared to pay higher prices for good quality seed, and do so in some cases (Chamberlain, 1999). However, there are a number of factors which currently prevent a greater price being realised by seed collectors, and these are listed below:

- Lack of knowledge about seed collection leading to the sale of poor quality seed mixed with gravel and soil.
- Inadequate marketing facilities, or lack of access to marketing facilities.
- Lack of knowledge about seed handling leading to poor quality fruits and seeds.
- Sale of seed only, and not value-added products, e.g. kernels, oil.

In India, there is a recognition that the market for neem seed is unorganised and under-developed (Chamberlain, 1999), and the establishment of co-operatives for marketing and oil extraction could increase the price realised by seed collectors.

9.3 THE ECONOMICS OF VILLAGE NEEM PLANTATIONS

Hegde (1993) estimates that an average neem tree can generate an annual income of Rs. 50 (US $1.25). A hectare of trees (150-200) could therefore generate an income of approximately Rs. 10 000 (US $350), which is more than the returns received for some food crops. Ruthyunyaja and Dayanatha (1993) highlighted a number of issues that they felt have to be addressed prior to farmers establishing neem plantations. They also provide a list of the shadow prices that should be taken into account in order to assess correctly the income generated from a neem plantation. A list of factors that will affect whether a farmer is willing to establish a neem plantation is provided in Table 12, together possible solutions to the problems encountered.

It should be noted that in addition to neem plantations providing seed, they could also be established to provide timber and fuelwood. Kalla *et al.* (1975) calculated that returns from a commercial neem fuel plantation were low in comparison to *Acacia tortilis, Albizzia labbek* and *Prosopis juliflora*. However, Ruthyunjaya and Dayanatha (1993) argued that if the multiple uses of the neem tree were taken into account then returns could exceed those derived from *Albizzia labbek* and *Prosopis juliflora*. In addition to the multiple uses of the tree, calculations should also examine the multiple uses of a single product such as fruits. Marz (1989) reported that the value of neem fruits was increased by up to 50% when the use of neem cake as a nitrification inhibitor was taken into account.

[19] M. Ansare-Ansah, Jeloise Company Ltd., P.O. Box 8568, Kumasi, Ghana.

Table 12: Factors that might affect whether farmers are willing to establish neem plantations.

Problem	Explanation	Possible solution
Fixed cost	The establishment of a one hectare plantation would require an investment of Rs. 3 650, equivalent to approximately US $ 128 (Hedge, 1993). It is therefore likely that access to credit is required.	Mechanism for credit provision created.
Income generation	The plantation will not become productive until five years after establishment, therefore no income can be realised from the portion of land under neem. Intercropping may alleviate this problem, but at the same time farmers have to take into account the opportunity cost of not having that land under full crop production.	Income generation through intercropping with food crops (coriander, cowpea, peerkai) up to year five. Income generation through intercropping with fast growing leguminous tree crops for fodder and mulch up to 8-10 years. Credit provision and support in first few years.
Management	Labour requirement in the first few years after establishment. Seedlings need to be watered, depending on site conditions up to year five. Weeding is also required, and the plants should be protected from cattle.	Plantations managed on a co-operative basis.
Finding a site	May mean a reduction in common grazing land, land available for food production, etc.	Plantations at the village scale organised on a co-operative basis are more likely to succeed. Plantations could be established along field boundaries, or around the home to minimise the reduction in land available for grazing or food production.
Theft	Neem products may be stolen, or trees and fences vandalised.	Vivekanandan (1998) reports of villagers employing village guards to protect trees.

9.4 THE VALUE OF NEEM TO THE NATIONAL ECONOMY

Neem can contribute to both the local and national economy. The species has probably had the greatest impact in India where neem fruits have the greatest commercial potential, although only 25-30% of fruits are collected per annum (Hegde, 1993; see Figure 1). The majority of neem seeds are crushed for oil of which 95% is used for soap production. This represents an inferior use as greater value can be added to the seeds through the manufacture of medicines and pesticides.

Most commercial companies buy unprocessed seeds from traders, or large neem seed markets. Parmar and Ketkar (1993) estimate that in India there are 141 seed collection centres and 70 oil producing centres. A large manufacturer of neem-based pesticides in India, produces five neem products that are sold locally, or exported: Azadirachtin Technical, Azadirachtin EC 3.0%, 0.15% and 0.03%, neem oil and neem seed cake. The company's processing plant in Andra Pradesh has an annual processing capacity of 6 750 tons of seed, but has yet to reach full capacity. Table 13 illustrates the seed price per ton, production and computed total price of seed bought for the years 1997-2000.

Assuming that a tree is capable of producing 20-25 kg of seed on an annual basis, then to meet the projected demand of 2800 tons in 1999/2000, the company will require the seed harvest of 112 000 to 140 000 trees. To meet the full processing capacity of the plant (6 750 tons), then a total of 270 000 to 337 500 trees are required. At present, seeds are sourced adequately from the states of Karnataka, Tamil Nadu and Andhra Pradesh. As can be seen from Table 12, the value of neem products this year to this company alone is worth at least 2.5 million US dollars.

The average market price for neem seeds paid to collectors is US $0.05-0.1 per kg (based on Ahmed, 1988; Hegde, 1993; Moser, 1996; Chamberlain, 1999), equivalent to a maximum of US $100 per ton. The company expects to buy at US $200-270 during 1999/2000, hence traders or middlemen can expect to achieve a profit of between 50-170% on their purchase price.

Table 13: Seed processing costs at a neem pesticide factory in Andra Pradesh, India for 1997-2000.

	1997-1998	1998-1999	1999-2000
Procurement (tons)	600	1000	2800 (projected)
Seed price per ton (US $)	152-208	197-280	200-270
Estimated expenditure on seed based on an average price per ton calculated from data above.	108 000	238 500	658 000
Value of final products (in US $ million)	0.5	1.0	2.5

Not all manufacturers purchase unprocessed seed. The company SPIC Biotech based in Chennai, India purchase 40 tons of neem seed kernel and 100 tons of neem oil on an annual basis from private oil mills within a radius of 300-500 km. From this they manufacture approximately 120 000 litres of pesticide sold directly to SPIC dealers all over India. Some of the points raised by commercial companies contacted within the scope of this study identify weaknesses in the marketing chain within India. The main points are listed below.

- Neem cultivation is not organised in the way other agricultural commodity crops are.
- Neem seed collection is not organised properly by the vendors and is a low profile activity.
- Marketing of neem-based pesticides is still a concept selling.

9.5 THE ECONOMICS OF COMMERCIAL NEEM PLANTATIONS

Considering the expanding market for neem-based products, it is likely that commercial companies may explore the possibilities of developing their own neem plantations. At least two Indian companies represented at the World Neem Conference 1999, Canada, had already started to develop plantations. One company has established a plantation of 60 000 trees in a southern part of Tamil Nadu using local seed sources, and a second aims to have a plantation covering 800 hectares (BAIF, 1999). The latter company has identified trees with high azadirachtin content and hopes that the cultivation of their progeny will reduce the cost of producing neem pesticides substantially. Neem has also been planted on a large scale in Mexico, Colombia and Australia. It would seem clear that commercial ventures and companies acknowledge the variation within the species for both azadirachtin and oil, and are willing to invest in the establishment of plantations.

Currently, however, an optimum management regime that provides a high economic return is likely to be a constraint to the establishment of commercial plantations. Marz (1989) calculated an internal rate of return (IRR) of between 10-30% for a 24 year rotation cycle, when both wood and fruit were harvested. Ruthyunjaya and Dyanatha (1993) studied the economics of plantations and calculated that an IRR of 46% could be achieved if total output (fruits, fuel, wood, twigs and top feeds) were brought into the equation for a 23 year rotation cycle. They identified additional factors for consideration, which included a range of management and policy issues, and calculated that a positive cash flow from a neem plantation would only be achieved in the 5th year, i.e. the time the tree starts producing fruit (Chaturvedi, 1993). Research is undoubtedly needed in this area, however, a number of other considerations need to be taken into account if plantations are to be developed on a commercial scale (see Table 14).

Table 14: The advantages and disadvantages of commercial neem plantations.

Advantages of commercial plantations	Disadvantages of commercial plantations
• May be able to obtain seeds with higher azadirachtin and oil contents. • May be able to obtain better quality seeds. • May be able to improve seed yields per tree. • Fruiting is largely synchronous. • May generate employment. • Could provide economic benefits to commercial companies.	• Little silvicultural information available. • Risk of disease and other problems associated with a monoculture increased. • Negative impact on those already engaged in neem seed trade as they risk loss of income. • Considerable investment required. • Gestation period prior to plantations becoming profitable. • Risk of reducing biodiversity. • Costly if market for neem products collapses.

9.6 FUTURE PROSPECTS

It seems likely that the market for neem derived products is going to continue to expand both locally and globally. It also seems that there is great potential for increased sustainable use of home-made neem insecticides. Hellpap and Leupolz (1999) conclude that the prospect for a sustainable use of home-made neem insecticides will depend on the factors listed below.

- Availability and cost of raw material.
- Quality and effectiveness of the preparation.
- Labour requirements.
- Access to and attitude towards synthetic pesticides.
- The ability and willingness of farmers to spend more energy on pest control.
- The image of neem in the community.
- The plant protection knowledge of the farmer.
- Awareness of the harmful effects of synthetic pesticides on health and the environment.

Although many of these factors may be universal, it is essential not to underestimate the importance of micro-information, as described by Radcliffe *et al.* (1999) and it is recommended that each of these factors be evaluated at the community level when promoting home-produced neem based pesticides.

10.0 GENETIC IMPROVEMENT, WITH REFERENCE TO CHEMICAL COMPOUNDS

10.1 THE INTERNATIONAL NEEM NETWORK

In 1994, the International Neem Network (INN) was established with the long-term objective to improve the genetic quality and adaptability of neem, and to improve its utilisation, throughout the world, as a contribution to development in the countries concerned, with particular focus on meeting the needs of rural people (Thomsen and Souvannavong, 1994). The Network collaborators decided to undertake activities in relation to provenance exploration, seed collection and exchange for the establishment of internationally co-ordinated trials. They also decided to undertake research in seed physiology and technology, genetic diversity and reproductive biology, as well as studies on variation in chemical compounds.

The national institutions of 21 countries, in Asia, Africa, Latin America and Europe, are collaborating in the Network (Table 15). The Food and Agriculture Organisation of the United Nations (FAO) and the International Plant Genetic Resources Institute (IPGRI) also participate in the Network activities, as well as a number of FAO/UNDP regional forestry field projects *viz*. “Improved productivity of man-made forests through tree breeding” (FORTIP), based in the Philippines; “Afforestation and Reforestation - Formulation of National Policies” (STRAP), based in Vietnam; and “Forestry Research Support Programme for Asia-Pacific Region” (FORSPA) and the “ASEAN Tree Seed Centre Project”, based in Thailand. The Network is co-ordinated by a panel formed by Indian Council for Forestry Research and Education (ICFRE, India), Royal Forest Department (Thailand), Institut Sénegalais de Recherche Agronomique, (ISRA, Senegal), Département Forestier du Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD-Forêt, France), DANIDA Forest Seed Centre (DFSC, Denmark), FORTIP and the FAO. Global co-ordination is entrusted to FAO, which facilitates inter-regional co-operation and exchanges of information and genetic material.

Table 15: Countries collaborating in the International Neem Network and focal point institutions.

Country	Focal point institution (FPI)
Bangladesh	Forest Research Institute
Burkina Faso	Centre National de Semences Forestieres and Institut de Recherche en Biologie et Ecologie Tropicale
Chad	Direction des Forêts et de la protection de l'Environnement
Denmark	Danida Forest Seed Centre
France	CIRAD-Forêt
Ghana	Forest Research Institute
India	Indian Council of Forestry Research and Education
Lao P.D.R.	Department of Forestry
Mali	Institut d'Economie Rurale
Myanmar	Forest Research Institute, Yezin
Niger	Direction de l'Environnement
Nepal	Forest Research and Survey Centre
Nicaragua	Centro de Mejoramiento Genetico de Semillas Forestales
Nigeria	Federal Department of Forestry
Pakistan	Pakistan Forest Institute
Philippines	Ecosystem Research and Development Bureau
Senegal	Institut Sénegalais de Recherche Agronomique
Sudan	Forestry Research Institute
Tanzania	National Tree Seed Project
Thailand	Royal Forest Department
Vietnam	Forest Science Institute

During 1993 and 1994, seed-sources were surveyed and documented throughout the natural range of the species and in areas of introduction. Pilot seed collection and exchange activities were undertaken to improve the procedures used, and a training workshop was organised in July 1994, in Coimbatore, India, to familiarise INN collaborators with the improved procedures.

Provenance exploration, collection and testing

25 seed sources, representing the entire eco-geographical variation in the distribution range of neem were identified for seed collection and exchange among INN collaborators in 1995 for the establishment of international provenance trials (Hansen *et*

al., 1996). All seed sources included in the international trials have been described using a common set of descriptors, including maps (FAO, 1998). A number of collaborators have, in addition to the seed sources identified for international trials, selected and collected a number of local seed sources to be included in the national trials.

Seed collection took place between March and August 1995 and followed common procedures determined by a working group of the INN (FAO, 1995a). In all cases, seeds were collected from at least 25 trees, 100 metres apart. Immediately after collection and appropriate processing, seed from the 25 provenances was rapidly dispatched among collaborators in 19 countries.

Nursery production of seedlings followed common guidelines developed by a working group of the INN (FAO, 1995b). The nursery production was successful in most countries, and a sufficient number of plants of acceptable quality were raised for trial establishment. In some countries, surplus seedlings were available, and it was recommended that these seedlings be used to establish *ex situ* conservation/provenance stands.

The design and establishment of international provenance trials

The objective of the international provenance trials of neem is to study, on multiple sites, the genetic variation, overall adaptation and growth of the provenances included in the trials, and to assess site/provenance interactions. Guidelines for trial design and establishment were prepared by a working group on trial design (FAO, 1996). Considering the extent of variation, across the Network, in trial site conditions and number of seedlings available, it was not considered realistic, nor desirable, to use one single design for all the trials. Instead, the guidelines were designed to provide practical advice for the design and establishment of statistically sound, robust trials, adapted to local conditions and available resources.

A total of 36 international provenance trials were established during 1995-1997 (Table 16). However, due to low survival rates, the trials in Chad, Nicaragua and the Sudan have been closed. In the remaining trials, the number of provenances per trial varies between 15 and 25, and some countries included local seed sources as controls. The funding for the establishment and maintenance of trials was the responsibility of each collaborating country in the INN.

Table 16: Number of field trials established within the INN during 1995-1997.

Country	Number of trials established	Country	Number of trials established
Bangladesh	2	Nicaragua	1*
Burkina Faso	1	Pakistan	1
Chad	1*	Philippines	2
India	6	Senegal	3
Lao P.D.R.	1	Sri Lanka	1
Mali	2	Sudan	1*
Myanmar	3	Tanzania	4
Nepal	2	Thailand	2
		Vietnam	2

**Due to low survival rates, the trials in Chad, Nicaragua and the Sudan have been closed.*

Supportive research components

In addition to the main INN activities on seed exchange and the establishment of international provenance trials, the network has a number of associated supportive research components, related to:

- Genetic variation and reproductive biology;
- Seed physiology and technology;
- Genetic variation in chemical compounds.

Genetic variation and reproductive biology
This component is co-ordinated by CIRAD-Forêt, France. A research proposal was prepared by CIRAD-Forêt in co-operation with concerned INN collaborators. The proposal was presented to the Government of France, but was not accepted for funding (Thomsen *et al*., 1996).

Seed physiology and technology
This component is co-ordinated by the DANIDA Forest Seed Centre, Denmark and has been incorporated in a collaborative research project entitled: IPGRI/DFSC Project on handling and storage of recalcitrant and intermediate tropical forest tree seeds. The project is funded by IPGRI and DANIDA and has participation from research institutions in some 20 countries. Neem is one of 30 tree species being tested in the programme. Work on neem has concentrated on seed storage and seed desiccation studies, and a number of countries, which have agreed on common objectives and goals are collaborating within this group.

Component on genetic variation in chemical compounds
This component is co-ordinated by the Indian Council for Forest Research and Education (ICFRE). Research in this area is on going among a number of INN collaborators, but development of this component will not proceed until trees in the trials begin flowering and fruiting. Activities have included the estimation of azadirachtin content in neem seed, determination of fatty oil variation in neem seed, plus isolation and characterisation of active constituents in these compounds.

Network programme and future activities

Work of the INN is currently concentrating on the continued management and care of the established international provenance trials (Hansen *et al*., 1996). Assessment of trials started in 1997, and guidelines for trial assessment, including identification of characters to assess and assessment methodology were developed. Seed characteristics and azadirachtin content in neem seed will be assessed for the first time in year four. Only those collaborators with an interest in this area and with equipment available for the analysis of azadirachtin content will assess these traits (Chamberlain, 1999). There is no standard methodology for estimating azadirachtin content currently available to the collaborators in the INN (C.J.S.K. Emmanuel[20], pers. comm.).

AFRI has established three INN trials at Jodhpur. Jaipur and Palampur (Emmanuel, 1998). They each contain 17 provenances replicated four times in a randomised block design. After one year of growth, tree height varied from 0.57 to 2.05 m, and stem girth from 8.04 to 13.36 cm with two provenances from India (Sagar and Kulapackam) performing well. The TFRI established an identical trial at Jabalpur where tree height varied from 1.63 to 5.49 m and girth from 3.6 to 6.63 cm (Sharma, 1998). Provenances from Tanzania (Chamwion) and Thailand are performing well in this trial. In Sri Lanka, the University of Peradeniya established an INN trial with eleven provenances from Thailand, India, Pakistan, Nepal and Sri Lanka (Wickremasinghe and Gunasena, 1998). After two years of growth, provenances from Thailand and a local land race from Sri Lanka were found to be the best performing in terms of height, basal diameter and branch number.

Future activities of the INN include:

- Further assessment/survey of the genetic diversity and variation of neem;
- Conservation (*in situ* and *ex situ*) of the genetic resources of neem;
- Genetic improvement and production of improved planting material in countries concerned;
- Further studies on chemical compounds and their genetic variation, linked, and co-ordinated with, other genetic diversity studies.

10.3 OTHER IMPROVEMENT ACTIVITIES

Many organisations around the world have conducted genetic improvement work for neem in response to national and local research needs. A number of research institutes in India have made plus tree selections from various locations across the country (Chamberlain, 1999). The choice of selection criteria was an acknowledged problem and varied from region to region and according to the main use to which neem was to be put. Often selections of plus trees was made on the basis of multiple traits using a ranking system (for example, see Venkateswarlu *et al*., 1999). The limitations of this were acknowledged, and the role of the environment was felt to be unpredictable when selecting plus trees in one location for planting in another. The Research Section of the Royal Forest Department of Thailand has established a clonal gene bank of 32 plus trees selected from three regions of Thailand (Boontawee *et al*., 1993).

[20] C.J.S.K. Emmanuel, AFRI, New Pali Road, Jodhpur, India.

The Forest College and Research Institute of TNAU have some of the oldest provenance trials in India, dating back to 1991 (TNAU, 1999). They have a mixture of trials based on material from Tamil Nadu only (28 families), and others containing material collected from all over India (34 families). The main selection criteria in the TNAU trials have been stable production of seeds with high azadirachtin and oil content. In 1992, AFRI established a large provenance trial of neem containing 40 provenances from 10 Indian states representing different agro-climatic zones of the country (Mishra, 1995). There is enormous variation within the trial and tree height varies from year to year. In 1998, the best performing provenances were Rajkot (Gujarat), Gandhi Nagar (Gujarat) and Amarawati (Maharashtra) with increases in height of 5.80, 5.42 and 5.35 m respectively (Emmanuel, 1998). CAZRI have a collaborative project with AFRI funded by the NOVOD Board. The objective is to evaluate the seed resources and potential of neem in Gujarat (co-ordinated by AFRI) and in Rajasthan (co-ordinated by CAZRI) (S. Vir[21], pers. comm.). The research activities include seed resources assessment and the selection of plus trees, i.e. trees with high azadirachtin and oil contents and high seed yields. In 1994, the NRCAF established a provenance trial of neem with 26 provenances collected from central India (Solanki, 1998). The best performing provenance after a three-year period was found to be that from Damoh, which along with six other provenances out-performed the local provenance. The NRCAF also collected seed from plus trees selected on the basis of bole straightness, high fruit yield and canopy shape. The seeds were planted in the field, and after three years six progenies were found to out-perform the local material.

11.0 SUMMARY

In summary, a large body of literature is available on neem and substantial and detailed research has been carried out in many areas. However, other areas of research have been neglected or poorly funded. New or revitalised initiatives in these areas could improve the use of neem by poor farmers, especially for crop protection on farms. Some of the constraints discussed in the preceding sections are summarised and possible interventions suggested in Table 17.

[21] S. Vir, CAZRI, Jodhpur, India.

Table 17: Researchable constraints and interventions that could improve the use of neem by poor farmers.

Factor	Constraints	Possible interventions
Biological	• Poor understanding of the effect of andromonoecy on seed production in neem. • Poor understanding of the environmental and genetic control of flowering and fruiting. • Unknown qualities and potential benefits of neem hybrids. • Potential for the invasiveness of neem poorly understood. • No comprehensive and range-wide molecular diversity study completed. • Lack of farm-scale seed harvesting, drying and storage methods.	• Research on the role of andromonoecy in neem. • Research on the effect of environment on seed production in neem. • Development of hybrids of neem and assessment of their qualities. • Research on the biological and participatory monitoring and evaluation of neem's invasiveness. • Research on the molecular diversity of neem. • Participatory research on farmer harvesting, drying and processing techniques to identify constraints and solutions.
Silvicultural	• Lack of information on optimum management regimes and silvicultural practices for a range of neem products.	• Research on optimum silvicultural practices for seed production. • Participatory silvicultural research to identify current practices and areas of weakness.
Technical	• Study on the commercial production of tissue-cultured material for azadirachtin production incomplete. • No clear information on neem product-crop-pest packages. • Lack of a standard methodology for estimating azadirachtin content. • Lack of information on the role of neem in IPM and INM programmes. • Lack of information on the use of neem as a fodder for livestock. • Lack of research on the use of neem in veterinary and human medicine.	• Funding required to complete study. • Synthesis of the large body of literature on neem's target organisms and efficacy. • Support to develop a standard methodology for estimating azadirachtin content. • Research on the role that neem can have in IPM and INM programmes further explored. • Research on neem's fodder qualities. • Research on neem as a source of veterinary products. • Research on neem as a source of medicinal products for humans.
Socio-cultural	• Poor awareness amongst farmers and extension services of the benefits of neem to farming systems. • Lack of accurate information disseminated to farmers. • No targeting of communities for whom neem could be beneficial. • No socio-economic studies that assess the social, economic and environmental benefits of the use on neem products on farms. • Market structure for neem products is poor. • Low prices are paid for seed, which limits income-generating activities based on neem.	• Raised awareness amongst extension services and NGOs of neem role in farming systems. • Training of extension staff. • Participatory farmer research to identify groups of farmers most likely to adopt and benefit from neem products. • Socio-economic studies to assess the social, economic and environmental benefits of the use on neem products on farms. • Research on the commodity chain. • Participatory farmer research to identify communities interested in village industries based on neem.
Genetic improvement	• Lack of funding and support for the supportive research programmes within the International Neem Network. • Lack of necessary facilities for assaying azadirachtin content in Network collaborating countries • Reliance on the micropropagation of neem as a genetic improvement activity. • Poor information exchange.	• Research funded on the role of reproductive biology, and genetic and environmental factors controlling seed azadirachtin content. • Collaboration with a suitable laboratory initiated. • Rapid and effective means of transporting neem seed between countries • Initiate programmes of selection and testing prior to the mass micropropagation of neem. • Development of new structures for the dissemination of information, e.g. interactive database, neem discussion group, simultaneous, subject-specific conferences, supra-regional office offering a broad and effective means of disseminating information.

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