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Volume I: The Neem Tree

Edited by
Martin Jacobson

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Volume I

The Neem Tree

Editor

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FOCUS ON PHYTOCHEMICAL PESTICIDES

SERIES INTRODUCTION

There is ample evidence to show that the plant kingdom is a vast storehouse of chemical substances manufactured and used by plants for defense from attack by insects, bacteria, and viruses. Many of these plants, as well as their chemical components, have been used since ancient times to prevent and treat diseases occurring in higher animals, including humans. The scientific and pseudoscientific literature is replete with such reports, some of which have been confirmed by laboratory and clinical trials, and yet others which have been shown to be worthless for these purposes.

The CRC Series *FOCUS ON PHYTOCHEMICAL PESTICIDES* is envisioned as a comprehensive series of state-of-the-art volumes covering all aspects of plant use as crop protectants from attack by insects, diseases, fungi, nematodes, and predatory wildlife such as coyotes, wolves, and rodents. Coverage will not, however, be limited to protection of crops but will also include the use of plants to protect humans and farm animals from diseases transmitted through mollusks, fungi, and viruses. Each volume in this series will contain detailed compilations contributed by known authorities in the particular field. The high quality of the information contained in these volumes will be assured with the aid of an Advisory Board composed of worldwide authorities in the phytochemical pesticide field.

M. Jacobson
Editor-in-Chief

PREFACE
Volume I: The Neem Tree

Approximately one third of the world food crop is damaged or destroyed by insect pests during growth, harvest, and storage. Losses are considerably higher in many underdeveloped countries of Asia and Africa. The monetary loss due to feeding by larvae and adults of pest insects amounts to billions of dollars each year. Furthermore, the comfort and well being of humans and beneficial animals are affected directly by household and environmental pests such as lice, ants, roaches, ticks, wasps, and mosquitoes, some of which are disease carriers and transmitters. Many of the synthetic pesticides previously used for insect control have been banned or their use seriously curtailed because of concern about health and environmental effects. Also, the adaptability of insects threatens to undermine the effectiveness of existing pesticides. It is therefore imperative that safe, biodegradable substitutes for the synthetic pesticides be discovered.

Over the years, a wealth of literature has accumulated in scientific journals, books, and other reports on the effectiveness of plants as insect feeding deterrents, repellents, toxicants, and disruptants of insect growth and development. Heading the list of effective plants, from the standpoints of number of pest species affected, high activity, availability, safety, and resistance to predators, is the subtropical neem tree, *Azadirachta indica* A. Juss, a hardy member of the plant family Meliaceae. It is therefore fitting that the first volume in the series *Focus On Phytochemical Pesticides* should be devoted exclusively to this "wonder tree".

Based on the wealth of scientific records, both oral and printed, on the effectiveness of all parts of this tree against countless species of insects, nematodes, bacteria, and viruses, the First International Neem Conference was held June 16—18, 1980, at Rottach-Egern, West Germany, with more than 40 scientists (chemists, entomologists, botanists, physiologists, and zoologists) from 4 continents in attendance. At this Conference, an informal steering committee was appointed that quickly became known as the "Neem Mafia", consisting of Professors K. R. S. Ascher (Volcani Center, Bet Dagan, Israel), E. D. Morgan (University of Keele, U. K.), H. Rembold (Max-Planck-Institute of Biochemistry, Munich, West Germany), R. C. Saxena (International Rice Research Institute, Manila, Philippines), H. Schmutterer (Justus Liebig University, Giessen, West Germany), L. M. Schoonhoven (Agricultural University, Wageningen, The Netherlands), and me. This Conference was so successful in stimulating worldwide interest and activity in the efficacy of the neem tree that it was followed by the Second International Neem Conference, held May 25—28, 1983, in Rauischholzhausen, West Germany (105 participants), and the Third International Neem Conference, held July 10—17, 1986, in Nairobi, Kenya (64 participants).

We express our heartfelt thanks to the Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, West Germany, for sponsoring and providing generous funding of all three Conferences, making possible the attendance and participation of numerous scientists from Asia and Africa, where the neem tree is naturally endemic and widely used as a pesticide. We are also grateful to Drs. B. S. Parmar and R. P. Singh, Indian Agricultural Research Institute (IARI), New Delhi, India, for their continuing efforts to keep neem scientists worldwide informed of progress through quarterly publication and distribution of the *Neem Newsletter,* which began in 1984.

Cooperative research between botanists, chemists, and entomologists has very recently resulted in the commercialization of neem formulations as insect control agents in Asia, Europe, and the U. S., as well as the successful cultivation of the tree in many areas where it had not previously existed.

M. Jacobson

THE EDITOR

Martin Jacobson received his B.S. degree in chemistry from the City University of New York in 1940. He then accepted an offer as a chemist with the Industrial Hygiene Division of the National Institutes of Health in Bethesda, MD. In 1942, he transferred to the Bureau of Entomology and Plant Quarantine of the U.S. Department of Agriculture (USDA) Agricultural Research Center, Beltsville, MD, as a research chemist to isolate, identify, and synthesize phytochemical pesticides, insect hormones, and insect sex pheromones. During this period he pursued evening graduate studies in chemistry and microbiology at George Washington University, Washington, D.C. He also served as a part-time Research Associate in Chemistry at that University during the period 1944 to 1948.

From 1964 to 1972, Mr. Jacobson was an Investigations Leader with the Entomology Research Division at Beltsville, Chief of the Biologically Active Natural Products Laboratory from 1973 to 1985, and Research Leader (Plant Investigations) with the Insect Chemical Ecology Laboratory until his retirement from Federal Service in 1986. He is currently an agricultural consultant in private practice in Silver Spring, MD.

During his long career with the USDA, Mr. Jacobson spent several weeks in 1971 as a Visiting Scientist teaching a graduate course on insect pheromones and hormones in the Department of Chemistry, University of Idaho, Moscow. He was invited to organize numerous symposia and speak at national and international scientific meetings in the U.S., Europe, Asia, and Africa, in the field of pesticides and sex pheromones occurring naturally in plants and insects, respectively. His awards include the Hillebrand Prize of the Chemical Society of Washington in 1971; USDA Certificates of Merit and cash awards for research in 1965, 1967, and 1968; the McGregory Lecture Award in Chemistry at Colgate University (Syracuse, NY); two bronze medals for excellence in research at the 3rd International Congress of Pesticide Chemistry, Helsinki, Finland in 1974; USDA Director's Award on Natural Products research in 1981; and an Inventor's Incentive Award for commercialization of a boll weevil deterrent in 1983.

Mr. Jacobson has been a member of the American Chemical Society, Chemical Society of Washington, Pesticide Science Society of Washington, American Association for the Advancement of Science, New York Academy of Sciences, and a Fellow of the Washington Academy of Sciences. He is the author or coauthor of more than 300 scientific reports in numerous journals, the author of four books (*Insect Sex Attractants,* John Wiley & Sons, 1965; *Insect Sex Pheromones,* Academic Press, 1972; Insecticides From Plants. A Review of the Literature, 1941—1953, USDA Handbook 154, 1958; Insecticides From Plants. A Review of the Literature, 1954—1971, USDA Handbook 461, 1975), and editor of the book *Naturally Occurring Insecticides,* Marcel Dekker, 1971. He also holds six U.S. Patents on naturally occurring insecticides.

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1 Cultivation and Propagation of the Neem Tree

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I. DISTRIBUTION

Neem is thought to have originated in Burma and is common throughout the open scrub forest in the dry zone and on the Siwalik hills; and if it is native to India, it occurs naturally only in Karnatak and in parts of the Deccan Peninsula.[1] In its native environments, neem is generally found growing in mixed forests, and associated with other broadleaf species, such as *Acacia* sp. and *Dalbergia sissoo.* It grows in tropical to subtropical regions; semiarid to wet tropical regions; and from sea level to over 610 m (2000 ft). It is cultivated throughout India, and in many places has become wild. (The fruit is not toxic to birds and bats and it is reported that they are mainly responsible for the spread of wild neem.) It is now found in many places outside its native distribution to the sub-Himalayan track, including the northern part of Uttar Pradesh at 610 m (2000 ft) and the southern part of Kashmir at 670 m (2200 ft).[2]

However, according to Ahmed and Grainge,[3] neem is native to the Indo-Pakistan subcontinent, while others attribute its nativity to the dry forest areas of India, Pakistan, Sri Lanka, Malaysia, Indonesia, Thailand, and Burma.[4] Nevertheless, neem is found throughout Pakistan, Sri Lanka, southern Malaysia, Indonesia, Thailand, and the northern plains of Yemen and has been recently introduced into Saudi Arabia. The Philippines has also begun widescale plantings of neem for fuelwood and pesticide production. It is known that 19th century immigrants carried the tree from the Indo-Pakistan region to Fiji, and it has now spread to other islands in the South Pacific.

East Indian immigrants introduced neem to Mauritius, and it is thought that they took it to a number of African countries. It is now widely cultivated on the African continent in Ethiopia, Somalia, Kenya, Tanzania, Mozambique, Mauritania, Togo, Ivory Coast, Cameroon, Nigeria, Guinea, Ghana, Gambia, Sudan, Benin, Mali, Niger, Burkina Faso, Chad, and Senegal, particularly in rainfall-deficient regions.

Neem was also introduced into several Caribbean nations by East Indian immigrants, and is now propagated by Indian communities as a medicinal plant in Trinidad and Tobago, Jamaica, Suriname, Guyana, and Barbados.[5] Neem plantings are also abundant in Guatemala, Bolivia, Ecuador, Honduras, Argentina, Brazil, Cuba, Nicaragua, Dominican Republic, St. Lucia, and Antigua and large numbers are now being planted in Haiti. In addition to the ongoing experimental cultivation of neem in Puerto Rico and the U.S. Virgin Islands, plantings in southern Florida are thriving, and the field cultivation of neem in Oklahoma, southern California, and Arizona has begun.[3,6-9]

II. ADAPTATION

Neem grows well from sea level to over 670 m (2000 ft), and can be established in hot and dry regions without irrigation. Neem thrives under subhumid to semi-arid conditions and can be established in areas with an annual rainfall of 450 to 750 mm (18 to 30 in.). Optimum growth is obtained in higher rainfall areas (1150 mm); 130 mm/year is sufficient for survival,[4] but it needs 450 mm to grow successfully. It grows where maximum shade temperature may be as high as 49°C (120°F), but it does not stand excessive cold. Neem is frost-tender, especially in the seedling and sapling stages, but it is grown in frost zones of the sub-Himalayan tract by protecting seedlings during the winter with screens.[7] Fire often kills it outright.[2,8,9] According to Gorse,[10] neem is not a very sociable tree, does not grow well in pure stands (plantations in Africa often die out in 3 to 10 years), and is very competitive for water and soil nutrients; thus it does not grow well on marginal soils.

Neem seems to grow best in deep sandy soils that are well drained, but can grow in practically all sorts of soil; it thrives on black cotton soil in India and does not do badly even on clay. It does better than most species in dry localities, on sandy, stony shallow soils with a waterless subsoil or in places where there is a hard calcareous or claypan (hardpan) not far from the surface. However, neem will grow much better if this hardpan is broken up before planting. Occasionally, neem will initially grow well on soils that appear to be sandy, but quickly die out when roots hit a deep layer of dense clay. Neem can grow even on saline and on alkaline "usar" soils:[11] however, neem has been reported to be susceptible to moderate salinity in the Sudan.[12] Thus within the species, some provenances must be more genetically tolerant to salinity than others. Fishwick[13] observes that the best neem growth is found on sites with a soil pH of between 6.2 and 7+.

Neem does not tolerate waterlogged soils, and does not do well on soils with impeded drainage and on soils subject to inundation. Growth is not good on poorly drained soils, because the taproot tends to rot and the trees gradually die. In Nigeria, De Jussieu[14] reported that the best neem groves grew where the water table was 1.5 to 1.75 m down; at 2.5 m, the groves were only mediocre; and at 8 m, the groves died out. In his report, the method of planting the neem trees was not given, and in many places in Africa it was commonplace to establish plantings by stump cuttings, whereby the taproot was pruned. When this is done, a normal length taproot will not regenerate, and the tree develops extensive lateral root systems with only pseudo-taproots developing that do not penetrate deep into the subsoil. In some soils, the water table markedly rises during the rainy season, and if this rise persists, the roots of neem trees may smother.

Neem does not grow well in soils with high proportions of very fine sand or silt or finely divided mica; the yellowing of leaves is often followed by death.[8] This may be a result of nutrient deficiency. Research by Zech[15] determined that zinc and potassium deficiencies reduce neem growth evidenced by chlorosis of leaf tips and leaf margins, particularly on the older leaves: the first symptom of zinc deficiency is yellow coloration of the intercostal areas leading to complete breakdown of the chlorophyll. The shoots exude much resin with shedding of the older leaves. With potassium deficiency, leaf tip and marginal chlorosis and necrosis result.

In Nigeria, where systematic tests have been conducted, it was observed that very successful neem groves could be found in soils having a high clay content (67%), while trees died out on soils with a high sand content (83%).[14]

Neem has been planted on plantation scale in Nigeria since 1936. Most of the forests in the Sokoto region are of this species. The introduction of neem to Sokoto was cited as the greatest boon of the century. The tree grew quickly and met the local demand for firewood and poles for house construction and fence posts, in addition to providing welcome shade in towns and villages.[16] Gorse[10] states that neem is often the preferred species for planting in semiarid areas because animals do not readily browse it, and when they do, mortality is low and neem recovers rapidly. However, Welle[17] reports severe stunting of neem girdled from bark feeding by goats.

III. SILVICULTURAL AND PLANTATION CHARACTERISTICS

In India, neem is generally found in mixed forests. So far, little is known about the behavior of neem in plant communities and its ecological potential and limitations. Individual neem trees are reported to live for 200 years.[2] It seems to do much better on an isolated basis than in full groves, and grows beautifully along roadsides, or as isolated shade trees. It also does well in mixed species plantings and in relatively well-spaced rows (approximately 3 m apart) along contour line ditches.[14] Michel-Kim and

Brandt[18] report that experience in India and Africa indicates that neem may not be suited for monoculture. This contention is supported by Gorse[10] who states that neem is not a sociable tree and plantations often die after 3 to 10 years, especially on poorer sites. He contends that neem must be pruned or it will die back, which can be avoided by pollarding the tree. However, many report neem growing well in monoculture in plantations.[9,13,19,20] One explanation for this variance is that neem is very demanding on both water and mineral nutrients, and on soils where nutrients are limited neem will not do well in monocultural plantations.

Neem grows better with shade in its early stage of growth, but demands light as it matures. Therefore, it has a great capacity for pushing its way through thorny scrub in its youth. Welle[17] reports neem growing exceedingly well in plantations in Haiti where *Leucaena leucocephala* is interplanted as a nurse crop, with trees having a better form (the elephant-foot stump type growth with a large taper is reduced). Radwanski and Wickens[8] report that transplants are likely to be seriously injured by developing leaf spot (clorosis) as a result of insolation (grown in full sunlight), thus neem does best in its earlier years when planted with a nurse crop. However once mature, neem does best in full sunlight, and does not do well as an understory.

IV. GROWTH

Neem is reported to grow relatively fast, but varies greatly depending upon its environment, site characteristics, and the genetic capability of the plant material. Slower growth results at higher elevations, at colder temperatures, and on drier sites. Radwanski[7] reports that 66% of the total growth of the tree will occur in the first 3 years, during which it will reach a height of 4 to 7 m; it will reach 5 to 11 m in the following 5 years. Seedlings show moderate development, ordinarily reaching a height of 10 to 20 cm (4 to 8 in.) by the end of the first year. As a rule, trees put on a mean-annual girth increment of 2 to 3 cm (0.9 to 1.2 in.), though more rapid growth is obtained under more favorable conditions. De Jussieu[14] reports that in irrigated groves in India, 16-year-old neem trees reached diameters over 40 cm, but trees grown in this way break more easily and are subject to wind damage. Under mediocre conditions, the average diameter of trees in a 44-year-old grove was 25.5 cm and average height was 10.5 m. In Africa, it is generally assessed that at 1 year in good soil, a grove reaches a height of about 1.5 m, at 2 years a height of 2 m, and during the fourth year trees reach a diameter of 7 to 8 cm and a height of about 4.5 m.

Fishwick[13] notes that on poor sites, there was evidence that neem stagnated after the first 5 to 6 years, and for this reason rotations were reduced to 7 years, which appeared to be more profitable. Furthermore, it appears that the critical time in the development of the trees in the plantation occurs when crowns begin to touch: the third or fourth year with a spacing of 8 ft (2.44 m) $\times$ 8 ft, and fifth and sixth year at a spacing of 15 ft (4.57 m) $\times$ 15 ft; thus on poor sites the wider spaced trees would cost less to plant, would be larger, and would have a greater economic value. (Comparing two plantations on poor sites, the value of the trees at the wider spacing was four times greater.)

Because weeds compete for moisture and nutrients, early growth of seedlings is much retarded, and regular weeding and cultivation stimulates neem growth and vigor. Research carried out in Dehra Dun, India, has shown that seedlings that were weeded reached a height of 0.6 to 1.4 m (2 to 4.5 ft) by the end of the second season, but only 0.5 to 1 m (1.66 to 3.25 ft) if not weeded. Later, the seedlings that were not weeded were killed by weed suppression and frost.[1]

V. YIELD

According to Michel-Kim and Brandt,[18] the yield of neem varies between 10 and 100 tons of biomass (dried material) ha/year, depending upon rainfall, site conditions, and spacing, and 40 tons [12.5 m^3 solid wood/ha/year (based on 1 m^3 = 800 kg)] can be achieved easily under the proper conditions. About 50% of the biomass is contained in the leaves, about 25% in the fruit, and 25% in the wood.

Gravsholt et al.[9] reports that the first rotation yield in Ghana was 30 to 38 cords of fuelwood per hectare (approximately 13.5 to 17 m^3/ha/year solid wood); and in Samaru in northern Nigeria, 7.5 to 67 cords (approximately 2.4 to 21 m^3/ha/year). Commonly in West Africa, plantations are cropped on an 8-year rotation, with a spacing between trees of 8 × 8 ft (2.4 m × 2.4 m).

Fishwick[13] reports that on more suitable sites in Bornu Province in Nigeria, the yield was 15 to 27 cords/ha/year (13.5 to 24.3 m^3 solid wood) on a 7-year rotation. The plantation spacing was 8 ft (2.43 m) × 8 ft, and site conditions included soils comprising drift sands with a pH ranging from 5.0 to 7.5 and a mean annual rainfall varying from 380 to 762 mm (15 to 30 in.). An average annual yield for all plantations was 7 to 15 cords/ha (6.3 to 13.5 m^3). In Nigeria, neem poles are in great demand for house construction and fence posts because they are semiresistant to termites; poles thus realize a greater price than fuelwood.

McComb[19] reports plantation yields in Samaru, Zaria, Nigeria, of 300 to 2250 ft^3/acre for the first 8-year rotation crop (2.55 to 19.67 m^3/ha/year solid wood); and 350 to 2250 ft^3 (3 to 19.67 m^3/ha/year) for the 8-year coppice crops on the same plantations. (The lower yields were for class IV sites, while the higher ones were for class I sites, and the spacing between trees was 2.4 × 2.4 m.) Interestingly, the first 8-year rotation crop on class I plantation sites showed an average incremental growth rate of 350 ft^3/year (after the second year), while the coppice crop averaged only 250 ft^3/year. There were no significant growth rate nor yield differences on the class IV sites, and on the class I sites the volume of the coppice growth by the third year was almost equal to the growth by the fifth year of the first 8-year rotation crop.

Radwanski[21] gives the yields of the Majiya plantation near Sokoto, Nigeria, as 520 ft^3/acre of fuelwood after 7 years (5.2 m^3/ha/year) and after coppicing, 820 ft^3 solid volume of fuelwood and 290 ft^3 solid volume of timber per acre (total yield of 8.6 m^3/ha/year). The plantation was planted in 1945 with "open-root" neem seedlings (assumed to mean bare-root), spaced 6 × 6 ft (approximately 1.8 × 1.8 m). The average annual rainfall in this region was 31 in. (787 mm) with a maximum of 47 in. (1194 mm) to a minimum of 20 in. (508 mm).

Welle[17] reports that trees grown in plantations in Haiti at 4 years of age averaged a yield of 1 pole plus and 0.09 m^3 of fuelwood, but the volume of the pole was not given. Radwanski[22] gives a volume of 1.05 m^3 for neem poles in one plantation in Nigeria, while McComb[19] reports a pole volume ranging from 37 to 85% of the total wood produced.

VI. COPPICE GROWTH

Early growth is faster from coppice than from seedlings, reaching a height of 8.5 m (28 ft) in 3 years after cutting. However, in Nigeria, the height of 8-year-old coppice was reported to have only equaled that of 8-year-old trees started from seedlings. In plantations there, trees reached a height of 7 m (23 ft) in 3 years and 12 m (40 ft) in 8 years. Approximately 66% of height is achieved in the first 3 years after planting.[23] Fishwick[13] reports that plantations in Nigeria were cut to a stump height of 8 cm (3 in.), and coppice from such low stumps is less likely to suffer from wind damage than from higher stumps. Higher stumps also have a higher incidence of dying off. Grose[10] observed that by cutting at a stump height of 1 to 2 m, the number of poles produced by coppice will increase. Radwanski[7] recommends a coppice management system every 3 years for maximum biomass yield based on the observation that 66% of the growth of the tree occurs in the first 3 years. However, this merits further research, since much faster growth of coppice occurs once the root system is established, and a much shorter rotation may give a maximum yield.

VII. INTERCROPPING

Radwanski and Wickens[8] report, "Neem cannot be grown among agricultural crops since it will not tolerate the presence of any other species in its immediate vicinity, and if not controlled, may become aggressive by invading neighboring crops." Troup[1] reported that seedlings that were not weeded were suppressed and eventually killed because of weeds (and frost). But Makay[24] reported that even though neem seedlings had been hidden from August and September under a 10-ft (3-m) high crop of millet, neem did surprisingly well. The seedlings were still healthy, did not appear to have been retarded after the millet was harvested in October, and a healthy stand of neem was left behind. Others state that neem can be planted in combination with fruit cultures and crops for feeding cattle (e.g., *Pennisetum pedicellatum,* as suggested by Misra).[25] Also, recommendations have been made for combinations of neem with sesame, cotton, and hemp;[26] with peanuts, beans, sorghum;[7,27,28] with *Acacia arabica* (synonym *A. nilotica*) and cotton;[1] and with *Khaya senegalensis.*[29]

In Nigeria, a form of taungya was used for neem plantation establishment and farmers cultivated groundnuts, beans, and millet between the trees, but the forest department planted the trees. These plantations were superior in survival and quality to plantations established by other means, and the cost was much lower. In areas where neem plantations were cleared, groundnuts were cultivated and yielded three times the average for other fields.[13]

It is known that the compounds found in neem are not only effective against insect pests, and beneficial in the efficient use of nitrogen, but they also affect some fungi and bacteria. Thus, the tree may have a significant influence on the balance within the microfauna, fungi, and bacteria communities. Because plants depend upon a certain microfauna and a special complex of bacteria and fungi, it is possible that where neem changes the composition significantly, problems may arise. The effect of neem may be both positive and negative, and research is needed to prove or disprove these factors.[18]

Perhaps neem is allelopathic to some crops. There are many conflicting statements as to its compatibility for intercropping with food crops; some agree that it has poor agroforestry potential because of its interference with other crops or vice versa. There is no clear explanation made as to the intolerances, either of neem to other crops or vice versa. Or the reason may be that since neem fruits produce a systemic, somewhat repugnant chemical, food crops may take up this chemical from fruits falling on the ground once the tree begins bearing fruit (usually at 5 years). Food crops might then have a bitter taste; hence the reference that neem is not a good species for agroforestry. Research is surely needed to prove or disprove the incompatability of neem as an intercrop and agroforestry species.

The answer may be to plant neem in mixed forests in combination with pasture. Michel-Kim and Brandt[18] suggest that up to 20% of the area could be planted to neem, and village plantings could constitute up to 15%. Neem would also be a good species for use in a sequential agroforestry system as illustrated in the Radwanski and Wickens paper.[8] Another excellent use of neem in agroforestry systems is for windbreaks. In the Majjia Valley in Niger, over 500 km of windbreaks (a form of agroforestry) comprising double rows of neem trees have been planted to protect millet crops and to supply wood to local villagers. This has resulted in a 20% grain yield increase for local farmers and the windbreaks are lopped and provide needed fuel and construction wood to villagers.[30,31]

Perhaps one of the best agroforestry potentials of neem is growing it for its various useful products where it is not intercropped with food crops, and the products (leaves, neem cake, etc.) are processed or used in a cut-and-carry system and applied to food crops as a fertilizer and pesticide.

VIII. NEEM SEEDS AND PROPAGATION

Neem begins to bear fruit in 3 to 5 years.[32] The period of collection of neem fruits naturally varies from place to place, depending upon the regional climatic conditions. In India, collection may begin as early as May and extend through September; however, there seems to be two distinct fruiting periods, May — June and August — September. The fruits are collected from the trees when fully ripe or are gathered from beneath trees.

A. YIELD

Neem produces fruits in 3 to 5 years and becomes fully productive in 10. Ketkar[2] gives a yield of about 50 kg (110 lb)/tree/year; Ahmed and Grainge[3] 30 to 50 kg (66.6 to 110 lb); and Radwanski[33] lists 11.4 to 34 kg (25 to 75 lb), averaging about 20.5 kg (45 lb). About 2000 to 3000 fruits weigh 1 kg, the depulped fruit yields about 1800 seeds/kg,[14] and 9 to 10 dry seeds weigh 1 g.[34] The ratio of seed to pulp is approximately 1:2, and fruit pulp and kernels account for 47.5 and 10.1%, respectively, of fruit weight.[35] For reproduction seed preparation, the fruits are rubbed and washed to remove the flesh from around the seeds. After washing, the seeds are dried in the shade and preferably stored in dry, airtight containers.

B. VIABILITY

Usually, neem seeds remain viable for only a few weeks, about 1 to 2 months, and normally they are collected when thoroughly ripe and sown as soon as possible. But when mature seeds are depulped and adequately dried and cooled, they can be stored for longer periods. Reportedly, germination rates rapidly decline during storage. However, Brouard[36] cites work by Dr. Paul B. Tompsell at the Royal Botanical Gardens in Great Britain, who froze seeds after drawing the seed moisture content to below 8% and they remained viable up to 2 years. To obtain a high germination percentage, seeds must be collected when they are fresh, cleaned thoroughly, and handled carefully (to avoid cracking).

C. GERMINATION

Seeds germinate in about 2 weeks after sowing. Fresh neem seed germinates quite readily and scarification is generally not needed. Research at the Royal Botanic Gardens in Great Britain indicates that germination is improved if the inner shell is removed to expose the embryo before planting,[8] and Smith[37] reports the same. However, Singh[34] recommends that the seeds be cut across with a sharp blade and the cotyledons examined: if the cotyledons are green the seeds are sound, but if they have turned yellow or brown, they will not germinate.

In more efficient containerized nurseries, it is desirable to produce a sprouted seed in every container because less space is required and it reduces per-seedling labor costs. Experiments were conducted by Operation Double Harvest in Haiti in an attempt to pregerminate neem seeds for transfer to container; however, the research showed that 47% of pregerminated seed had a major taproot deformity (crooked or looped), while the roots of only 7% of dry sown seed were deformed.[38]

Fagoonee[39] found that germination is best when seeds that have fallen from trees during the preceding week are soaked in water for about 3 d, depulped and cleaned, then sown directly into the nursery in damp soil. The soaking breaks the dormancy by neutralizing the germination-inhibiting chemicals found in the shell of the seed.

However, Ezumah[40] concludes that neem seeds do not require a period of after-ripening. Seed origin, year, and time of producton have no significant effect on germination and longevity. Sun-drying does not adversely affect viability and appears preferable to air-drying to bring seed moisture content to 10% or less before storage. The method of seed cleaning also has no significant effect on germination and longevity; thus, decomposing the pulp before washing by keeping the fruits in a heap is easier than peeling the pulp from fresh fruits. Cold storage adversely affects the viability of neem seed; seeds stored at room temperature (20 to 28°C) retained some viability for 16 weeks, while viability lasted for only 12 weeks at cold storage (6 to 7°C).

IX. PROPAGATION TECHNIQUES

Most commonly, neem seedlings are propagated in the nursery and transplanted to the field, although direct sowing has been successful in some areas if rainfall is adequate.[1,17]

Although neem needs light, young seedlings can suffer from strong solar radiation; thus a light shade is desirable during the first season of growth. Sudden exposure of seedlings without first hardening off will result in a high rate of mortality. Seedlings naturally regenerated under old stands often die when the trees are cut and the canopy is opened.[13]

A. NURSERY CARE

In the nursery, seedlings are either grown in containers (plastic bags or root-trainers) or in seedbeds. Germination starts in about 8 d and continues to about 3 weeks.

1. Bags and Other Containers

Seeds are sown directly into the container filled with potting soil and are ready for transplanting in 12 weeks.[41] In Haiti, seedlings are grown in containerized nurseries and transplanted in 3 to 5 months, depending upon the rainfall pattern.[17]

2. Seedbeds

If the nursery is irrigated, seeds can be harvested early, in April, and planted in the nursery. The seed should be lightly covered with earth and sparingly watered, the soil kept loose to prevent caking. Singh[34] recommends a spacing of 5 cm in-row and 20 cm inter-row, planting the seed at a depth of no less than 1 cm to minimize rodent damage. Fishwick[13] states that seeds should be sown thickly in lines 30 cm apart, selectively thinned when the seedlings are about 8 cm high (3 in.) to a spacing of 8 cm, and selectively thinned again in 4 to 5 months with only the best stock remaining at a spacing of about 23 cm (9 in.).

3. Seedlings

Recommendations when seedlings are ready and what the height is at the time of transplant vary. If seeds are planted early in April, seedlings should be ready for transplanting by July (4 months), reaching a height of 15 to 20 cm. De Jussieu[14] and Troup[1] report that neem fruits from April to July, and seeds are planted in seedbeds in a partially shaded nursery as soon as possible after harvest, around the middle of July when the rains begin, and are ready for transplant by the next rainy season, after reaching a height of about 0.80 to 1 m. Radwanski[7] and TAREC[41] indicate that seedlings are ready for transplant in about 12 weeks when they are 7.5 to 10 cm high (3 to 4 in.), with a taproot approximately 15 cm long (6 in.). Mitra[42] recommends transplanting when seedlings reach 7.5 to 10 cm. (3 to 4 in.) high. According to Singh,[34] seedlings transplanted younger than 1 year have a poor survival rate; this does not hold true according to experience in Haiti, where the survival rate of 3 to 5-month container-grown neem transplants is 85%.[17]

4. Root Balls

Seedlings that have not been planted during the first year are kept until the following season and sometimes until they are 2 years old. Year-old seedlings are carefully uprooted from the nursery leaving a ball of soil around the roots, and transplanted as soon as possible. Planting is done in July — August in pits dug in April — May, which allows weathering of the soil, and if rain immediately follows, good survival rate is ensured. In dry areas, about 90% of the leaves are removed, reducing evapotranspiration, and decreasing transplant shock. The areas in the vincinity of the trees must be kept weed-free.[34]

5. Stumps

In India, stumps are usually prepared from 2-year-old seedlings, although in irrigated nurseries, year-old seedlings may attain the desired size for stump preparation. The seedlings should be uprooted with care to avoid splitting or breaking the taproot. Stumps are prepared with 22-cm roots and 5-cm shoot portions and wrapped (bare-rooted) in moist gunney sacks and kept in the shade until transplanted. Just before planting in 30 cm^3 pits, desiccated root and shoot tips are pruned.[34] In Nigeria, Fishwick[13] found that seedlings cut to a stump height of 0.3 m (1 ft) were better than taller ones because they were easier to handle and provided sufficient buds for sprouting, and were not damaged by wind, which whipped taller ones, loosened the soil, and exposed the roots. Roots were trimmed to 30 cm (12 in.), with most of the new growth produced by the callus that forms at the point where the roots are trimmed. Survival was increased when the seedlings were cut in the seed bed rather than at the time of lifting because shock was reduced by not cutting, lifting, and transplanting at the same time, and a callus tissue would form on the shoot wound before lifting. In Africa, Gorse[10] cut canes to a height of 1.5 m and removed all leaves before transplant, and in this way the bark is already hardened and not as susceptible to damage by animals.

6. Disadvantages

There are distinct disadvantages to planting overage seedlings. First, it is very costly to keep and care for seedlings for 1 to 2 years. The added weight of seedlings with a soil root ball drastically increases transportation costs and reduces the number of seedlings that can be delivered to the planting site, especially if they are hand carried. Another problem: when seedlings are transplanted bare-rooted, they suffer severe transplant shock, roots dry out, root hairs and beneficial mycorrhizae die. Survival rate is decreased, and growth rate is retarded.

B. TISSUE CULTURE

The use of tissue culture and cuttings to produce neem for reforestation has been deemed unrealistic in most cases because of the high cost of a production facility, and the relative ease of producing seedlings.[43] Also, it is questionable whether tissue-cultured plantlets and cuttings will develop full taproots. However, it could be economically justified to screen and reproduce plants of unique germplasm (such as a tree with an unusually high azadirachtin content) in this manner for seed orchard establishment in more moist areas, which would not be affected by limited taproot development.

Neem has been successfully tissue-cultured from leaflet callus tissue and from stem tissue by growing it in modified Murashige and Skoog media, producing roots in 40% of the cultures and developing into complete plantlets in a supplemented medium.[44-46] In further tissue culture research, Schultz[47] was not able to achieve root initiation as reported by Sanyal et al.,[44] which supported research by Rangaswamy and Promila[48] describing the differentiation of "growth centres" in *Azadirachta* callus and the eventual shoot bud formation with rarely any rooting. Again, it is questionable whether a normal length taproot will develop from tissue-cultured plantlets, which would exclude their planting in water-stressed areas.

C. CUTTINGS

Neem can also be propagated by cuttings, which require a production period of 6 months to 1 year,[41] but again the development of a normal taproot would be doubtful. Air-layered branches treated with IBA or NAA in lanolin paste at 0.1% develop roots satisfactorily.[49] In Nigeria, Fishwick[13] records that in Maiduguri a number of neem shoot cuttings were treated with a rooting hormone (Seradex B) and then placed in pots. A number took, but did not survive after being transplanted. In Sokoto, the work was repeated, but cuttings were covered with polythene bags, and a number survived after being transplanted. It was found that a significantly higher proportion of the cuttings took root when they were taken and prepared at the start of the rainy season.

D. DIRECT SEEDING

In the literature, the term "direct seeding" (sowing) is used in two ways — direct seeding in the nursery and direct seeding in the field. In India and Nigeria, direct sowing is reported to have proven more successful for reforestation than transplanting; however, this is when areas to be sown are well prepared (similar to land preparation for sowing food crops). Direct seeding on hard and inhospitable soils has not been very successful, but establishment and growth can be greatly enhanced when seeds are sown in bore holes that have been dug in these hard soils and filled with a fertile potting mix. Research has shown that hole size on difficult sites can significantly enhance establishment and growth of transplanted seedings. Although drilling bore holes with a post-hole auger and filling them with a potting mix may to some seem expensive, the cost is comparable to nursery raising and transplanting seedlings.

When direct-seeded, neem establishes an extensive root system before aerial growth becomes rapid.[4] Site preparation and transplanting are the two biggest costs of reforestation, and direct seeding can markedly reduce transplanting costs. De Jussieu[14] reports that aerial seeding has been tried but yielded poor results, since the chances of survival for the seeds is much lower than direct seeding on prepared land. Gorse[10] recommends the use of a groundnut planter and weeder for direct seeding and weeding, and covering the seed beds with a 10 to 15-cm mulch of groundnut hulls.

Welle[17] reports that direct seeding has proven to be a viable method of establishment in Haiti. Seedlings raised in nursery beds are ready for tranplanting during the first rains when they are 7.5 to 10 cm (3 to 4 in.) high. Sometimes seedlings are retained in nursery beds and transplanted during the second rainy season.[11]

Methods of direct seeding vary.[7,11,34] In India:

1. The soil is worked to a depth of about 15 cm and the seeds are sown at a depth of 1.5 cm. Sowing is done either in patches or lines; in the former they are spaced about 3 × 3 m, and spacing between lines is about 3 m, using 3 to 4 kg of seed per hectare. Weeding is necessary and seedlings are thinned at the end of the first season, leaving two seedlings per patch or two seedlings per meter length of the line.
2. Seed was sown at high and dry sites that had been plowed twice. No watering was done, but the seedlings were kept free of weeds. In less than 3 years, the plants were 7 to 8 ft high, the growth being equal to or better than that of transplants that had been carefully watered and tended. Trees in similar plantings at another site measured up to 12 ft in 3 years.
3. Direct seeding into mounds of earth 12 × 4 × 1.5 ft on sites receiving 24 in. (600 mm) of rain annually produced plants that reached a maximum height of 4.5 ft in 1 year.
4. Neem was sown in combination with the cultivation of sesame, cotton, and the lesser hemp in an area with an annual rainfall of less than 500 mm (20 in.). The sown lines were 0.3 m (1 ft) apart, three lines of field crops to one line of trees, so that the latter were 1.2 m (4 ft) apart. Sowing of both field crops and trees was done after site preparation by plowing and harrowing. The lines of trees were weeded twice during the first rains. The trees reached a height of 5 m (16 ft) and girth of 43 cm (17 in.) in 3 years.
5. Direct sowing into plowed furrows in black cotton-soil produced trees with a maximum height of 1.5 m (5 ft) after 1 year.
6. Success has been achieved by dibbling neem seed under Euphorbia bushes.

In Nigeria, Fishwick[13] reports successful direct seeding at the bases of the native cover, with a survival rate of about 40 trees/ha. It was observed that although the rate of growth is generally slower than on cultivated sites, it had merits of simplicity and cheapness to enrich degraded forest area.

In northern Nigeria, neem interplanted on farms among groundnuts, beans, and millet showed markedly superior growth. When the crop was harvested, a healthy stand of neem seedlings was left behind.[4]

E. SPACING

Neem seems to be very nutrient-demanding, and has been known to send out lateral surface roots reaching over 18 m.[50] In Nigeria, a spacing of 1.8 × 1.8 m is recommended,[14] and Gorse[10] recommends a much wider spacing on poorer sites.

F. ROOT FORMATION

Roots that have been pruned (as suggested in the stump planting method) may not regenerate into a long, normal taproot (rather they develop several shorter pseudo taproots, which are not as long as a normal one). Fishwick[13] found, by digging, that a 2-year-old tree planted from a stump possessed seven taproots, each with a 1.27-cm ($^1/_2$-in.) diameter at a depth of 12 ft (full depth of penetration was not recorded). The author does not know if neem, under normal circumstances from a seed with an undamaged root system, would develop only a single, deep taproot. Without a normal taproot, the plant would be limited in its ability to penetrate into low water tables and reach nutrients in lower soil horizons. During drought, when water tables drop considerably, the trees may die. Similar difficulties would be encountered when trees are established from cuttings, for they do not generate normal taproots. This might explain the die-off of the neem plantations (established by stump cuttings and from seedlings with the taproot pruned) in Maiduguri, Nigeria, reported by Fishwick[13] and elsewhere by others.[50]

G. SURVIVAL

The rate of seedling survival is influenced by a number of factors besides age of seedlings and methods of transplanting. Genetics play an important role, and seeds should be gathered from plus trees of the desired phenotype and ecotype. Also the size of the seed influences survival and early plant growth; larger seeds produce a much stronger seedling (maternal influence). Seedlings with a well developed root system (such as those promoted by "root trainers," and through fertilization, and those which have been inoculated with mycorrizae) can withstand drought much better and have the capacity for a more immediate and larger uptake of moisture and minerals, thus will have a higher survival rate.

H. NATURAL REPRODUCTION

Under natural conditions, the fruit (seed) ordinarily drops to the ground during the rainy season, and germination takes place in 1 to 2 weeks. Neem reproduces naturally with tolerable freedom, especially around trees growing in moist, sandy soils. Naturally regenerated seedlings have been used for reforestation, but they do not compare in vigor with good nursery stock. Their root systems are poorly developed, they are very sensitive to sunlight, and they lack buds.[13] In Haiti, a number of volunteer seedlings were dug up from under a tree; 22% were highly deformed, and only 39% could be rated as having well shaped taproots.[38] Neem establishes well under bushes and scrub,[1] though initial growth is usually slower.[4] Bats and birds are reported to spread neem by eating the fruit and depositing the seed elsewhere, and spontaneous individual trees and stands of neem trees are reported to have been established in this manner in several countries in Africa, India, and Haiti. Some feel that bats spread more seeds than birds, and larger numbers of volunteer seedlings can be found under trees where they roost.[10,14,51]

X. GERMPLASM

There is great variation in the germplasm of neem in terms of azadirachtin content, seed oil content, seed yield, form (clean, straight bole, branchy, etc.), fast-growth, tolerances to different environments, and resistance to diseases and pests. If neem is to be grown for pesticide production, it is necessary to develop trees that produce high yields of fruit with maximum azadirachtin content. Therefore, there is a great need to exploit the germplasm resources of neem in the area of its origin as well as in exotic regions, and to conduct research on its performance. There is also a need to broaden out the germplasm in exotic areas to avoid disease and pest infestations where it is widely planted. Since neem is native to the Burma-India area, all germplasm originates there.

There is a great variance in the azadirachtin content of the seed, which may depend upon a number of variables, and it is difficult to determine which one(s). The differences