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Agronomy and Physiology of Tropical Cover Crops

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ABSTRACT

Cover crops are important components of a sustainable crop production system. They can be planted with plantation crops such as cacao, coffee, banana, rubber, and oil palm or in rotation with cash crops. Their use in a cropping system is mainly beneficial for soil and water conservation, recycling of nutrients, control of pests and improved microbiological activities. However, beneficial effects depend on the selection of appropriate cover crops and their management. Hence, understanding their agronomy and physiology is fundamental for their use in sustainable cropping systems. Growth and development of a crop (physiological aspects) is determined genetically as well as influenced by environmental variables. This information can be useful in improving production of these crops and, consequently, their incorporation in farming systems, wherever it is possible. There are hundreds of tropical cover crops and, therefore, it is not possible to include all of them in one article. Hence, selected cereals and legumes are included.

Keywords: legume cover crops, cereal cover crops, soil and climatic requirements, plant morphology

INTRODUCTION

Agricultural productivity gains since the 1950s resulted from the development of farming systems that rely heavily on external inputs of energy and chemicals to replace management and on-farm resources (Oberle, 1994). However, in recent years, high chemical input costs and concerns about soil degradation and environmental pollution demanded adoption of alternative management

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practices to overcome these problems. The future sustainability of crop production will greatly depend upon improvements in the soil resource base through its effective management in an environmentally benign manner (Singh et al., 2004). Use of cover crops in farming systems is one of such management practices to improve soil health, reduce environmental pollution, and improve crop yields (Fageria et al., 2005).

Cover crops can be leguminous and non-leguminous. The use of legume cover crops in improving agricultural sustainability is well recognized (Fageria et al., 2005). Legume benefits to subsequent crops are attributed to the addition of nitrogen (N) and non-N rotation factors such as disease and weed control, and to improved soil water holding capacity (Fageria et al., 2005). Legumes may also be used to reduce carbon (C) and N losses from agricultural systems and increase soil C sequestration (Drinkwater et al., 1998).

The main functions or use of cover crops in a cropping system are as N supplier or source, soil builder, erosion controller, subsoil loosened, weed controller and pest fighter. Appropriate cover crop species should be identified that provide satisfactory biomass production to cover the soil surface area and bring other benefits to improve yield of succeeding cash crops or plantation crops. The C/N ratio of plant residues has frequently been used as a tool for predicting the rate of decomposition. Carbon/N ratios of 25 to 30 have been suggested as the threshold between net mineralization and immobilization of N (Ranells and Wagger, 1997). Generally, nonlegume cover crops have higher C/N ratio (>25). This means that legumes have advantages over nonlegume cover crops by minimizing the potential for short term N immobilization as well as biological N fixation (Odhaiambo and Bomke, 2001).

Man has selected and bred crops suited to a wide range of environments and can modify the conditions under which they are grown by cultural practices. The numbers of crops grown under tropical conditions are much larger than those grown in temperate climatic conditions (Purseglove, 1988). This is also true for cover crops. Source of information regarding the agronomy and physiology of tropical cover crops are scattered. Hence, the objective of this review is to compile this information in a single review article for principal tropical cover crops.

In this overview we have discussed agronomic and physiological issues related to major tropical cover crops. Extensive coverage of these issues can be found in Fageria (1992), Doggett (1988), Duke (1981), Hanum and Van der Maesen (1997), ICAR (2000), National Academy of Sciences (1979), Norman et al. (1995), and Purseglove (1974).

COVER CROP SPECIES

Legumes, cereals, grasses, and brassicas have been used as cover crops (Fageria et al., 2005). However, they should have some desirable characteristics for their beneficial effects for the succeeding cash or plantation crop and easy adoption in cropping systems. Principal desirable characteristics of a cover crop are: low

Table 1
Major tropical nonlegume and legume cover crop species

Common name	Scientific name
Pearl millet	*Pennisetum glaucum L. R. Br.*
Sorghum	*Sorghum bicolor* L. Moench
Cowpea	*Vigna unguiculata* L. Walp.
Pigeon Pea	*Cajanus cajan* L. Millspaugh
Mung bean	*Vigna radiate* L. Wilczek
Moth bean	*Vigna acontifolia* Jacq. Marechall
Guar	*Cyamopsis tetragonoloba* L. Taub.
Peanut	*Arachis hypogaea* L.
Tropical Kudzu	*Pueraria phaseoloides* (Roxb.) Benth.
Calopo	*Calopogonium mucunoides* Desv.
Hairy indigo	*Indigofera hirsuta* L.
Jackbean	*Canavalia ensiformis* L. DC
Lablab bean	*Lablab purpureus L. Sweet*
Sunnhemp	Crotalaria juncea *L*.
Velvet bean	*Mucuna pruriens* L. DC
Tepary bean	*Phaseolus acutifolius* A. Gray
Lima bean	*Phaseolus lunatus* L.
Butterfly pea	*Centrosema pubescens* Benth
Crotolaria	*Crotalaria pallida* Aiton
White tephrosia	*Tephrosia candida* (Roxb.) DC.
Vogel tephrosia	*Tephrosia vogelii* J. D. Hooker
Black gram	*Vigna mungo* L. Hepper
Egyptian clover	*Trifolium alexandrinum* L.
Brazilian stylo	*Stylosanthes guianensis* Aubl. Sw.
Adzuki bean	*Vigna angularis* Willd. Ohwi & Ohashi
Rice bean	*Vigna umbellate* Thunb. Ohwi & Ohashi
Sesbania	*Sesbania bispinosa* Jacq.W. F. Wight

cost of seeds, minimum management, requirement water use efficiency, a soil improving root system, short growing cycle with good dry matter yield, weed suppressive growth habit, quick growth, resistance to pest and not harbor or attract pests. It should also have high nitrogen fixing capacity and not release allelochemicals. Cover crop should also give the grower additional income as a forage or cash crop if used in plantation crops. Sometimes it is difficult to find all these desirable characteristics in a single cover crop, but when selecting, consideration should be given to a crop, which has maximum beneficial characteristics. It is widely reported in the literature that legume cover crops can reduce fertilizer N requirements), minimize soil erosion, maintain organic matter and improve soil structure, as well as reduce weed density and biomass (Fageria et al., 2005). Table 1 provides list of major nonleguminous and leguminous cover crops. In this list there are two cereals and the remaining are legumes. Their agronomy and physiology are discussed in the following section.

CEREALS

Corn, rice, sorghum, and pearl millet are the most important cereals grown in the tropics for human food and other cereals grown having only local importance. The temperate cereal wheat and barley are also grown to a limited extent in the tropics, largely at high altitudes (Norman et al., 1995). Cereals do not contribute directly to N addition in the cropping systems but help to improve soil physical, chemical, and biological properties as soil cover materials. Among cereals, pearl millet and sorghum are widely used as cover crops in the tropics due to their wide adaptability to abiotic stresses. Furthermore, these cereals belong to the C_4 plant group and produce large amount of residues in a short growth period. Hence, the agronomy and physiology of these two cereals have been discussed.

PEARL MILLET

Pearl millet (*Pennisetum americanum* L. R. Br.), also known as bulrush millet, cat-tail millet, spike millet, and bajra (India), is a robust annual bunchgrass (Fageria, 1992). It is primarily grown in Africa and the Indian sub continent for fodder and grain. In India, this crop is grown on over 12 million hectares, representing 30% of the acreage of the world and 11% of total cereal production in India (ICAR, 2000). There is no evidence exist regarding dates of its domestication, but pearl millet probably originated in western tropical Africa where the greatest numbers of cultivated and related wild forms occur. The crop was taken at an early date, probably at least 3000 years ago, to East Africa and from there to India (Purseglove, 1988). Peal millet was introduced to the United States in the 1850s (Rachie and Majmudar, 1980).

In the United States it is mainly grown as a forage crop but in the Southeast region of the USA, it is also grown for grain production as a result of recognition of the high feeding value of this cereal by the poultry industry. In Brazil it is mainly grown as a cover crop starting before the end of the rainy season to protect soil from erosion and to improve soil physical, chemical, and biological properties. Pearl millet is a tropical C_4 cereal.

Climatic and Soil Requirements

Pearl millet is a tropical cereal and considered one of the most drought-resistant crops and is extensively grown in the arid and semi-arid regions of the world (Fageria, 1992). Planting pearl millet in cold soils can result in poor stand establishment, but Smith et al. (1989) found that it germinates better than grain sorghum under low temperature and drought. Ong and monteith,

(1985) reported that planting pearl millet at soil temperatures above 18°C is recommended, even though the minimum temperature for growth is 10 to 12°C. Garcia-Huidobro et al. (1982) reported that the base temperature for germination is around 12°C, the optimum 33 to 35°C and the maximum for germination 48°C. Pearson and Hall (1984) reported that, although germination may occur at mean daily temperatures as low as 12°C, seedling establishment is not successful where the mean monthly minimum is below 15°C. High photosynthetic ratio and a relatively high temperature optimum for growth and development characterize pearl millet.

Pearl millet is grown largely in the African Sahel and India with a 200–800 mm average annual rainfall, and it particularly dominates cropping systems within 400–600 mm average annual rainfall region (Pearson and Hall, 1984). Crop water use by pearl millet has been studied by Kassam and Kowal (1975), and the ratio of evaporation to pan evaporation averages about 0.8 throughout the life of the crop. Crop water use reported by these authors was about 300 mm or 148 g water per g (top dry weight) in northern Nigeria. Flowering and grain-filling growth stages are the most sensitive to water stress in pearl millet (Mahalakshmi and Bidinger, 1985).

Pearl millet is grown on a wide range of soils varying from clay to sandy soils. However, it is eminently suited to light texture soils. (ICAR, 2000). It is one of the few crops adapted to the sands of the Sahelian region in Africa and similar areas such as the Rajasthan desert in India (Fageria, 1992). Pearl millet does not tolerate waterlogging (Kowal and Kassam, 1978). It is reported to be tolerant to soil acidity and moderately susceptible to salinity (Hoffman, 1981). It can tolerate $>50\%$ aluminum saturation of the soil cation exchange capacity and is generally more tolerant of acid soils than sorghum (Flores et al., 1991). Singh et al. (1988) reported that the yield of pearl millet was reduced by 50% when exchangeable sodium percentage was raised from 28 to 45.

Nutrient Requirements

Pearl millet can grow on infertile soils due to its tolerance to soil acidity and its ability to grow roots deeply and rapidly (Norman et al., 1995). It is adapted to soils of low fertility, it is capable of taking up large amounts of nutrients when fertilized or grown on fertile soils. An improved cultivar yielding 3200 kg ha^{-1} of grain in the West Africa Savanna is reported to have removed per hectare: 132 kg N, 28 kg phosphorus (P), 65 kg potassium (K), and 56 kg calcium (Ca) (Kowal and Kassam, 1978). Similarly, data on fertilizer response of the new hybrids have shown that the economic optimum doses are 40 kg N ha^{-1} in severe drought prone areas, 80 kg N ha^{-1} in areas of limited to adequate moisture and 100 kg N ha^{-1} in regions of adequate rainfall (ICAR, 2000). Algarswamy et al. (1988) reported differences in N use efficiency among pearl millet genotypes.

Responses of pearl millet to P have been reported in Africa rates above 66 kg P ha^{-1} can depress yields if soil moisture is insufficient (Christianson et al., 1990). This crop has a high requirement for potassium. Mehta and Shah (1958) reported 121 kg K ha^{-1} applied at the soft dough stage produced 6749 kg ha^{-1} of dry matter. The same crop removed 63 kg N, 28 kg P, 21 kg Ca, and 10 kg magnesium (Mg).

Morphology, Growth, and Development

Knowledge about plant morphology, growth, and development helps in understanding physiological processes controlling the yield and adoption or manipulation of crop management practices favoring higher yields. Pearl millet is an erect (height 1.5–2.5 m), tillering, annual member of the subfamily Panicoideae, tribe Paniceae. Tillering begins 10 to 20 d after emergence and tillers are formed more rapidly as temperature increases to about 24°C (Pearson and Hall, 1984). Pearl millet is characterized by high a photosynthetic rate and a relatively high temperature optimum for development and growth processes (Pearson and Hall, 1984). Cultivars range from 0.5 to over 3 m tall and mature in 50 to 180 d (Jones, 1985).

Grain is produced on a stiff, compact, cylindrical inflorescence 2 to 3 cm in diameter and 15 to 45 cm long (Fageria, 1992). Seeds are white, yellow, grey, or light blue, and weigh 3 to 15 mg each, with 900 to 3000 in each inflorescence (Jones, 1985). Pearl millet is largely cross pollinated, has a C4 photosynthetic pathway, and has a high dry matter production rate (Fageria, 1992).

Plant leaf area is an important plant parameter for interception of solar radiation, and consequently, for improving yield. In India, maximum pearl millet leaf area index (LAI) reported was in the range of 1.7 to 3, corresponding to 40 to 70% interception of radiation (ICRISAT, 1987). Complete light interception was attained at a LAI of 5 to 8 in North Australia (Begg, 1965). Pearl millet is a drought resistant crop due to its fibrous and deep root system. Pearl millet roots may penetrate to a depth of about 1 m within 33 days after sowing (Gregory and Squire, 1979). Root penetration has been recorded to 3.6 m in North Australia (Begg et al., 1964), although values of 1.2 to 1.5 m are probably more common (Wetselaer and Norman, 1969). Root length reaches a maximum at about anthesis (Fageria, 1992). Pearl millet takes 15 to 20 d, or one-sixth to one-quarter of its growth cycle, to progress from differentiation of the inflorescence to anthesis (Powers et al., 1980).

Yield Constraints and Management Strategies

Water deficit, nutrient deficiency, weeds, and diseases are common yield constraints in major pearl millet producing tropical regions (Pearson and Hall, 1984). Adopting appropriate soil and plant management practices can help in reducing these constraints and improving yields of this crop. These practices include planting at an appropriate time to avoid or escape a drought period, controlling weeds and diseases and planting adapted genotypes. Plant breeding efforts in the USA have resulted in improved grain yield potential of this crop by reducing plant height for mechanical harvesting, and reducing lodging risk, but little research has been conducted on production practices needed to optimize yield (Pale et al., 2003).

SORGHUM

Sorghum (*Sorghum bicolor* L Moench) is a staple food in the semiarid regions of Africa and India (Dowling et al., 2002). Grain sorghum is an important grain crop in the Great Plains, of the U.S with an annual harvested area of 3.1 to 5.3 million hectares per year during the past decade (Pale et al., 2003). Currently, about 48% of world sorghum grain product is fed to livestock (Dowling et al., 2002). Sorghum is often compared with maize (*Zea mays* L.) for which it a close substitutes. Consequently, international sorghum prices move very closely with those of maize and are usually about 5% lower (FAO, 1996). It has similar feed characteristics, provides about as much metabolically energy, and has a higher crude protein content, but less digestibility than corn. Overall, total digestible nutrients in sorghum are roughly 95% of those in dry rolled yellow dent maize (Dowling et al., 2002). Recently, new lines of grain sorghum, which exhibit substantially greater digestibility of protein than normal cultivars, have been identified (Dowling et al., 2002). In recent years sorghum has been used as a cover crop and also used as silage for animal feed in South America, mainly in Brazil. It is a drought tolerant crop and can provide sufficient dry matter to cover soil surface at low soil moisture content. Additionally, sorghum seed cost is relatively low and less management practices are required to grow this crop compared those for legume cover crops.

Climatic and Soil Requirements

Temperature, precipitation, and solar radiation are main climatic features. In the tropics, there is generally sufficient solar radiation during most of the year and this is rarely a limiting factor for crop production. Adams (1967) reported that time to germination decreases by 1 d for each .9°C increase in mean temperature. Similarly, Lawn and Imrie (1991) reported that sorghum seeds took 8.9 d for germination at temperature of 16°C, 6.5 d at 18°C temperature and only 3.3 d when temperature was 25°C. The optimum temperature for sorghum germination is reported to be in the range of 21 to 35°C (Kanemasu et al., 1975). The optimum temperature for photosynthesis is 30–36°C (Vong and Murata, 1977). The sorghum plant requires about 356 mm of water during its growth cycle and water use efficiency is reported to be about 12.4 to 13.4 kg grain ha^{-1} mm^{-1} (Maman et al., 2003). In India, the sorghum belt receives an annual rainfall ranging from 400 to 1000 mm per annum, usually distributed between the last week of June and the first week of October (ICAR, 2000). In addition to its tolerance to drought, sorghum is also more tolerant to water logging than corn.

Sorghum can grow on a wide range of soils. Medium and deep black (Vertisols and Alfisols) soils are suitable for growing sorghum in India (ICAR, 2000). The soil texture of Vertsols and Alfisols ranges from heavy clays to loamy sands. Sorghum can also be grown on light textured sandy soils and can grow with a wide range of soil pH from 5.0 to 8.5 (Doggett, 1988). In Brazil it is mostly grown on Oxisols and Ultisols in the central part of the country locally known as "cerrado" region. Sorghum is considered moderately tolerant to soil salinity. The salinity threshold (the maximum allowable salinity level without yield reduction) reported for this crop is about 6.8 dS^{-1} (Maas, 1986). However, genotypic variation has been reported (Francois et al., 1984).

Nutrient Requirements

Nutrient requirements of a crop depend on yield level, climatic conditions, soil type, and genotype. Sorghum grown for cover crops is generally grown to have sufficient dry matter to cover the soil surface, and sometimes, residual fertilizer from previous crop may be sufficient to produce reasonably good growth. For example in Brazil, sorghum as a cover crop is grown after soybean, common bean or rice, and only a small amount of nitrogen (30 to 50 kg ha^{-1}) may required to produce reasonably good dry matter yield. Most of the Brazilian soils are acidic and sufficient liming, and P and K are required to produce good crop yields (Fageria and Baligar, 2003). The Mehlich-1 extractable soil P and K of more than 10 mg kg^{-1} and 50 mg kg $^{-1}$, respectively, produce good yields of most crops on Brazilian Oxisols/Ultisols (Fageria, 1992). Critical aluminum (Al) saturation for sorghum grown on Oxisol/Ultisol is reported to be 20.5 of the soil CEC (Fageria and Baligar, 2003).

Morphology, Growth, and Development

Sorghum is a member of the subfamily Panicoideae, tribe Andropogoneae. The domestication of sorghum took place in Africa but doubt exists concerning the exact place of domestication. Doggett (1988) regards the Ethiopian highlands as the primary center of domestication. Sorghum is an erect grass usually 1–4 m tall. Most, but not all, cultivars are freely tillering (Norman et al., 1995). Tillers are terminated by an inflorescence, which is a panicle with a centered rachis carrying primary, secondary, and sometimes tertiary branches which bear the racemes of spikelets (Norman et al., 1995). Sorghum is a self pollinated plant, but some cross-pollination always occurs.

Growth duration of the crop depends on climatic conditions and genotype. However, Vanderlip and Reeves (1972) presented a growth stage scale of sorghum and reported that physiological maturity and maximum dry matter accumulation takes place about 95 d after germination. Sorghum is a C_4 crop with a high carbon dioxide (CO_2) assimilation capacity and potentially high rates of dry matter production. Leaf photosynthesis rates of 72 mg CO_2 dm^{-1} ha^{-1} have been reported under field conditions (Eastin, 1983).

Leaf area index (LAI) is often used as an index of plant growth and for evaluating assimilation and transpiration rates in plant physiological studies (Fageria et al., 1997). Maximum leaf area index in sorghum is usually achieved just before anthesis, and LAI of approximately 5 is found in productive commercial fields in the United States. Fields in drier areas can have LAI values of 2-4 (Eastin, 1983). Fageria et al. (1997) reviewed development of the sorghum root system and reported that maximum root weight was achieved at about anthesis. These authors also reported that 80 to 85% of the root system was in the top 30 cm soil layer. Significant genotypic variation has been reported in sorghum root development, suggesting that sorghum could be improved by selection for more extensive root development at depth (Nour and Weible, 1978).

Yield Constraints and Management Strategies

Biotic and abiotic factors are main constraints of sorghum. Drought and low fertility are the main abiotic factors in most of the sorghum growing regions around the world. Among biotic factors are diseases and weeds, which mainly restrict sorghum yield. Breeding genotypes for drought and disease resistance is a desirable strategy for improving sorghum yields. Drought may be avoided by matching crop phenology with periods during the cropping season when water supply is likely to be more abundant (Purcell et al., 2003). This approach has been an effective tool for crops grown in monsoonal climates where they are sown near the beginning of the wet season and mature before the dry season (Monteith and Virmani, 1991). In tropical acid soils, liming and addition of essential nutrients may improve sorghum yield.

THE LEGUMINOUS COVER CROPS

The legumes are a very large group of plants second in number only to the cereals in the plant kingdom. They belong to the family *Leguminosae,* subfamily *Papilionoideae.* Legumes usually have alternate, compound, trifoliate leaves and fruits of legumes are known as pods. Over half of the world area sown to grain legumes is in tropical countries. Tropical legumes contribute about 35% to world production of legumes which is higher than for tropical cereals (30%) but lower than for tropical root crops (Norman et al., 1995). Legume plants have several uses for man and animal, and are important plants to be included as cover crops in a sustainable cropping system. Major tropical legume cover crop agronomy and physiology are discussed in this section.

COWPEA

Cowpea (*Vigna unguiculata* L. Walp) is an annual legume and mainly cultivated in the Tropics or Subtropics during warm seasons. West Africa and India are centers of diversity for cowpea (Fageria et al., 1997). It is grown for dry seeds, edible pods, fresh peas, hay, forage, green manure, or a cover crop. The highest seed producing countries are India, Brazil, Nigeria, and other West African countries (Summerfield et al., 1983). Cowpea is also grown in southern USA and Australia (Sellschop, 1962). Cowpea has been considered the most suitable and most rapidly growing legume for covering the ground and reducing soil erosion in northern Nigeria (Dennison, 1956).

Climatic and Soil Requirements

Cowpea is an important cover or green manure crop in the tropics due to its biotic and abiotic stress resistance characteristics. Cowpea seeds germinated in 8.6 d when temperature was 16°C and germinated in 3.3 d when temperature was raised to 25°C (Lawn and Imrie, 1991). Optimum temperature for cowpea growth is around 30°C and minimum threshold temperature is around 20°C (Fageria et al., 1997). Temperatures higher than 30°C decrease pod number and those lower than 20°C decrease seed number and seed size. Cowpea is mostly grown as a rainfed crop in major producing region, or as a cover crop between two major crops. Cutler (1979) reported that some cultivars in Mali (Africa) produced well with only 290 mm of rainfall. Flowering and pod filling growth stages are most sensitive to drought (Fageria et al., 1997).

Cowpea can grow on a wide variety of soils ranging in texture from light sandy to clays. However, best growth is attained on well drained sandy loam soils (Wien and Summerfield, 1984). In the Thar Desert of Rajasthan, India, adapted genotypes of cowpea grow well on sandy soils with limited water during crop growth period. Cowpea can grow well on alkaline as well as acidic soils. In Brazilian Oxisols, good yields were obtained at a pH of about 6.0 (Fageria, 1991). Critical Al saturation is reported to be 55% of soil cation exchange capacity (CEC), indicating its acid tolerance. Cowpea is considered be moderately susceptible to soil salinity, with an initial yield decline (threshold) at around 1.3 dS m^{-1} (Fageria et al., 1997). Yields decrease about 14% per unit of salinity increase beyond this threshold (Maas and Hoffman, 1977).

Nutrient Requirements

Generally, farmers in Latin America, Africa, and Asia do not apply fertilizers to a cowpea crop. But with fertilization crop growth and yield can be improved if sufficient water is available during the season (Fageria et al., 1997). If inoculated with appropriate Rhozibium, cowpea can fix sufficient nitrogen for its normal growth. Phosphorus and potassium application rates should be determined on the basis of soil analysis. Smyth and Cravo (1990) determined that the critical P level in an Oxisol for cowpea by Mehlich 1 extracting solution was 8 mg kg^{-1} and by Bray 1 solution, 13 mg kg^{-1} of soil. Similarly, Cox and Uribe (1992) determined that the critical K level in a humid tropical Ultisol was10 $cmol_c$ kg^{-1} of soil by a modified Olsen method.

Morphology, Growth, and Development

Cowpea belongs to family Papilionaceae and tribe Phaseoleae. It is an annual legume, and germination is epigeal and no seed dormancy has been reported in the cultivated cowpeas. Under favorable environmental conditions, (humidity and soil temperature), germination is completed in 3–4 d. Although, germination is epigeal, cowpea cotyledons that emerge from the soil do not persist. They can lose as much as 91% of their dry weight by emergence (Fageria et al., 1997). Such effective mobilization of cotyledon reserve probably contributes to rapid hypocotyl elongation and might improve emergence in adverse edaphic conditions.

Cowpea is largely self pollinated, but there are always a small proportion of outcrosses, especially in humid climates. The inflorescence of cowpea consists of a penduncle on which 4–6 units of flowers are formed, alternately, in acropetal succession. It is a C_3 crop and growth duration is governed by genetic and environmental conditions. As a cover crop, a 60 to 70 d growth period is enough to produce sufficient dry matter to cover soil surface under favorable environmental conditions. The rate of dry matter production is controlled by radiation interception, which depends on leaf area index. Under favorable climatic conditions, with genotypes of short growth duration, a leaf area index of 3 can be achieved in 35 to 40 d (Fageria et al., 1997). In tropical conditions, Littleton et al. (1979) reported maximum daily crop growth rates of 16 to 25 g m^{-2}, which is equivalent to 1.6 to 2.5 Mg ha^{-1} over a 10 d period. Cowpea has a tap root system and maximum root weight is achieved in about 56 d by a genotypes having a growth cycle of 76 d (Fageria, 1991). Root and shoot weights are strongly correlated with grain yield of cowpea (Fageria, 1991).

Yield Constraints and Management Strategies

Main constraints for cowpea as a cover crop are water deficiency, low soil fertility, and weed control. When the crop depends entirely on rainfall, planting time may be critical to use residual soil moisture for producing sufficient dry matter as a cover crop. Furthermore, planting short duration cultivars (50 to 60 d maturity) is another important strategy to improve yield in water limited environments. Genotypic differences in drought resistance have been reported

(Turk et al., 1980). Hence, planting drought resistant genotypes can be helpful in drought prone environments. Inoculation of cowpea seeds with appropriate Rhizobia strain is an important management practice to supply nitrogen to this crop and to improve yields. Phosphorus and potassium should be added to improve yields on low fertility soils.

PIGIONPEA

Pigeonpea (*Cajanus cajan* L. Millspaugh), or red gram, is an ancient African grain legume which has been cultivated in the Nile Valley for more than 4,000 years (Cobley and Steele, 1976). It is grown mostly in Africa and the Indian-subcontinent. Its origin is reported to be India (Sheldrake, 1984). Main uses of pigeonpea are to provide mature or immature seeds and green pods for human consumption, forage, or a cover crop and a nurse crop for young cocoa and oil-palms. The main advantages of growing pigeon pea as a cover crop are its tolerance to high temperature and drought, efficiency in utilizing nutrients from low fertility soils and its freedom from diseases and insects.

Climatic and Soil Requirements

Pigeonpea is a warm season crop and does not grow well under cooler temperatures. Optimum temperature for germination and hypocotyl elongation is reported to be in the range of 29 to 36°C (Lawn and Troedson, 1990). These authors also reported that no germination occurred at 7.1°C or at 46.5°C, and the rate of germination was significantly reduced below 19°C. They reported further that at a temperature of 18°C pigeonpea took 11.2 d for seedling to emergence, while at a temperature of 25°C, only 4.8 d were required.

Pigeonpea is well adapted to drought-prone environments but is sensitive to waterlogging. In India, where about 90% of world production occurs, pigeonpea is sown mainly as a rainy-season crop, and grown through to maturity in the subsequent dry season on stored soil moisture (Lawn and Troedson, 1990). The water requirement is more than 500 mm per crop (Fageria, 1992).

This crop can be grown on a wide range of soils, preferring those that are well suited to grow corn, sorghum, and millet. Pigeonpea can grow and produce relatively good yield on fertile soils with a pH of 5 to 8 (Akinola et al., 1975). In India it is grown on alluvial soils of the Indo-Gangetic plains to heavy black cotton soils of central and southern India (ICAR, 2000). However, it does best on well drained, light to medium textured soils, moist and deep enough to permit a free development of roots. It grows well on limed Oxisols and Inceptisols of Brazil as a grain or green manure crop (Fageria and Souza, 1995; Fageria and Baligar, 1996). It is highly susceptible to waterlogging, and genotypes differ in tolerance to temporary waterlogged conditions (Fageria, 1992).

Nutrient Requirements

The wide soil adaptation of pigeon pea has led to the belief that it can derive the necessary plant nutrients from comparatively less available forms of nutrients in the soil, in contrast with many other crops (Fageria, 1992). However, it is probable that the deep and extensive root systems of the plant gives it access to minerals not reached by species having lesser root systems (Fageria, 1992). Very little work has been done on nutrient requirements of this crop but it responds well to fertilizers (Fageria, 1992). Pigeonpea is nodulated by Rhizibium of the cowpea (*Rhizobium japonicum*). Hence, under optimum environmental conditions, it can fix sufficient N for growth and development, if seeds are inoculated.

Morphology, Growth, and Development

Pigeonpea belongs to the family *Leguminosae* and subtribe *Phaseoleae*. Its germination is hypogeal and seedling emergence generally occurs more slowly than in epigeous species such as cowpea, mung bean, and soybean. Perhaps because of its hypogeal germination, pigeonpea emerges well from depth. Although emergence is progressively reduced when seed is below a 5 cm depth, some seedlings can emerge from as deep as 30 cm (Lawn and Troedson, 1990). There is no dormancy problem in this crop and germination is generally good except under cool temperatures. In seedlings, the first two leaves are simple and opposite, and the subsequent leaves are trifoliate. Plant may grow in height from 1 to 2 m depending upon environmental conditions and genotype. In most cultivars, the inflorescence develops as axillary recemes, 4 to 12 cm long, and flowering proceeds acropetally both within the racemes and on the branches. Pigeonpea is a self pollinated crop but some cross pollination always occurs. The growth duration of a cultivar is one of the most important factors affecting its adaptation to a particular cropping system. For cover crops, genotypes of short duration are desirable. Some genotypes can flower in 80 to 90 days and may produce sufficient dry matter to cover the soil surface.

Like all food legumes, pigeonpea is a C_3 plant. The dry matter yield is associated with leaf area index (LAI is defined as the leaf area per unit area of ground). In Australia, the leaf area index reached a maximum of 4.9 after 49 d at the higher population density, 1×10^6 plants ha^{-1} (Rowden et al., 1981). The maximum LAI reported at Hyderabad, India is 12.7 for some long duration cultivars (137 d). However, the maximum LAI of medium duration cultivars (97 d) grown in a normal season at Hyderabad usually range from 3 to 6 (Sheldrake, 1984). The critical LAI, that is the LAI necessary to ensure 95% interception of photosynthetically active radiation for pigeonpea varies from 3.9 to 6 (Lawn and Troedson, 1990).

Dry matter production and crop growth rate in the earlier stage of growth are very low. The initial slower growth rate appears to be due mainly to smaller seedling leaf area. Comparative studies showed that 10 d after sowing, the leaf area of pigeonpea seedlings was about one-third that of soybean and one fifth that of cowpea (Brakke and Gardner, 1987). Peak crop growth rate of 7.65 g m^{-2} day^{-1} was attained between 80 and 100 d after sowing at ICRSAT, India by a medium duration cultivar (Saxena et al., 1983). When pigeonpea was grown in a normal season at ICRISAT, the aboveground dry matter production generally ranged between 6 to 8 Mg ha^{-1} for medium duration cultivars and between 3 to 5 Mg ha^{-1} for early duration cultivars (Sheldrake and Narayanan, 1979).

Pigeonpea has a deep and wide spreading root system and maximum root weight may be achieved at flowering. Roots may grow up to 2 m deep, but most extensive development is in the upper 60 cm soil layer (Sheldrake, 1984). Regardless of soil moisture distribution, around 70% of root biomass and 50% of root length are commonly found in the top 30 cm of soil layer (Lawn and Troedson, 1990).

Yield Constraints and Management Strategies

Slower initial growth rate is a drawback for pigeonpea because it can not compete with growing weeds in the early growth stage. Breeding genotypes of higher growth rate or higher leaf area in the beginning is an important strategy to overcome this problem. Pigeonpea is very sensitive to water logging in heavy textured soils. Waterlogging damages the root system and plants are extremely vulnerable to attack by the fungus *Phytophthora drechslerif,* that causes blight, and to N deficiency through the inhibition of N_2 fixation (Lawn and Troedson, 1990). Selecting or breeding genotypes having waterlogging tolerance may be an important strategy to overcome this constraint. Pigeonpea is drought tolerant crop; however, water adequacy improves its biomass production. Hence, matching phenology to water supply may be an important strategy to reduce water deficit and improve yield.

MUNGBEAN

Mungbean (*Vigna radiata* L. Wilczek) is also known as green gram. It is native of India and grown mostly in the Indian sub-continent, Africa and tropical America. The main uses of this crop are for human consumption (green pods, sprouts, and seeds), forage, and a cover or green manure crop. Some cultivars of mung bean flower in 40–60 d after germination and can be killed by herbicide at this stage to provide reasonably good dry matter to serve as cover crop mulch.

Climatic and Soil Requirements

Mung bean well adapted to warm climates. The crop is often grown with limited rainfall by utilizing residual moisture in the soil. Optimum temperature for growth and development of mung bean is reported to be in the range of 20 to 30°C, but temperatures higher than 34°C and lower than 15°C are harmful (Tu, 1978). It is a fairly drought tolerant crop, and its season should not coincide with periods of heavy rainfall. The water requirement of mung bean is about 410 mm per crop or 3.2 mm day^{-1} for a crop of an average growing period of 60 to 70 days (Fageria, 1992). The most sensitive period of water deficit in the mung bean crop is before and during flowering (Fageria, 1992).

Mung bean is grown on a wide range of soils. It does well on deep, well drained loams in the alluvial tract in the north as well as on the red and black soils of peninsular and southern India (ICAR, 2000). It is also cultivated on range of light or shallow stony soils to clay soils in many parts of India (ICAR, 2000). Acidic soils adversely affect the growth of the rhizobia bacteria and availability of nutrients. Optimum pH range is 5.8 to 6.5 (Quebral et al., 1977).

Nutrient Requirements

Mung bean has relatively high requirements for mineral nutrients. Quebral et al. (1977) reported that a 2 Mg ha^{-1} mung yield removes about 87 kg N ha^{-1}, 20 kg P ha^{-1}, and 23 kg K ha^{-1}. These authors also reported that general fertilizer recommendations for this crop were 20 kg N ha^{-1}, 13–20 kg P ha^{-1} and 25–40 kg K ha^{-1}.

Morphology, Growth, and Development

Germination of mung bean is epigeal and the growth duration ranges from 60 to 90 d, depending on cultivars, climatic and soils conditions. Short duration varieties (60 d) fit easily into cropping systems as a cover crop. It is a warm season annual crop. It has a taproot and the rooting system is well branched and extensive, thus permitting exploration of soil moisture to considerable depths. It is a self pollinated C_3 plant. Mung bean plants are erect, reaching a height of more than 1 m. The stout stems carry alternate dark-green trifoliate leaves on long petioles subtended by broadly ovate stipules (Cobley and Steele, 1976).

Yield Constraints and Management Strategies

Major yield constraints for mung bean growth are drought and nutritional deficiencies. To improve dry matter yield, genetic improvement is necessary for drought resistance and efficiency in nutrient absorption and utilization. In addition, yield improvement is possible by use of proper plant population and sowing to adjust the growth cycle to avoid severe water deficiency.

MOTH BEAN

Moth bean (*Vigna acontifolia* Jacq. Marechall) originated in the semiarid regions of India, most probably in the State of Rajasthan (Fageria, 1992). It is grown in the states of Rajasthan, Haryana, Utter Pradesh, Punjab, Maharastra, and Gujrat of India as grain legumes, green pods are consumed as vegetables and also used as a fodder for animals. It is grown mostly rotation with pearl millet and sometimes as mixed crop with pearl millet, sorghum, guar, or mung bean. Moth bean may be good cover crop for arid and semiarid tropics if appropriate management practices are adopted. Due to its spreading habit, it is a good cover crop to prevent soil erosion.

Climatic and Soil Requirements

Moth bean is a warm-season crop and planted in the rainy season in North-West India in the month of July or August. It is a drought resistant crop and some varieties in the Thar desert of Rajasthan grow with a rainfall about 50 to 60 mm during the season (Fageria, 1992). If this rainfall is distributed equally, three or four episodes during a growth cycle of 60–70 d, a reasonably good crop of moth bean are expected. The optimum temperature for the growth and development is about 25 to 30°C (Fageria, 1992). Supplementary irrigation may improve dry matter and crop yield.

Moth bean is largely grown on well-drained light textured sandy to sandy loam soils. It is a salinity tolerant crop and grows well on alkaline soils having pH around 8.0 (Fageria, 1992).

Nutrient Requirements

Moth bean is normally grown on light soils, without fertilization. This crop has not been given much importance, and research data are not available about nutrient requirements.

Morphology, Growth, and Development

An annual legume, which grows to maturity in 60 to 90 d; moth bean is a slender, creeping, hairy, herbaceous plant that attains a height up to about 30 cm. The leaflets are characteristically deeply lobed; the terminal leaflets largest and five-lobed, the lateral leaflet four-lobed. The leaves are subtended by large stipules, up to 12 mm long. Very small, yellow flowers are clustered on axillary peduncles 5 to 10 cm long (Fageria, 1992). It is self fertilized and produces thin, narrow, beaked pods 2 to 4 cm long. The pods contain four to six seeds, and the germination is epigeal. It has taproot and a well spread deep root system, which is very efficient in absorption of water and nutrients.

Yield Constraints and Management Strategies

This crop has not been given adequate attention in relation to production agronomy. Hence, experimental work is necessary to define appropriate plant population, fertilization, and water requirements. In the State of Rajasthan, India, weed infestation during the early growth stage often reduces yields of this crop. Screening crop genotypes for drought and weed control may be useful in improving its yield.

GUAR

Guar (*Cyamopsis tetragonoloba* L. Taub.) is an important grain legume of the tropics and is indigenous to India. It is grown mainly in the Indian-subcontinent for human consumption (pod as vegetable), as cattle feed, and as a green manure or cover crop (Fageria, 1992). It is also grown for gum production in India and the southern United States. Guar has remained a minor crop in the United States since it was introduced in 1903 by the US Department of Agriculture as a potential soil-building and seed producing crop (Alexander et al., 1988).

Climatic and Soil Requirements

Guar has been characterized as a warm season, drought resistant, deep rooted summer annual legume adapted to semiarid climates (Whistler and Hymowitz, 1979). Guar is generally grown under rainfed conditions in India, Pakistan, Myanmar, Sri-Lanka, and the United States (Fageria, 1992). It can sustain growth at high temperatures and at higher water deficits, may thus be due to its ability to deplete soil water deep within the profile and to a thick foliar epidermis that may reduce transpiration losses (Alexander, 1988). The average seasonal soil water depletion (estimate of evaporation) was previously determined to be 590 mm, with a peak water use rate of 7 mm day^{-1} in Arizona for forage production (Erie et al., 1982). Alexander et al. (1988) recommended three post establishment irrigation's for the guar crop as follows: one before flowering, between 20 and 35 days after stand establishment; a second during flowering and initial pod development about 60 days after establishment; and a third at midpod-filling, about 80 d after establishment. The irrigation at midpod-filling was the most critical for seed yield. The optimum temperature for guar growth and development is in the range of 24 to 30°C (Fageria, 1992).

Guar grows well under a wide range of soil conditions. However, it performs bets on fertile, medium-textured, and sandy loam soils, with good structure and well drained sub-soils. There is little available data about pH requirement, but guar can be grown in the pH range from 5.5 to 8 if appropriate cultivars are selected for acid and alkaline soils. It is rated as a medium salt tolerant plant (Maas, 1986).

Nutrient Requirements

On fertile soils, or where preceding crops have been fertilized, guar usually requires no additional fertilizer. In the Indian State of Rajasthan, it is a very common practice to plant a guar crop after 2 to 3 years on fallow land that has been used as a pasture (Fageria, 1992). If properly inoculated, guar will fix atmospheric nitrogen in amounts similar to that of cowpea. An application of 20-30 kg P ha^{-1} is recommended for good yield of guar. Research data related to nutrient uptake by this crop are scarce.

Morphology, Growth, and Development

Guar is a bushy annual plant 1 to 3 m tall, with a long taproot and lateral roots on which are many large, lobed nodules. There are many stiff, erect branches, with alternate trifoliate leaves on long, grooved petioles. Guar has an indeterminate growth habit and will remain vegetative and continue to flower and set pods from about 4 to 6 weeks after emergence (Stafford and Hymowitz, 1980). Guar is completely self-fertile and is highly self-pollinated.

The inflorescence of guar is a raceme, about 9 to 13 cm long in the branched types and 15 to 20 cm long in the erect or sparsely branching types. Guar plant possesses pods in clusters, each about 6 cm long, that have terminal beaks and contain about six to eight seeds (Fageria, 1992). Due to cluster pods, guar is also known as cluster bean. Yields of about 4500 kg ha^{-1} of greenfodder under rainfed conditions and yields nearly double this have been obtained under irrigated conditions (Purseglove, 1974).

Yield Constraints and Management Strategies

Like other cover crops water stress, diseases and weeds affect guar. wherever, feasible, applying supplementary irrigation and controlling diseases and weeds are important cultural practices to produce good guar yields. Planting drought and disease resistant genotypes is an important and economical strategy for guar cultivation. Furthermore, guar is requires large quantities of P and hence, it should be appropriate to apply P in adequate quantity for good growth and development.

PEANUT

Peanut (*Arachis hypogaea* L.) originated in South America and probably in southern Bolivia or northern Argentina (Gregory et al., 1980). This crop was probably brought to Africa from Brazil by Portuguese early in sixteenth century and somewhat later was transported from the west coast of South America to Asia. Peanut may have reached the United States by way of slave ships from West Africa, although precisely when and where they were introduced is not known (Gibbsons, 1980). The cultivated peanut is found throughout the tropical and temperate regions of the world. India, China, and Indonesia have the largest peanut growing areas in Asia, while in Africa the major producers are Nigeria, Senegal, and Sudan. In the Western Hemisphere, the United States, Brazil, and Argentina are the leading peanut producers (Fageria et al., 1997).

Climatic and Soil Requirements

Although peanut is predominantly a crop of the tropics, the approximate limits of present commercial production are between latitude 40°N and 40°S, where rainfall during the growing season exceeds 500 mm (Gibbons, 1980). Peanuts perform well in the temperature range between 24 to 33°C, but can survive up to 45°C if adequate moisture is maintained (Saxena et al., 1983). In Asia and Africa, peanuts are mostly grown as a rainfed crop. Kassam and Kowal (1975) showed that, from sowing to harvest, a rainfed crop in Nigeria used 438 mm of water to produce a seed yield of 1.6 Mg ha^{-1} in 4 months. In the United States, irrigation to obtain high peanut yields is becoming popular. In Georgia, 45% of the allotted peanut acreage was under irrigation and increasing steadily (Henning et al., 1979).

Soil Requirements

In practice, peanuts are grown on a range of soils from alkaline to acid and from clays to fine sands (Fageria et al., 1997). However, the most suitable soils for peanut production are well drained, light sandy loams with an ample supply of calcium and moderate organic matter (Gibbons, 1980). Adams (1981) reported that peanuts are one of the most acid tolerant crops, with a critical pH range of 5 to 5.5. Peanuts are considered moderately susceptible to soil salinity, and a salinity threshold (salinity at initial yield decline) of 3.2 DS m^{-1} has been reported (Maas and Hoffman, 1977). Peanut is sensitive to water logging.

Nutrient Requirements

An adequate supply of essential nutrients is necessary to obtain high yields of peanuts. It fixes atmospheric nitrogen if inoculated with appropriate Rhizobium. Peanut nodulate well with the *Bradyrhizobium* strain. Other nutrients, which are necessary for good peanut yield, are P, K, Ca, and Mg.

Morphology, Growth, and Development

Germination of peanut is neither epigeal nor hypogeal but intermediate. The hypocotyls carry the cotyledons to the soil surface and remain there. Peanuts are a self-pollinated, annual, herbaceous legume and belong to the family Papilionaceae. The plant is erect or prostrate, sparsely hairy, and 15–60 cm high or higher. The peanut has a relatively deep taproot system with a well developed lateral root system. The maximum root density is reportedly in the top 30 cm soil depth (Fageria et al., 1997). The dry matter accumulation pattern in peanuts is similar to that of most other field crops. It is slow in the beginning, increases sharply in the late vegetative and early pod-filling stages, and reaches a plateau during late pod filling. Maximum crop growth rate values ranging from 13 to 24 g m^{-2} day^{-1} have been reported under different environmental conditions and for different cultivars (Fageria et al., 1997). Misa et al. (1994) and Duncan et al. (1978) reported that maximum leaf area index among 11 peanut genotypes ranged from 3.2 to 4.0 and optimum leaf area is 3.0.

Yield Constraints and Management Strategies

Drought, diseases, and insects are the main yield limiting factors for peanut growth and development. Hence breeding genotypes for resistance to these factors is a promising strategy for improving yields.

TROPICAL KUDZU

Tropical kudzu (*Pueraria phaseoloide* Roxb. Benth.) is indigenous to the lowlands of South-East Asia and cultivated throughout the wet tropics. It is mainly grown as a component of grazed and ungrazed cover crop mixtures in rubber, oil-palm and coconut plantations in South-East Asia, Africa, tropical America, and Australia (Halim, 1997). It is also grown as a pasture legume in these regions. It is planted on sloping sites to control erosion and in rotation with annual crops as a green manure. The Centro Internacional de Agricultura Tropical (CIAT) Cali, Colombia, maintains a large germplasm collection of tropical kudzu.

Climatic and Soil Requirements

Tropical kudzu is best suited to the humid lowland tropics up to 1000 m altitude with an annual rainfall in excess of 1500 mm. Optimum temperature for growth is reported to be 32/24°C (day/night) (Halim, 1997). This author also reported that yield of kudzu was reduced by 35% when temperature was dropped to 26/15°C. It is tolerant to water logging and can grow well under shaded conditions. Due to its shade tolerance, it is suitable in integrated livestock/plantation cropping systems. It prefers heavy textured soils and is well adapted to acid soils. It is susceptible to soil salinity.

Nutrient Requirements

Tropical Kudzu is particularly susceptible to Ca, Mg, and sulfur (S) deficiencies and responds to fertilization on infertile Oxisols and Ultisols. Tropical Kudzu responds well to added P; linear yield responses to P up to 50 kg P ha^{-1} have been reported on infertile soils (Halim, 1997).

Morphology, Growth, and Development

Tropical kudzu is a perennial herb with climbing or twining, hairy stems. Main stems are about 6 mm in diameter, extending 4.5–10 m, rooting and at nodes if in contact with moist soils. It is a deep rooting plant and roots are subtuberous. Leaves are large and trifoliate. Inflorescence is an axillary, unbranched raceme and 10–46 cm long (Halim, 1997). Seedling growth of tropical kudzu is only moderately vigorous during the first 3–4 months. Once established, it is very vigorous and quickly smothers weeds. Under optimum growing conditions, it can form a tangled mat of 60–75 cm deep (Halim, 1997). It usually nodulates with native cowpea rhizobia but inoculation with an appropriate strain of *Bradyrhizobium* is recommended in newly planted areas.

Yield Constraints and Management Strategies

When planted under plantation crops, some initial control of weeds is necessary for good growth of kudzu. The species has a wide range of germplasm but screening for biotic and abiotic stresses has not been done. Hence, research in this field is needed to identify and select tolerant genotypes.

CALOPO

Calopo (*Calopogonium mucunoides* Desv.) is indigenous to tropical America and the West Indies. It was introduced to tropical Africa and Asia in the early 1900s and to Australia in the 1930s (Peng and Aminah, 1997). It is a valuable legume cover crop to protect soil from erosion, fix atmospheric nitrogen, reduce soil temperature, improve soil fertility, and control weeds. It is an important cover crop for rubber and oil palm plantation crops and is also used as a forage crop.

Climatic and Soil Requirements

Calopo is a warm season crop and grows well where annual rainfall exceeds about 1250 mm. It is moderately drought tolerant but prolonged dry period may reduce yield significantly. It can grow on a wide range of soils varied from sandy loam to clay. It is tolerant to soil acidity and grows well at soil pH (H_2O) values ranging from 4.5 to 5.0 (Peng and Aminah, 1997). It is poorly adapted to shade and growth is significantly reduced under low light intensities.

Nutrient Requirements

Although it tolerant to soil acidity use of the dolomitic lime improves growth and yield of calopo on Oxisols and Ultisols. If seeds are inoculated with an appropriate rhizobium strain, it can fix sufficient atmospheric nitrogen for proper growth and can leave substantial amounts of N in soil for succeeding crops. Application of P generally improves growth of this crop on acidic soils. Chemical analysis of plant tissue showed 38 g kg^{-1} N, 2.4 g kg^{-1} P, 20 g kg^{-1} K, 10 g kg^{-1} Ca, and 2.5 g kg^{-1} Mg (Peng and Aminah, 1997). Research data are not available concerning nutrient requirements of this cover crop.

Morphology, Growth, and Development

Calopo is a vigorous, creeping twining or trailing herb, up to several m long, forming a tangled mass of foliage 30–50 cm deep (Peng and Aminah, 1997). Leaves are trifoliate and the inflorescence is a slender raceme up to 20 cm long. Calopo grows rapidly and is able to cover the soil in 3–6 months after sowing and even sooner on newly cleared fertile land. Its root system is considered shallow but may grow up to a 50 cm depth. It is a self pollinated C_3 plant. When pods are mature, dry matter yields up to 14 Mg ha^{-1} can be obtained in a single cutting. Lower yields of 4–6 Mg ha^{-1} are obtained when calopo is cut every 9–12 weeks. Seed yield of 200–300 kg ha^{-1} has been reported (Peng and Aminah, 1997). These authors also reported that the weight of 1000 seeds of calopo is about 13–15 g.

Yield Constraints and Management Strategies

Calopo is an important cover crop of the tropics for plantation agriculture. However, no improved genotypes of calopo are known to exist. Hence, selection and breeding genotypes of higher growth rate and adapted to environmental stresses may improve its value as a cover crop.

HAIRY INDIGO

Hairy indigo (*Indigofera hirsuta* L.) is synonymous with *Indigofera indica* Miller, *Indigofera ferruginea* Schum. & Thonn., and *Indigofera angustifolia* Blanco (Djarwaningsih, 1997). It is native to Asia and Africa. However, it is now grown throughout the tropics. It is also grown in the USA in the States of Florida and Texas. This is an important green manure or cover crop and mainly grown with plantation crops like rubber, tea (*Camellia spp.*) and coffee (*Coffea spp.*). In Florida it is grown as a cover crop in citrus plantations. In Brazil it is grown as a fodder crop in mixtures with grasses.

Climatic and Soil Requirements

Hairy indigo is a warm season crop and requires an annual rainfall of more than 900 mm. Its annual mean temperature requirement is 15–28°C and it is sensitive to frost. Hairy indigo requires well drained soils and can grow well on soils with a pH range from 5–8 in water (Djarwaningsig, 1997). It can also grow on sandy to clay textured soils.

Nutrient Requirements

Hairy indigo does not require high fertility soils. It fixes atmospheric nitrogen symbiotically with cowpea-type Rhizobium. Phosphorus and potassium fertilization increases growth and yield. Generally, 15–30 kg P ha^{-1} and 25 to 40 kg K ha^{-1} are recommended in Florida (Djarwaningsih, 1997).

Morphology, Growth, and Development

Seeds of hairy indigo germinate in 7–9 d. It is an annual herb up to 1.5 m tall with erect branches. Brown hairs cover stems and branches. The inflorescence is a densely flowered raceme, 10–30 cm long with fruit a reflexed straight pod with 6–9 seeds (Djarwaningsih, 1997). It is a cross pollinated C_3 plant. Dry matter yields of 10–13 Mg ha^{-1} seed yield of 100–300 kg ha^{-1} have been reported (Djarwaningsih, 1997).

Yield Constraints and Management Strategies

Very little breeding work has been done to adapt this species to different agroecological condition. Hence, selection and breeding work is needed to investigate its potential to produce high organic matter yields. Its efficacy reducing nematode infestation needs further investigation. In addition, genetic variation in tolerance to nematodes has been reported (Djarwaningsih, 1997). This aspect should be further investigated.

JACKBEAN

Jackbean (*Canavalia ensiformis* L. DC.) is also known as horsebean. It is native to Central America and has now been widely grown throughout the tropics. It is used as a green manure, cover crop, forage for animals, and green pods and immature seeds are used as a vegetable mainly in the tropical Asia. The immature seeds contain about 7% protein and 13% carbohydrate (Purseglove, 1974). However, mature seeds contain about 22% protein (National Academy of Sciences, 1979).

Climatic and Soil Requirements

Jackbean is grown under a wide range of climatic and soil conditions. It is grown successfully where average annual temperature ranges from 14 to 30°C, from warmer parts of the temperate zone to hot, tropical, rainforest areas. Jackbean grows well where annual rainfall as high as 4.200 mm and as low as 700 mm (National Academy of Sciences, 1979). Once established, a deep root system allows the plant to draw on stores soil moisture and to survive dry conditions. It requires full sun for optimum growth, but can also grow well in shade. It grows well on the highly leached, nutrient depleted, lowland tropical soils. Further, it grows well on acid soils in the pH range of 4.5 to 7.0 and is less affected by waterlogging and salinity than other pulse crops. Although generally grown in lowlands, it can also be grown at elevations as high as 1,800 m (National Academy of Sciences, 1979).

Nutrient Requirements

Jackbean can grow well on low fertility soils. However, the use of lime and fertilizers on acidic infertile soils may improve growth and yield. Practically, no research data are available regarding nutrient requirement of this legume crop.

Morphology, Growth, and Development

Germination of jackbean is epigeal. The jackbean is usually an erect, somewhat shrubby annual about 1 m tall, although some climbing varieties also exist. Leaves are trifoliate, hairy, and the petiole is usually longer than leaflets. The florescence is a curved raceme with 10–50 flowers borne in groups of 3–5 on swollen pedicellar glands (Purseglove, 1974). Pods are flat, straight, 20–30 cm long, and 2.5–3.5 cm wide, and containing 8–20 seeds. These seeds are among the largest of any domesticated legumes (National Academy of Sciences, 1979) and are white in color. It is a fast growing plant and usually produces a crop in 3–4 months. As a cover crop it may produce sufficient dry matter in about 60 to 70 d under favorable environmental conditions. On fertile soils, yields of jackbean are equal to that of cowpeas.

Yield Constraints and Management Strategies

There have been few agronomic studies of this crop. Methods now used for planting, fertilization, and harvesting are nearly always traditional ones that should be subjected to modern analysis or improvement. Hence, agronomic studies are needed to define appropriate management practices for improved growth and development. Breeding genotypes for vigorous and rapid growth, and a deep root system would contribute to adoption of this species as a cover crop under a wide range of environmental and agroecosystems. Another important line of research is the study of all aspects of the utilization of this crop.

LABLAB BEAN

Lablab bean (*Lablab purpureus* L. Sweet) is probably of Asian origin and has been cultivated in India since earliest times. Now it is widespread throughout the tropics. It is also known as Indian bean, Egyptian bean and scientific name as *Dolichos lablab* L. or *Lablab nige*r Medik. It has many uses such as for green manure, cover crop, forage crop, and as an ornamental plant. Green pods used as vegetables and its sprouts are comparable to those of soybean or mung bean.

Climatic and Soil Requirements

Lablab bean has a very wide adaptability depending on cultivars. It can grow under arid, semiarid, and humid regions, with annual precipitation ranging from 200–2,500 mm. Similarly, it can grow under warm temperatures, in subtropical, and humid rainforest regions where mean temperatures range from 22 to 35°C, Furthermore, it can grow in lowland and highlands up to 2,100 m altitude and soils ranging from acid to alkaline (pH 4.4 to 7.8) (National Academy of Sciences, 1979).

Nutrient Requirement

Lablab bean is tolerant to acid infertile soils, however growth and yield can be improved with liming and fertilization on such soils. It nodulates easily either with lablab or cowpea Rhizobium strains common in soils worldwide. Thus, its growth is generally unaffected by low-nitrogen content of soils.

Morphology, Growth, and Development

Lablab bean germination is epigeal. There are two types of lablab bean plants. One group is a garden type, which is twining and another is a field type, which is erect and bushy. The first group is mainly grown for green pods and the seconds one is used for seeds and forage. The second group lablab bean is sometimes also known as Australian pea. Botanically, lablab bean is an herbaceous perennial herb, often grown as an annual, 1.5 to 6 m tall, very variable in color of stems, foliage, flowers, pods and seeds, and in shape of pods (Purseglove, 1974). Leaves are alternate, trifoliate, and triangular to lanceolate. The florescences is axillary, erect, long-stalked, with stiff racemes, 30 cm or more in length. Pods and seeds differing in size, shape, color (white, purple, yellow, and green). Pods are generally 5–8 cm long, flat, broad and scimitar shaped. A well established plant has a deep root system that may be as deep as 2 m or more.

Yield Constraints and Management Strategies

There is a large lablab bean germplasm scattered through the Indian subcontinent and the tropics. This material might have different environmental requirements and yield potential. Despite the wide occurrence of lablab beans, agronomic and physiological information on this crop are limited. As a cover crop it should produce sufficient dry matter in a short time to cover the soil to protect from erosion and supply organic matter. There is need for research into genetic and breeding for faster growth and resistance to diseases, insects, adverse soils, and climatic conditions.

SUNHEMP

Sunnhemp (*Crotolaria juncea* L.) belongs to the family *Fabaceae* or *Leguminosae*. It is also known as Indian hemp, Madras hemp or brown hemp and is native to India. Important sunnhemp producing countries are India, Pakistan, Bangladesh and Brazil. In the USA it is cultivated in Hawaii, California, and to some extent in Alabama. It is traditionally an important fiber crop and is also used as a forage crop. Furthermore, in the tropic it serves as an excellent green manure/cover crop in rotation with rice, corn, cotton, sugarcane and tobacco. It is grown as a cover crop in plantations and fruit orchards. In Brazil it is grown as a cover crop with coffee. Sunhemp helps to control erosion, root-knot nematodes and to suppress weeds. Sunhemp serves as an excellent cover crop in rotation with vegetables.

Climatic and Soil Requirements

Sunhemp is a warm season crop and grows well in tropical and subtropical climates (National Academy of Sciences, 1979). Sunnhemp grows well at annual temperature from 10 to 30°C. Sunhemp is a hardy drought resistant crop, during the growing season it requires a minimum of 400 mm of rainfall distributed in not less than 50 rainy days is a primary requisite (ICAR, 2000). It is susceptible to water logging but can be grown on a wide range of soils; however, well drained alluvial soils, having a sandy loam or loamy texture are most suitable (ICAR, 2000). This species can be grown in soil having pH ranging from 5.0 to 8.4. It is particularly suitable in reclaiming saline alkaline soils.

Nutrient Requirements

Sunhemp can grow reasonably well under low fertility but responds to fertilization. It fixes atmospheric nitrogen by cowpea-type rhizobia that nodulate its roots. Under favorable environmental conditions it can fix as much as 300 kg N ha^{-1} (Rao and Sadasivaiah, 1968). For this reason the plant is a valuable soil builder, used even more widely as a green manure/cover crop than a fiber crop. Application of P and K at the rate of 20 kg ha^{-1} each is recommended (ICAR, 2000). It requires high calcium and hence, liming significantly improves growth and yield of this crop in acid soils.

Morphology, Growth and Development

The germination of sunnhemp seeds is epigeal and seedlings appear above ground in about 3 days. The seedlings grow very fast and rapidly produce a thick ground cover that smothers competing weeds. The species is erect shrubby annual, 1–3 m in height. The inflorescence is a terminal open raceme upto 25 cm in length with minute linear bracts (Purseglove, 1974). The plant is covered with short, downy hairs. It has a long taproot and vigorous lateral roots. As a cover crop, it can produce sufficient ground cover within 60 to 75 d depending on environmental conditions and cultivar. Green matter yields of about 20 Mg ha^{-1} are average (ICAR, 2000).

Yield Constraints and Management Strategies

Although it is somewhat disease and insect resistant, crop but many diseases and insects attack this crop. Hence, developing disease and insect resistant genotypes should be done through breeding. Furthermore, cultural practices to obtain maximum dry matter yield within short growth period need to be defined. Lines of sunnhemp found on the Indian subcontinent, show variability and they need to be collected, compared, and classified. Improved types suited to specific localities need to be selected.

VELVET BEAN

Velvet bean (*Mucuna pruriens* L. DC.) is synonymous with *Mucuna utilis*. Velvet bean originated in the tropical South or South parts of East Asia and has been widely distributed throughout the tropics. It was introduced to Florida (USA) in 1876, from where its range was extended into temperate and subtropical areas by breeding (Wuljarni-Soetjipto and Maligalig, 1997). It is mostly grown as a cover crop in Australia, Fiji Islands, Indonesia, Malaysia and Philippines. It is considered one of the most suitable crops for reclamation of fields infested with weeds, especially with burmuda grass (*Cynodon dactylon* L. Pers), *Cyperus rotundus* L. and *Imperata cylindrical* L. Raeuschel. It is recommended for use in rotation with cotton in Brazil to control *Fusarium oxysporum* and *Meloidogyne incognita* infestation (Wuljarni-Soetjipto and Maligalig, 1997).

Climatic and Soil Requirements

Velvet bean is grown in areas receiving annual rainfall in the range of 400 to 3000 mm and annual temperatures of 20 to 30°C. Velvet bean is susceptible to frost, and temperatures below 5°C for more than 24 h are fatal (Wuljarni-Soetjipto and Maligalig, 1997). It has a shallow root system and is not resistant to drought. It is also sensitive to waterlogging. This crop requires high light intensity and grows poor when intercropped with cassava or corn. It can grow on a wide range of soil textures ranging from sandy to clay. However, yields are optimum on light sandy soils with a mean pH of 5.8 (Duke, 1981). This crop is considered tolerant to acidity.

Nutrient Requirements

It is a lugume crop and hence fixes atmospheric nitrogen if nitrogen fixing bacterias are present in the soil. Rbizobia of lima beans, cowpeas, and lespedeza can be used to inoculate velvet beans. The crop grows relatively well on infertile soils, hence fertilizer is seldom applied to the crop. However, liming acid soils may improve root growth and growth and yield of velvet beans.

Morphology, Growth, and Development

Velvet bean is an annual plant with bushy and vining type growth habits. Seed germination is hypogeal. Leaves are alternate, 3-foliolate, and the inflorescence is an axillary raceme, up to 32 cm long. Stems are slender, slightly pubescent with white, straight, short and long hairs. It is a C_3 self-pollinated plant. Velvet bean grows very fast and can cover the ground in 2–3 months, forming a thick mat of about 60 cm deep and smothering weeds. Flowering start 90–145 d after sowing and pods begin to ripen 2–3 months after flowering. The first harvest of dry seed may be expected after 200–230 d (Wuljarni-Soetjipto and Maligalig, 1997). As a cover crop using an appropriate herbicide after 2–3 months of growth can kill it.

Several cultivated forms of *Mucuna pruriens* L. DC. have been described as distinct species. Among these prominent species are: *Mucuna aterrium* (Piper and Tracy) Merrill. This species is also known as Mauritius bean and is grown mainly in Brazil, Australia, West Indies and Mauritius as a cover or green manure crop. *Mucuna capitata* (Roxb.) Wight and Arnott, is cultivated in India and Indonesis for seeds. *Mucuna deeringiana* (Bort) Merrill, known as Florida or Georgia velvet bean, and is grown mostly in the USA for fodder or a cover crop. *Mucuna hassjoo* (Piper and Tracy) Mansf., also known as Yokohama velvet bean and is grown mostly in Japan. *Mucuna nivea* Wight and Arnott, known as Lyon bean is cultivated as a green pod vegetable crop in South-East Asia. Other species of velvet beans are *Mucuna pachylobia* (Piper and Tracy)

Rock, *Mucuna utilis* Wall. ex Wight and *Mucuna velutina* Hassk These species are grown mostly in Indian sub-continent as green vegetable crops (Wuljarni-Soetjipto and Maligalig, 1997).

Yield Constraints and Management Strategies

Deficiency of mineral nutrition, diseases and insects are main constraints of this cover crop. Hence, fertilizer studies are necessary to determine adequate rates of P, K, and other essential nutrients. In addition, developing diseases and insect resistant genotypes of this crop may be the best management strategies to improve yield under different agroecological conditions.

TEPARY BEAN

Tepary bean (*Phaseolus acutifolius* A. Gray) may have originated in Arizona or North-West Mexico (Purseglove, 1974). It is mainly grown in the USA and Mexico but is also grown to limited extent in Africa, Asia and Australia. Besides growing as a cover crop, tepary bean is grown to produce dry shelled beans and edible forage for livestock. Dry seeds contain 23–25% protein and this makes tepary bean nutritionally comparable to most economic legumes. In northern Mexico it is also consumed in soup and stews (National Academy of Sciences, 1979)

Climatic and Soil Requirements

Tepary bean grows well in regions where temperatures range from 20 to 30°C. This crop can not be grown where night temperature falls below 8°C. Tepary beans are susceptible to water logging and frost and are not suited to wet tropics (Duke, 1981). It is a drought tolerant crop and thrives in arid and semiarid regions. It can grow successfully where rainfall during the growing period is 500 to 600 mm and well distributed. It can be grown on a wide range of soils but is susceptible to salinity. It can grow on soils with a pH range of 5.0 to 7.1 but optimum pH for maximum growth is around 6.3 (Duke, 1981).

Nutrient Requirement

Tepary bean is grown mostly as a rain fed crop or on fallow soils with conserved soil moisture and fertilizers are generally not applied. However, on infertile soils, tepary bean responds favorably to applications of nitrogen, phosphorus and potassium (Duke, 1981). Although, research data are not available concerning nutrient requirements of this crop, but applications of 30 kg N ha^{-1}, 30 kg P ha^{-1}, and 30 kg K ha^{-1} can improve growth and yield. Similarly, liming acid soils at the rate of about 3 Mg ha^{-1} dolomite lime may be beneficial for growth and development of this crop. Rhizobium strains that nodulate lima beans and C*anavalia* species also cause nitrogen fixation in tepary beans. If roots are properly nodulated, application of nitrogen fertilizer is not necessary.

Morphology, Growth, and Development

Germination of tepary bean is epigeal. The plant is sub-erectannual with a height of 25 cm height and has spreading or twining type of growth habit. The first pair of leaves simple, each about 5.5 cm long and 3.5 cm wide, with petioles shorter at 4–5 mm long. The inflorescences is axillary with 2–5 white or pale lilac flowers (Purseglove, 1974). Pods are small with seeds resembling navy beans. It is a self-pollinated C_3 plant. It is quick maturing; some genotypes can produce beans in a 2 month growth period. As a cover or hay crop, it can produce 5.5 to 10 Mg ha^{-1} dry matter depending on soil fertility and climatic conditions. Seed yields of 500–800 kg ha^{-1} are common under dry farming conditions (Duke, 1981). Fertilization and moderate irrigation can obtain seed yields of 1,100 to 2,200 kg ha^{-1} obtained (National Academy of Sciences, 1979).

Yield Constraints and Management Strategies

Main yield constraints for tepary bean are infestation of diseases and insects. Hence, developing diseases and insect's resistance germoplasm are best management strategies for improving growth and yield of this cover crop. In addition, low soil fertility may also be constraints and supply of adequate amount of deficient nutrients can improve growth and yield.

LIMA BEAN

Lima bean (*Phaseolus lunatus* L.) is synonmous to *Phaseolus limensi*s Macf., *Phaseolus inamoenus* L. and also known as butter bean, Madagascar bean, Burma bean, towe bean, sieva bean and sugar bean. Indigenous to tropical America, undomesticated lima bean varieties can still be found growing in the Caribbean area as well as in central and South America. It is well adapted to the lowland tropics, especially to highly leach infertile soils of humid regions (National Academy of Sciences, 1979). Besides serving as a cover crop, lima bean is also grown for dried shelled beans and green beans used for canning and freezing. Sprouts are also eaten. Lima bean is a valuable soil fertility restoring plant and with humid lowland plantation crops such as rubber, the viny lima bean can be cultivated as a cover/green manure crop to protect soil from the ravages of heavy rainfall.

Climatic and Soil Requirements

Lima bean is a crop of wet tropical regions from sea level to 2,400 m in altitude. Seeds do not germinate satisfactorily at soil temperature below 20°C. Optimum temperatures for growth and development are 21 to 30°C. Above a temperature of 32°C flower shedding and pod drop may occur (Duke, 1981). It requires well drained soils having a sandy loam texture. Varietals differences in acidity tolerance have been reported; however, optimum pH for growth is reported to be around 6.2 (Duke, 1981). Although it is adapted to low humid regions, once established lima bean is highly resistant to drought.

Nutrient Requirements

As a legume lima bean can fix atmospheric nitrogen if appropriate nodulating Rhizobium strains are present in the soil. Bacterias that infect cowpea also infect lima bean for nitrogen fixation. Application of 30-40 kg P and 20–30 kg K ha^{-1} can improve yields of this crop when it is grown on low fertility soils. Acidic soils can be limed to bring pH around 6.0 for good growth of lima bean and consequently higher yields. In poor soils of the lowland humid tropics, it is better adapted and gives more reliable yields than common dry beans (*Phaseolus vulgaris* L.) (National Academy of Sciences, 1979).

Morphology, Growth, and Development

Lima bean germination is epigeal and it is a C3 plant. It is a self pollinated plant, some cross pollination always occurs. The plant is annual or perennial herb, having bush forms grow 0.6 m tall, and climbing forms up to 4 m. Leaves are trifoliate, usually hairy, 5–13 cm long and 3–9 cm wide. The inflorescence is an axillary raceme up to 15 cm long, with many flowers, and with 2–4 flowers at each node. The root system is tap and fibrous. Early maturing cultivars can be harvested from 100 d onwards. If the objective is to use this as a cover crop, to improve soil fertility and protect soil from erosion, plants can be moved or killed by using appropriate herbicide 75 to 90 d after sowing. It produces a grain yield of about 1500 kg ha^{-1} but some cultivars can produce up to 3000 kg seeds ha^{-1} (National Academy of Sciences, 1979).

Yield Constraints and Management Strategies

Information is limited concerning the range of adaptation of about lima beans under different agroecological regions and agronomical aspects of their cultivation. Hence, more research is needed to study these aspects. Furthermore, selection and breeding of genotypes for better adaptability to adverse soil and climatic conditions is an important strategy to improve its yield. This requires assembling, exploration, and evaluations of an extensive germplasma collection. Research is also needed on the symbiotic nitrogen fixation process in the physiology of plant growth.

BUTTERFLY PEA

Butterfly pea (*Centrosema pubescens* Benth), also known as centro and is synonymous with *Centrosema molle* Martius ex Benth. Origin of butterfly pea is reported to be South and Central America, and most probably originated in Costa Rica (Teitzel and Peng, 1997). It is one of the widely distributed legumes in the humid tropics. It is grown as a cover crop with rubber and oil palm plantation in Indonesia, Sri Lanka and Malaysia. It is also grown as a cover and pasture legume in Australia and other countries of South-East Asia.

Climatic and Soil Requirements

Butterfly pea is grown in humid tropics up to 600–900 m altitude with annual rainfall varying from 800 to 1500 mm. It can not tolerate prolonged drought and low temperature. The optimum temperature for growth is in the range of 20 to 30°C. Temperatures below 20°C can reduce germination and growth. The species can grow on wide range soils varied from sandy loams to clays. Optimum pH for growth is reported to be in the range of 5.5 to 6.0 (Teitzel and Peng, 1997). It is very susceptible to Al, manganese (Mn), and salinity toxicities. Nitrogen fixation is adversely affected by Al and Mn toxicities.

Nutrient Requirements

Information is unavailable concerning nutrient requirements of this cover crop. However, as a legume, it can fix atmospheric nitrogen, provided that seeds are inoculated with an effective *Bradyrhizobium,* and environmental conditions are favorable. It not only uses atmospheric fixed nitrogen for its growth but also supplies N to companion plantation crops. In acid soils liming improves growth of butterfly pea. The amount of lime applied should be sufficient to raise soil pH to around 6.0. Liming not only supplies Ca and Mg and reduces toxicities of Al and Mn in acid soils, but also improves P uptake efficiency of the crop (Fageria, 1992). Application of P and K in soils having low levels of these nutrients can improve growth and yield of this crop.

Morphology, Growth, and Development

Butterfly pea is propagated by seeds the and seed rate required is about 5 kg ha^{-1}. Butterfly pea is a vigorous climbing perennial herb. Leafy stem arises from the main runners at 0.5–1.5 m intervals. Leaves are trifoliolate, slightly hairy, 1–7 cm long and 0.5–4.5 cm wide, and the petiole up to 5.5 cm long. Flowers are, large, pale with purple lines in the center, born in axillary racemes, with 3–5 per raceme. Pods are linear, 4–17 cm long and 6–7 cm wide, flattened, dark brown when ripe, and contain up to 20 seeds. Growth is slow in the beginning but when grown in a pure sward butterfly pea forms a dense cover 35–45 cm deep within 4–8 months after sowing. Dry matter yields of cover crops are rarely measured. Pure stands of butterfly pea yields up to 12 Mg ha^{-1} and seed yield may vary from 200 to 500 kg ha^{-1} (Teitzel and Peng, 1997).

Yield Constraints and Management Strategies

Soil acidity and P and K deficiencies are the main yield constraints of this cover crop. Hence, experimental work to determine adequate lime and P and K fertilization may be the best management strategies to improve growth and yield of this crop.

CROTOLARIA

Crotalaria (C*rotalaria pallida* Aiton) is synonymous with *Crotalaria mucronata* Desv., and *Crotalari striata* DC. and is also known as smooth rattlebox. It originated in tropical Africa and is mainly grown as a cover crop in central and South America, India, Indonesia, Malaysia, Sri Lanka, Indo-China, and Australia. As a cover crop, it is mostly planted in plantation crops such as cocoa, coffee, tea and succeeding cash crops such as rice, corn, and tobacco. It is also used as fodder for livestock. In countries like Laos, Cambodia and Vietnam it is also used as a medicinal plant.

Climatic and Soil Requirements

Crotalaria grows under a wide range of climatic and soil conditions. It grows best on lowland areas, but is generally grown up to 1800 m in altitude. It can grow in a temperature range of 16 to 27°C and annual rainfall ranging from 850 to 3000 mm. Sandy loam to clays soils can sustain growth of crotalaria. In West Africa it is considered well suited to sandy soils (Aguilar, 1997). The optimum soil pH for its growth is reported to be around 6.0 (Duke, 1981).

Nutrient Requirements

As a legume it can fix atmospheric N if Rhizobia are present in the soil or seeds are inoculated. Legumes generally require additions of P, Ca, and Mg for good growth. Hence application of phosphate fertilizers and dolomite lime in acid soils to raise pH to 6.0 can improve dry matter yield of this crop.

Morphology, Growth, and Development

Crotalaria is an erect well branched annual or short-lived perennial herb, 1–2 m tall, with yellowish silky hairs; leaves are trifoliate and flowers are yellow. The inflorescence is a terminal, shortly pedunculate raceme, 15–40 cm long with 20–30 flower. Plants have to be topped when about 30 cm tall to promote branching. *C. Pallida* should be cut at least 20–25 cm above the ground to ensure good regrowth. It can be cut 3–4 times before it dies, generally after 1.5–2 years. Dry matter yield of 5.2 Mg ha^{-1} and 10.2 Mg ha^{-1} are reported from Florida and southern Brazil, respectively (Aguilar, 1997). The dry matter of *C. pallida* contains about 35 g N kg^{-1} (Aguilar, 1997).

Yield Constraints and Management Strategies

Genotypic adaptability to adverse environmental conditions may be a main constraint in growing this cover crop. Hence, evaluation of germplasm and breeding for tolerance to such adverse stresses may be an economically viable strategy.

WHITE TEPHROSIA

White tephrosia (*Tephrosia candida* Roxb. DC.) is synonymous with *Kiesera sericea* Reinw, *Robinia candida* Roxb., *Xiphocarpus candidus* Roxb. and *Cracca candida* Kuntze. In North America it is also known as white hoary pea. It originated in India and is cultivated in South-East Asia, Africa, South America, New Zealand and Hawaii. It is an important cover species for plantation crops such as rubber, oil palm, citrus, coffee, tea, and coconut. It is also grown as a cover crop in rotation with annual crops. Tephrosia is considered an effective in controlling erosion and restoring fertility of degraded land. It is grown occasionally as an ornamental plant.

Climatic and Soil Requirements

White Tephrosia is grown from -1600 m in altitude in the tropics with an annual rainfall of 700 mm to over 2500 mm and annual temperatures of 18–30°C. It is sensitive to frost and waterlogging. It thrives in poor, eroded, and mine spoils soils. Tephrosia grows in sandy to clay textured soils. It can grow on soils having a pH from 5 to 7, but optimum pH is reported to be around 6.0 (Oyen, 1997). Cultivars adapted to acidic conditions are sensitive to salt affected soils. It can be grown on acid soils, however liming to raise soil pH around 6.0 may improve its growth and yield.

Nutrient Requirement

As a legume, White Tephrosia fixes atmospheric nitrogen, if nitrogen fixing Rhizobia (*Bradyrhizobium*) are present in the soil or seeds are inoculated. As a legume it requires more phosphorus, calcium and magnesium than grasses. In low fertility soils, applications of 30–40 kg P ha^{-1} and 20–30 kg K ha^{-1} improve yield of this cover crop.

Morphology, Growth, and Development

White tephrosia is a shrub with branches growing from the base up to 3.5 m tall. Leaves are compound, 1–2 cm long; stipules are 5–11 mm × 8–1.5 mm, leaflets (6–13 pairs), are opposite, and narrowly ovate (Oyen, 1997). The inflorescence is a terminal, axillary, having many flowers, solitary or 3–6 together; and petals are white to pale rose (Duke, 1981). Pods are linear, 7–12 cm long and 0.5–1 cm wide with about 10–15 seeds each (Oyen, 1997). It is a deep rooted crop and which grows slowly in the beginning but faster after establishment. Maximum growth normally takes place in the second year after planting, but with regular pruning a dense cover can be maintained for many years. It can produce 10–20 Mg green matter ha^{-1} and 350 to 500 kg ha^{-1} of seeds (Oyen, 1997).

Yield Constraints and Management Strategies

Tephrosia is susceptible to many root fungal diseases and to the nematode. Selecting and breeding germplasm resistance to these diseases can be helpful in reducing cost of production and improving yields.

VOGEL TEPROSIA

This species is native to tropical Africa. Vogel tephrosia (*Tephrosia vogelii* J. D. Hooker) is also known as fishbean and synonymous with *Cracca vogelli* J. D. Hooker and *Tephrosia periculosa* Baker. It is used as a cover crop for coffee, tea, rubber and coconut in tropical countries. It is also used for ornamental plants, hedge, fence or windbreak. In some areas it is also used as a medicinal plant.

Climatic and Soil Requirements

Vogel tephrosia can be grown at altitude up to 2100 m with 850–2650 mm annual rainfall and at annual mean temperatures ranging from 13 to 27°C. It grows well on well drained sandy loam to clay loam soils having pH 5 to 6.6 (Sunarno, 1997). It is susceptible to waterlogging and frost.

Nutrient Requirements

Data are not available for nutrient requirements of this crop in the literature. Hence, research work is needed to determine influence of essential nutrients, especially P and K on the growth and yield.

Morphology, Growth, and Development

Germination is epigeal and this plant is a soft woody branching herb or short-lived shrub 1–4 m tall. Leaves are compound with leaf rachis 10–25 cm long, including a petiole 1–3 cm long (120). The inflorescence is a terminal or axillary pseudoraceme, 8–26 cm long, with flowers in fascicles of 2, and 18–26 mm long. Pods are linear, slightly turgid, 5.5–14 cm long and contains 0.8–1.8 cm wide and 6–18 seeds each (Sunarno, 1997). Under favorable environmental conditions, growth of this crop is fast. In Indonesia plants may achieve 36 cm height in 3.5 months and 2 m or more in one year after planting. Maximum biomass is obtained before flowering starts and green matter yield of 5 months old crop was reported to be 27 Mg ha^{-1} (Sunarno, 1997).

Yield Constraints and Management Strategies

Vogel tephrosia crop is frequently reported to be attacked by fungal diseases and nematodes (Duke, 1981). Hence, selection and breeding for diseases and nematodes resistance can improve yields of this crop.

BLACK GRAM

Black gram (*Vigna mungo* L. Hepper) is also known as urd in India and is synonymous with *Azukia mungo* L. Masamune and *Phaseolus mungo* L. It is one of the most important legumes in India, eaten whole or split, boiled or roasted, ground into flour and used to make cakes, and breads. Green pods are eaten as vegetables. It has been introduced to the southern United States, West Indies and other tropical areas. It is an important green manure or cover crop and also used as forage for livestock and as a medicinal plant.

Climatic and Soil Requirements

It is grown as a rainfed crop in the warm plains as well as in the cool hills of India up to an altitude of 2,000 m. Black gram can be grown in areas with a temperature range of 8 to 28°C, with optimum about 22°C. It is a dry area crop where rainfall is less than 900 mm annually. It is not suitable for the wet tropics and in for heavy rainfall areas where it may be planted after the rains cease. It requires loamy to clay soils having high water holding capacity. It does well on black cotton and brown alluvial soils (ICAR, 2000). It is well suited to lowland rice soils and grown before and after rice planting. It can be grown on soils having a pH range from 4.5 to 7.5 but optimum pH is around 6.4 (Duke, 1981).

Nutrient Requirements

Being a legume, black gram can fix atmospheric nitrogen; however, application of 30–40 kg P ha^{-1} and 20–30 kg K ha^{-1} can improve yields of this crop. On acid soils lime and gypsum can improve yields.

Morphology, Growth, and Development

Black gram is an erect, branched annual herb that grows up to 90 cm tall. Leaves are trifolioate, ovate, 5–10 cm long, on long petioles; flowers are yellow, 5–6 developed in an elongated axillary raceme. Pods 4–7 cm long and 6 cm wide with long hairs. Germination is epigeal and the plant has a strong taproot with many laterals. It is a self pollinated C_3 plant. Plants flower about seven weeks after sowing and pods are ready for harvest in about 75 to 140 d, depending on cultivar and climatic conditions. Seed yields of 350 to 600 kg ha^{-1} are common. Dry matter yield is about 3 times that of seed yield (Duke, 1981).

Yield Constraints and Management Strategies

Poor genotypic adaptability, low nitrogen fixing capacity and lack of information about lime and fertilizer requirements are main constraints to the growth of black gram. Genotypes with high nitrogen fixing capacity should be identified to add more nitrogen in the cropping systems. Genotypic adaptability to different agro-ecological regions should be tested. The crop is sensitive to many diseases and insects. Hence, disease and insect resistant material should be developed.

EGYPTIAN CLOVER

Egyptian clover (*Trifolium alexandrinum* L.) is also known as berseem clover. It is native to the Mediterranean region, near East and India and is cultivated mainly in the tropical and subtropical regions. It is a very important forage crop in India, Pakistan and Egypt. It is also cultivated in California and Florida in the USA and is widely used as a forage crop but can be used as a cover crop.

Climatic and Soil Requirements

Egyptian clover is least winter hardy of the cultivated clovers. It can be grown in the temperature range of 7 to 30°C, but the optimum temperature is between 20 to 25°C. Critical maximum temperature for leaves to retain biological activity is between 43 to 45°C. Temperatures near 35°C result in lower concentrations of total available carbohydrates, condition that is detrimental to root growth (Bowley and Taylor, 1984). Mature plants can stand much lower temperatures than seedlings. This species can grow in areas with annual precipitation in the range of 380 to 1660 mm, with mean annual of 8700 mm (Duke, 1981). Some cultivars are as tolerant to drought as alfalfa. On sandy loam soils, maximum water uptake of Egyptian clover was estimated to at 5 mm day^{-1} (Bowley and Taylor, 1984).

Berseem can be grown on a wide range of soils, varying from sandy loam to clay. Soils should be well drained for good berseem growth. It can grow in the pH range of 4.9 to 7.8 with optimum; however, the reported optimum pH is around 6.8 (Duke, 1981). At pH values lower than 5.0 nitrogen fixation is significantly reduced. Berseem clover is moderately susceptible to salinity with a threshold reported to be about 1.5 EC_c dS m^{-1} for shoot dry weight (Maas, 1993). Growth of berseem clover is reduced at exchangeable sodium percentage of 20–40%. Seed germination is less than 70% at electrical conductivities greater than 7.5 dS m^{-1} (Bowley and Taylor, 1984).

Nutrient Requirements

Berseem clover fixes atmospheric nitrogen and seeds should be inoculated with the appropriate Rhizobium. Clover fixes dinitrogen (N_2) through a symbiotic relationship with *Rhizobium leguminosarum* biovar *trifolii* (Bowley and Taylor, 1984). Nodules may form with other biovarieties of Rhizobium; however, these nodules appear incapable of N_2 fixation (Bowley and Taylor, 1984). Commercial white clover inoculants are effective. In acid soils liming improves yield and rates varying from 2.5 to 5 Mg ha^{-1} can be used depending on original soil acidity level. Research data are not available regarding fertilizer requirements. However, Duke (Duke, 1981) reported that on Florida flatwood soils an application of 700–800 kg ha^{-1} of −12–12 plus 5% copper oxide (CuO), manganese oxide (MnO), zinc oxide (ZnO), boric oxide (B_2O_3), or equivalent fertilizer should be applied and disked in prior to drilling the seed.

Morphology, Growth and Development

Berseem clover is an annual legume of 30–60 cm height and having basal and profuse branching. Cultivars with longer growth cycles have longer stems than early types. Seed germination is epigeal and begins about three days after imbibition of water by the seed. Seeds of berseem can germinate when the soil surface is moderately dry and from a greater depth than white clover. Seeds should be planted 1.5 to 2.5 cm depth. As a dicotyledonous, plant leaves of berseem are alternate phyllotaxis. The first true leaf is unifoliolate whereas succeeding leaves are palmately trifoliolate. The critical leaf area index (95% light interception) is around 5.0. The inflorescence of clover is a terminal capitulum's or head, which arises from an axillary bud at the shoot apex. Pods are oblong ovoid, included, and 1 seeded similar to those of red clover but larger (Duke, 1981). Botanically, the fruit of clover is a pyxidium. This is a cross pollinated C_3 species. It grows faster than white clover. It has a deep tap root system with many lateral adventitious roots, which give it a drought tolerance. Maximum root growth occurs at the full bloom stage. This species produces a yield of 3–7 Mg ha^{-1} dry matter and seed yields of 200 to 500 kg ha^{-1}.

Yield Constraints and Management Strategies

Information on the agronomy and physiology of Egyptian clover is scant relative to the current and potential use of this cover crop. Research on use of this crop in crop rotation and in plantation crops should be expanded covering soil ameliorating properties to environmental adaptability. Diseases and insects reduce yields of this crop. Hence, breeding of disease and insect resistant clover cultivars should be given top priority.

BRAZILIAN STYLO

Brazilian stylo (*Stylosanthes guianensis* Aubl. Sw.) also known as simply as stylo, Brazilian lucerne and is synonymous to *Stylosanthe gracilis* H. B. K., *Stylosanthe surinamensis* Miq., and *Trifolium guianense* Aubl. It is a wide spread native legume of tropical central and South America. Its origin is considered The State of Minas Gerais, Brazil. It is also grown in Africa, Asia and Australia as a pasture and cover crop. In the humid tropics, it is widely grown as a pioneer legume in grass/legume pasture on infertile soils. It is a good choice for soil building and forage purposes. However, its use in plantation crops such as coffee, banana, oil palm and cacao need to be tested because its light requirement is reported to be high (Duke, 1981).

Climatic and Soil Requirements

It can be grown at an altitude of 2000 m or lower and with an annual precipitation of 530 to 4100 mm with a mean of 1560 mm (Duke, 1981). Brazilian stylo can be grown in areas with annual mean temperatures of 18 to 28°C with an optimum around 25°C. It can be grown on sandy to clay soils but sandy loam soils are best for its growth. It can not tolerate water logging and hence soils should be well drained. It can grow on soils with pH range of 4.3 to 7.7 but optimum pH reported to be around 5.7 (Duke, 1981).

Nutrient Requirements

Although it grows reasonably well on low fertility, acidic soils liming and fertilization have improved yields of this crop. As a legume is can fix atmospheric nitrogen if *Rhizobium* strains are present in the soil. Otherwise, seeds should be inoculated with *Rhizobium*. Lime application should be determined by pH or base saturation. A pH around 6.0 and base saturation about 50% is considered adequate for maximum growth of this crop. Quantities of P and K to be applied should be determined by soil testing for these nutrients. In Brazilian Oxisols, Mehlich 1 extractable soil P levels of about 8 mg P kg^{-1} can produce good yield of this crop. Similarly Mehlich 1 extractable K of 60 mg kg^{-1} is adequate.

Morphology, Growth, and Development

Brazilian stylo is an perennial herb, semi-erect, rarely prostrate, often much branched with a height that may reach 1 m. Leaflets are lanceolate to oblong or linear-lanceolate, densely hirsute, with yellow hairs, and acute at apex and base. The inflorescence of stylo is a terminal capitulum with 1–40 flowers. Pods are 1-jointed, the lower joint usually aborted, the upper one glabrous, and reticulated; seeds pale brown or purple. Dry matter yields of 3.5 to 10 Mg ha^{-1} are common, depending on cultivar and environmental conditions (Duke, 1981).

Yield Constraints and Management Strategies

In Brazil stylo is mostly grown in the cerrado region or central part of the country. Soils of the cerrado regions are predominantly Oxisols and Ultisols. These soils are acidic and have low natural fertility. Hence, liming and application of P and K as well as some micronutrients (Zn, Cu, and B) can improve yields. Breeding for nutrient efficiency, especially P is important because P is one of the most yields limiting nutrients in Brazilian acid soils. Some fungal diseases also attack the stylo plants and germplasm selection for disease resistance is an important strategy.

ADZUKI BEAN

Adzuki bean (*Vigna angularis* Willd. Ohwi and Ohashi) is also known as adsuki bean and is synonymous with *Azukia angularis* Willd. Ohwi & Ohashi, *Dolichos angularis* Willd. and *Phaseolus angularis* Willd. Wight. It is probably native to Japan or India and now is cultivated throughout tropical and subtropical regions.

Besides a cover crop, it is also used as human food in several forms and as a forage crop. In China it is used as a medicinal plant.

Climatic and Soil Requirements

The climatic requirements for Adzuki bean are similar to those for soybeans. It can tolerate high temperature, however soil temperatures above 16°C are required for good germination. Optimum temperature is in the range of 20 to 30°C. It can grow well with annual precipitation ranging from 530 to 1730 mm with a mean of about 1250 mm. It is fairly drought tolerant and susceptible to water logging. It grows well on sandy loam soils with a pH ranging from 5.0 to 7.5, with an optimum pH of around 6.1.

Nutrient Requirements

Adzuki bean is a legume and fixes N very efficiently (Duke, 1981). However, small amounts of N as a starter fertilizer are recommended. Duke (1981) reported that in India applications of 20 kg N ha^{-1}, 60 kg P ha^{-1}, and 50 kg K ha^{-1} are recommended for adzuki bean. Liming in acid soils will improve yield of this legume. Lime rate should increase soil pH around 6.0.

Morphology, Growth, and Development

Seed germination of adzuki bean is hypogeal. It is a summer annual, usually bushy and erect, 30–80 cm in height. However, some late maturing cultivars may be slightly winy and may be some prostrate. Leaves are trifoliate, petiole long, and leaflets ovate. The inflorescence is axillary, short, 6–12 clustered bright yellow flower on short pedicles Pods are cylindrical, 6–12 cm long and 0.5 cm wide with 5–12 seeds. Hundred seeds weight is 10–20 g (Purseglove, 1974). It is a self-pollinated C_3 plant having vigorous tap root system. Adzuki bean matures in 3–5 months depending on cultivar and environmental conditions. Grain yield may vary from 500–1200 kg ha^{-1}.

Yield Constraints and Management Strategies

Yield is generally low and research data are not available on genotypic adaptability and nutrient requirements. Hence, experimental work should be conducted along these lines to improve yields.

RICE BEAN

Rice bean (*Vigna umbellata* Thunb. Ohwi & Ohashi) is also known as climbing mountain bean, mambi bean and oriental bean. It is synonymous with *Azukia umbellata* Thunb. Ohwi, *Phaseolus calcaratus* Roxb., and *Phaseolus pubescens*

Bl. Rice bean may have originated in India or China. As a cover/green manure crop, it is also grown for human food in Asia and Pacific Islands. It is also grown to a limited extent in Australia, USA, Africa and West Indies.

Climatic and Soil Requirements

It is tolerant to high temperature and moderately drought tolerant. It grows well where temperature average is 18–30°C and rainfall is 1000–1500 mm. Loamy soils are best for its growth with a pH range of 6.8 to 7.5 and average of 7.2.

Nutrient Requirements

As a legume rice bean fixes nitrogen. An application of 30–40 kg P and 25–30 kg K ha^{-1} is recommended.

Morphology, Growth, and Development

Germination is hypogeal and it is a self pollinated C_3 species. Rice bean is an annual, erect to sub-erect or twining and stems 30–75 cm tall, producing vining branches 102 m long. The stem is grooved with short hairs. Leaves are trifoliate, petioles 5–10 cm long, leaflets large, ovate, apex acute, 6.5–16 cm long, 4–10 cm wide, lateral leaflets oblique. The inflorescence is an erect axillary raceme, penduncle 7.5–20 cm long with 5–20 flowers. Pods are long and slender, 6–12.5 cm long and 0.5 cm broad and having 6–12 seeds. Time to maturity is about 60–140 d and grain yields of 300–800 kg ha^{-1} are common. Cover crop or forage rice bean can be harvested in 70–80 d after sowing.

Yield Constraints and Management Strategies

Some fungal diseases such as *Corticium solani*, *Myrothecium roridum* and *Woroninella umbilicata* reduce yield of this crop. Breeding disease resistant genotypes may be a sound strategy for improving yield of this crop.

SESBANIA

Sesbania (*Sesbania bispinosa* Jacq.W. F. Wight) is also known as danchi, dunchi fiber and canicha. There are about 50 species of sesbania. However, synonymous or most closely related species are *Sesbania aculeata* Willd. Pers., *Sesbania cannabina* Retz. Poiret, *Sesbania rostrata* Bremek & Oberm, *Sesbania sericea* Willd Link, Sesbania australis F. Muelle. *Sesbania grandiflora* L. Poiret, *Sesbania javanica* Miquel, and *Sesbania pubescens DC* (Ipor and Oyen, 1997). Sesbania is grown as a green manure/cover crop, and as a fiber and forage crop throughout the tropics and subtropics. It is commonly grown as a cover crop with tea in India and with banana in Taiwan (Ipor and Oyen, 1997). Seeds of sesbania are also used in making medicines and gums.

Climatic and Soil Requirements

Sesbania is grown in areas with an annual temperature range of 20 to 30°C and annual rainfall varying from 570 to 2210 mm (Duke, 1981). It can not tolerate frost. This crop requires heavy textured soils and can tolerate waterlogging. It can grow in the pH range of 5.8 to 7.5 with an optimum of 6.9 (Duke, 1981). Ipor and Oyen (1997) reported that in India it grows in the pH range of 5.6 to 9.3. It is moderately tolerant to soil salinity (Maas, 1993). Under irrigated conditions, like rice, sesbania can tolerate high concentration of sodium (exchangeable sodium percentage $\geq$50 of soil CEC (Ipor and Oyen, 1997).

Nutrient Requirements

Generally, fertilizers are not applied to this crop. As a legume it can fix atmospheric nitrogen if proper Rhizobium strains are present in the soil or seeds are inoculated. Acid soils should be limed to get good growth of sesbania. An application of 30 kg P and 20 kg K ha^{-1} improves yield of this crop in acidic as well as alkaline soils.

Morphology, Growth, and Development

Sesbania is an erect annual, or short lived perennial, herbs or slightly woody shrub, with a stem height of 1–3 m and stem diameter of about 30 cm (National Academy of Sciences, 1979; Duke, 1981). It is a self pollinated C_3 plant. Under waterlogged conditions, stems produce spongy mass of aerenchyma to transport oxygen, which provides tolerance to water logging. Some species of sesbania produce nitrogen fixing nodules even on the stem. Leaves are pinnate, up to 38 cm long, leaflets 18–55 pairs, 1.2–2.5 cm long and 0.3 cm wide (Duke, 1981). The inflorescence is an axillary or terminal raceme, 2–8 flowered and 2.5 to 7.5 cm long (Duke, 1981). Pods are up to 25 cm long with up to 50 seeds per pod. As a cover/green manure crop, it can produce sufficient dry matter in 2–3 months. Seeds mature in about 5–5.5 months in India and about 2 months in the United States. Dry matter yields of 4–10 Mg ha^{-1} and seed yields of 600–1000 kg ha^{-1} can be obtained depending on cultivar and environmental conditions (Duke, 1981; Ipor and Oyen, 1997).

YIELD CONSTRAINTS AND MANAGEMENT STRATEGIES

Sesbania is attacked by several nematodes and hence, genotypes resist to nematodes should be developed. There is no information on its nutritional

Table 2
Minimum, maximum and mean temperature and precipitation tolerance of major cover crops

	Temperature (^{0}C)			Precipitation (mm)		
Crop species	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Pearl millet	20	40	30	400	600	500
Sorghum	10	36	23	400	1000	700
Cowpea	20	30	25	300	400	350
Pigeon pea	19	43	33	530	4030	1450
Mung bean	8	30	19	280	410	345
Moth bean	25	30	28	100	400	250
Guar	8	30	19	380	2410	1395
Peanut	12	30	21	500	700	600
Tropical kudzu	22	34	28	1000	1500	1250
Calopo	19	28	24	870	1250	1060
Hairy indigo	16	28	22	900	1450	1175
Jackbean	14	30	22	640	1710	1175
Lablab bean	22	35	29	320	1290	805
Sunnhemp	10	30	20	400	1490	945
Velvet bean	20	30	25	400	2210	1305
Tepary bean	17	20	19	640	1730	1185
Lima bean	6	30	18	310	1550	930
Butterfly pea	19	30	25	800	1500	1150
Crotolaria	16	30	18	850	3000	1925
White tephrosia	18	30	19	700	2500	1600
Vogel tephrosia	13	27	20	850	2650	1750
Black gram	8	28	18	600	900	750
Egyptian clover	7	30	19	380	1660	1020
Brazilian stylo	18	28	20	530	4100	1560
Adzuki bean	20	30	25	530	1730	1130
Rice bean	18	30	24	1000	1500	1250
Sesbania	20	30	25	570	2210	1390

Source: Duke (1981), ICAR (2000), Hanum and Van der Maesen (1997).

requirements and nitrogen fixing capability of this species when grown under different plantation crops. These aspects should be studied for better management of this crop in plantation agriculture.

CONCLUSIONS

Evaluating the impact of agricultural practices on agroecosystem functions is essential in determining the sustainability of a management system. In recent years, increasing costs of crop production and concern for environmental

Table 3
Soil type, seed rate and spacing required for growing cover crops

Crop species	Soil type[1]	Seed rate (kg ha^{-1})	Spacing between row (cm)
Pearl millet	S-CL	5–6	25–35
Sorghum	SL-CL	10–12	30–45
Cowpea	SL-C	20–25	40–50
Pigeon pea	SL-CL	12–15	50–90
Mung bean	SL-CL	20–25	20–30
Moth bean	S-CL	25–40	10–20
Guar	SL	30–60	15–25
Peanut	SL-L	110–120	30–60
Tropical kudzu	L-CL	6–8	80–100
Calopo	SL-C	1–3	Broadcast
Hairy indigo	SL	6–10	Broadcast
Jackbean	SL-CL	25–30	60–75
Lablab bean	SL-CL	20–30	75–100
Sunnhemp	Sl-L	90–100	Broadcast
Velvet bean	SL	45–90	Broadcast
Tepary bean	SL	15–20	60–70
Lima bean	SL	60–80	80–90
Butterfly pea	SL-C	5–6	20–30
Crotolaria	SL-C	10–20	45–50
White tephrosia	SL-C	15–20	Broadcast
Vogel tephrosia	SL-CL	5–6	40–45
Black gram	L-C	13–22	25–30
Egyptian clover	SL	20–25	Broadcast
Brazilian stylo	SL-CL	2–2.5	30–40
Adzuki bean	SL	25–30	30–40
Rice bean	SL-CL	70–90	Broadcast
Sesbania	C	20–60	30 or broadcast

[1]S = Sandy, CL = Clay loam, SL = Sandy Loam, L = Loam, C = Clay.
Source: Duke (1981), ICAR (2000), Hanum and van der Maesen (1997).

pollution hence led to significant developments in cropping practices. A great deal of emphasis has been placed on the use of cover crops to prevent soil erosion, and improve nutrient management, particularly the use of legumes in supplying N to nonleguminous crops and control of pests. The most important decision requiring the use of cover crops in a cropping system is the choice of species and genotypes within species that are well suited to the soils and climatic conditions where they are to be grown. When crops are adapted to their growing conditions, the benefits of good agronomic practices can greatly increase their yields. Therefore, information provided in this review about selected cover tropical crops will help in selecting a crop for a particular situation,

Table 4
Minimum, maximum and optimum soil pH and nutrient requirements for major cover crops

	pH in water			
Crop species	Minimum	Maximum	Optimum	Nutrient (kg ha^{-1})[1]
Pearl millet	5.0	8.0	6.5	40-30-30
Sorghum	5.0	8.5	7.0	50-50-30
Cowpea	5.5	6.5	6.0	0-60-40
Pigeon pea	5.0	8.0	7.0	20-50-30
Mung bean	5.8	6.5	6.2	20-20-40
Moth bean	7.0	8.0	7.5	0-20-30
Guar	5.5	8.0	7.0	0-30-20
Peanut	5.0	5.5	5.3	20-70-30
Tropical kudzu	5.5	6.5	6.0	0-50-40
Calopo	4.5	8.0	6.3	0-40-40
Hairy indigo	5.0	8.0	6.5	0-30-40
Jackbean	4.5	7.0	5.8	0-35-30
Lablab bean	4.4	7.8	6.1	20-40-30
Sunnhemp	5.0	8.4	6.7	0-20-20
Velvet bean	5.0	5.8	5.4	0-40-20
Tepary bean	5.0	7.1	6.1	0-30-30
Lima bean	6.0	7.0	6.5	0-40-30
Butterfly pea	5.5	6.0	5.8	0-40-30
Crotolaria	5.5	6.0	5.8	0-40-20
White tephrosia	5.0	7.0	6.0	0-40-30
Vogel tephrosia	5.0	6.6	5.8	0-30-30
Black gram	4.5	7.5	6.0	0-40-30
Egyptian clover	4.9	7.8	6.4	0-80-80
Brazilian stylo	4.3	7.7	6.0	0-40-30
Adzuki bean	5.0	7.5	6.3	20-60-50
Rice bean	6.8	7.5	7.2	0-40-30
Sesbania	5.8	7.5	6.7	0-30-20

[1]Nutrient rate corresponds to N, P and K, respectively.
Source: Duke (1981), ICAR (2000), Hanum and Van der Maesen (1997).

better planning of production practices and, consequently, in increasing yields. It is difficult to cover all the cover crops of the tropics in one review. Therefore, some major cereal and legume cover crops were selected and their agronomy and physiology are synthesized. Major climatic, soil and cultural requirements of these cover crops are presented in Tables 2, 3, and 4. Readers who need detailed information about physiology and production practices may refer to several references cited at the end of the review.

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