Chapter 2

LITERATURE REVIEW

1. Green manure and soil productivity

Many studies have shown that green manure contributed positively to soil productivity in terms of the soil's organic matter and N availability, both in the short and long terms.

Many green manure legumes provide a succeeding rice crop with an equivalent of 50 to more than 100 kg N fertilizer per ha and, consequently, increase rice yields from about 1.5 to 2.5 t/ha (Bouldin, 1988; Abrol and Palaniappan, 1988). Westcott and Mikkelsen (1988) reported that green manure crop can supply 30-50% of the N required for rice; the percentage of N supplied depends on the quality and quantity of green manure, the time and method of application, the soil fertility status, and the kind of crops and cultural methods.

However, green manure has important effects on soil properties other than the ability to supply N. In the long term, these effects may be economically more important than the value of green manure as N source (Bouldin, 1988). Ishikawa (1988) also concluded that beneficial effects on soil properties are more important than N source.

Approximately 50-80% of the total N content in most green manure legumes decomposes within the first rice crop. The remaining N decomposes slowly over several years (Bouldin, 1988). Therefore, annual application of green manure has cumulative residual effects on both the

N supply and the soil´s organic matter. These effects produce greater and greater benefits to the soil´s properties as time goes on.

In general, green manure can substitute an important portion of N fertilizer in the short-run. In the long-run application, green manure increases the soil´s N content and the available phosphate content in the soil; maintains and renews soil´s organic matter and improves soil´s structure and physical characteristics (Ishikawa, 1988; Rinaudo et al., 1988).

2. *Sesbania rostrata* as potential green manure species in paddy fields

The N_2-fixation potential of *S. rostrata* is much higher than that of soybean (Dreyfus et al., 1983).

The most distinctive characteristic of *S. rostrata* is the presence of predetermined nodulation sites along the stems which form nitrogen-fixing nodules when infected by the appropriate rhizobium. *S. rostrata* can bear nodules on roots as well as on stems (Dreyfus et al., 1983). However, in flooded soil, the stem nodules are more important than root nodules that are located only on the surface of the lateral roots floating in water. The total weight of root nodules are low (2 to 4 g fresh weight per plant compared to that of stem nodules (15 to 40 g fresh weight per plant). Thus, N_2-fixing activity is mainly due to stem nodules (about 96% of total acetylene reduction assay -Dreyfus et al., 1983; Ladha et al., 1988).

S. rostrata can give a high biomass and N_2-fixation over any leguminous green manure crops (10 to more than 30 t fresh weight per ha and 50-270 kgN/ha within 30-75 days after sowing) and increase successive rice yield from 0.2 to 2 t/ha (Vejpas et al., 1990). *S. rostrata* contains high amounts of N, P, K and micro-elements. N and P are found in large amounts in leaves, with lesser amounts found in roots and stems, respectively. K content is highest in the stems (Chungchu, 1988).

Palaniappan and Srinivasulu (1990) reported that *S. rostrata* not only enhances rice yield but also maintains soil fertility in a highly intensive rice-based cropping system. They quantified that green manure increases the levels of the soil's total N content (by 0.006% increased), and the soil's organic carbon content (by 0.018% increased) and does not deplete the level of the soil's available N, even after 2 years of continuous cropping.

Moreover, in paddy field, *S. rostrata* probably acts as a plant trap for nematodes (*Hirschmanniella oryzae* and *H. spinicaudata*) (Rinaudo et al., 1988) and as a limiting factor on pathogenic nematode population that can help rice to avoid damage. This protective effect is a beneficial characteristic of *S. rostrata* in paddy fields.

3. Biological characteristics of *Sesbania rostrata*

3.1. Adaptation to physical environments:

Climate

Rinaudo et al. (1988) reported that, at 15^{o} N latitude of Senegal, under 17-38^{o}C of mean temperature, and 11-13 hours of daylength, *S. rostrata* grew well in flooded soils during the rainy season (June-September). Plant height is 2m or more after 3 months and flowered at the second or third month. It is particularly sensitive to temperature and photoperiod. It needs a relatively long photoperiod and high temperature to grow well. Monthly planting of *S. rostrata* in Tamil Nadu showed that seeding in February to August biomass and N accumulation increase sharply with planting dates. In addition, the Tamil Nadu case showed that the highest biomass (54 t/ha) and N accumulation (282 kg/ha) are obtained at 60 days after seeding with planting date in May. Planting in December, *S. rostrata* gives the lowest biomass and N accumulation (11 t/ha and 52 kgN/ha, respectively) (Rinaudo et al.,1988). Similar results have been reported by Kim et al.(1990) in Cantho, Vietnam. Nodulation and N content of above ground portion are higher in the crop sown during warmer part of the year and lower when sown during the cooler part of the year. Palaniappan and Srinivasulu (1990) reported that there are strong and positive correlations between the minimum temperature and plant height, biomass, nodulation and N-fixation. There is no-significant correlation between these with maximum temperature, diurnal temperature difference, relative humidity, solar radiation or sunshine duration.

Soil

S. rostrata can grow well on waterlogged soils. It is tolerant to a certain level of soil salinity, alkalinity and acidity (Dreyfus et al., 1983). It can grow on many types of soil but infertile sandy soil reduces its growth rate, nodulation and nitrogen fixation.

3.2. Nodulation:

S. rostrata can bear nodules on roots as well as on stems. Root nodulation begins as early as 14-30 days after sowing (DAS) when grown on non-inundated soil. The large nodules are at the base of main root having 2 or 3 lobes and are 0.2 to 1.5 cm in length. Another type of root nodule which is located on lateral roots is spherical in shape, small (0.1-0.2 cm in diameter) and numerous. When grown on inundated soils, the large nodules disappear rapidly and only those nodules located on the surface of the lateral roots remain (Dreyfus et al., 1983).

Stem nodulation is an important advantage of *S. rostrata*. It initiates at about 21 DAS and, by 45 DAS, the nodulation is profuse throughout the stems. Number and weight of stem nodules may vary from plant to plant. Mature plants can bear 15 to 40 g/plant of stem nodules in fresh weight compared to 2 to 5 g/plant of root nodules. Nodulation sites are continuously formed and remain sensitive to *Rhizobium* infection throughout the life of the plant. Thus, nodule formation can occur at any time during the growth cycle. In contrast with temperate legumes, infection in *S. rostrata* does not occur through root hairs. Dust, insects and rain seem to play a significant role in stem nodulation as bacteria carriers (Dreyfus et al., 1983; Subbarao, 1988).

3.3. Rhizobium:

Two types of *Rhizobium* strains have been isolated. Stem strains are capable of nodulating on both stems and roots, and are identified as *Azorhizobium caulinodans* type ORS 571 (IRRI, 1987). Another type is a root strains which nodulates only on the roots. ORS 571, known as the competitive and effective strain in N_2-fixation, is able to grow and fix atmospheric N as the sole N source (Dreyfus et al., 1983). Inoculation of ORS 571 can increase number and weight of stem nodules, therefore, increase nitrogen fixation. Dreyfus et al. (1983) also identified that the stem strain of rhizobium on *S. rostrata* (type ORS 571) is fast-growing and assimilates both soil and atmospheric N. It also has the ability to nodulate and fix N even with level of combined N in the soil high enough to inhibit root nodulation.

3.4. Nitrogen fixation:

N_2-fixation of *S. rostrata* exhibits 2 unique properties. First, *S. rostrata* is considered as one of the most powerful nitrogen fixing system. Its N_2-fixing rate, by the acetylene method, is about 600 µmole C_2H_4/hour/plant (or about 200 kg N/ha in 50 days by the nitrogen balance method), a much greater rate than that of Soybean (14-120 µmole C_2H_4/hour/plant (Dreyfus et al., 1983). Second, *S. rostrata* has ability to nodulate and fix N_2 even when the combined N levels in the soil are as high as 200 kg N/ha (Dreyfus et al., 1983). It is capable of assimilating both soil and atmospheric nitrogen.

Application of inorganic fertilizers (P, N) and organic matter has been reported to stimulate nodulation and N_2-fixation processes (Gibson et al., 1982, adapted from Ladha et al., 1988). P is required for efficient N_2-fixation. P fertilizer increases biomass and N content of green manure crops. A low level of N as a starter dose is found to promote nodulation and N_2-fixation of grain legume crops. But in lowland soil, this may not be needed because their natural fertility is higher. It is also noted that applying combined N reduces root nodulation but increases nodulation and N_2-fixation of stems until it reaches the critical level of N fertilizer as high as 100 kgN/ha, at which point the processes of stem nodulation and N_2-fixation begin to decline (Dreyfus et al.,1983). The positive effect of organic matter application could be due to increased plant growth and better survival and growth of rhizobia (Gibson et al., 1982, adapted from Ladha et al.,1988).

3.5. Pest damages on *Sesbania rostrata:*

In rainfed and well drained soils, *S. rostrata* is susceptible to nematode (*Meloidogyne sp.*) (Dreyfus et al., 1983). Garrity et al. (1988) reported that pod borers, leaf rollers and mealy bugs in India, and cabbage loopers in Taiwan, are the primary insects causing damage to *S. rostrata*.

4. Green manure management in rice-based cropping systems

There are 2 types of green manure (GM) management in rice-based cropping systems: (1) GM sole planting, then incorporating GM into soil before rice crops and (2) intercropping with rice. A large number of research and practice has been done on the former. The results can be found in many references. However, there is very little information on intercropping GM with rice. In 1988, Chen and Chungchu reviewed and monitored the uses of GM in China. They revealed that *Sesbania spp.* is either seeded onto the rice field, under rice canopy 1 month before rice harvest by broadcasting or mound sowing; or transplanted at approximately 30 days after transplanting early rice. After early rice harvest, *Sesbania spp.* is incorporated as basal manure for the following late rice crop. If the second rice is not planted, due to inadequate rainfall, *Sesbania spp.* will be allowed to produce seeds and its stems are used as firewood. These practices can also be found in Northern Vietnam. In Southern Vietnam, *Sesbania spp.* is transplanted, using stem cuttings, at the time of transplanting of the mono-traditional rice in August, when the field is flooded. After harvesting rice (in December), *Sesbania spp.* is left until July of the following year. Twenty to thirty days before transplanting rice, *Sesbania spp.* is cut. Its leaves are allowed to drop on the field and bare stems are collected for firewood. The same procedure is repeated for the next year's cultivation.

The fresh biomass of *Sesbania spp.* in intercrops with rice is reported as 6-8.5 t/ha in China (Chungchu, 1988), 15-20 t/ha in Vietnam (Herrera et al., 1990).

Herrera et al., (1990) also reported that a number of research projects on the density and types of propagation of *S. rostrata* in intercropping with rice at IRRI (Philippines) and Ubon (Thailand). They concluded that to avoid significant competition with rice, the plant population of *S. rostrata* must be kept less than 1 plant/ 2 sq.m. It gives an average of 811 kg/ha of seeds regardless of the type of planting material (seedlings or cuttings). However, on the acid poor soils in the Northeast Thailand, rice yields are not depressed by *S. rostrata* at densities greater than 1 plant/sq.m. because of poor growth of *S. rostrata*. *S. rostrata* is also seeded or transplanted along paddy bunds and planted as an upland crop in vacant areas for seed production. At IRRI, *S. rostrata*, planted along the bunds, shades the adjacent rice but does not have a strong yield depressing effect on the adjacent rice (IRRI, 1987). Whole seedlings at high population (3 plants per 1 linear meter) with clipping give 881 g of seeds per 4m-length of bund (220 g/m). While at Ubon, the highest seed yield is 30 g/3m bund length. Thus, to produce 30 kg of seeds, 3 km bund length is needed on poor soil. Late maturity, excessive plant height and low seed yield of local *Sesbania* species are the major limitations (Herrera et al., 1990).

5. Intercropping - Concepts, Interactions and yield advantages.

5.1. Concepts of intercropping:

Intercropping is the process of growing two or more crops simultaneously on the same field. Crop intensification is in both time and space dimensions. There is intercrop competition during all or part of crop growth. It can be mixed intercropping, row intercropping, strip intercropping or relay intercropping depending upon the spatial or time arrangement (Francis, 1986).

The underlying basis for evaluating the intercropping performance is a comparison of the performance in intercrop to the performance in monoculture. Typically, there are two kinds of intercropping design based entirely on population density: substitutive or replacement design and additive design. In an additive design, the intercrop is constructed by adding one species to the other in such a way that the population of the one species is kept unchanged and the other species is added. Therefore, the overall population densities of intercrops are larger than those of monocultures. In a replacement design, the intercrop is formed by removing a proportion of one species and substituting it with the same proportion of the other species. Therefore, the overall population desity is the same in monocultures and intercrops. A replacement series is then the result of generating a range of mixtures by starting with a monoculture of one species and progressively replacing plants of that species with plants of another species until all plants of one species are replaced by the other. As a result, a monoculture of the latter is produced (Vandermeer, 1989).

The additive design is often used where the production of the main crop is expected to be the major output, and the other crop is the minor. In this case, the population of the main crop is kept constant and the additional crop is added. The major pitfall of the additive design is that the yield benefit of intercrops may only be due to a greater density, and may also be obtained with the monocultures growing at the same density as the mixture (Spitters, 1980). The replacement series is, therefore, useful for evaluating the advantages of intercropping, in which the optimal density may be determined in separate experiments; with the mixtures at different densities and in accordance with what is used by farmers.

5.2. Interactions in intercropping:

Most interaction studies have examined 2 species grown in a "replacement series". Expected yields are those that would be obtained if each species experienced the same degree of competition in mixture as pure stands (i.e. if inter-specific competition is equal to intra-specific competition).

Willey (1979), later reviewed by Francis (1989), attempted to simplify the interactions in intercropping into 3 broad categories:

(1) *Mutual inhibition*, in which the actual yield of each species is less than expected. It is rare in practice.

(2) *Mutual cooperation,* in which the actual yield of each species is greater than expected. This can occur more frequently at low levels of technology and when crop densities are relatively low and sub-optimal.

(3) *Compensation,* in which one crop produces more and the other produces less than expected. This is the most common situation involving a more competitive (dominant) crop and a less competitive (dominated) crop in the mixture.

5.3. Yield advantages and stability:

Intercropping has long been recognized as a very common practice throughout developing countries, and interest in this practice has increased rapidly. The reasons for intercropping in farming practice are the possibility that intercropping can provide yield advantages compared to sole cropping, and the greater stability of yield over different seasons.

A main reason of yield advantages is that intercropping better utilizes growth resources. This is because the component crops differ in their spatial and temporal use of resources; in their nutrient requirements, in the forms of nutrients they can readily take up and in their abilities to extract nutrients from the soil. The component crops may have their peak demands for nutrients at different stages of growth. They may not compete for exactly the same overall resources and thus, inter-crop competition is less than intra-crop competition. The component crops may also exploit different soil layers via different rooting patterns, thus in combination they may exploit a greater total volume of soil. The better distribution of leaf areas over time and the proper arrangement of combined leaf canopy may make better use of light. The interaction between the rhizosphere micro-organisms of component crops could also benefit nutrient uptake of intercropped crops (Kibani et al., 1976; Shantaram and Rangaswami, 1967 adapted from Willey, 1979).

Therefore, maximizing intercropping advantages is a matter of maximizing the degree of supplement between components and minimizing the inter-species competition. This can occur where the component crops are very different (Willey, 1979). Many studies have shown that the presence of legumes in intercrpping, with N-fixing ability, produces a greater yield of companion non-legume crop (by making possible N transfer) than its in sole cropping (Willey, 1979). In addition, the better control of weeds, pests or diseases may be obtained by intercropping (Willey, 1979; Francis, 1989).

Another reason for the predominance of intercropping in poorly developed agriculture is that it can give greater stability of yield over different seasons. The basis for this is that if one crop fails or grows poorly, the other can compensate. Such compensation is not possible if the crops are grown separately.

To evaluate the interactions and yield advantages of intercropping, the Relative Yield Total (RYT) or Land Equivalent Ratio (LER) are commonly used. RYT (suggested by de Wit and van den Bergh, 1965) is the sum of the relative yields (ratios of yields) of component crops in intercropping to their yields in sole cropping. LER (proposed by Willey and Osiru, 1972) is defined as sum ratio of area required under sole cropping to that under intercropping at the same management level to give the same yield (Ofori and Stern, 1987).

The definitions of the two are somehow interpreted in different ways, but the concepts are identical. However, in the calculation of LER, the replacement principle has not always been used (Trenbath, 1986 and Spitter, 1980) because it based on the land area basis. Both could be used as an index of biological efficiency to evaluate the advantage of intercropping systems compared with sole cropping. In the replacement series, the densities of intercrops and sole crops are equal so that RYT is used without possible conpounding effects of density variation. RYT = 1 indicates no advantage from intercropping as compared to sole cropping (compensation effect). RYT > 1 indicates mutual cooperation: intercropping yields advantages when compared to sole cropping. More specifically, to produce the same yield of crops, a larger area of land will be needed when each crop is grown as monoculture. RYT < 1 occurs in the case of mutual inhibition: the inter-specific competition is greater than intra-specific competition.

Heibsch (1980) and McCollum (1982) proposed the concept of Area Time Equivalency Ratio (ATER) as a modification of LER. This takes into account the duration of the component crops and the growing periods of the intercrops as well. It also permits an evaluation of crops on a yield-per-day basis (Heibsch and McCollum, 1987, adapted from Pantollana, 1992). ATER is preferably used to evaluate the intercrop advantages when component crops are different in time of maturity.