POTENTIAL OF *SESBANIA ROSTRATA* GREEN MANURE

IN RICE PRODUCTION

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ABSTRACT

The potential of *S. rostrata* as a green manure for rice production was evaluated in two pot, glasshouse experiments at Morogoro using a sandy clay (Vertic ustifluvent) soil. A split plot experiment was conducted to study the plant biomass production and nitrogen fixation/accumulation. Plants were raised both under flooded/waterlogged paddy and drained conditions for 60 days. The effects of inoculating with *Rhizobium* either the seeds, seeds + stems, or stems alone were studied. The plant's manurial effect in terms of nitrogen release under flooded and drained soil conditions were studied in a factorial experiment. A 45-day old *S. rostrata* green manure (3.26% N) was incubated in soil at 0, 10, 20 and 30 ton/ha and the nitrogen release patterns studied for a period of 28 days.

S. rostrata, generally, grew well in both soil moisture regimes. Biomass and nitrogen accumulation were in favour of drained soils up to 45 days, and, thereafter, flooded soils due to infestation by nematodes in drained soils. Inoculation increased root and/or stem nodulation, plant biomass, and N_2 fixation compared to non-inoculated plants. No significant differences were observed between inoculation techniques. The equivalent of up to 20 and 34 ton/ha green biomass and 97 and 200 kg N/ha were recorded in 45 and 60 days, respectively.

On decomposition, no differences were observed between flooded and drained soils in terms of soil total N. Available N released was substantial but significantly more in flooded soils where NH_4-N dominated than in drained soils dominated by NO_3-N. Higher levels of green manure released higher amounts of N.

The larger amounts of N accumulated by the plants, and the substantial amounts of mineralized N during the green manure decomposition in the soils, qualify S. rostrata as a potential biofertilizer in rice production.

DECLARATION

I, PRUDENCE EDWARD LWEKORAMU, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has not been submitted, in whole or in part, for a degree in any other University.

Date: 14/07/1993 Signature: ....

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DEDICATION

This dissertation is dedicated to my late mother who through her tireless efforts I got my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

With most cereal crops, rice included, nitrogen (N) is the most limiting nutrient (De Geus 1973). Adequate nitrogen nutrition in rice is the dominant factor in obtaining high yields.

A fertile soil's natural supply of N may be adequate to maintain rice yields at modest levels for long periods of time (Russell 1988), but additional nitrogen must be applied to obtain higher yields (De Datta and Magnaye 1969). Thus, a major task in rice production is to find ways and means to improve and maintain soil fertility levels that will increase and stabilize rice productivity at reasonably high levels. It must be borne in mind, however, that apart from fertilizers, any spectacular rise in rice yields will result in from a combination of crop husbandry approaches including crop improvement by breeding for high yields, improved cultural methods, use of pesticides, and weed control.

Due to the very low yield potential of indigenous rice varieties, emphasis is now being placed on recently-bred high-yielding varieties like the International Rice Research Institute (IRRI) varieties IR 8, IR5, IR54 and others, in order to meet local consumption demands and, if possible, for export. But the most outstanding feature of these new varieties is their demand for, and response to, high rates of fertilizer application. Therefore, these high-yielding varieties need high rates of nitrogen application if their potential is to be realised. In their study using long term fertility trials, Mamaril et al. (1985) found that N remained the most limiting nutrient even after 8-15 seasons of nitrogen fertilizer use.

But for many farmers in developing countries like Tanzania, inorganic fertilizers are too costly to afford. Organic fertilizers like farm-yard manure and compost, on the other hand, contain only low concentrations of N, P and K. The bulk needed to provide adequate levels of these nutrients necessitates the use of additional labour, which is unavailable in the peasant setting, for handling and transport. In addition, only few farmers can generate such quantities of these manures. Therefore, taking advantage of biological nitrogen fixation, in the form of in situ green manure, offers a promising and probably inexpensive nitrogen source for increased rice production for both flooded and upland rice conditions. If soil nitrogen can be maintained or improved while at the same time producing a crop, a stable agricultural system can be developed for continuous production.

Agroforestry systems based on in situ mulch can eliminate tasks such as hauling of the green manure, which presents problems for the farmers. Legumes are the most common plants used as green manure because they are nitrogen-fixing and have comparatively high nitrogen concentrations in their shoots. Use of these manures _in situ_ in rice cultivation will overcome problems of haulage, thus streamline labour requirements from the peasant farmers. In the Far East, use of nitrogen-fixing plants as green manure is well documented (Vichhani and Murty 1964; Patnaik and Rao 1979; Watanabe and App 1979).

In the traditional systems of the humid tropics soil nitrogen levels are maintained by the contributions of microorganisms. The potential for taking advantage of biological N_2-fixation in many farming systems lies in the incorporation of legumes into the cropping systems (Greenland 1977). So the potential of biologically fixed nitrogen using _in situ_ legume green manure in rice production should be re-examined as an alternative to expensive inorganic nitrogen fertilizers. But before devising and developing such systems it is appropriate to determine the actual contribution which would be made by such a system. In lowland areas with heavy textured soils, for instance, excessive moisture and the accompanying reducing conditions can reduce nodulation unless tolerant legumes are used (Ayanaba 1977). Because of their ability to grow in heavy soils, to withstand flooding and waterlogging, and to tolerate soil salinity, _Sesbania_ species are often the preferred green manure crops for rice production (Evans and Rotar 1987).

Use of sesbanias as nitrogen source in paddy rice in East Asia is well documented (Bhardwaj et al. 1981; Beri and Meelu 1981; Ghai et al. 1985; Kolar and Grewal 1988). Sesbania rostrata as green manure is a more recent addition and research on it has been going on at the IRRI and in some eastern Asian countries. Being aquatic, it has been found to possess all the promising indications of being a good green manure for paddy rice. Unlike other green manure plants, it has nitrogen fixing nodules on its stems and branches as well as on roots (Evans and Rotar 1987).

Sesbania rostrata is an annual legume common in Senegal (Evans and Rotar 1987). Its distribution, according to Evans and Rotar (1987), extends from Senegal to the Sudan, Congo, Zaire, Malawi, Zimbabwe, Botswana, the Caprivi Strip and Madagascar. Its discovery in the Dodoma Region, Central Tanzania (Prof. M.P. Salema personal communication 1989), has prompted the initiation of the present study.

According to Singh et al. (1988) and the IRRI Reporter (1988) this legume attains a height of about 1.5m in 45-60 days, covers a field rather quickly, and can fix 60-90 kg N/ha in that time span. Such a potential should be exploited and enhanced.

Research on *S. rostrata* in rice cultivation in Africa has been going on at the Office de la Recherche Scientifique et Technique Outre-Mer et Centre National de la Recherche Scientifique (ORSTOM) in Senegal. Experience on the performance of this legume in tropical Africa is either minimal or non-existent. Furthermore, most of the rice growing areas depend on rainfed conditions, which result in fluctuating soil moisture regimes. Temperature, humidity and photoperiods are also not constant. These factors will affect greatly the life cycle, growth and, therefore, the use of *S. rostrata* as a green manure (Dreyfus *et al*. 1983, 1985).

In flooded lowland rice cultivation, the soil passes through annual anaerobic-aerobic cycles. Under these conditions nutrient transformation rates and consequent changes in nutrient availability associated with the fluctuating soil oxidation states will influence the turnover of N from incorporated green manure.

Therefore, studies on the adaptability of *S. rostrata* in both waterlogged and drained soil conditions are essential. Its growth, nitrogen accumulation, nitrogen transformation and release patterns upon incorporation into soil should be conducted for a given geographical location. From such studies ways may be explored for maximizing the utility of the green manure technology in rice production. All these things have not been done in Tanzania.

The research reported here was, therefore, undertaken to evaluate S. rostrata as a green manure plant in rice cultivation, with the following objectives:

1) To determine whether S. rostrata can thrive well under the prevailing climatic and soil conditions at Morogoro.

2) To evaluate the effects of inoculation with Rhizobium on growth of, and nitrogen fixation by, S. rostrata.

3) To study the nitrogen release patterns upon incorporation of S. rostrata into soil as a green manure.

2. LITERATURE REVIEW

2.1 Biological nitrogen fixation by Sesbania

Biological nitrogen fixation is the conversion, in biological systems, of nitrogen gas to ammonia. In agricultural systems, the fixed nitrogen can then, in time, be used by growing plants. Legume plants provide one such biological system. Legumes with a high potential for nitrogen fixation should, therefore, be the most preferred plants to be used as green manure in rice production.

Morris *et al*. (1986) demonstrated that a fast growing tropical legume accumulated 80 kg N/ha in 45 days and that rice yields exceeding 2 tons/ha were possible following application of such material as green manure. This is a tremendous advantage economically to the rice farmers especially as regards the high prices of chemical fertilizers. However, achievement of high nitrogen fixation rates depends on a complex set of interactions involving the plants, *Rhizobium* strains, climatic factors, and soil physical and chemical properties (Graham and Harris 1982, Russell 1988).

Given environmental conditions favouring good growth and nitrogen fixation, *Sesbania spp*., due to its ability to grow in heavy, flooded/waterlogged soils, and to tolerate salinity, has been found to be the best among legumes to be used as green manure in rice production (Evans and Rotar 1987). However, there were marked differences in nitrogen content and biomass accumulation among species of _Sesbania_ (Ghai _et al_. 1988).

Beri _et al_. (1989a) found that _S_. _aculeata_ had higher numbers and fresh weights of nodules per plant as compared to those of cowpea, sunhemp and clusterbean. Dreyfus and Dommergues (1981) reported in Senegal that _S_. _rostrata_ had five to 10 times more nodules than most nodulated crop plants although specific nodule activity, as measured by acetylene reduction, was comparable to nodules of soybean and cowpeas. Consequently, _S_. _rostrata_ fixed as much as 270 kg N/ha (Rinaudo _et al_. 1983). Such high rates of nitrogen fixation should be taken advantage of.

The high nitrogen fixation rates of _S_. _rostrata_ were also related to occurrence of nodules on stems in addition to those on roots. These additional nodules fixed nitrogen over and above that fixed by root nodules. For that reason, unlike other legumes, _S_. _rostrata_ had the ability to nodulate and to fix nitrogen even when the levels of combined nitrogen in the soil were as high as 200 kg N/ha (Dreyfus _et al_. 1985). So, _S_. _rostrata_ was capable of assimilating both soil and atmospheric nitrogen, which constituted a significant advantage. Other studies have shown that S. rostrata responded to aerial inoculation with appropriate rhizobia, resulting in more gains in nitrogen accumulation by the plant (IRRI 1987, 1988; Singh et al. 1988). This was further supported by the fact that under favourable conditions, stems were quickly nodulated and this was difficult to control since transmission of rhizobia was through vectors such as dust and insects (Evans and Rotar 1987); otherwise, uninoculated plants produced only root nodules attributed to native Rhizobium (IRRI 1987).

2.2 Adaptation of S. rostrata to environmental conditions

Sesbania rostrata plants can grow well both in drained and in flooded soils. Research at the IRRI (IRRI 1987) showed that total biomass of plants grown under flooded conditions was higher, but plants grown under nonflooded conditions showed more nodules and nitrogenase activity. Sesbania, however, thrived best when the soil moisture was high and consumed the maximum amount of water in comparison to other legumes (Singh et al. 1981).

The flourishing of S. rostrata plants in waterlogged soils, as found under flooded rice culture where other legumes would not survive, gives this legume a decided advantage as the green manure plant of choice in rice production. In Senegal, it was found to grow well during the hot summer season when moisture was plentiful. But it grew poorly and flowering set in earlier during the cool dry season (Dreyfus et al. 1985). This seasonal effect, therefore, determined the magnitude of the biomass accumulation and, thus, the extent and amount of nitrogen fixed.

Nodulation, especially on stems, was also affected by weather conditions. Temperature and humidity, for instance, played an important role in the infection process and, as observed by Dreyfus et al. (1983), infection was difficult to achieve during the cool season. But during summer, it was difficult to prevent control plants from nodulating.

2.3 Nitrogen gains from green manure

It is generally recognised that green manuring is an efficient way of transferring biologically fixed nitrogen to the soil. In flooded soil the decomposition of added biomass occurs under anaerobic conditions, leaving the ammonium nitrogen (NH_4-N) as the end product of N mineralization. Under upland rice conditions, nitrification of the NH_4-N occurred resulting in the formation of nitrate nitrogen (NO_3-N), which was prone to denitrification and leaching (Patnaik 1978).

Flooded rice will depend largely on the availability of nitrogen under the prevailing largely anaerobic conditions. Upon incorporation of the green manure into soil, the balance between ammonium or nitrate release and nitrogen immobilization is mostly a function of the carbon:nitrogen (C:N) ratio of the material undergoing degradation. In anaerobic soils, incorporation of organic substances containing less than about 1.5% nitrogen generally immobilized the soil nitrogen which would otherwise have been available to crop plants growing there (Tanaka 1978). Researchers at the IRRI found that incorporation of rice straw, which ordinarily has high C:N ratio (as is the common farmer's practice), depressed soil solution NH_4-N while Sesbania enhanced it (IRRI 1988). Mohapatra (1988) concluded that the presence of large amounts of mineral N in Sesbania-treated soil was attributed to its rapid decomposition and its narrow C:N ratio. The superiority of Sesbania in rice production was further demonstrated by comparing it with the most efficient Azzola (IRRI 1986, 1987). Beri et al. (1989a) showed that Sesbania-amended soil released large amounts of NH_4-N, surpassing those released from sunhemp, cowpeas or clusterbean. Chakraborty et al. (1988) showed that soil treated with Sesbania maintained the highest levels of NH_4-N up to 120 days after incorporation. Earlier, Debnath and Hajra (1972) had demonstrated that with Sesbania, NO_3-N levels in soil increased gradually up to 120 days without any nitrate depression during decomposition, unlike the rice-straw-treated or control soil. The soil which supplied nitrogen continuously throughout the period of plant growth played a crucial role in the growth and yield of rice (Shiga and Ventura 1976). Incorporation of S. rostrata green manure was found to increase N uptake by rice plant two to three-fold over non-manured plots. This was due to increased levels of readily available NH_4-N in soil solution over a longer time period in the manured plots (IRRI 1988).

The ability of Sesbania green manure to maintain higher levels of NH_4-N in flooded conditions has been applied in fertilizer use technology. Green manure-fertilizer combinations were found to result in efficient utilization of nutrient N as well as fertilizer economy (IRRI 1988). It was shown that ammonia volatilization losses were considerable when urea was applied in flooded soil (De Datta et al. 1983) mainly due to rapid hydrolysis of urea accompanied by rise in floodwater pH (Khind et al 1990). Sesbania, although high in N content and released appreciable amounts of NH_4-N in floodwater, also produced enough carbon dioxide (Debnath and Hajra 1972) which maintained or even reduced the floodwater pH (IRRI 1988). Consequently no ammonia volatilization occurred in the soil amended with sesbania green manure. Ammonia volatilization was very low when green manure was incorporated together with urea but was high with urea applied alone (Khind et al. 1989).

2.4 Time of application of *S. rostrata* green manure

Sesbania, due to its fast growth and high N content, should be a suitable green manure to be adopted by rice farmers. The most appropriate stage of growth of this green manure before it is incorporated may be debatable. However, it should not exceed two months, otherwise it may interfere with the maturity of the rice crop. This has been the subject of much research.

Chela and Gill (1973) reported that *S. aculeata* should be ploughed into the soil at 60 days of growth, but Bhardwaj (1982) suggested that its incorporation be at the 45 days stage. Bhardwaj and Dev (1985), studying the effect of *S. cannabina* green manure, found that mineralization was highest with 45 day old plants. Although the amount of N accumulated increased with biomass and time of growth, it was demonstrated that for *Sesbania* species, the N content (on dry weight basis) was highest at 45 days of growth, according to Ghai *et al*. (1985). These workers recommended that going beyond 57 days before incorporation was not appropriate since sesbanias became hard, and this reduced the rate of their decomposition. Consequently, rice transplanting would have to be delayed, and this would result in yield reductions.

Hati (1987) showed that a 22-day old S. aculeata green manure could increase rice yields appreciably by contributing 4.2-6.3 ton/ha green manure, but could not do better than S. cannabina which, at 45 days, provided 18 ton/ha green matter and 98 kg N/ha (Bhardwaj and Dev 1985). Thus, S. cannabina was comparable to S. aculeata at 60 days, which supplied 20 ton/ha green matter and 108 kg N/ha (Beri et al. 1989a). Kolar and Grewal (1988), however, working with S. esculentus and other green manure legumes, came to the conclusion that the additional growth between the 40th and 60th days had no significant effect.

The timing of green manure incorporation is very important in any cropping system. Singh, et al. (1981) found sharp increases in dry matter and nitrogen content of green manure legumes between the fifth and seventh weeks of growth. Khind et al. (1983) showed that the N content of S. bispinosa increased many fold (i.e. from 8-58 kg N/ha) during the second month of growth, and then doubled again during the third month. According to Evans and Rotar (1987), upland rice yields increased with the age of the preceding green manure at the time of its incorporation. It is, therefore, important that the actual nitrogen contribution of the green manure and its fate upon incorporation into the soil be known, with respect to the intended crop.

Thus, proper timing of green manure incorporation in relation to planting rice is critical. The decomposition of incorporated green manure may sometimes be fast, and appreciable amounts may be decomposed in the first day of incorporation (Debnath and Hajra 1972). Beri and Meelu (1979) compared inorganic N turnover from S. bispinosa green manure incorporated at 20, 10, and 0 days before transplanting rice with or without supplemental N fertilizer. The beneficial effect of transplanting soon after incorporation was evident. Khind et al. (1985) incubated soils with Sesbania and found that NH_4-N release peaked on the 14th day after incorporation. Rice transplanted the day after the incorporation of a two month old sesbania manure containing 120 kg N/ha yielded over 5 ton/ha grain. This was the same as the yields of rice supplied with 120 kg N/ha as urea in three equal split applications.

Palm et al. (1988) found that due to rapid decomposition of S. sesban shoot material, this green manure did not behave like a slow-release N fertilizer. Therefore, it was not necessary to apply a basal dose of N fertilizer. Therefore, for each type of green manure, the optimum timing of its incorporation into soil has to be critically determined.

2.5 Agronomic effectiveness of green manure

2.5.1 Effect on rice yields

Green manuring, a tradition among Asian rice farmers, has stood the test of time due to increment in grain yields over those from fields which were left fallow for long periods. Tiwari *et al*. (1980) found that green manure increased rice yields significantly. Grain yield increases of 200 g/m^2 (≡ 2 ton/ha) over control treatments were reported by Morris *et al*. (1986) using a legume manure which had accumulated 80 kg N/ha in 45 days. A similar increase was reported by Palm *et al*. (1988) using *S*. *sesban* at a rate of 4.4 ton/ha (dry biomass), which supplied 92 kg N/ha. Significant yield increases due to *S*. *rostrata* green manuring were reported by various workers (Rinaudo *et al*. 1983; Dreyfus *et al*. 1985; Mulongoy 1986; Singh *et al*. 1988).

It is in this context that the potential of *S*. *rostrata* green manure was investigated in the present study. Beri *et al*. (1989a), working with various green manures on an alkaline sandy loam, found that rice yields with green manure alone (i.e. *Sesbania aculeata* at 5 ton/ha dry biomass, furnishing 108 kg N/ha) was comparable to those due to 120 kg N/ha applied as urea. Bhardwaj and Dev (1985) demonstrated that *S*. *cannabina* green manure added 98-165 kg N/ha and its performance was equivalent to 100-120 kg N/ha as chemical fertilizer N, depending on its stage of growth at incorporation. Rinaudo et al. (1983) found that S. rostrata green manure could substitute fertilizer N up to 130 kg N/ha. Dreyfus et al. (1985), in Senegal, showed that the effect of inorganic nitrogen application at 60 kg N/ha as ammonium sulphate was significantly less than that of S. rostrata green manure obtained from a seed rate of 20 kg/ha and grown for six to seven weeks before incorporation. It was not stated whether the green manure supplied 60 kg N/ha or otherwise. It was further demonstrated that whether S. rostrata was incorporated wholly (including roots) or partially (leaves and stems only) it could reduce or replace costly fertilizers while sustaining higher rice yields. Singh et al. (1988), comparing this biofertilizer to chemical fertilizer, found that S. rostrata increased paddy yields by 3-7 ton/ha while its equivalent, 60 kg N/ha as urea, increased yields by only 1.7 ton/ha.

2.5.2 Effect of Sesbania green manure on fertilizer N efficiency

The facts presented above indicate that in most cases green manuring, using nitrogen fixing legumes, can replace inorganic fertilizer N in rice. However, combined application has been found to be of maximum advantage and profit. Morris _et al_. (1986), working with mungbean and cowpeas, observed that apparent recovery of N from both inorganic N fertilizer and green manure was 33%. Nevertheless, small quantities, less than or equal to 30 kg N/ha, of topdressed inorganic N supplemented to green manure N could increase yields by 0.5 ton/ha. Tiwari _et al_. (1980) found that the interaction was positive and significant. Research at IRRI (IRRI 1988) showed that combined application of sesbania and urea supplying a total of 90 kg N/ha (i.e. 45 kg N/ha each) produced the same yields as sole urea at the same level of N application. The positive effects of the urea/sesbania combination was further demonstrated by Palm _et al_. (1988) who obtained higher yields from combining _S_. _sesban_ than from inorganic fertilizer N or _Sesbania_ alone. Similarly, Rabindra _et al_. (1989) showed that _S_. _rostrata_ supplying 70 kg N/ha gave almost the same rice yields as those from urea at the same level of N application (i.e. 3.4 and 3.2 ton/ha, from sesbania and urea, respectively). But at 100 kg N/ha supplied as 30 kg N from _S_. _rostrata_ and 70 kg N/ha from urea, significantly higher yields (5.2 ton/ha) were observed as compared to those (4.5 ton/ha) from 100 kg N/ha supplied as urea alone. These results were in agreement with those of Chakraborty _et al_. (1988) who demonstrated that urea/sesbania combinations at higher levels of N application (90 kg N/ha) could effectively compete with the sole urea treatments at equivalent quantities of N.

2.6 Soil fertility improvement

The above review suggests that green manuring by sesbania, apart from supplying the much needed nitrogen for plant nutrition, creates conditions more favourable to plant growth. Kute and Mann (1969) found that the N, P and K composition of the soil and the wheat plants were increased by green manuring. Palm et al. (1988) found that S. sesban contained more K than would be recommended in soil treatment but was low in P, implying that when using this legume, potash fertilizer was not required. Swarup (1987) observed that S. aculeata green manure in highly sodic soils considerably improved organic carbon, available P, and K status and enhanced the uptake of N, P, Ca, Mg, S, Fe, Mn and Zn by the rice crop.

Residual effects due to green manuring have been reported by several workers. Singh et al. (1988), working with various N sources, found significant increases in total N, organic carbon and available P in the soils analysed after harvest. In the following season, Sesbania treated soils showed higher N than soils under other treatments. Sharma and Mitra (1988) found that residual fertility in terms of organic carbon and available N, P and K increased under green manuring on an acid lateritic soil, while inorganic N fertilizer alone made no such impact. Gopalswamy and

Vidhyasekaram (1987) concluded that, generally, green manuring increased the soil fertility status.

2.7 Additional benefits of *Sesbania* green manure

The potential of *Sesbania* as a green manure, especially on paddy rice, lies in its ability to grow in varying soil conditions. Waterlogging, as shown earlier, did not affect the plant growth after establishment (IRRI 1988). Also, though the farmer might incur some cost in terms of labour during green manure production, he would reduce substantially the rates of inorganic fertilizer used. This would be a saving both in labour and money.

An additional advantage was that this type of green manure was based on *in situ* growth and incorporation which eliminated problems of transportation of the manure. In addition, green manure had the ability to suppress weeds (Singh 1984; Palm *et al*. 1988).

Green manure was valuable in some areas, especially on soils low in organic matter, because it improved and maintained good soil structure in the initial stages of flooding thereby allowing adequate percolation. This removed harmful substances and products of fermentation toxic to rice seedlings (Russell 1988). Swarup (1986, 1987) reported that application of S. aculeata green manure in submerged sodic soils enhanced the process of reclamation of those soils by decreasing their pH and exchangeable Na. Moreover, Germani et al. (1983) reported of the ability of S. rostrata to limit pathogenic nematode populations in rice fields.

It can, therefore, be seen that there are many reasons in favour of advocating the use of green manures.

3. MATERIALS AND METHODS

3.1 Soil sampling and analysis

Surface (0-15cm) soil samples were collected at random from a fallow paddy field in the Sokoine University of Agriculture (SUA) farm. The samples were composited, air dried and ground to pass through an 8mm sieve and thoroughly mixed. Twenty-kg portions were weighed into 20 litre plastic buckets for the inoculation trial (section 3.2.1.3). Another portion of this soil was ground to pass through a 2mm sieve and 5-kg portions weighed into 5-litre plastic pots for nitrogen transformation studies (section 3.2.2). A subsample of this soil was used for laboratory analysis to determine the relevant physico-chemical properties of the soil.

Total N was determined using the Kjeldahl Method (Bremner 1965) and organic matter was determined through loss on ignition at 550-600 ^{o}C in a muffle furnace according to Broadbent (1965). Extractable P, as a measure of available P, was determined by the Bray and Kurtz No.1 method (Bray and Kurtz 1945). Exchangeable bases were extracted using the ammonium acetate saturation method (Chapman 1965). Exchangeable K and Na in the filtrate were determined by flame photometry while Ca and Mg were by atomic absorption spectrophotometry. The effective CEC was obtained by summing up the exchangeable bases.

The pH was determined in water (1:1 w/v) using the glass electrode. For ammonium and nitrate nitrogen determination, the soil samples were treated according to Hesse (1971). Nitrogen was extracted using KCl and steam-distilled in the presence of Devarda's alloy and copper oxide into boric acid, which was backtitrated using sulphuric acid according to Bremner (1965). The texture of this soil was determined using the Bouyoucus hydrometer method (Dewis and Freitas 1976).

The soil's physico-chemical properties are presented in table 1. The pH, at 7.1, indicated a neutral soil. Therefore, the exchangeable acidity should be almost nil (Bohn et al. 1985). The soil was a Vertic ustifluvent (Kaaya 1989), in the sandy clay textural class. It had an appreciable organic matter content, relatively high amounts of available nitrogen, but low levels of P. Generally, the soil was taken to be a moderately fertile soil for rice (De Geus 1978; Patnaik 1978).

3.2 **The pot experiment**

Two pot experiments were carried out at SUA, Morogoro, under controlled soil moisture conditions simulating both waterlogged paddy and drained upland rice soils. The first experiment was for the establishment and inoculation of S.

Table 1. Some physico-chemical properties of the soil used

Property	Magnitude
pH	7.1
Sand	49%)
Silt	12%) sandy clay
Clay	39%)
Organic Matter	8.8%
Exchangeable Ca	15.36 m.e./100g
" Mg	2.82 "
" Na	0.42 "
" K	1.84 "
Effective CEC	20.44 "
Extractable P	3.10 mg/kg
NO3-N	33.37 "
NH4-N	22.25 "
Total N	0.18%

rostrata both in flooded and drained soils. The second was on the effect of incorporating into soil this legume material as green manure on nitrogen release patterns under those two soil moisture conditions.

3.2.1 The inoculation experiments

3.2.1.1 Source of *S. rostrata* seed and *Rhizobium* inoculum

Sesbania rostrata seeds were obtained from *S. rostrata* plants growing as weeds in paddy fields in Dodoma Region, Central Tanzania, in the 1989 rice growing season (January-May). Nodules were collected from the same plants in the same area. Both the seeds and nodules were transported to the Soil Science Laboratory at SUA. From the nodules, a pure culture of rhizobia was isolated which became the source of inoculum for the inoculation experiment.

3.2.1.2 Preliminary experiment

Since the seeds and inoculum had never been used here before, it was felt appropriate to test them before the actual experiments.

Four Leonard jars were each filled with sand and a nitrogen-free plant nutrient solution (Vincent 1970) containing all the other essential macro- and micronutrients. The entire assembly was sterilized by autoclaving. Five surface- sterilised *S. rostrata* seeds were sown in each jar at a depth of 2cm into the sand. They were then placed in the glasshouse. After emergence, the plants were thinned to one per jar. The jars were subsequently watered using the sterilized nitrogen-free nutrient solution. The four jars were each treated as follows, either:

a) Seed-inoculation with *Rhizobium* culture at sowing,

b) Seed-inoculation with subsequent stem-inoculation 20 days after emergence,

c) Stem-inoculation only, 20 days after emergence, or

d) Control, without inoculation.

Effective nodulation of the plants by the *Rhizobium* inoculum was observed with both the roots and stems nodulating in response to the inoculation. There was no nodulation in the control jar, where the inoculum was not applied. This *Rhizobium* strain was then multiplied for use in the inoculation experiment (section 3.2.1.3).

3.2.1.3 The main experiment

This inoculation experiment was conducted in a split-plot design with moisture conditions as main-plot treatments and inoculation techniques as sub-plot treatments. The treatments were replicated three times.

The soil moisture conditions, as main-plot treatments, were:

1) Drained conditions, with soils maintained at around field capacity, and

2) Waterlogged conditions, where the soil was kept flooded, with a 5cm height of water maintained above the soil level.

The sub-plot treatments, that is the inoculation techniques, were:

1) Seed inoculation with Rhizobium at sowing by spraying the seeds with the rhizobia culture before sowing, and the soil itself after sowing.

2) Seed treatment as above, with plant stems wetted (using a brush) with the Rhizobium suspension 20 days after emergence.

3) Only stems were inoculated at 20 days after emergence, and

4) No inoculation.

The following order in the assignment of the treatments into main-plots and sub-plots was adopted taking into account the practical realities. Normally the rice farmer has no choice between flooded or drained soil conditions. It is either one or the other. Hence, the soil moisture conditions, as treatments, were assigned to the main plots. It was of greater interest here to examine the extent of the responses when different inoculation methods were compared. Therefore, the inoculation treatments were assigned to the subplots (Montgomery 1984).

The age of the green manure at incorporation is of outmost interest. If it is left to grow for long before sowing the rice, it may mean that the rice crop will not have enough time to mature. Usually, in this region, the rainy season is not more than five months and so it was thought that raising the legume for more than two months would interfere with the maturity of the succeeding rice crop. Indeed if S. rostrata could be grown for less than two months, and still accumulate enough biomass and nitrogen, it would be even more advantageous from the standpoint of the succeeding rice crop. Because of these considerations the sesbania plants were grown for only 60 days.

About 25 seeds were sown in each bucket and the plants thinned to 12 at twenty days after emergence but before stem inoculation. No soil amendment was applied apart from its original fertility. Three plants were randomly uprooted at 30, 45 and 60 days after emergence and the following observations recorded:

1) Plant height

2) Nodulation pattern, and nodule sizes and shapes

3) Number of effective nodules (as demonstrated by presence of the pink pigment)

4) Weight of biomass accumulated (both fresh and when dried to constant weight at 70 °C)

5) Weight of dried nodules

6) Total nitrogen of above ground parts of the plant using the Kjeldahl method.

Insect pests were controlled by repeated spraying of Rogor (Dimethoate) insecticide at a concentration of 1.25 ml active ingredient per litre.

3.2.2 Green manure decomposition (nitrogen release) experiment

Forty five day-old *S. rostrata* plants raised at the University Horticulture Unit were harvested and the above ground parts (19.7% dry matter; 3.26% N in bulk material and 5.47% N in leaves alone) were chopped into 3-4cm long pieces. This was weighed and thoroughly mixed with 5 kg soil and placed in pots for the incubation experiment at 0, 25, 50 and 75 g of the green manure per pot. These corresponded with 0, 10, 20 and 30 tons of green manure per hectare, respectively.

For the waterlogged soils, the soil was kept flooded with a 5cm water height above the soil level. In the case of the drained conditions, the soil was kept at around field capacity by watering it once a week immediately after the weekly soil sampling. It was ensured that any water which drained out of the pots was not lost from the system. This was done by placing an aluminium plate beneath the pot to collect any drained water which was, later, returned to the soil in the pot.

Soil samples were collected from all the pots after 1, 7, 14, 21 and 28 days after green manure incorporation. The soil was analysed for ammonium and nitrate N immediately after sampling. The moisture percentage in the soil samples was separately determined and the concentrations of the two N-fractions were expressed on dry-weight basis. Total N was determined after air drying the soil samples. The recognisable parts of the undecomposed green manure were removed and the soil was ground and passed through a 2mm sieve before total N determination was undertaken. All the nitrogen determinations were carried out as described in section 3.1. The data, for each soil moisture regime, were analysed statistically using the factorial arrangement.

4. RESULTS AND DISCUSSION

4.1 Effect of inoculation and soil moisture regime on growth and biomass accumulation by *S. rostrata*

If the practice of green manuring became incorporated into the farming system, the *S. rostrata* green manure would ordinarily have to be grown or raised by the farmer prior to its use. It was, thus, desirable to carry out some studies on some aspects of the growth and management of the *Sesbania* "crop."

4.1.1 Effect of soil moisture regime on S. rostrata plant height and biomass

An initial slow growth of the plants was observed in the first 30 days under both soil moisture conditions. Significant (P = 0.01) differences in height were recorded at 30 days in favour of the drained soils but by the 60th day the trend was reversed in favour of the waterlogged soil condition (Figure 1). At 45 days, the plants grown in drained soils had significantly (P = 0.05) accumulated more biomass than those in waterlogged soil. This did not show up at 60 days at which time plants growing in waterlogged soils

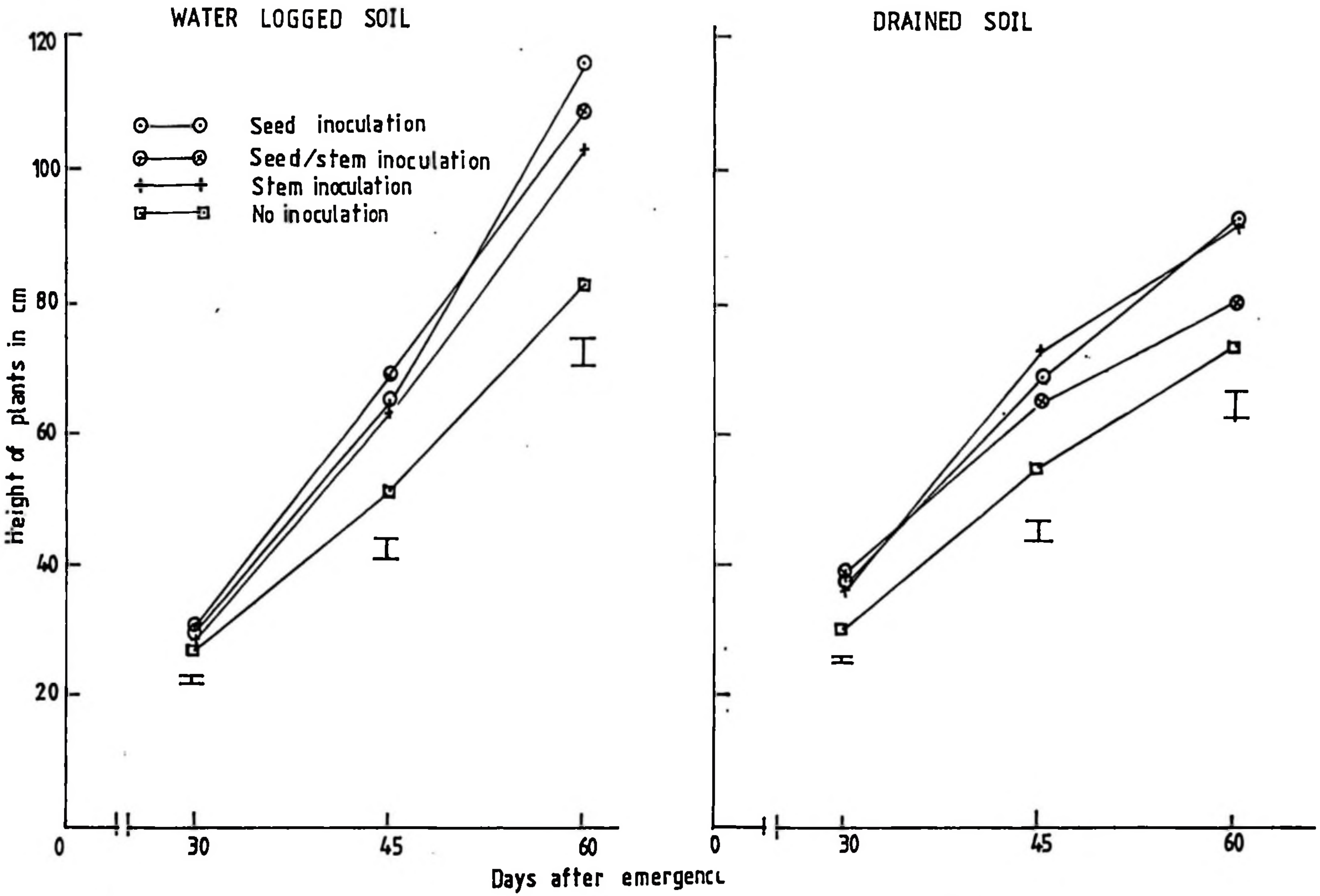

Figure 1. Effect of soil moisture regime and inoculation on *S. rostrata* plant height.
A Bar indicates one standard error (SE)

registered relatively more, but not significantly so, biomass accumulation than those in drained soils (Figure 2). At 60 days, most of the plants in drained soils were found to be infested, some heavily, by root-knot nematodes.

During the first 30 days, the young S. rostrata plants may have not developed an extensive root system to utilize the soil N and other nutrients required for plant growth. Differences in plant height at 30 days and biomass at 45 days may suggest that the drained soils were more favourable to S. rostrata growth than the waterlogged ones. Waterlogging has not been found to seriously affect sesbania growth after establishment, but it seriously damaged sesbania during germination and emergence (IRRI, 1988). Thus, S. rostrata was found to tolerate waterlogged or flooded soil conditions as an adaptive response (Moudiongui and Rinaudo 1987; Singh et al. 1988).

The trend noticed at the 60th day in favour of waterlogged soils may be ascribed to the damage/ infestation of the plants by root-knot nematode infestation in the drained soils. Susceptibility of S. rostrata to soil-borne nematodes of the Meloidogyne sp. in moist but well drained soils was also reported by Dreyfus et al. (1985).

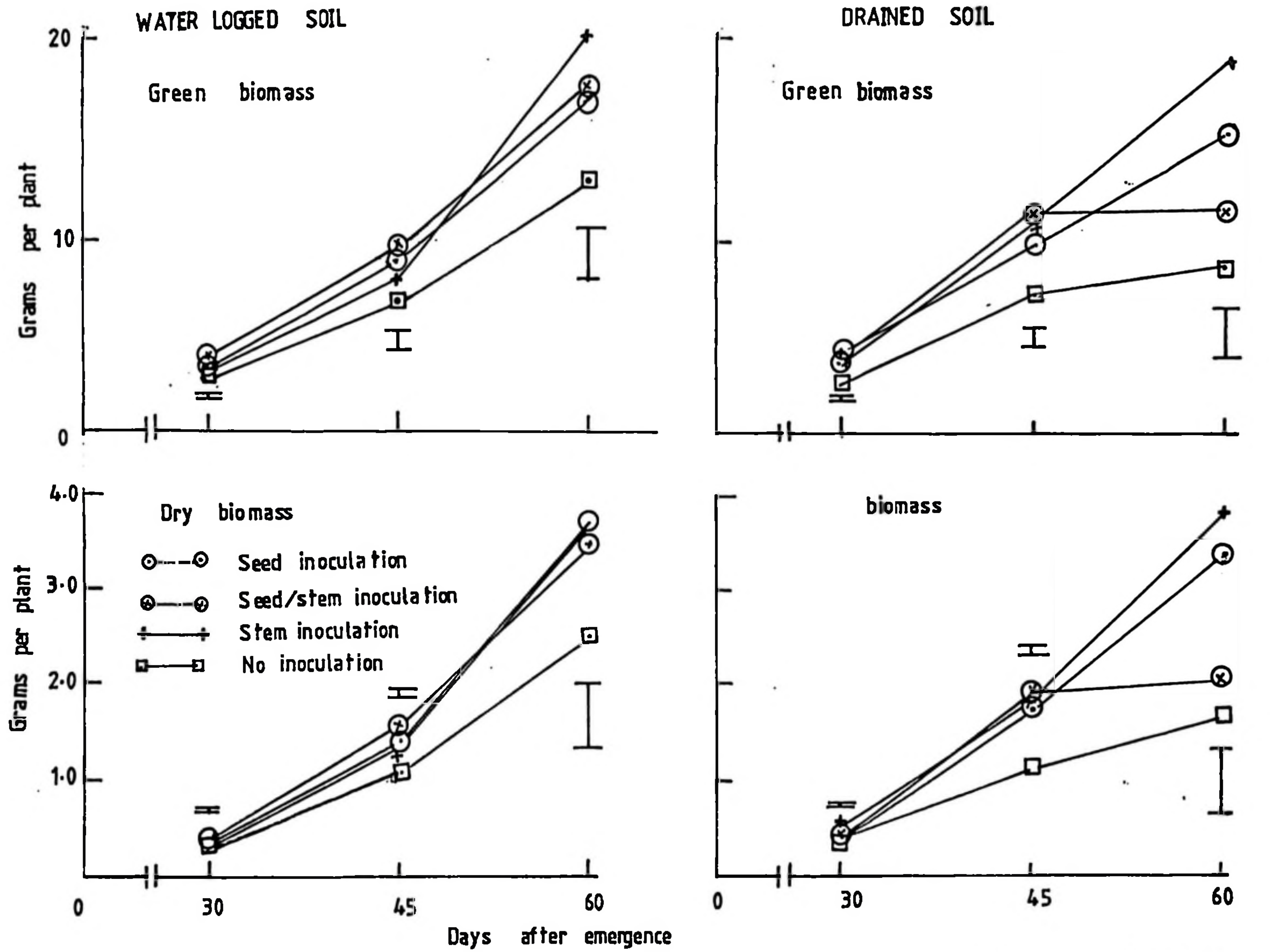

Figure 2. Effect of soil moisture regime and inoculation on *S. rostrata* biomass accumulation. A Bar indicates one SE

4.1.2 Effect of inoculation on *S. rostrata* plant height and biomass accumulation

Generally, as from the 45th day, inoculated treatments recorded significantly ($P = 0.05$) greater height and biomass than the uninoculated one (Table 2, Figures 1 and 2).

Before the 30th day only few nodules may have been formed, and those formed probably were too immature to fix considerable amounts of nitrogen for plant use. Indeed stem nodulation started only after 30 days of plant growth. Nodulation was high between 30 and 60 days (Figure 3) and by this time these nodules may have been able to fix substantial amounts of N_2. It has been observed (Russell, 1988) that 70%, or more of the nitrogen fixed by legumes was translocated to the above-ground parts of the plant. This may have been true in the present studies because all inoculated treatments (short of those heavily infested by nematodes) which showed increased nodulation (nodule weights) also accumulated more nitrogen. They also had the largest biomass as compared to those with the least nodulation, including uninoculated treatments (Figures 2, 3 and 6).

Table 2. Effect of inoculation of S. rostrata on its green biomass

Inoculation method	Growth period (days)		
	30	45	60
	g/plant		
Seed inoculation	3.92a	9.41a	16.20ab
Seed/stem inoculation	3.86a	10.59a	14.75ab
Stem inoculation	3.44a	9.73a	19.66a
No inoculation	2.83a	7.01b	10.92b

Means within a column followed by the same letter did not differ significantly ($p = 0.05$) according to the Duncan's New Multiple Range Test.

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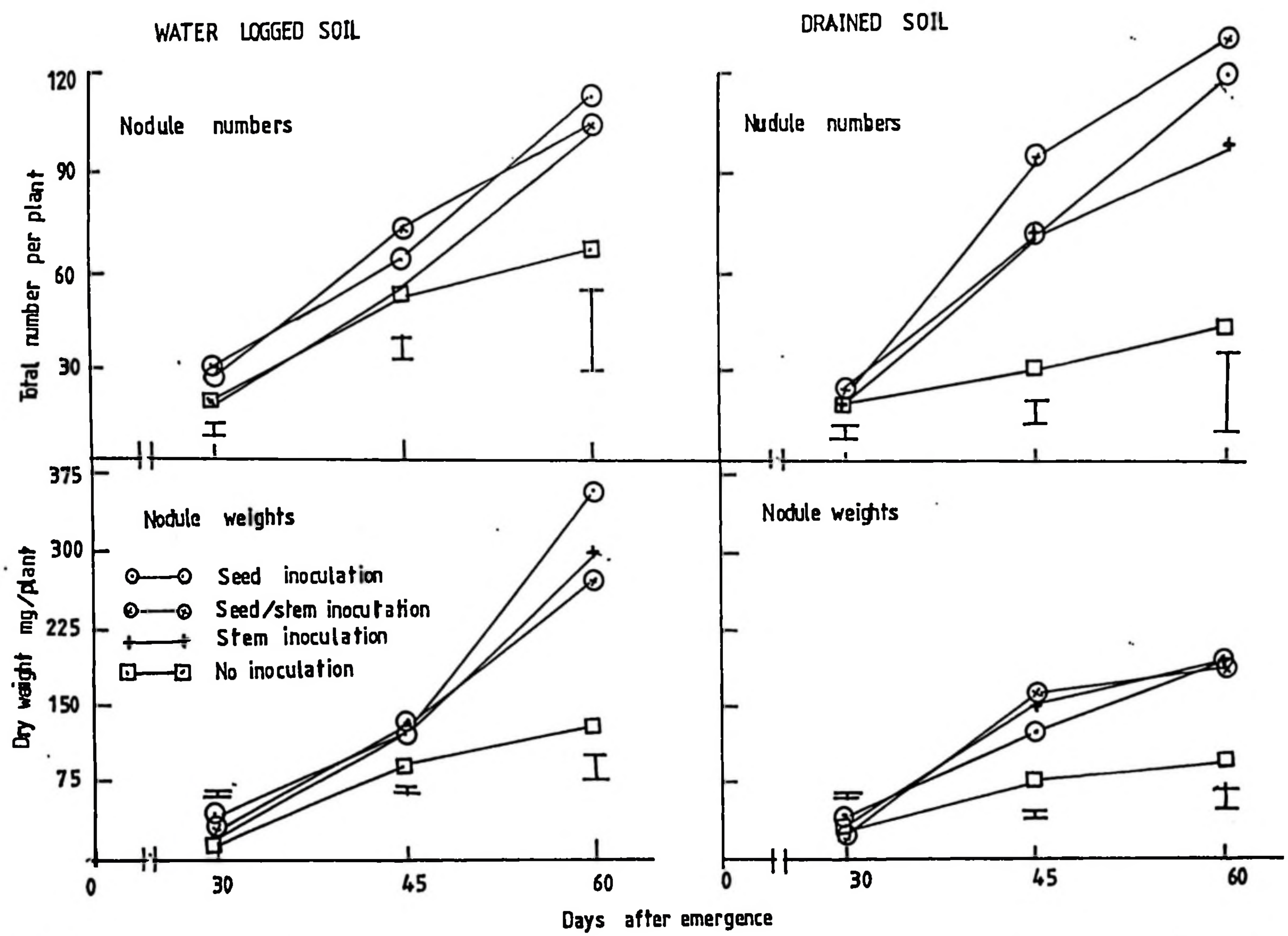

Figure 3. **Effect of soil moisture regime and inoculation on S rostrata total nodulation. A bar indicates one SE.**

From the above results it is concluded that it is possible to raise _S. rostrata_ green manure at Morogoro and probably other areas with similar agroecological conditions. Based on the pot size used in this experiment and the _S. rostrata_ plant population, a rough calculation reveals that the maximum average green biomass generated in a period of 45 and 60 days was equivalent to 16.27 and 19.65 ton/ha, and 34.42 and 32.31 ton/ha under waterlogged and drained soil conditions, respectively. If these were extrapolated to field conditions, these amounts of green manure would contribute large amounts of N (section 4.4), a substantial proportion of which would be released in soil once the incorporated green manure decomposed (section 4.5).

4.2 Effect of soil moisture regime on nodulation

4.2.1 Total nodulation

Generally, nodule numbers did not differ significantly between moisture regimes up to 45 days of plant growth. At 60 days, however, nodule dry weights were lower ($P = 0.05$) under drained soil conditions (Figure 3). But in _S. rostrata_, there may be stem nodules in addition to root nodules. These are further analysed below (section 4.2.3).

The lack of significant differences in nodule numbers between the moisture regimes in this case may be related to the ability of _S_. _rostrata_ to grow well both in drained and in waterlogged soil conditions. _Sesbania rostrata_ is adapted to grow in submerged soils (Moudiongui and Rinaudo 1987; Singh _et al_. 1988) through development of aerenchyma tissues (Evans and Rotar 1987) which ensured ample oxygen supply in the rhizosphere. This then contributed to good _S_. _rostrata_ growth under those conditions. The lower nodule weights under drained soils may be attributed, in part, to the infestation by root-knot nematodes as reported in section 4.1. Thus, while the nodule numbers were similar under both soil conditions, the development/growth of the nodules under drained conditions was retarded, as was the growth of the plants themselves, by the nematodes. Therefore, sizes and weights of the nodules were lower under drained conditions where there were nematodes than under waterlogged conditions where there was no nematode infestation.

4.2.2 Root nodulation

Generally, neither the nodule numbers nor the nodule weights differed between the moisture regimes up to 45 days. But by the 60th day, nodule weights under waterlogged soils were higher (P = 0.05) than under drained soils (Figure 4).

The nodule weight differences between the two moisture regimes in favour of the waterlogged soils at 60 days may be attributed to the damage, by root-knot nematodes, of plants (roots) under drained soil conditions, as discussed in section 4.2.1 above.

4.2.3 Stem nodulation

Stem nodules appeared after 30 days since plant emergence. This was 10 days after stem inoculation of the plants, which was done at 20 days after plant emergence. In the stem-inoculated treatments, there were generally more (P = 0.01) stem nodules under drained than under waterlogged soil conditions. However, the nodule weights, especially under the seed/stem-inoculated treatments, were slightly higher though not significantly so under waterlogged conditions (Figure 5).

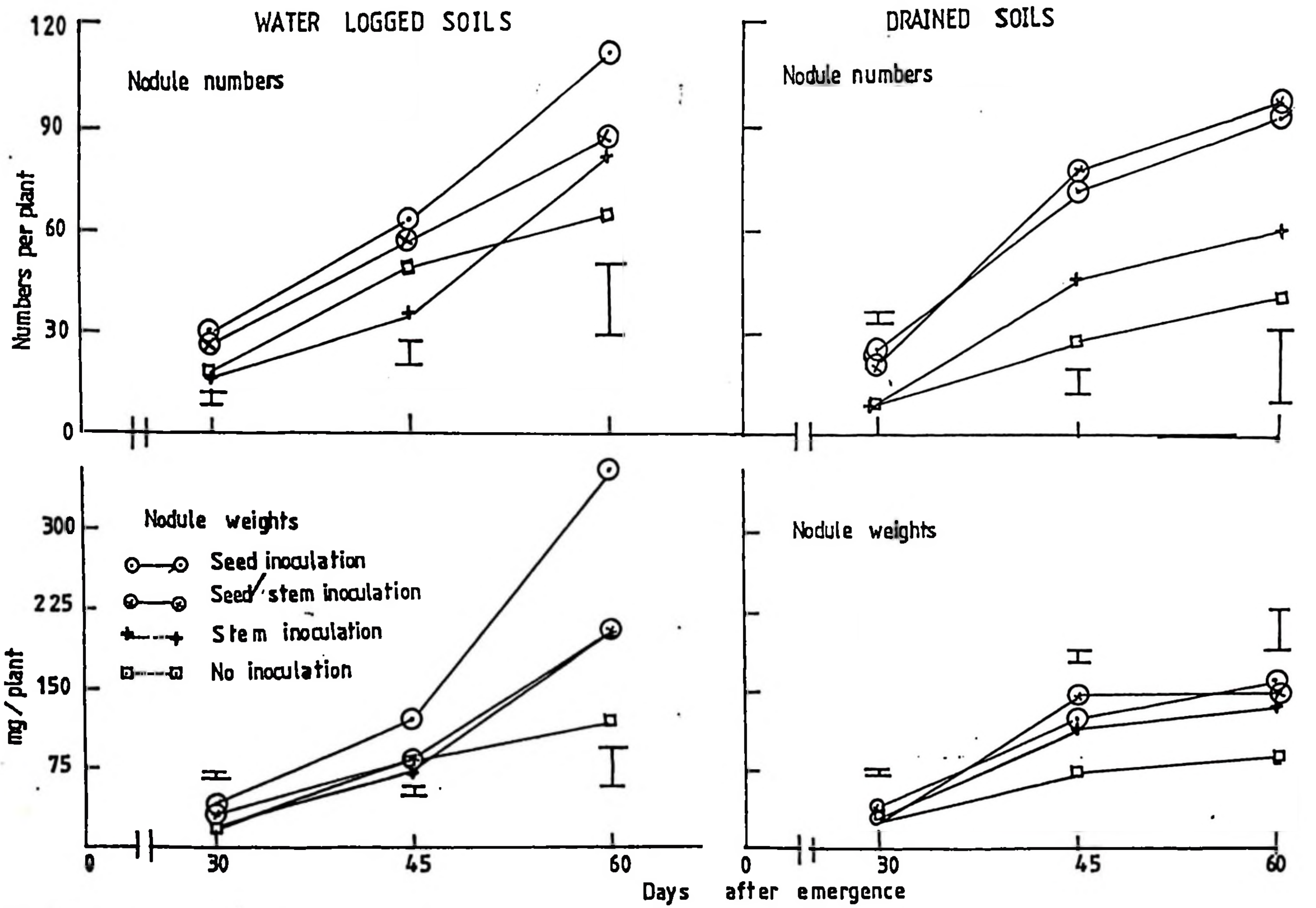

Figure 4. Effect of soil moisture regime and inoculation on *S. rostrata* root nodulation. A Bar indicates one SE

The slight difference in stem nodule weights between plants growing in drained and those in waterlogged soils may be related to nodule sizes. Whereas in drained soils stem nodules were many in number, they were relatively smaller compared to the large-sized, though relatively fewer, nodules under waterlogged soils. Bergersen (1977) observed that low nodule numbers in legumes could be compensated for by the few nodules so formed becoming larger, as was observed in the present studies. The nematode infestation under drained conditions, which retarded plant growth in general (section 4.1), may have likewise retarded the further development of the nodules in particular under those drained conditions.

4.3 Effect of inoculation on nodulation

4.3.1 Total nodulation

Generally, all the inoculation treatments resulted in more ($P = 0.05$) nodulation (both nodule numbers and weights) as compared to the control (Table 3). There were no significant differences between the inoculation treatments themselves.

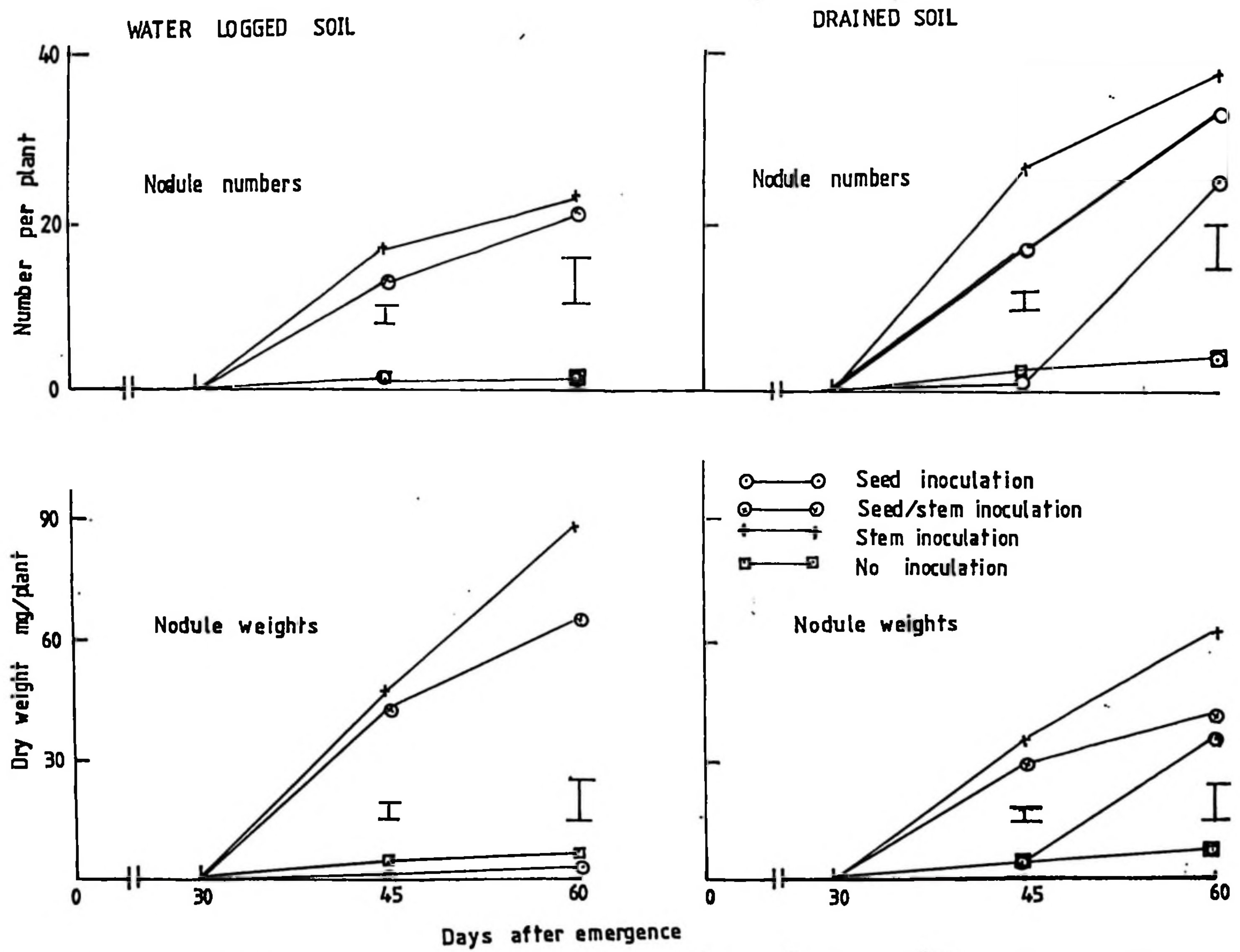

Figure 5. Effect of soil moisture regime and inoculation on stem nodution of _S. rostrata_. A Bar indicates one SE

Uninoculated plants produced only root nodules, attributed to native rhizobia in soil. The greater competitiveness of the introduced Rhizobium over the native ones (Date 1977) may have been responsible for the increased nodule numbers and nodule weights in the inoculated treatments compared to the control.

4.3.2 Root nodulation

The number of root nodules were not significantly different between the inoculation treatments (Table 3). However, nodule weights in the seed-inoculated treatment was significantly ($P = 0.05$) higher than in the un-inoculated control. Root nodules were the bigger contributor to the total nodulation as compared to stem nodules (Table 4).

The superiority (in terms of nodule weights) of the seed-inoculated treatments over the control may be due to higher efficiency of the introduced Rhizobium strain(s) complementing that due to native Rhizobium as discussed above (section 4.3.1). Uriyo (1974) and Chowdhury (1977), both working with newly introduced soybean at Morogoro, also found that control plants nodulated appreciably but in most cases nodule numbers and weights were increased significantly by inoculation.

Table 3. Effect of inoculation on root and stem nodulation by *S. rostrata* plants at 60 days of growth.

Inoculation technique	Total nodules		Root nodules		stem nodules	
	Number per plant	Dry weight mg/plant	Number per plant	Dry weight mg/plant	Number per plant	Dry weight mg/plant
Seed inoculation	115a	279.33a	102a	260.17a	13b	19.17b
Seed/stem inoculation	118a	234.17a	93a	180.83ab	25a	53.33a
Stem inoculation	100ab	249.0a	71a	173.67b	29a	75.33a
No inoculation	54b	114.0b	52a	107.33b	2b	6.67b

Means within a column followed by the same letter did not differ significantly ($p = 0.05$) according to the Duncan's New Multiple Range Test.

Table 4. Relative contributions of root and stem nodules to total nodulation of *S. rostrata*

Moisture regime	Type of nodules	Stem inoculation		Seed/stem inoculation	
		Nodule numbers	Nodule weights	Nodule numbers	Nodule weights
		% of total nodules			
Water logged	Root	78	71	81	77
	Stem	22	29	19	23
Drained	Root	61	70	75	78
	Stem	39	30	25	22

The greater extent of root nodulation relative to stem nodulation as observed in the present study (Table 4) deviated from observations reported in the literature (Dreyfus et al. 1985) where stem nodules outnumbered and outweighed the root nodules. One reason for this discrepancy in the present studies may be that the Rhizobium strain(s) of the present inoculant were those capable of nodulating the roots more than the stems. It has been observed that all rhizobial strains capable of nodulating S. rostrata stems were also able to nodulate roots as well, but the vice versa has not necessarily been true (Evans and Rotar 1987). Also, a part of the stem inoculum, which was applied in the present studies in the form of a non-sticky, water suspension, may have been washed down the stem into the soil by dew. This, then, may have left fewer rhizobia on the stem, thereby limiting the extent of stem nodulation of the stem-inoculated plants.

4.3.3 Stem nodulation

The stem-inoculated treatments resulted in significantly (P = 0.01) more stem nodulation (both nodule numbers and weights) than in the control or the seed-inoculated treatments (Table 3). However, under drained soil conditions stem nodules appeared even in the seed-inoculated treatments (Figure 5). The t-test revealed a significant (P = 0.05) contribution by stem nodules to total nodulation in the stem-inoculated treatments as compared to the non-inoculated control treatment.

Generally, stem nodulation appeared only after inoculating the stems. The significantly higher nodulation upon stem-inoculation may imply that the scope exists of increasing N_2 fixation through stem nodules. The proportion of the total nodulation contributed by stem nodules (Table 4) was found to be significant ($P = 0.05$). Assuming the effectiveness of root nodules and stem nodules to be equal, it may be reasonable to predict that stem nodules would therefore contribute significantly to total N_2 fixation. Studies conducted by the IRRI (1988, 1989) showed that acetylene reduction, as a measure of N_2 fixation, by stem nodules, was appreciable and increased with plant growth. Such an increase may be consistent with the increase in nodule numbers and weight with time as observed in the present studies. This may reflect the potential of stem nodules to contribute to N_2 fixation by _S. rostrata_.

The appearance of stem nodules on the seed-inoculated plants under drained conditions may have been due to contamination. Cross-infection and subsequent nodulation of stems from recently stem-inoculated plants to non-inoculated ones was found to be easy through vectors such as wind, rainfall/high humidity or insects (Rinaudo *et al*. 1983; IRRI 1987). Ants which may have roamed the experimental site of the present study, may have also contaminated stems of the seed-inoculated plants with *Rhizobium* from soils of their respective treatments. As these insects could not get into contact with the flooded soil, only drained soil treatments were affected.

4.4 Effect of moisture regime and inoculation on N_2 fixation

Taking the cumulative value at 60 days more (P = 0.05) N_2 was fixed, as measured by N accumulation per *S. rostrata* plant, in waterlogged soils than in drained soils. The N_2-fixation was significantly (P = 0.01) higher in the inoculated treatments relative to the uninoculated control (Figure 6, Table 5). A rough calculation and conversion of the amount of N_2 fixed by the 45th and 60th days into kg N/ha reveals substantial N_2-fixation by *S. rostrata* (Table 5). The extent of N fixation due to inoculation may be best reflected by comparing with uninoculated treatment, assuming that no N fixation took place in this treatment. Thus, according to Table 5, the fixed N as a proportion of the total N in the plants (i.e.(a-b)/a where a = amount of kg N/ha from inoculated treatments and b = amount of kg N/ha from the uninoculated treatment) was 0.34, 0.23 and 0.29 for waterlogged and 0.52, 0.21 and 0.66 for drained treatments, respectively for seed, seed/stem and stem inoculated treatments. However, it should be noted that nitrogen fixation might have also taken place in the uninoculated treatment because of its considerable nodulation (Table 3). So the N accumulated in the uninoculated plants was not solely due to mineral N in the soil.

At 60 days plants from the seed/stem-inoculated treatment in drained soils had much lower N content than it had at 45 days (Figure 6, Table 5).

The higher N accumulation/fixation by S. rostrata plants in waterlogged soils was in agreement with higher nodulation (nodule weights) under that soil moisture regime (sections 4.2.1 and 4.2.2). This was consistent with, and may have contributed to, the better growth performance of the plants under the waterlogged conditions (section 4.1).

The significantly higher N_2 fixation in the inoculated treatments is reflected in the improved nodulation upon inoculation (Table 3, Figures 3, 4 and 5). These results are in agreement with those reported by various workers in the Philippines (IRRI 1987, 1988), and at the ORSTOM in Senegal (Dreyfus et al. 1985).

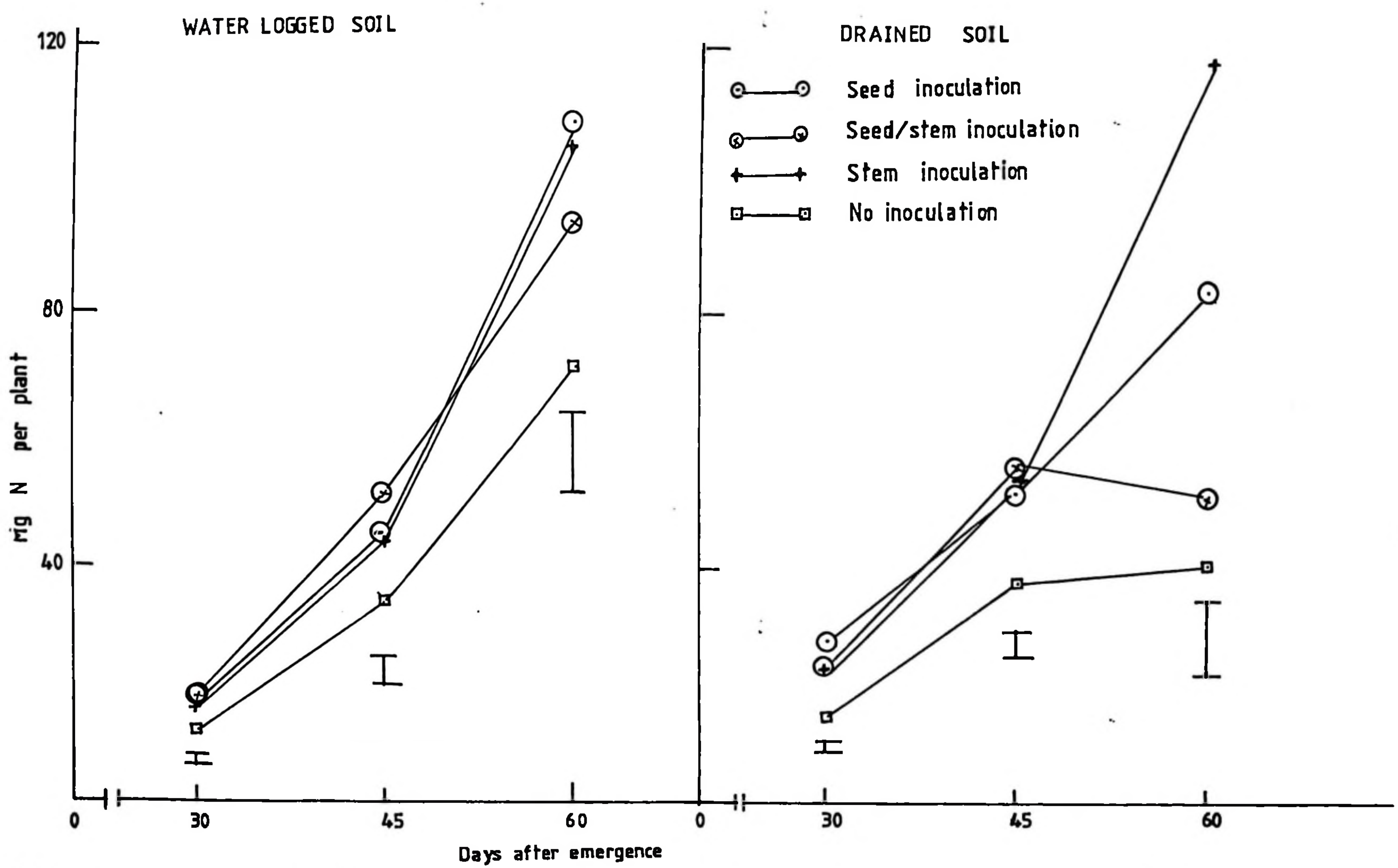

Figure 6. Effect of soil moisture regime and inoculation on N_2 fixation by *S. rostrata* plants. A Bar indicates one SE

Table 5. Influence of soil moisture regime and Rhizobium inoculation on N2- fixation/ accumulation by *S. rostrata*

Inoculation Technique	Water logged soil				Drained soil			
	45 days		60 days		45 days		60 days	
	g N/pot	kg N/ha	g N/pot	kg N/ha	g N/pot	kg N/ha	g N/pot	kg N/ha
Seed inoculation	0.55a	78.32a	1.31a	184.58a	0.64a	90.95a	1.01b	143.30b
Seed/stem inocu.	0.62a	87.84a	1.28ab	159.49ab	0.69a	97.29a	0.62c	87.70c
Stem inoculation	0.53a	75.09a	1.23ab	173.31ab	0.65a	92.09a	1.42a	201.28a
No inoculation	0.41b	57.83b	0.86b	122.30b	0.45b	64.11b	0.49c	68.82c

Means within a column followed by the same letter did not differ significantly (P = 0.05) according to the Duncan's New Multiple Range Test

g N/pot is converted to kg N/ha by the calculation kg N/ha = ax 10^5/u where a is the amount in g N and u is the surface area in cm^2 of the soil in the pot i.e.

$$\text{kg N/ha} = \frac{\text{a g N/pot} \times 40^8 \text{ cm}^2 \text{/ha}}{\text{u cm}^2 \qquad 10^3 \text{ g/kg}}$$

$$= \frac{\text{a kg N} \times 10^5}{\text{u} \qquad \text{ha}}$$

$$= \frac{\text{a} \times 10^5}{\text{u}} \text{ kg N/ha}$$

The amount of nitrogen generated by *S. rostrata* per unit area of land will depend on the plant population in the field. The potential for N_2 fixation by *S. rostrata*, which contributed the equivalent of up to 97 and 201 kg N/ha at 45 and 60 days, respectively, in the present studies (Table 5), suggests that yields of rice could be greatly increased upon application of this manure under the Morogoro conditions. At the IRRI (IRRI 1988) substantial yields of rice were obtained when *S. rostrata* green manure was used.

The lower N content of plants from the seed/stem-inoculation treatment under drained soil conditions may have been due to root-knot nematode infestation which subsequently had reduced the growth of *S. rostrata* (section 4.1) as well as its nodulation (sections 4.2.1 and 4.2.2). Therefore the N_2 Fixation rate and, hence, N accumulation by those plants was reduced.

4.5 Effects of moisture regimes and *S. rostrata* green manure on soil N indices

4.5.1 Soil total N

The trend of N turnover as decomposition of the incorporated green manure proceeded is presented in Figure 7.There was no significant difference of soil N accumulation between the two soil moisture regimes. Soil total N increased progressively with time of incubation for all levels of green manure, including the control, up to 21 days after which it levelled off or decreased slightly. Higher levels of green manure contributed significantly (P = 0.05) more nitrogen to the soil in both moisture regimes.

The lack of significant difference in soil N accumulation between the soil moisture regimes may imply that the rates of soil total N accumulation were more or less the same, even if different mechanisms were involved. The increase in total N with time may have been brought about by the rapid N mineralization accompanying the decomposition of the high-nitrogen organic manure (Tanaka 1978), in this case the sesbania green manure. After 21 days, the rate of mineralization may have been slowed down probably due to the exhaustion of the easily decomposable green manure components (Palm et al. 1988). Beri et al. (1989b) also found that 80% of total N in S. aculeata green manure was released in about 10 days and Bhardwaj and Dev (1985) reported that a considerable quantity of N in S. cannabina was mineralized in the first three weeks of incubation. It is probable that the S. rostrata green manure used in the present study behaved in a similar manner.

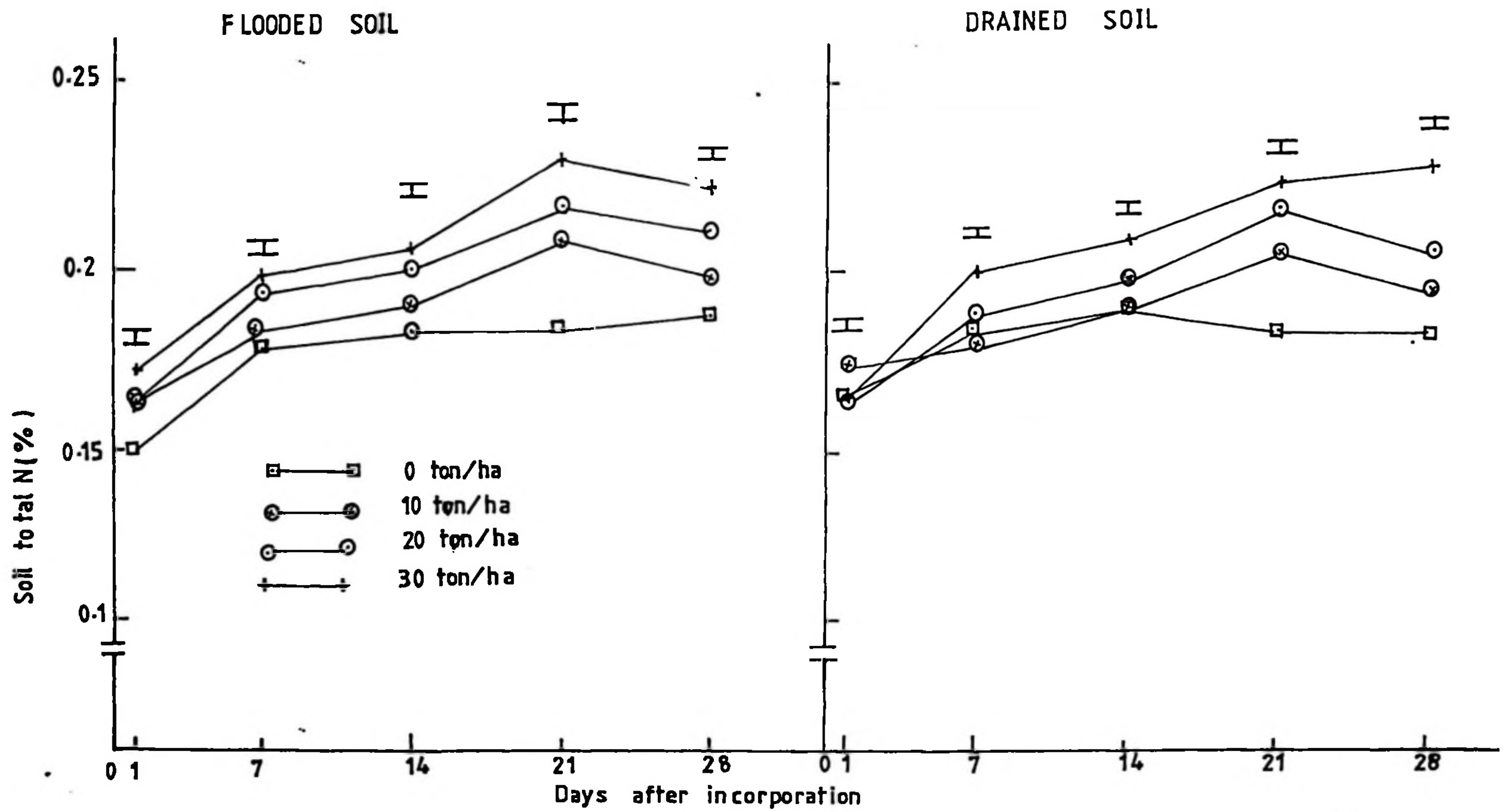

Figure 7. Changes in soil total N after *S. rostrata* green manure incorporation. A Bar indicates one SE

The depression at 28 days may have been due to decreasing mineralization because of the depletion of easily decomposable components. According to Watanabe (1984) mineralization of organic nitrogen was also accompanied by simultaneous immobilization at rates depending on the soil moisture content. Some of this mineral N was also prone to denitrification (Bhardwaj and Dev 1985) and this may account for the overall reduction in the soil total N as was starting to become evident in Figure 7.

As regards the contribution by different levels of green manure to soil total N, it can be inferred from the present study that the larger the amount of green manure applied, the more N added to the soil.

4.5.2 Ammonium nitrogen release pattern

In the flooded soils, the ammonium (NH_4-N) form dominated the soil mineral nitrogen content and increased with time of incubation (Figure 8a, Table 6). Significant ($P = 0.05$) differences in NH_4-N turnover were recorded even in the first day of incubation, with green manure levels at 20 and 30 ton/ha surpassing those at 0 and 10 ton/ha. These differences were maintained up to 28 days. No such differences were observed in the case of drained soils where

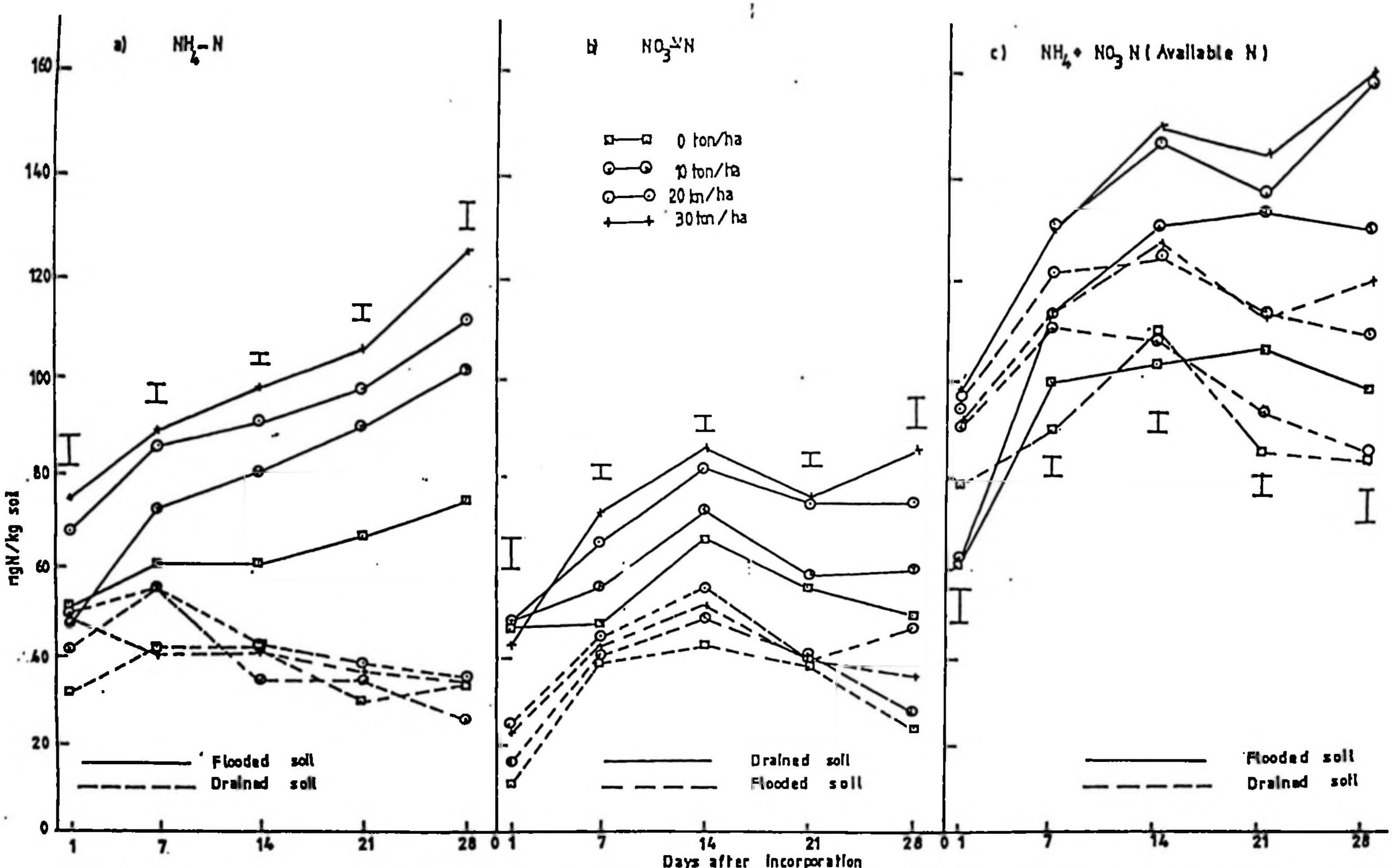

Figure 8. Comparative effects of soil moisture regime on mineral N release patterns upon S. rostrata green manure incorporation. A bar indicates one SE.

Table 6. Effect of soil moisture regime and incubation of *S. rostrata* green manure on mineral nitrogen release in soil.

Incubation/ Decomposition Period (days)	Levels of green manure (ton/ha)	Flooded soil		Drained soil	
		NH_4-N	NO_3-N	NH_4-N	NO_3-N
1	0	50.73bc	10.48a	32.22a	44.66a
	10	46.90c	16.20a	42.15a	47.59a
	20	68.40ab	25.14a	49.97a	48.07a
	30	74.57a	23.09a	47.71a	42.91a
28	0	74.97c	23.63a	34.11a	49.85c
	10	102.4b	28.35a	25.50a	59.94bc
	20	111.68ab	47.15a	34.55a	75.10ab
	30	124.85a	35.65a	34.79a	86.08a

For each decomposition period, means within a column followed by the same letter did not differ significantly ($P = 0.05$) according to the Duncan's New Multiple Range Test.

NH_4-N was comparatively lower and generally decreased with time of incubation.

The accumulation and dominance of NH_4-N under flooded conditions was due to reduced aeration under the flooding, which may have suppressed nitrification (Bartholomew and Clark 1965). This was unlike in the drained soils where nitrification would continually take place, thereby depleting the NH_4-N so mineralized. A similar trend of NH_4-N accumulation was also reported elsewhere (IRRI 1986) where flooded soils amended with S. rostrata accumulated NH_4-N progressively, reaching a maximum at 60 days, and then remaining constant. In the present studies the NH_4-N was determined only up to 28 days, but the peak had not yet been reached. This may mean that more NH_4-N may continue to be released over a longer period of time.

4.5.3 Nitrate nitrogen release pattern

In the drained soils, nitrate (NO_3-N) dominated the soil mineral N content (Figure 8b), as NH_4-N had in the flooded soils. The rate of nitrate release peaked after 14 days of incubation in both soil moisture regimes, then generally decreased. There were significant ($P = 0.05$) differences at the 28th day in the rate of NO_3-N turnover under different levels of green manure application (Table 6). In the waterlogged soils NO_3-N remained generally low.

The dominance of NO_3-N in drained soils was probably due to the aerobic conditions prevailing, which favoured nitrification of most of the NH_4-N generated during ammonification (Abichandani and Patnaik 1958). Beri et al. (1989a) observed that about 40% of the carbon (and hence N) added through leguminous green manure was mineralized in the first two weeks of incubation. The subsequent depression in NO_3-N levels after 14 days in the present study may be attributed to denitrification. Some denitrification was found to occur even in well drained soils because these contained water filled anaerobic microenvironments where the diffusion of oxygen was inhibited (Grant and Long 1981). In the present study these microenvironments may have existed, taking into account the texture of the soil (Sandy clay) (section 3.1) and the frequent watering during the course of the experiment. Beri et al. (1989b) also demonstrated that under field capacity or saturated soil moisture regimes some of the NO_3-N formed from decomposition of sesbania was highly susceptible to loss by denitrification.

The persistent and initially increasing NO_3-N levels in the flooded soil may have been due to fluctuating redox potentials in the system. This may have been brought about by frequent addition of fresh water, and returning of drainage water, into the pots, alternating with periods of aeration as the water drained through the soils. This "disturbance" of the "flooded" conditions may have increased the oxygen concentration to levels high enough to allow an appreciable extent of nitrification of NH_4-N (Amoine 1962), thereby increasing the levels of NO_3-N.

4.5.4 Available nitrogen

By summing up the NH_4-N and NO_3-N generated under each moisture regime, an estimate of available N was obtained (Figure 8c). On the whole, there was more available N under the waterlogged regime than under the drained one but, overall, the levels of available N were generally high (over 80 mg N/kg soil, which is equivalent to over 176 kg N/ha). Such levels can very well sustain high rice yields. The lower levels of available N under drained soil conditions may be due, in part, to loss of NO_3-N through denitrification.

4.6 General discussion

It was observed (section 4.1) that S. rostrata grew well under glasshouse culture. It is inferred that S. rostrata may be successfully grown for green manure purposes under the Morogoro conditions. This is because in the present studies, the equivalent of up to 20 and 34 ton/ha green manure could be raised in 45 and 60 days, respectively. It was observed that although *S. rostrata* may be nodulated by native rhizobia, artificial inoculation with rhizobia increased nodulation (section 4.3), nitrogen accumulation (section 4.4) and, subsequently, biomass yields (section 4.1.2). Thus, the potential to utilize this relatively inexpensive technology exists, so as to meet the nitrogen needs of a rice (or other) crop.

The N accumulation as a result of use of the manure was enormous, up to 200 kg N/ha (section 4.4). This is the kind of N amount which can suffice the needs of a growing crop (e.g. rice) and result in substantial yield increases, as has been amply reported elsewhere (Rinaudo *et al*. 1983; Dreyfus *et al*. 1985; Mulongoy 1986; IRRI 1987, 1988). Green manure decomposition studies (section 4.5) showed that substantial quantities of the N contained in the green manure can be mineralized. This would then be available to be utilized by crop plants growing under these conditions, if losses of N (e.g. by leaching, denitrification) can be prevented.

All the above considerations point to the feasibility of using this N_2 fixation and green manuring technology to increase rice yields. But before this technology is recommended to the farmers as standard practice, there are other considerations which should be addressed and clarified, such as the following:

It has been shown that stem inoculation significantly increased total nodulation (section 4.3). Before recommending stem inoculation as standard practice, a detailed and wide-ranging analysis should be carried out as to whether the resultant stem nodulation results in significantly higher N_2 fixation to warrant adoption of stem inoculation. An evaluation should also be conducted as to whether the labour costs and other expenses involved would be comparatively lower, and thus maximise farmers' profits, than the costs involved in investing in supplemental mineral fertilizers if so required.

Another consideration is the timing of the raising/sowing of the green manure "crop" to fit within the (usually limiting) short growth season. This assumes that the manure would be raised and used during the same season. This means that a compromise will have to be worked out, for example, with regard to how early the harvesting of the green manure could be undertaken (relative to its N content) so as not to lose the season in question in terms of the crop intended to be raised/grown.

Alternatively, raising of the manure in one season and using it at the next after it has decomposed in place should be evaluated. This consideration is also related to the size of farmland available, such that some portion could be used for raising the manure in one season, only to be cultivated in the following season.

In short, the research reported herein indicates that the potential exists of using S. rostrata green manure in the production of rice (or other crops). Still, other considerations remain which need to be rationalized in order to fit this technology well into the existing rice (or other) farming system.

5. SUMMARY AND CONCLUSIONS

Generally, S. rostrata plants grew well both in waterlogged and in drained soil conditions. In the first 45 days, plants growing in drained soils were relatively more vigorous than those in waterlogged soils. This was reversed during the last 15 days due to the infestation, by root-knot nematodes, of plants growing in drained soils.

Inoculation with Rhizobium resulted in significantly more S. rostrata biomass, its higher nodulation and higher N_2 fixation than the non-inoculated plants. Lower nodule weights in drained soils despite equal or higher nodule numbers than in waterlogged soils were attributed to retardation in nodule growth due to nematode infestation in drained soils. Although the stem nodules' contribution to total nodulation was appreciable, root nodulation contributed more in terms of nodule numbers and nodule weights. The native Rhizobium population was found to be active in nodulating the roots. Inoculating the stems had no influence on total nodulation when compared to the seed-inoculated plants.

More N_2 fixation/accumulation was recorded in drained soils at 45 days and the vice versa at 60 days of plant growth. The trends of biomass accumulation by plants, their extent of nodulation, and the N_2 fixation were found to be consistent.

Following incoporation of Sesbania green manure into the soil there was no difference in soil total N between flooded and drained soils. In flooded soils, NH_4-N dominated the mineralized N content and its concentration increased with time, probably due, in part, to suppressed nitrification. In drained soils, where conditions for nitrification prevailed, NH_4-N was least pronounced and Nitrate-N dominated the soil mineral N content, increasing up to 14 days and then followed by a depression which was attributed to N loss probably by denitrification in the anaerobic microenvironments. In flooded soils, though, NO_3-N was comparatively lower than in drained soils. Presence of NO_3-N in the otherwise reducing flooded conditions may be attributed to frequent disturbance, through partial water drainage in the flooded soils, which may have increased the redox potential to levels allowing some nitrification to take place.

The available N was significantly higher in waterlogged than in drained soils. The relatively low levels of available N in drained soils was attributed to loss of NO_3-N by denitrification, as pointed out above. In all cases, higher levels of applied green manure contributed significantly higher nitrogen turnover (soil total N and mineral N) than lower manure levels.

From the above results it is concluded that S. rostrata can successfully be raised as a green manure "crop" for rice production under the Morogoro conditions. Inoculation of S. rostrata seeds and/or stems can significantly increase the green biomass of the plants as well as the amount of nitrogen fixed. The high amounts of nitrogen fixed/accumulated by this legume and the higher levels of plant available N generated both under drained soil and flooded/waterlogged soil conditions suggest that yields of rice can be greatly increased and sustained upon sustained application of this biofertilizer. However, the results of the present studies create grounds for further research especially with regard to timing of the raising of the green manure plants in order to fit within the rice crop's optimum growing period within the growth season. Also, the cost-benefit analyses involving labour costs and other expenses consequent upon green manure use in comparison with the farmers' present practices need to be given proper consideration before any definite recommendation is made. Otherwise, the potential does exist of using S. rostrata as a green manure in rice production.

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