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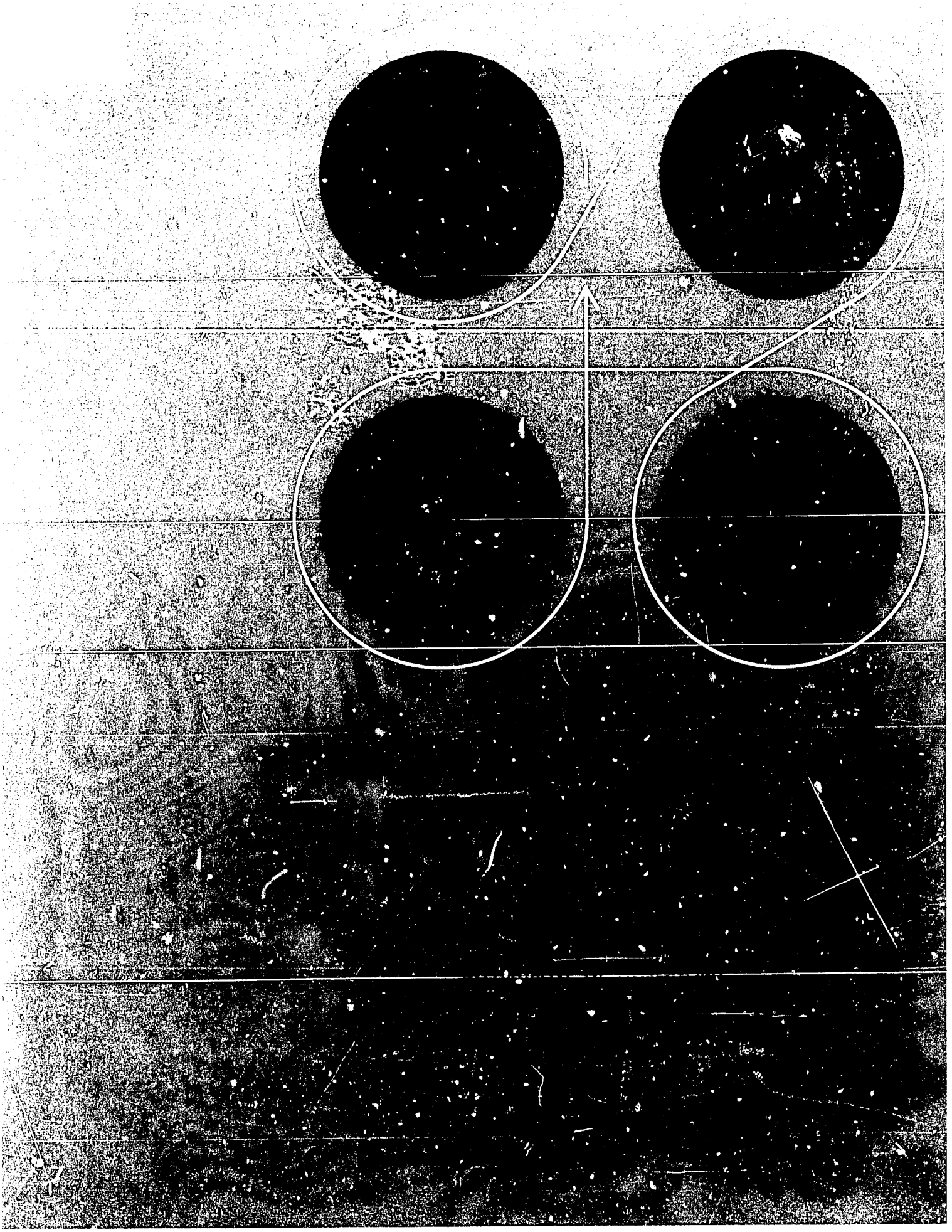

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NITROGEN FIXATION BY LEGUMES IN THE TROPICS

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September 1979

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NITROGEN FIXATION BY LEGUMES IN THE TROPICS

Cultivated plants continuously require nitrogen. This nitrogen is ordinarily supplied by mineralization of native soil nitrogen, but is sometimes supplemented by fertilizer nitrogen in the case of non-legumes or by these two sources plus dinitrogen fixation in the case of legumes. Legumes have been used in building and conserving soil fertility since the beginning of agriculture and there have been numerous investigations centered around the nitrogen economy of leguminous plants. Rhizobium bacteria in association with the host plant are able to fix dinitrogen from the atmosphere. This symbiosis process is estimated to account for approximately 20% of the dinitrogen fixed annually in the world (Dazzo & Hubbel, 1974). Even in the cases where the native soil nitrogen is very low, effectively nodulated legumes can fix enough dinitrogen for acceptable yields.

In addition to its incorporation in the legume crop, the fixed nitrogen may make significant contributions to succeeding non-legume crops. This residual effect is mainly dependent upon the amount of nitrogen in legume residues which remain after the legume crop is removed. Another way legumes may supply nitrogen to non-legumes is by growing the two crops together, when some benefits in nitrogen nutrition are realized by the non-legume.

The objective of this review is to summarize the estimated amounts of nitrogen fixed by legumes and the conditions which maximize benefits from the legume-Rhizobium symbiosis.

1. Potential benefits from legumes

Consumption of fertilizer nitrogen has increased by a factor of about 10 in the last 25 years and in 1978-79 it approached 52 x 10^6 tons. From

these figures, Hardy and Havelka (1975) predict that 25 years from now, 200 x 10^6 metric tons of fertilizer N will be required annually in the absence of alternative techniques for producing fixed nitrogen. Furthermore, most of this fertilizer is used in developed countries. Unfortunately, even though N fertilizers may be available, their cost, and the difficulties in transportation and distribution to farmers makes them uneconomic or impractical in many areas of the world. Lately, the situation has been accentuated by increased energy costs and/or unavailability of foreign exchange.

In view of these facts, the Rhizobium-legume based symbiosis offers great opportunities for increasing inputs of nitrogen in food production. Although other organisms fix dinitrogen, including free-living organisms such as Clostridium Azotobacter, and many algae, their contribution to total biological nitrogen fixation is not as great as the Rhizobium-legume symbiosis (Hardy & Havelka, 1975). Hardy and Hevelka estimated the Rhizobium-legume symbiosis contributes 40 x 10^6 tons of nitrogen annually to grain legumes, and for global overall estimates, Graham and Hubbell (1975) gave an estimate of biological nitrogen fixation varying from 100 to 500 x 10^6 tons $year^{-1}$, with the Rhizobium-legume symbiosis estimates varying from less than 100 kg ha^{-1} $year^{-1}$ to more than 600 kg ha^{-1} $year^{-1}$.

1b. Concepts for managing symbiotic fixation

Conditions essential for optimum symbiotic dinitrogen fixation are as follows: a) the host plant and Rhizobium strain must be compatible, b) the soil and environmental conditions must be favorable for survival of the Rhizobium, and c) nitrogen content, and usually symbiotic fixation, will increase with increasing yield of the host plant; therefore, management practices which insure high yields of the host plant will insure high

symbiotic fixation or, at least, high yields of the host plant are an essential condition for high symbiotic fixation. Basically, managing symbiotic fixation is reduced to insuring proper infection with rhizobium and high yields of the host plant.

de Souza (1969), in nodulation studies carried out in Kenya, compared several legumes and found that the introduced legumes (Trifolium semipilosum and Glycine max.) were not able to nodulate effectively without the aid of inoculation by an appropriate rhizobial strain. On the other hand, indigenous legumes such as Crotalaria spp. and Dolichos spp. need not be inoculated. As Vincent (1974) pointed out later, inoculation is necessary in soils where the rhizobia are ineffective, or where they are absent or sparse. There is also a requirement to utilize a rhizobial strain which has the ability to persist in the soil.

The influence of specific soil conditions on plant growth and/or nitrogen fixation varies among legumes, and among the environmental conditions under which the legumes are grown. The basic idea which we wish to emphasize is that adding required nutrients or eliminating toxic effects will increase the yield potential of the legumes and thereby the need for N either from the soil or by fixation. Given an effective Rhizobium-legume association, most of the nitrogen for high yields can be obtained by fixation. Thus we wish to manipulate the soil amendments so that biological systems supply most or all of the nitrogen rather than fertilizer nitrogen fixed with fossil fuel. These conditions will be dealt with in some detail in the second section.

2. Nitrogen fixation by legumes

Legumes fix nitrogen only if insufficient nitrogen is supplied by the soil. Inorganic nitrogen in the soil or mineralized during the course of

the growing season will be utilized to the extent that such nitrogen is available to the roots. The remainder of the crop nitrogen will be derived from atmospheric N_2. Thus the legumes generally conserve what soil nitrogen is available and add to it in direct proportion to the size of the "sink" created by the yield potential of the crop. In soils low in available nitrogen, most of the legume nitrogen will be derived from atmospheric N_2. In soils high in available nitrogen most or all of the legume nitrogen may be derived from the soil. As a corollary, the net increase in total nitrogen in the soil-plant system may be fairly large if the available soil nitrogen is relatively low, but not much net increase in total nitrogen will be realized if the available soil nitrogen is high. In the case of grain legumes, there is often a net depletion of soil organic nitrogen (Juo and Lal, 1977; Wetselaar, Jakobsen, and Chaplin, 1973).

The basis for the supposition that legumes utilize the available soil N is based on several kinds of observations. First, the amount of inorganic nitrogen which is found in the soil under legumes or leached from soil growing legumes is small (Wetselaar, 1967a; Lyon and Bizzell, 1921; Stewart, Viets, and Kemper, 1967; Schwartz and Miller, 1972).

Second, the presence of inorganic nitrogen has been found to reduce the volume of nodules, and reduce the amount of nitrogen derived from the atmosphere (Hardy et al., 1968; Hardy, Burns, and Holsten, 1973; Thornton, 1956; Allos and Bartholomew, 1955; Allos and Bartholomew, 1959; Bhangoo and Albritton, 1976; Weber, 1966; Rennie, Paul, and Johns, 1976).

The amount of nitrogen accumulated in the soil-plant system by fixation is as follows:

$$N_F = N_S + N_H + N_R - N_A$$

where N_S is the change in total nitrogen in the soil during the experimental period, N_H is the nitrogen removed in the harvest, N_R is the nitrogen in the plant residues at the end of the experiment, and N_A are the additions from the precipitation, fertilizer, seed, etc.

In this equation the basis for comparison is the change in nitrogen in the soil-plant system. Other bases might be comparison with fallow plots or comparison with plots cropped to a non-legume without fertilizer nitrogen. While there are advantages and disadvantages to these alternative methods, we think the above is an acceptable approximation.

The above equation is not always useful because the soil may contain several thousand kg of organic nitrogen per hectare and estimation of changes in the size of the soil nitrogen pool (N_S) is not experimentally feasible except over several years. Other techniques for measuring fixation include comparison of nitrogen content of legumes and non-legumes grown on subplots of the same field, use of isotopes of nitrogen, acetylene reduction, or accumulation of nitrogen by plants when grown on media not containing nitrogen.

The amount of nitrogen fixed (that is, net accretion of nitrogen in the soil-plant system) by several legumes each year is presented in tables 1, 2, and 3. They do not always include nitrogen contained in the roots or nitrogen in the roots and tops which are produced during the growing season but are sloughed off before harvest. For the most part, these results were obtained under experimental conditions and hence are often higher than could be expected even under good management in farmers' fields.

The emphasis in tables 1, 2, and 3 is on legumes grown in the tropics, although the data are not exclusively tropical. The important point is that nitrogen fixation obtained in the tropics with tropical legumes is

comparable in quantity to that obtained in temperate regions with temperate legumes. Hence there can be little doubt that the potential exists for utilizing legumes to supply nitrogen for food production in the tropics. In relation to this potential, deliberate utilization of legume nitrogen in the tropics is not very extensive at the present. Utilization of more of this potential will not be a simple matter because a whole array of cropping systems and associated management must be developed.

Comparison of the results in table 3 with various estimates of nitrogen accretion under fallow systems in the tropics also indicates that some legumes may accumulate nitrogen at a much more rapid rate than natural systems. This suggests the possibility that a short fallow with a legume green manure may be substituted for a much longer natural fallow, at least so far as nitrogen accumulation is concerned.

A study of average yields of grain legumes in various areas of the world clearly illustrates the vast gulf between the potential yield and the yield farmers actually obtain. Traditional cropping systems in developing countries seldom include leguminous green manures, although they may include several years of native fallow in which legumes play a role. Many animal production systems are based on low yielding and low quality forage grasses. Thus the present extent of legume-*Rhizobium* nitrogen fixation in food production in the tropics seems to be only a small fraction of its demonstrated potential.

3. Benefits of legume nitrogen to non-legumes

Legumes contribute ntirogen to non-legumes in two ways. First, they may be associated with an intercropped non-legume (that is, a non-legume and legumes are grown together). Second, legumes and non-legumes may be grown in rotations where the legume residues furnish nitrogen to the succeeding non-legume crop.

Table 1. ESTIMATES OF N_2-FIXATION BY GRAIN LEGUMES

Legume	Estimated N_2-Fixed kg/ha/annum	Source
Soybeans	29	Norman, 1943
	33-40	Hardy et al., 1971
	42-63	Bear, 1942
	114	Lyon & Bizzell, 1934
	40-140	Sundara Rao, 1971
	70	Erdman, 1959
	56	Shrader & Voss, 1972
Beans (Phascolus)	64	Lyon & Buzzell, 1934
Peas	30-140	Nutman, 1965
	52	Lyon & Bizzell, 1934
	88	Reisenauer, 1963(??)
	148	Erdman, 1959
Pigeon peas	98 (control)	Sen, 1958
	133 (with P)	Sen, 1958
Cowpeas	96	Erdman, 1959
	90	Wetselaar et al., 1973
Peanuts	41	Wetselaar et al., 1973

Table 2. ESTIMATES OF N_2-FIXATION BY HAY AND/OR PASTURE LEGUMES

Legumes	Estimate N_2 fixed kg/ha	Source
Clovers	50-200	Nutman, 1965
	112	Walker et al., 1950
	604	Sears & Evans, 1953
	100-200	Erdman, 1959
	28-170	Williams, 1970
Lucerne	248 on Gila clay loam	Smith, 1944
	822 on Mohave clay	Smith, 1944
	300-333	Lyon & Bizzell, 1933 and 1934
	56 (120 days)	de Souza, 1969
	40-350	Nutman, 1965
Tropical kudzu	189	Abruna & Figarella, 1957
	150-196	Vicente-Chandler et al., 1953
	336	Smith et al., 1951
Centrosema pubescens	269	Whitney et al., 1967
Stylosanthes guyanensis	100	Henzell & Norris, 1962
Desmodium intortum	381	Whitney et al., 1967
Desmodium canum	95	Whitney et al., 1967
Medicago sativa	90-220	Bell & Nutman, 1971
	112	Erdman, 1959
Tropicals	40-80	Wetselaar, 1967b
	20-260	Henzell, 1968
Stylosanthes humilis	70	Wetselaar, 1973

Table 3. THE NITROGEN YIELD OF TROPICAL GREEN-MANURE LEGUMES

Legume	Period (months)	Sample	N fixed kg/ha	Place
Cassia leschenaultiana	3.5	Tops + roots	86	Philippines
Phaseolus calcaratus	2.5	Tops + roots	226	Philippines
Desimodium intortum (Mill) Urb.	12.0	Tops only	123	Philippines
Calopogonium mucunoides Desv.	6.0	Tops + roots	370	Philippines
Crotalaria usaramoensis Ba k.f.	6.0	Tops + roots	535	Philippines
Indigofera hendecaphylla Jacq.	6.0	Tops + roots	331	Philippines
Mucuna deringiana (Bort) Holland	---	Tops only	134	Nigeria
Cajanus cajan (L.) Mill	5.5	Tops + roots	248	Hawaii

4a. Benefits of legumes in polycropping

Grain legumes are an integral part of many polycropping systems for food grain production throughout the world (Papendick, 1976; ICRISAT, 1975 contain examples). The advantages of polycropping under a variety of conditions have been described (Papendick, 1976, for example). In addition, many forage production systems utilize legume and grass-legume mixtures. An obvious question pertinent to this SOTA is the effect of the legume on the nitrogen economy of the cropping system.

Any attempt to isolate the effect of the legume on the nitrogen economy of the cropping system is likely to result in ambiguous answers since the basis for comparison cannot be defined clearly. Considering forage systems first, the common measure is either forage production or production of an animal product. The comparisons are often between grass-legume mixtures vs. grass plus fertilizer nitrogen. These comparisons are relatively easy. With respect to food grain production, the basis of comparison is not so simple because stability of yield, human nutrition and economic yield are all of overriding importance; the net effect of these other considerations make the effect of the legume on the nitrogen economy of the soil primarily of academic concern only. For the purposes of this SOTA, we consider the following question of more than academic interest: Is the nitrogen accretion in the soil-plant system limited by inadequacy of the legume-*Rhizobium* association? That is, would nitrogen accretion be enhanced by infection of the legumes with an effective *Rhizobium*? Would some soil amendment enhance the nitrogen accretion potential of the crop-soil system and hence the food yield or economic yield? Would a superior variety of the host crop enhance nitrogen accretion?

Unfortunately these questions have received little attention in field experiments. Most polycropping experiments have been concerned with the multitude of management variables other than effectiveness of the legume-Rhizobium association and its contribution to the overall nitrogen accretion of the system.

The substance of the preceding discussion is the following: The influence of grain legumes on nitrogen accretion in polycropped food grain production systems is an academic question because usually the legume is included in polycropping systems for reasons which overshadow their importance as nitrogen fixers; little experimental attention has been given to the more pertinent queston of whether or not relatively simple things like inoculation with Rhizobium will improve nitrogen accretion. We are left then with the relatively unsatisfactory comparison of nitrogen accumulation in monoculture vs. nitrogen accumulation in legume-non-legume polycrops.

The direct transfer of nitrogen between the legume and non-legume appears to be relatively unimportant, at least based on laboratory and greenhouse cultures (Wilson, 1940; Seager, 1961; Agboola and Fayemi, 1972; Whitney and Kanehiro, 1967). The decomposition of sloughed nodules, root tissue, and foliar residues are probably more important to the nitrogen nutrition of the non-legume (Wilson, 1940; Seager, 1961; Agboola and Fayeme, 1972; Whitney and Kanehiro, 1967; Whitney et al., 1967; Thairu, 1972; Jones, 1967a; Simpson, 1976; Oki, 1966). This probably means that in a polycropping system the influence of legumes on the nitrogen content of the soil and the non-legume is likely to be measurable only over a long period of time, or at least after much more than one cropping season.

In a polycrop system containing both a legume and a non-legume each crop competes for whatever inorganic soil nitrogen there may be present in the system. The legume component however, has the potential to obtain nitrogen via symbiotic fixation. The net result, as will be shown later, is that the total nitrogen content of both crops usually is greater than that of the non-legume when grown in a monoculture.

In the following paragraphs, some of the more interesting experiments on polycropping of grain legumes and non-legumes are reviewed with the objective of analyzing the nitrogen content (and indirectly protein yield) of the grain and the influence of fertilizer nitrogen on yields of both components.

Dalal (1974) grew maize and pigeon peas separately, planted together in the same rows, and planted in alternate rows. The maize was harvested after 16 weeks and the pigeon peas after 24 weeks. The results tabulated below illustrate that the intercropping increased accumulation of nitrogen markedly on a unit area basis. Note that a hectare of maize alone accumulated more nitrogen than did maize interplanted with pigeon peas; presumably some of this nitrogen was taken up by the pigeon peas and hence remained in the soil-crop system. However, the accumulation of nitrogen in the crop was much higher when pigeon peas and corn were intercropped relative to either monoculture.

	Grain kg/ha			Nitrogen kg/ha		
	Maize	Peas	LER[1]	Maize	Peas	Total
Maize + pigeon peas in same row	2025	1710	1.56	48	100	148
Maize + pigeon peas in alternate rows	2606	1854	1.82	54	127	181
1 ha maize alone	3120	--		66	--	66
1 ha peas alone	--	--		--	120	120

[1]LER = Relative land area required to obtain same yield in monoculture as obtained with 1 unit of area in intercrop.

Dalal (1977) studied the effect of polycropping of maize and soybeans on yields. These results illustrate the increase in nitrogen in the grain associated with the polycropping; presumably some of this results from dinitrogen fixation by the legumes. Note that the yield of maize grain and presumably accumulation of nitrogen by the maize is reduced by polycropping. The results are shown in the following table:

	No fertilizer nitrogen				100 kg N/ha fertilizer			
	Grain mT/ha		LER[1]	N[2]	Grain mT/ha		LER[1]	N[2]
	Maize	Beans		kg/ha	Maize	Beans		kg/ha
Polycrop, maize + beans in same row	4.3	0.2	.99	74	4.6	0.2	.93	81
Polycrop, maize + beans in alternate rows	4.9	0.5	1.31	104	5.4	0.4	1.24	111
Polycrop, maize + beans in alternate pairs of rows	4.8	0.3	1.49	90	5.3	0.3	1.11	98
Monoculture, maize	5.0	--	--	75	5.6	--	--	84
Monoculture, beans	--	1.5	--	90	--	1.8	--	108

[1]Relative area of monoculture to obtain same yield as 1 ha of polycrop.

[2]Nitrogen content of grain assuming 1.5% and 6.0% N in maize and soybean grain, respectively.

Agboola and Fayemi (1971) measured the yields of maize polycropped with 3 legumes over 4 cropping seasons. Cowpeas (Vigna sinensis), Calopo (Calopogonium mucunoides), and green gram (Phaseolus aureus) were the legumes. The plots were split and 50 pounds/A of nitrogen, 9 pounds/A of P and 50 pounds/A of K were added to one split and no fertilizer to the second split. Average yields of maize grain without fertilizer were increased from 1400 to about 1800 pounds/A by polycropping with the legumes while maize yields were 2300 when fertilizer was added without a polycropped legume. Yields of the grain legumes were 400 to 700 pounds/A, and were increased by fertilizer addition in 2 out of 3 cases.

CIMMYT (1974) reported the results of several fertilizer treatments at 3 locations in Mexico on yields of grain and protein with beans, maize, and polycrops of these 2 crops. Selected results are presented below:

	Yield of Grain T/ha			N Content of Grain kg/ha		
	Maize	Beans	LER[4]	Maize	Beans	Total
Polycropped maize + beans, average of 11 treatments, with fertilizer N + P[1]	3.2	1.4	1.9	44	50	94
Polycropped maize + beans + 10 tons/ha chicken manure[3]	4.0	2.4	2.9	61	97	158
1 ha maize[2]	4.6	--		64	--	64
1 ha beans[2]	--	1.2		--	40	40

[1]Average of 135 kg N/ha; 60 kg P_2O_5/ha as fertilizer.

[2]120 kg N/ha + 40 kg P_2O_5/ha on maize; 60 kg N/ha + 60 kg P_2O_5/ha on beans alone as fertilizer.

[3]50 kg N/ha + 40 kg P_2O_5/ha as fertilizer.

[4]LER = relative land area required to obtain same yield in monoculture as obtained with 1 unit of area in polycrop.

These data illustrate the advantages of intercropping on yields of protein relative to a monoculture of the two crops. Perhaps the most interesting aspect of the data is the very large increase in yields of grain and protein obtained when 10 tons of chicken manure was applied (in addition to 150 kg N/ha + 40 kg P_2O_5 ha); the yields of beans in one ha of the polycrop were double the yields of beans on one ha in bean monoculture!! A number of speculative hypotheses could be made about the reason for the latter observation, but perhaps the most important point is

that the soil fertility management of the beans in monoculture may have been deficient.

Oelslighle, et al. (1976) cite a similar study in Costa Rica. The yields of nitrogen in grain are given below:

	N in grain, kg/ha		
	0 Fertilizer Nitrogen	100 kg/ha Fertilizer nitrogen	300 kg/ha Fertilizer nitrogen
Polycrop corn and beans	45	75	113
1 ha beans	36	66	109
1 ha corn	45	55	56

The remarkable aspect of these data is the response of the beans alone to fertilizer nitrogen; this is excellent evidence that the legume-*Rhizobium* system was not operating properly.

Sabena and Yodav (1974) report results of polycropping of barley, wheat, linseed, and 3 safflowers with chickpea at 4 locations. Usually mixed cropping reduced yields of both components. They also report results of polycropping of pigeon peas with other crops. Generally, profits were increased by polycropping, but no data on nitrogen uptake were given so the effect on the nitrogen economy is unclear.

Enyi (1973) working in Tanzania found sizeable reductions in yield of both maize and sorghum when they were interplanted with beans (*Phaseolus vulgaris*), cowpeas, or pigeon peas. In all cases, 80 kg/ha of fertilizer N was added. Probably only in the case of pigeon peas was total N in grain increased relative to a monoculture of cereal, although no data on nitrogen contents are given.

With respect to legume-grass pastures, Thomas (1973) reviewed data from Africa and referred to much of the work in Australia and the temperate regions. He concluded that the African data demonstrate that the results with tropical pasture legumes under good management fall within the range of the results obtained in Australia and the temperate regions. Thus yields of grass-legume mixtures are considerably higher than those of pure grass without fertilizer nitrogen. However, there are relatively little data which demonstrates that the yields with grass-legume mixtures are as high as those obtained with grass with adequate fertilizer nitrogen. Vicente-Chandler (1967) reports that grass-legume mixtures in Puerto Rico are less productive than grass with adequate fertilizer nitrogen. Thus, it appears that sizeable increases in forage production can be obtained when grass without fertilizer nitrogen is compared with a grass-legume mixture (without fertilizer nitrogen), while the yield of the grass-legume mixture (without fertilizer nitrogen) is less than yields of grass with adequate fertilizer nitrogen.

The results of the preceding studies illustrate rather clearly that polycropping of a grain legume with a non-legume grain will usually result in larger yields of protein relative to a monoculture of the non-legume grain. However, yields of total grain in an intercropping situation are often not increased much and they may even be decreased relative to a cereal monoculture. In several cases, the legume responded to fertilizer nitrogen, which probably indicates the legume-*Rhizobium* symbiosis was not properly managed.

4b. Value of legumes to succeeding non-legumes

In a preceding section use was made of the following equation to estimate net accumulation of fixed nitrogen in the soil-plant system:

$$N_F = N_S + N_H + N_R - N_A$$

where N_F is the fixed nitrogen, N_S is the change in total nitrogen in the soil during the experimental period, N_H is the nitrogen removed in the harvested crop, N_R is the nitrogen in the plant residues at the end of the experiment, and N_A represents nitrogen additions. The residual effects then are approximately $N_F - N_H = N_S + N_R - N_A$ since the nitrogen in the harvest is removed. The net effect of the residual nitrogen on the nitrogen supply to a succeeding non-legume may be estimated in a simplistic way as follows:

$$N_{I,1} = a_1 N_S + b_1 N_R$$

where $N_{I,1}$ is the change in inorganic nitrogen available to a succeeding non-legume crop and a_1 and b_1 are coefficients which estimate the fraction of the nitrogen mineralized during the first cropping season.

Since not all of the residues will decompose during the first season, a series of equations for succeeding seasons could be visualized as follows:

$$N_{I,2} = a_2(N_S)(1-a_1) + b_2(N_R)(1-b_1)$$

where $N_{I,2}$, etc. refer now to the second crop and the quantities $N_S(1-a_1)$, $N_R(1-b_1)$ refer to the amount of residues remaining after the first crop, etc. The coefficients a and b and the quantities N_S and N_R are seldom estimated, but in spite of this the equations furnish a convenient conceptual framework for discussion.

Another procedure often utilized when these parameters are not available is to measure the amount of fertilizer nitrogen which the legume replaces. Still a third procedure measures the amount of nitrogen mineralized in an uncropped but cultivated fallow plot. All three methods of estimation are used and the suitability depends upon the specific objective of the experiment.

The foregoing discussion emphasizes 2 points: a) The soil may be enriched in organic forms of nitrogen by leguminous crops and b) these organic forms of nitrogen mineralize over a period of more than one cropping season. The economic value of the organic nitrogen to succeeding non-legumes rests on its amount and on the rate of its mineralization. Unfortunately neither factor is well known or easily estimated.

In the following sections, the discussion will be directed toward three situations: a) green manures and legume fallows, b) pasture/forage legumes, and c) grain legumes.

4b1. Green manures and legume fallows

Both green manures and legume fallows are grown for their contributions to the nitrogen economy and to improve soil physical conditions. Neither is harvested. We will use the term "green manures" for those legume crops grown for one cropping season or some fraction of a cropping season while the term "legume fallow" will be used for those legume crops grown (but not harvested) for more than one cropping season.

First with green manures the following approximations seem reasonable:

a) The changes in soil organic nitrogen (exclusive of the green manure itself) are not likely to be major, because green manure crops are usually grown for only a relatively short time. What changes do occur are likely to be negative because some of the soil organic matter will undergo mineralization. This nitrogen is usually accumulated in the plants so it is transferred from the soil organic matter to the plant residue.

b) The accumulation of nitrogen in plant residues both from the soil and by fixation may be appreciable as illustrated in table 3, which lists fixation only.

c) The contribution of nitrogen to the first succeeding non-legume is likely to be large since most green manure crops undergo rapid decomposition.

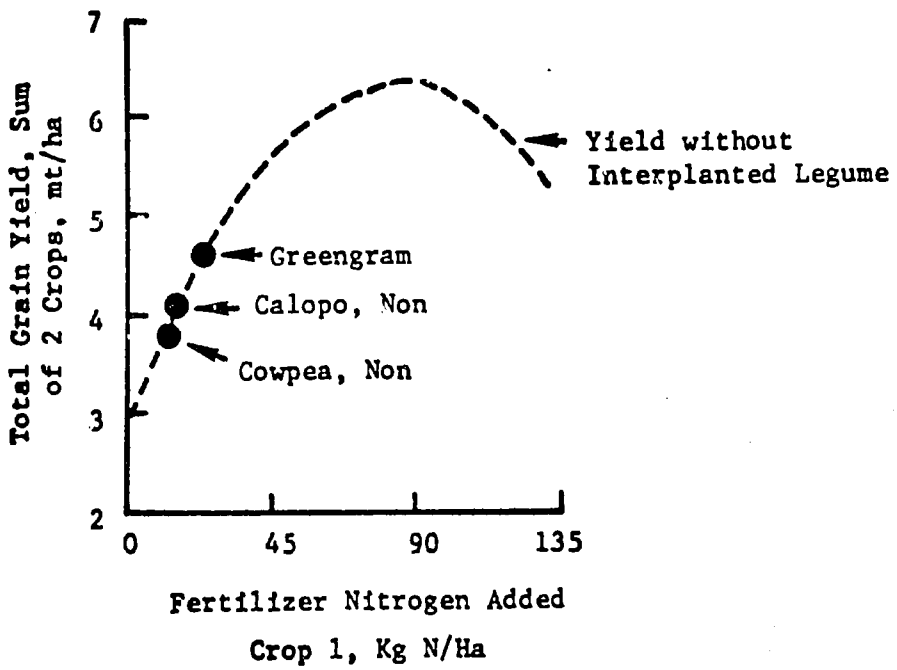
The principles discussed above are illustrated by data from the temperate region using an experiment performed in Iowa (Stickler, Shrader and Johnson, 1959). In this experiment, forage legumes were seeded with a small grain crop which was harvested during the summer. Subplots of the clovers were harvested late in the fall at the end of the growing season, and the total nitrogen content was determined. Maize was grown the following summer. The yield of maize following legume crops was measured. The experimental design included plots without legumes; fertilizer nitrogen was applied to these plots for the succeeding maize crop. Finally, the fertilizer nitrogen which the legume crops replaced was estimated by comparison of the maize yields on the plots without legumes but receiving fertilizer nitrogen with the maize yields on the plots growing legumes but which did not receive fertilizer nitrogen. The results can be summarized as follows:

1) The legumes accumulated about 100 kg N/ha during the growing season.

2) Based on yields of maize, approximately 30% of the nitrogen in the legumes mineralized the first year and over a two-year period approximately 70% of the nitrogen in the legumes was mineralized and recovered in the maize crop.

During the period the above experiments were performed, maize yields were relatively low because of dry weather. The measure of nitrogen made available to the maize was relatively insensitive.

Agboola and Fayemi (1972) working in Nigeria compared maize grown alone with maize polycropped with each of the legumes Calopo (Calopogonium mucunoides), Cowpea (Vigna sinensis), and greengram (Phaseolus aureus) at each of 4 levels of fertilizer nitrogen (0, 45, 90 and 135 kg N/ha). The yields of maize with no fertilizer nitrogen were increased significantly at the 5% probability level only with the interplanted greengram. Yields with 90 and 135 kg N/ha were not influenced by the interplanted legumes. A second maize crop was grown on these plots without further additions of fertilizer or intercropped legume. The residual effects of the fertilizer nitrogen increased yields in some cases, but the intercropped legumes did not influence yields for a given fertilizer nitrogen level. Illustrated in the figure below are the fertilizer nitrogen equivalents of the legume treatments:



The results illustrated indicate the greengram replaced about 22 kg fertilizer N over the 2 crops and the calopo and cowpea replaced about 15 kg fertilizer N over the 2 crops. When nitrogen fertilizer was added, yields of 2 crops were 6.3 mt for maize alone and 5.6 mt for maize plus the three interplanted legumes. Thus without fertilizer nitrogen the interplanted legumes are beneficial to yields, but in the presence of fertilizer nitrogen, the interplanted legumes are detrimental to yields of maize.

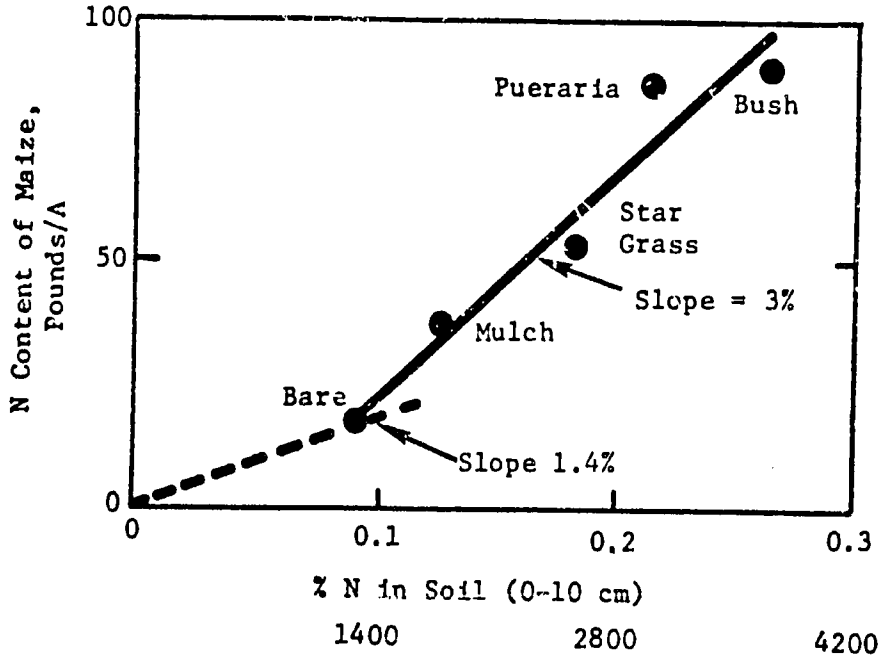
Kannegieter (1969) compared the effect of a 9-month Pueraria (Pueraria phaseloides) fallow with a weed fallow on the following maize crop at Kumasi, Ghana. The Pueraria cover crop accumulated 250 pounds of N/A (corresponding value for weed fallow not given). The Pueraria and weed fallows were killed with a herbicide and corn was planted in the trash. Yields of maize grain were 450 pounds/A following weed fallow and 2000 pounds/A following Pueraria fallow. Probably the maize crop following Pueraria contained 40-50 pounds more N per acre than the weed fallow which indicates 15 to 25% (at least) of the nitrogen in the legume residues was mineralized while the maize was growing.

Shelton and Hymphreys (1975) interplanted upland rice and Stylosanthes guyanenis. The yields of rice were not influenced by the stylo, but the stylo accumulated a fair amount of nitrogen, which presumably would become available to succeeding crops. The following table illustrates the accumulation of nitrogen by the stylo:

Fertilizer N Added	N in crop, kg N/ha			
		Rice + Stylo		
	Rice only	Rice	Stylo	Total
0	35	35	60	95
20	50	40	50	90
80	65	65	20	85

With respect to legume fallows, the objective primarily is to accelerate the accumulation of nutrients and to improve soil physical conditions relative to "natural" fallows. In the latter case, the accumulation of organic matter (as opposed to the residues of the current crop) is the important factor. In this review, we will discuss only the nitrogen effects, but the non-nitrogen effects may be of equal importance in some situations (Juo and Lal, 1977).

Because the accumulated soil organic nitrogen is likely to be larger than the current residues, the important issue (so far as nitrogen availability is concerned) becomes the amount of organic nitrogen accumulated and the rate of decomposition of the recent organic nitrogen relative to older more stable forms native to the soil. This is illustrated by data from Jaiyebo and Moore (1964). Five fallow treatments were imposed for 5 years on plots at Ibadan, Nigeria following clearing during which "much of the surface soil was removed". The five fallows were: a) maintenance of a bare soil, b) mulching at approximately monthly intervals with spear grass (Imperata cylindrica), c) planted to giant star grass (Cynodon plectostachyas), d) planted to Pueraria (Pueraria phaseoloides), e) allowed to revert to bush. Following 5 years of these treatments, the soil was sampled, cultivated and planted to maize. The nitrogen accumulation in the maize is shown in the next figure plotted against the organic nitrogen content of the soil. Clearly the line drawn through the points does not extrapolate to the origin and this can be interpreted to mean the nitrogen taken up and accumulated by the mulch or cover plants was mineralizing more rapidly than the "residual" organic nitrogen in the soil.



. The nitrogen content of maize plotted against the nitrogen content of surface 10 cm of soil following 6 years of various fallows (Jaiyebo and Moore, 1964).

These same workers (Moore and Jaiyebo, 1963) measured nitrate N and nitrifiable nitrogen (nitrogen mineralized during 2 weeks incubation in the laboratory) at fortnightly intervals during the last year of fallow and the change in nitrogen during the last 2 years of the fallow (Jaiyebo and Moore, 1963). The results are shown below:

Fallow	Average Nitrifiable N ppm	Change in Total N 0-16", lbs/A
Bare	16	+32
Mulch	36	+50
Stargrass	77	+57
Pueraria	84	+231
Bush	84	+193

Juo and Lal (1977) reported the results of 3 years of various fallow and cropping systems on organic nitrogen content at Ibadan, Nigeria. Beginning with plots cleared from forest, 4 fallow sytems and 4 cropping

systems were maintained for 3 years. The organic nitrogen content of the surface 15 cm of soil was as follows:

System	%N
Initial (after clearing)	0.16
After 3 years of	
Bush regrowth*	0.13
Guinea grass fallow*	0.18
Leucaena fallow*	0.15
Pigeon pea fallow*	0.16
Maize + residues**	0.14
Maize - residues**	0.11
Maize/cassava**	0.11
Soybean - residue	0.09

*No removal of residues
**Fertilizer added

These results illustrate several points. First, the decrease in organic nitrogen under bush is the result of mineralization of organic nitrogen; the nitrogen so mineralized probably was accumulated mostly in the biomass, but some may have been lost. The accumulation under the guinea grass fallow may represent non-symbiotic fixation associated with addition of large amounts of organic carbon. The relatively stable organic nitrogen under the leguminous fallows probably means the rates of mineralization of organic nitrogen approximately balances the returns from residues; presumably if the organic nitrogen content of the soil were lower, nitrogen would accumulate as Jaiyebo and Moore (1963) found under Pueraria.

The cropped plots all lost organic nitrogen during the cropping period, although the maize plus residue plots did not lose much organic nitrogen. In fact, the decrease in organic nitrogen could largely be accounted for by crop removal (100-125 kg N/ha/yr). All of the cropped

plots received adequate fertilizer to insure high yields. The loss of organic nitrogen under the maize-residue system represents about 1000 kg N/ha over 3 years--which exceeds the crop removal (170 to 200 kg N/ha/yr) by an appreciable margin. Results with other cropping systems were comparable.

Watson and Goldsworthy (1964) concluded from their studies in Nigeria that 3 years of fallow would not maintain "fertility" and that if no more than 4 years of fallow were possible, then pigeon pea or gamba fallows were better than "natural" or "bush" fallows.

Schofield (1945) in the northern, tropical region of Australia compared soil nitrate-nitrogen over a 7-month period in soil maintained in a bare fallow condition following 18 months of the fallows listed below:

Fallow	Average NO_3-N, 0-24" in 7 months, ppm	Total NO_3-N 0-24" #/A
Bare	17	340
Calopogonium mucanoides	43	550
Centrosema pubescens	39	410
Pueraria phaseoloides	100	1090
Stylosanthes guinanensis	34	480

No results were given on the organic nitrogen content of the soils at the beginning of the fallow period, but in any event, the rate of mineralizaton was very rapid.

The rate of decomposition of residues from some tropical legumes may be slow. Vallis and Jones (1973) found markedly different rates of mineralization of dried leaves of Desmodium intortum and Phaseolus atropurpureus. Over a period of 32 weeks incubation in the laboratory, the concentration of mineral nitrogen with Desmodium exceeded that in the control soil by an amount equal to 3% of the nitrogen added in the plant material, in contrast to 46% with Phaseolus. These results clearly demonstrate that plant

materials differ in their susceptibility to mineralization. Relatively little other work of this nature seems to have been done so that it is not clear how important this factor may be.

At Nsukka, Nigeria, Okigbo (1972) studied yields of maize supplied with fertilizer and mulched with plastic or with residues from non-legumes or residues from legumes. He concluded that the favorable effect of some of the mulches was related to "their manurial values especially in the rainy season". In one experiment, Cassava without fertilizer was grown following maize. The yields of Cassava roots were as follows:

Mulch on Maize	Yields Cassava, T/A
None	3.9
Plastic	4.6
Stylosanthes	9.1
Panicum	7.6
Pennisetum	6.1
Maize stover	7.8

No data was given on composition of the added organic mulches or how much mulch was used.

Clarke (1962) reports the yields of 3 years of sorghum in Kenya following 3 years of the following fallows: a) Cassava-weed, b) pigeon pea-weed, c) grazed stargrass. The total yields of 3 years of sorghum was 2800, 3024 and 2128 kg/ha, respectively.

The foregoing results illustrate that legume green manures and fallows do indeed increase the nitrogen available to a succeeding non-legume crop by an appreciable amount. The data do not furnish quantitative estimates applicable to a wide range of conditions. Despite this deficiency, it does seem reasonable to suppose that a) legume green manures in the tropics can accumulate 100 to 200 kg N/ha during a favorable growing season, provided

they are well managed, b) on the order of 20 to 60% of this accumulated nitrogen will be mineralized during a subsequent growing season under a non-leguminous crop, c) under some circumstances (mainly vigorous growth of legumes), soil organic nitrogen will accumulate at a faster rate under legume fallows than under other fallows, d) use of a legume fallow or legume green manure crop does not insure an ample supply of nitrogen to a succeeding non-legume; the legume must have the potential to accumulate large amounts of nitrogen (and carbon) and it must be managed so that this potential is realized.

4b2. Forage/pasture legumes

The following 3 general statements serve as an introduction:

1) The forage/pasture legumes (and any associated grass) will be harvested periodically with removal of some nitrogen. 2) In the case of grazed pastures, loss of nitrogen will likely far exceed the amount removed in animal products because of loss of nitrogen by ammonia volatilization from the manure (Whitehead, 1970; Denmead et al., 1974; Lauer et al., 1976). 3) Usually the pasture/forage crops will be left down for several years so that the amount of nitrogen in the living plant tissue which is incorporated into the soil at the end of the forage/pasture cycle is small relative to the accumulation of organic nitrogen. This being the usual case, two questions arise; a) How much organic nitrogen is accumulated; and b) How rapidly does this nitrogen mineralize once cultivation begins?

Moore (1969) working in the rain forest area at Ibadan, Nigeria (average annual rainfall 48 in, growing season April-November) compared the organic nitrogen content of soil under giant stargrass (*Cynodon plectostachyus*) and a mixture of giant stargrass and "centro" (*Centrosema pubescens*). After 2 1/2 years of grazing the organic nitrogen content of

the soil was 2040 pounds (0-30 cm) per acre for the pure stand and 2600 for the mixed stand; the legume thus increased the nitrogen content of the soil approximately 250 pounds N/A/yr. Growth rates of heifers grazed on the two pastures were higher on the mixture by about 0.25 pounds/head/day. The grass growth with the legume had higher nitrogen content than grass grown without legume. During 2 weeks incubation in the laboratory, samples of soil from the 0-5 cm depth produced 64 ppm nitrate N for the grass-legume mixture compared with 35 for the grass plots. Thus, it appears that the mineralization of nitrogen in the two week period was increased about 50 pounds per acre 12 inches by addition of 600 pounds of organic nitrogen or roughly 8% of the additional organic nitrogen mineralized in 2 weeks in the laboratory. This would indicate on the order of 30 to 60% of the accumulated organic nitrogen would mineralize during the one cropping season. Unfortunately no cropping was carried out in the field to verify these estimates.

Wetselaar et al. (1973) compared the organic nitrogen content of soil in northern Australia following 3 years of bare fallow, Guar (Cyamopis tetragonoloba), cowpea, peanuts, or Townsville stylo (Stylosanthes humilis). The crops were harvested annually so removal of nitrogen was appreciable and nitrogen fixation ranged from 40 to 90 kg N/ha/yr. The organic nitrogen content of the soil was maintained with the stylo, but decreased with the other 3 crops. With the cowpeas the decrease in organic ntrogen content was almost as large as with the bare fallow (The whole of the aboveground dry matter of the cowpea crop was removed.)

Jones, Davies, and Waite (1967) measured yields of dry matter of grass (Paspalum plicatulum) fertilized with nitrogen and of grass-legume mixtures (without fertilizer N) in northern Queensland over a 3-year period. The

legumes were 2 varieties of Phaseolus atropurpurins and Latonis bainesii. Nitrogen content of the harvested portion of the legume-grass mixture was equivalent to that obtained with about 140 kg fertilizer N/ha while the corresponding dry matter yields were equivalent to those obtained with about 84 kg of N/ha. Analysis of soil samples for total N (0-3") after 3 years showed that the soil nitrogen content under grass + L. bainesii was about equal to that in the unfertilized control while the soil under P. atropurpurins contained about the same amount of N as that under grass fertilized with 224 kg N/ha/yr (Jones, 1967). The net difference between these 2 extremes was about 560 kg organic N/ha; this 560 kg organic N/ha increased the nitrogen content of the sorghum by about 13.4 kg N/ha or an amount equivalent to 2% of the difference in organic nitrogen.

Smith (1962) measured the changes in nitrogen content of several pastures in Rhodesia after 3 years under Rhodes grass (Choris gayona) and Rhodes grass associated with several legumes. In all cases the organic nitrogen in the soil decreased by about 0.03%. Yields of maize grown following the pasture were approximately doubled by inclusion of a legume with the Rhodes grass.

In the temperate regions of Australia, several studies report increases of soil nitrogen ranging up to 200 pounds per acre per year under vigorous grass-legume and legume pastures (Simpson, 1976; Hengell et al., 1966; Watson et al., 1976; Watson, 1969; Watson, 1964; Watson, 1963).

Musa and Burhan (1974) grew several legumes for forage in forage-cotton rotations. The top growth was removed and the nitrogen content of residual roots plus nodules was found to range between 9 and 25 kg N/ha. There were no differences in yields of cotton without fertilizer N among the various legumes, probably because of the rather small amount of residual N. (There was no treatment without legume forage.)

The diversity of the foregoing data precludes any sweeping generalizations. Perhaps the best that can be said is that temperate region results indicate appreciable accumulation of nitrogen under pastures adequately supplied with nitrogen (either fertilizer or symbiotically fixed). While this same thing has not always been observed in the tropics, perhaps a working hypothesis is the following: Provided that a) the rate of mineralization of native organic nitrogen is slow, b) legumes having high yield potential are managed to obtain this potential, then organic nitrogen will accumulate in the soil under legume pastures/forage and the accumulated organic nitrogen will undergo fairly rapid mineralization during a subsequent cropping period.

4b3. Grain legumes

The grain legumes differ from the green manures and legume fallows as follows: a) a major fraction of the nitrogen accumulated by the plant is removed in the grain and b) the mineralization of soil nitrogen under grain legumes is likely to be as high as under non-legume grain crops and hence the potential for decline in soil organic nitrogen is fairly high.

This latter point is illustrated by Juo and Lal (1977), referred to earlier. They observed a decline of almost 50% in organic nitrogen content of a soil cropped to soybeans for 3 years. Wetselaar et al. (1973) report small losses of total soil N following 3 years of peanuts or cowpeas.

The influence of grain-legume crops on the nitrogen economy of succeeding non-legumes is difficult to interpret because a) the effects are usually fairly small, b) the experiments are seldom designed in such a way as to isolate the nitrogen effect from other effects.

Jones (1974) grew maize following cotton, sorghum, groundnuts, and cowpeas. All the aboveground dry matter from these crops was removed before the maize was planted. The yields of maize grain were 3000, 2400, 3400 and 2700 kg/ha following cotton, sorghum, groundnuts, or cowpeas, respectively. These results indicate the effect of the legume root residues was not appreciably different from that of the non-legumes that had been fertilized with fertilizer nitrogen.

Saxena and Telak (1974) measured the effect of inoculation of soybeans on soybean yields and yields of a following wheat crop. Inoculation of the soybeans increased yields of soybeans from 9.5 to 17.5 Q/ha and yields of wheat by an amount equivalent to the yield increase obtained from about 30 kg N/ha of fertilizer nitrogen.

Burhan and Mansi (1967) rotated cotton with grain legumes and found an effect on yield of cotton, but the increase in yield cannot be attributed to the nitrogen contributed to the cotton because of other effects.

The rather meager data set available indicates that substitution of a grain legume for a non-legume grain in a cropping sequence is unlikely to have any but a minor effect on either the soil organic nitrogen or nitrogen economy of a succeeding non-legume. However, it should be recognized that excellent yields of grain legumes can be obtained with no fertilizer nitrogen provided the proper Rhizobium is present and conditions are favorable for survival and infection of the host plant.

5. Summary and overview

a. Present situation

Monocultures of grain legumes and polycrops of grain legumes and non-legumes are widespread throughout the world in both the tropics and temperate regions. In tropical regions, the yields of grain legumes are low, but even so they are important sources of dietary protein. All of the

evidence in this review supports the supposition that in the tropics the most important influence of legume nitrogen fixation on the human diet is through the proteins in grain legumes. Although the evidence is rather sketchy, the influence of dinitrogen fixation by grain legumes on the production of non-legume grains appears to be relatively unimportant.

There appears to be no widespread, deliberate use of legume fallows and legume green manures in food production schemes in the tropics. The "natural fallows" in shifting cultivation accumulate nitrogen at a rate which is comparable to that of many legume fallows. The use of legume green manures seems to be very limited.

There appears to be no widespread, deliberate use of legumes in forage production in the tropics outside of northern Australia. Animal production based on forages in the tropics is usually based on extensive use of "natural" savannahs, which receive almost no management except perhaps an annual burning.

b. Potential

A recurring observation throughout this review has been that legume-Rhizobium associations in the tropics fix large amounts of dinitrogen under variety of conditions. Thus there can be no doubt that the potential exists for production of high yielding legume crops without fertilizer nitrogen and that nitrogen fixed by legumes can be substituted for fertilizer nitrogen in the production of non-legumes. Present use of legume nitrogen is only a fraction of the potential.

Currently grain legumes are important components in many crop production systems. Yields of grain legumes in most tropical countries are on the order of 700 kg grain/ha, which is low relative to yields in current experiments (ICRISAT, 1975). Commonly, fertilizer nitrogen is recommended

(Bazan, 1975) and, in experimental plots, responses to fertilizer nitrogen are common. Thus, the best means of realizing some of the potential for grain legumes is through increasing yields and provision of effective rhizobia.

The increased use of green manures, legume fallows, and legume forages requires development of economic and socially acceptable cropping systems since they are seldom used in current cropping systems. Undoubtedly interest in using legumes in this way will increase as the cost of fertilizer nitrogen increases. Two factors increase the utility of this: one is the availability of herbicides which makes control of the legume easy and the second is the need to protect the soil from erosion under intensive cropping. Fallows and forages in cropping systems are likely to reduce the erosion hazards, which are serious with many soils in the tropics under intensive cropping.

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