PRE-RICE GREEN MANURE PRODUCTION IN THE RAINFED ENVIRONMENTS: A SIMULATION APPROACH

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ABSTRACT

The rainfed lowland ricelands prone to waterlogging in the pre-rice season are a major potential niche for the use of farm-grown green manure crops tolerant to saturated soils. But year-to-year variability in green manure growth and N accumulation would be large due to quite variable field hydrology in the dry-to-wet transition months. We developed a simulation model of the green manure-rainfed rice system that was used to estimate the yield levels and relative stability of pre-rice green manures and the subsequent rainfed rice crops in three representative sites in southeast Asia. The average estimated green manure N yield over 25 years was higher in Los Baños, Philippines (65 kg N/ha) than in Ubon, northeast Thailand (40 kg N/ha) or Tuguegarao, northern Luzon, Philippines (18 kg N/ha), with yield stability following the same trend. Simulation of sesbania planting was compared when established early (at

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50 mm cumulative rainfall) or later (100 mm) at the beginning of the rainy season. N yields were higher for late planted crops (63 kg N/ha) compared to early establishment (51 kg N/ha) due to more favorable soil moisture. Estimated rice yields following the early and late establishment of sesbania were similar (2.9 and 3.0 t/ha) indicating that delayed sesbania planting would not adversely affect the rice. Optimal N-rates for rice were similar (85-86 kg N/ha) for both planting dates, consequently more purchased N is needed for earlier green manure establishment. The costs per unit of green manure N were higher than for urea N when full wage rates and intensive tillage were assumed. However, with zero tillage and/or a modest cumulative soil fertility benefit, the costs of producing N with green manures would be similar or lower than with urea-N. The implications of these finding for future research are discussed.

Single-crop transplanted rainfed wetland rice is estimated to cover more than 20 m ha in Asia. A large proportion of the single-crop ricelands have poor internal and surface drainage, and experience unpredictable short-term waterlogging during the dry-wet transition period. This is particularly common in ricelands on the floodplains of the major river systems.

Green manures are rarely used on rainfed ricelands at present. Our analysis suggests that waterlogging-prone rainfed areas are the largest potential environmental niche for GM cultivation in the future. This implies that a large relocation of GM production may occur, declining in fully-irrigated areas and increasing in rainfed areas. Environmental, technological, and economic factors will dictate the feasibility of future GM expansion in rainfed areas. There are numerous minimum necessary conditions which must be met before farmers grown GMs (Figure 1). Restructuring will require a determined research effort on problems of GM production in environments with uncertain moisture dependability.

Green manure-rice simulation model. Analysis of long-term biological and economic productivity and stability of *Sesbania*-rice crop sequences prompted us to develop a simulation model for application in rainfed environments. A submodel simulates the biomass production and nitrogen yield of *Sesbania rostrata*. This species was recently introduced into Asia and has been found to have outstanding N accumulation potential (Morris et al., 1989).

The submodel is based on the STET water balance model (Rahman, 1980; Reyes and Morris, 1989). It calculates the daily water balance of an *S. rostrata* crop from daily rainfall and Class A pan evaporation. The soil water balance includes the processes of infiltration, runoff, seepage and percolation losses, soil water storage in four layers, and surface water ponding in bunded rainfed rice fields of specified soil texture and landscape position. Actual evapotranspiration (ETA), potential crop evapotranspiration (ETP), and their ratio are calculated daily.

Potential daily Sesbania biomass accumulation was estimated using a growth function derived from experiments conducted with Sesbania at IRRI under nonlimiting moisture conditions (Figure 2). Estimated biomass accumulation in the absence of water deficit was 5.3 t/ha dry weight in 45 days with a nitrogen content conservatively assumed to average 106 kg/ha or 2.0%.

Actual daily biomass accumulation (ABDA) was determined as:

$$ABDA = PDBA * ETA/ETP$$

where PDBA is potential daily biomass accumulation. This relationship assumes a linear 1:1 reduction in daily biomass productivity as ETA/ETP is reduced.

Seasonal accumulation of N obtained from Sesbania is noted at the time of incorporation. This N amount is input into the simulation model of a transplanted rice crop which follows. The rice water balance model calculates the number of water stress days experienced by the crop during the reproductive stage, which includes the period from 55 to 10 days before harvest (dbh). Stress days were defined as days in which ETA/ETP was less than 0.9.

Number of stress days for a rainfed transplanted rice crop, and amount of N incorporated as _Sesbania_ were the two independent variables in a production function determining rice grain yield (Figure 3). This production function was derived by Huysman (1983) for rainfed rice under farmers' management in the central Philippines. The production function is based on applied inorganic N. Therefore, a relationship which estimated the amount of inorganic (urea) N equivalent to a unit of _Sesbania_ N was developed (Figure 4). The relationship assumed equal uptake and utilization efficiency between inorganic and _Sesbania_ N up to 50 kg/ha N application (Morris et al., 1985), and decreasing efficiency of _Sesbania_ N relative to inorganic N thereafter (Morris et al., 1989).

A simple flow diagram of the _Sesbania_-rice crop sequence models is shown in Figure 5. _Sesbania_ is planted on the basis of cumulative rainfall after April 1, using 50 mm or 100 mm as the planting date criterion. The GM remains in the field until incorporation at 45 days after seeding. After a 10-day turnaround period, rice is transplanted if surface water is present. If not, then transplanting occurs when surface water accumulates. The performance of a 110 day rice cultivar (IR36) with a field duration of 85 days is simulated.

The structure of the portion of the model which calculates optimal N-rates and the level of applied inorganic N and rice yields, is shown in Figure 6. Optimal N-rates are derived from the crop response function, the relative prices of urea N and rice, and the farmer's expectation of moisture stress in the forthcoming rice crop. Expected stress was estimated as a weighted function of the previous three years of observations:

$$E(s)_i = 0.5AS_{i-1} + 0.32AS_{i-2} + 0.18AS_{i-3}$$

where $E(S_i)$ is expected stress in season i; and

AS_{i-j} is observed stress in previous year (j = 1, 3).

In consequence, estimated yields are derived using total N (organic and inorganic combined) and actual stress days, calculated in the rice sub-program. Although the two nitrogen sources (i.e., Sesbania and urea) are different inputs (because of different unit costs, manner and rate at which N is made available and management requirement), in their mineralized form, they are assumed to be perfect substitutes in production using the conversion of Sesbania-N to inorganic (urea) N in Figure 4. That is

$$N = N_s + N_u$$

where

- N is N available to the rice crop;
- N_s is N supplied from Sesbania in urea N equivalents; and
- N_u is N supplied from urea

This model is simplistic in four important aspects:

a) in practice, relative and absolute level of nitrogen available from any source is dependent on the levels of other sources of nitrogen;

b) with Sesbania there may be carry-over effects from one crop to the next or from one season to the next. In this case it is assumed that there is no residual effect, which may underestimate long-term benefits of Sesbania;

c) Sesbania may enhance rice response, other than through its direct contribution to N, in which case the response to inorganic N is dependent on the biomass of incorporated Sesbania.

d) *Sesbania* growth limitation due to nutritional deficiencies other than water are not accounted for in the model.

Price relationships. Weather data used to drive the simulation model and most of the crop and soil relationships embedded in the model were derived from Los Baños. Consequently, the financial data used in the analysis are those prevailing in Laguna, Philippines in the first quarter of 1987. Cost data necessary to evaluate the *Sesbania* includes:

a) farmer-effective prices of rice and urea; and

b) costs of producing *Sesbania*

Farmer-effective prices of rice and nitrogen from urea are derived in Table 1 for two situations: farmers with access to formal credit, and those who purchase inputs using informal credit sources. The farmer effective price of rice is less than the market price because of harvesting and marketing charges. Similarly, the farmer-effective price of nitrogen is higher than the market price because of market transaction and application costs. The price per unit of N as urea is nearly $ 0.50/kg for farmers using informal credit sources.

Indicative costs of producing *Sesbania* in Laguna are listed in Table 2. The cost of *Sesbania* establishment --

one plowing and two harrowings with a power tiller -- may be about $ 70/ha. The second harrowing is a light harrowing to cover the broadcast seed. Sesbania seed is not available in the market in Laguna, hence seed costs was conservatively assumed at $ 1/kg, and at a rate of 15 kg/ha. The higher value shown in table is to allow for re-seeding which may be needed one year in five. The cost of Sesbania incorporation (two passes with a slicer plus an extra harrowing before traansplanting) may reach another $ 36/ha (i.e., the cost of two harrowings). The cost of biomass incorporation is dependent on the quantity of biomass produced so, precise figures are not available on the relationship between biomass level and the power necessary for incorporation.

Total cost, including the opportunity cost of farm resources, as developed by Rosegrant and Roumasset (1987) is nearly $ 130/ha, or nearly $ 1.30/kg of N produced by the Sesbania crop -- assuming this biomass produced 100 kg N or 82 kg N/ha equivalent. This is over 2.6 times the cost of N applied as urea (Table 2). Clearly, tillage costs for land preparation and incorporation must be reduced to improve the competitiveness of this N source.

This perspective ignores three important points:

a) because the opportunity cost of land is ignored, the cost of producing N from <u>Sesbania</u> is underestimated; however,

b) long-term beneficial effects of green manuring are not incorporated in the analysis, so implied long-term benefits of GM are underestimated; and

c) the relationship between the cost/unit of N and the quality of N derived from <u>Sesbania</u> are not recognized in the analysis.

The relationship between the cost/unit of N and the quantity of N supplied as <u>Sesbania</u> is graphed in Figure 7 for three assumed levels of tillage costs. The upper curve is the case with current tillage costs (Table 3), with al expenses charged at their opportunity costs. The lower curve models the situation with crop establishment by zero tillage -- that is <u>Sesbania</u> production costs are limited to seed and subsequent biomass incorporation. Cost/unit of N declines rapidly as N levels increases, then becomes asymptotic between 30 and 70 kg N/ha, depending on the assumed cost situation. At high N-rates (as reflected in the lower curve) unit costs may start to increase as: a) increment in N/unit of biomass commences to decline; and b) as tillage costs increase with high biomass levels.

The price of N as urea is approximately $ 0.50/kg in Laguna. Therefore, at assumed tillage levels -- or if tillage costs were reduced by 50% -- the cost of N as Sesbania remains substantially higher than the price of its substitute, urea.

The above analysis is at best indicative. Nonetheless, it highlights the benefits of reducing tillage costs and increasing N accumulation per unit time to increase the short-run cost-effectiveness of GM technology. Incorporation costs are also an important determinant of the profitability of GM -- and incorporation takes place at a peak demand period for labor and power.

<u>Sesbania N and rice grain yield stability</u>. Longterm productivity and stability of <u>Sesbania</u> <u>rostrata</u> as a green manure in a rainfed system was studied by running the simulation model for 26 years of wet season rainfall data for Los Baños. Figure 8 illustrates the crop sequence. Frequency distributions of <u>Sesbania</u> N yields were determined for two planting date criteria (Figure 8). <u>Sesbania</u> N yields ranged from <10 kg N/ha to 80 kg N/ha in response to severity of water deficit among years.

<u>Sesbania</u> N contribution was greater than 65 kg/ha in 50% of the years simulated, and greater than 50 kg/ha in

75% of the years (Figure 9). However, in a significant number of years the farmer would have lost his investment in the GM crop. Simulations indicated that a delay in the GM planting date until 100 mm cumulative rainfall had occurred (after April 1) resulted in an 11.4 kg N/ha average increase in Sesbania N yield compared to planting the GM with 50 mm cumulative rainfall. Delaying the planting of the GM increased N yield, but resulted in a delay in rice transplanting (Figure 10). However, no increase in water stress days during the rice cropping period was observed as a result of delay in planting. Therefore, rice yields were generally higher with the 100 mm planting date criterion (Figure 11). Rice yields with Sesbania alone as the N source varied from less than 1.0 t/ha to 3.9 t/ha among the 26 years simulated. In several cases water stress caused very low N response in the rice crop.

Longterm simulations compared Sesbania N accumulation among three locations (Figure 12). At a rainfed site with a poor distribution of transition period rainfall (Tuguegarao, Cagayan, Philippines) drought reduced the N contribution of 45 d Sesbania crops to less than 18 kg N/ha in 50% of the years simulated. At Ubon, NE Thailand, the water balance was unfavorable due to sandy surface soils with very low water holding capacity. Less than 40 kg N/ha accumulated in half the years. These data are probably optimistic since nutrients for Sesbania growth were assumed nonlimiting. This is reasonable for Tuguegarao and Los Baños, but probably not for Ubon, which has soils deficient in P and K.

Uncertain rainfall characteristics of the prerice period in some rainfed environments will make GM production unreliable. More analysis is needed to better define the subset of rainfed environments which will favor GM.

Waterlogging frequency. Occurrence of waterlogging events which destroy conventional crops is a major factor determining the potential niches for green manures in the prerice season. The extent of such ricelands may be in the range of millions of hectares, but no good estimates exist. Frequency of shallow surface flooding during the prerice season was estimated for three locations using simulation analysis (Table 3), assuming landscape positions with poor surface drainage. Surface flooding periods exceeding 3 d duration during prerice crop growth were found to occur between 30 and 65% of the years. This suggests that in the Philippines sites and the site in NE Thailand there is high risk associated with production of waterlogging-sensitive crops during this period. Thus, green manure production, if feasible, would not compete with other crops.

Waterlogging events would not seriously affect Sesbania growth after its establishment. However, Sesbania may also be seriously damaged by flooding during germination and emergence. Simulations determined that Sesbania crop loss due to flooding at emergence may expected one year in five at these sites (Table 1). This would necessitate replanting, and would result in increased GM production costs and risks that must be considered in the assessment of system viability.

Economic analysis of rainfed GM. The simulation model run for Los Baños weather data generated estimates of the contribution of Sesbania to N, the quantity of inorganic N applied, the costs of organic and inorganic N, and expected and actual rice yields. The mean values and CV's are listed in Table 4 for two trigger criteria of Sesbania establishment: 50 and 100 mm of accumulated rainfall, and for two Sesbania production costs: full costs as assumed in Table 2, and assuming a technology which resulted in a 50% reduction in land preparation costs.

Sesbania was estimated to contribute on average 51 kg N/ha from the early and 63 kg N/ha from the later planted GM crop. The relative year-to-year variation in

N supply from Sesbania was larger for the early (CV-48%) than the late planted GM crop (CV=32%). Optimal N-rates for rice were similar (85-86 kg/ha) for both Sesbania seeding dates. In consequence, the quantity of N applied as urea was higher for the early planted Sesbania crop (34 kg/ha) than for the later planted crop (23 kg/ha). However, the relative variability of applied inorganic N was substantially higher for the late (CV=98%) than the early planted Sesbania crop (CV=68%).

The cost of growing Sesbania was higher with the later planted crop because the greater biomass production, incorporation costs were higher. Nonetheless, the cost per unit of producing N from Sesbania was marginally lower for the later planted crop (ie. $ 2.00/kg N for the early and $ 1.70 kg N for the later planted Sesbania crop, given full tillage costs). Total nitrogen costs per hectare were similar for the two Sesbania planting dates; as were the cost/unit of total N applied.

Expected rice yields were similar for the early and later planted rice crops -- that is, late season stress was not a problem given transplanting dates and weather events. Actual yields were also similar at 2.9 to 3.0 t/ha, between planting dates.

Had all fertilizer been supplied as urea (assuming no other beneficial effects from Sesbania) cost saving would be about $ 42-43 given low tillage costs, and $ 76-78/ha if the higher cost situation prevailed. These short-term savings from not growing Sesbania may be directly converted to rice equivalents. If benefits from Sesbania are realized from the following rice crop, a yield increment of 0.4 t/ha (about 13%) would be necessary to equate the profitability of urea and Sesbania combined, with urea alone in the short run, given low cultivation costs. This figure increases to 0.9-1.0 t/ha (a 31% increase) if the higher tillage costs are assumed.

Long-term benefits. One benefit of incorporating green manures, in addition to reducing the levels of inorganic N, are the longer-term impacts of increasing and stabilizing rice yields. For example, experiments on IRRI farm have demonstrated yield gains in excess of 0.5 t/ha due to Sesbania, after differences in N rates are accounted for (Meelu and Morris, 1987). Thus, we briefly address the issue of longer term-yield impacts.

Because individuals prefer to receive returns now rather than later, future benefits (and costs) of green manuring must be discounted to the present when comparing the future streams of benefits and costs of green manuring. In the analysis which follows, we make two assumptions: first, the farmer has a 10 year or less planting horizon; and second, he borrows money in the informal credit market at 50% interest for a 5-month crop season.

Discounted cost and return streams for a 10-year period of Sesbania production are shown in Figure 13. Two rice-yield scenarios are presented: a 0.5 t/ha and 0.76 t/ha yield gain from Sesbania incorporation over and above its contribution to total nitrogen. Similarly, two cost scenarios for Sesbania production are advanced: a) full cost of crop establishment; and b) land preparation costs reduced by 50%. Figure 13 (a) depicts a situation where Sesbania is grown each year; in Figure 13 (b) the crop is planted every second year, after annual plantings in years 1 to 4.

Discounted benefits do not exceed discounted costs within 10 years for yield increments of 0.75 t/ha at the higher input-cost scenario (Figure 13a). However, with the lower cost scenario, a 0.5 t/ha yield gain is profitable from the first year (as also implied from Table 4). Alternatively, if the cost of Sesbania technology were reduced through planting each alternative year, the practice would be profitable after year 5, even at high tillage costs (Figure 13b). Again, a 0.5 t/ha yield gain would be immediately profitable if land preparation costs were reduced by 50% and Sesbania was grown each second year.

Analysis of the long-term benefits demonstrates the importance of:

a) yield gains attributed to Sesbania (which are not realized from inorganic N alone); and

b) the cost of producing the Sesbania crop,

as important determinants of the cost effectiveness of green manuring. While not shown in the figure, the inclusion of an opportunity cost for land would have shifted the cost curves upwards -- thus reducing profitability by increasing the time before the technology became profitable, if at all. Alternatively, reducing the cost of credit (for example, if farmers had access to formal credit sources) shifts the cost curves downwards, thus increasing the comparative profitability of GM technology.

THE RESEARCH AGENDA

Our analyses, the perspective of others (as Norman, 1982), and the longer-term reduction reported in GM use (e.g., in China) suggests that green manuring is not now a viable practice for rice farmers in many parts of Asia. However, we also recognize that inorganic fertilizers are derived from non-renewable resources, and that GM's may have definite ecological advantages as well as providing opportunities for resource-poor farmers to increase and sustain the productivity of their farming systems. The current less favorable economic comparison between GM's and sole use of inorganic fertilizer is not a sufficient basis to forego investment in a vigorous research program to increase yield through greater use of resources within the farm.

The competitiveness of GM requires that the unit cost of producing N from that source be reduced, and the beneficial impacts of GM on future crop production maximized. A research agenda leading to more cost-effective GM technology may include:

1. Identify cost-efficient methods of producing green manure crops:
   - reduce GM establishment costs;
   - reduce GM incorporation costs;
   - identify cost-efficient methods of increasing N fixed per day that the GM crop is in the field
2. Identify management practices which will increase the gain in rice yield from green manuring, over and above that realized by N substitution alone. In the process, quantify the short and long term

relationship between GM's plus inorganic N, plus inorganic N alone.

3. Within a farming systems framework:
   - Identify environmental niches where GM offers greatest potential;
   - Explore other ways to increase the economic benefit of GM's -- eg. harvesting as fodder or grain;
   - quantify the opportunity cost of land and other inputs (labor, power) to GM production;
   - examine existing systems of green manuring practiced by farmers and identify the parameters leading to area expansion or contraction.
4. Quantify the externalities (ie. benefits to society at large) of green manure production:
   - examine likelihood of reduction in groundwater or atmospheric pollution with GM adoption. Could similar reductions be achieved more cost-effectively, by other means for example, by increased efficiency in the use mineral fertilizer?
   - if externalities are large, i.e., public benefits exceed private profits, is there a case (and a capacity for government) to

subsidize GM technology to increase its private profitability?

The above research agenda is strongly interdependent in nature and requires the input of a range of disciplines as plant breeders, agronomists, pest management specialists and economists. An interdisciplinary perspective to increase the cost effectiveness of integrated nutrient management therefore appears to be a precondition to develop GM technology suited to Asian rice farmers.

ACKNOWLEDGEMENTS

We express our appreciation for the assistance in the simulation modeling work was provided by Mr. Julius Feraren, Ms. Ludy Velasco, and Ms. Anastacia Aclan, and manuscript preparation by Ms. Glorylyn Acaylar.

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Table 1. Market and farmer-effective prices of nitrogen and paddy rice in $/kg, in Laguna, Philippines; first quarter 1987.

	Market price	Farmer-effective price
Rice price	0.15[a]	0.11[b]
Price of nitrogen from urea[c]	0.29	0.32
Formal credit[d]	-	0.36
Informal credit[e]	-	0.49
Nitrogen/paddy price ratio		
Formal credit	1.93	3.12
Informal credit	1.93	4.30

Note: In the first quarter of 1987, P20.45 = US$1.00, approximately.

[a] National Food Authority floor price for cleaned paddy dried to 14% moisture.

[b] Rice price net of harvesting (about 10%), threshing and winnowing (10% of output), drying, transport and disposal costs (P6/cavan or P0.12/kg).

[c] A bag of urea (50 kg, 46% N) costs about $ 6.75; add transport costs (P0.20/bag) and application cost ($0.5/bag -- 1/4 day at P 20/labor day, or $0.32/kg on farm without interest payments.

[d] Bank rate 12% per season (Intensified Rice Production Program offers subsidized credit at 15% a year).

[e] Ten percent per month, or 50% per season of 5 months.

Table 2. Estimates of Sesbania production costs in Laguna, Philippines.

	Level (/ha)	Cost $/unit	Cost per hectare
Land preparation (animal traction)			
Plowing	1	35	35
Harrowing[a]	2	35	35
Seed[b]	18	1	18
Labor for seed	0.6	1	1
Incorporate sesbania[c]			
Slicer	2/4	18	18
Harrow to incorporate	2/4	18	18
Opportunity cost of land[d]	-	-	-
Opportunity cost of capital			4
Cost/hectare:			
Cash cost[f]			22
Full cost basis[g]			129

Note: Laguna effective prices, first quarter 1987. *Sesbania* incorporated at 45 DS.

a/ One pass following plowing plus light harrowing to cover seed.
b/ Assuming 15 kg/ha and that one year in five, the crop must be re-seeded due to stand loss from flooding in first 10 days of stand establishment (See Table 8.)
c/ For about 40-45 day-old sesbania: slice (2 passes at right angles) before plowing; plus two extra harrowing to incorporate.
d/ Opportunity cost of land as an alternative use in this rainfed environment is assumed to be zero. However, in the simulation analysis, an opportunity cost of land will be implied for comparative purpose if the *Sesbania* crop results in late rice harvest and reduced yields.
e/ Ten percent a month for two months, on seed costs only and assume land preparation is household resources.
f/ Assuming seed is purchased, but that all tillage costs are met with farm-owned resources.

Table 3. Frequency of flooding events longer than 2 days during the germination and seedling emergence period (0-10 days) and greater than 3 days during the growth period (0-10 d excluded) for a 45 d *Sesbania rostrata* crop in simulated plantings during the pre-rice transition period.

	Flooding Frequency		Years Simulated
	Emergence period	Growth period	
	----- (% years) -----		
Los Baños, Philippines	23	65	1959-1984
Tuguegarao, Philippines	5	30	1960-1980
Ubon, Ratchathani, Thailand	18	57	1963-1978

Table 4. Expected nitrogen contribution from Sesbania, applied N as urea, nitrogen costs and rice yields, by planting date and cost of cultivation with informal credit.

Sesbania seeding:		50 mm				100 mm			
Tillage cost	Unit	50%		Full		50%		Full	
		Mean	cv	Mean	cv	Mean	cv	Mean	cv
Nitrogen supply									
Sesbania	kg/ha	51	48	51	48	63	32	63	32
N as urea	kg/ha	34	68	34	68	23	98	23	98
Total N	kg/ha	85	14	85	14	86	13	86	13
Nitrogen cost									
Sesbania	$/ha	66	17	101	16	74	20	109	13
N as urea	$/ha	16	68	16	68	11	98	11	98
Total	$/ha	82	7	117	8	85	10	120	7
Urea only	$/ha	41	14	41	14	42	13	42	13
Cost/unit of N									
Sesbania		1.29	-	1.98	-	1.17	-	1.73	-
Total N		0.96	-	1.38	-	0.99	-	1.39	-
Rice yields									
Expected	t/ha	3.1	22	3.1	22	3.1	21	3.1	21
Actual	t/ha	2.9	40	2.9	40	3.0	38	3.0	38
Increment	t/ha	0.4	17	0.9	17	0.4	13	1.0	13

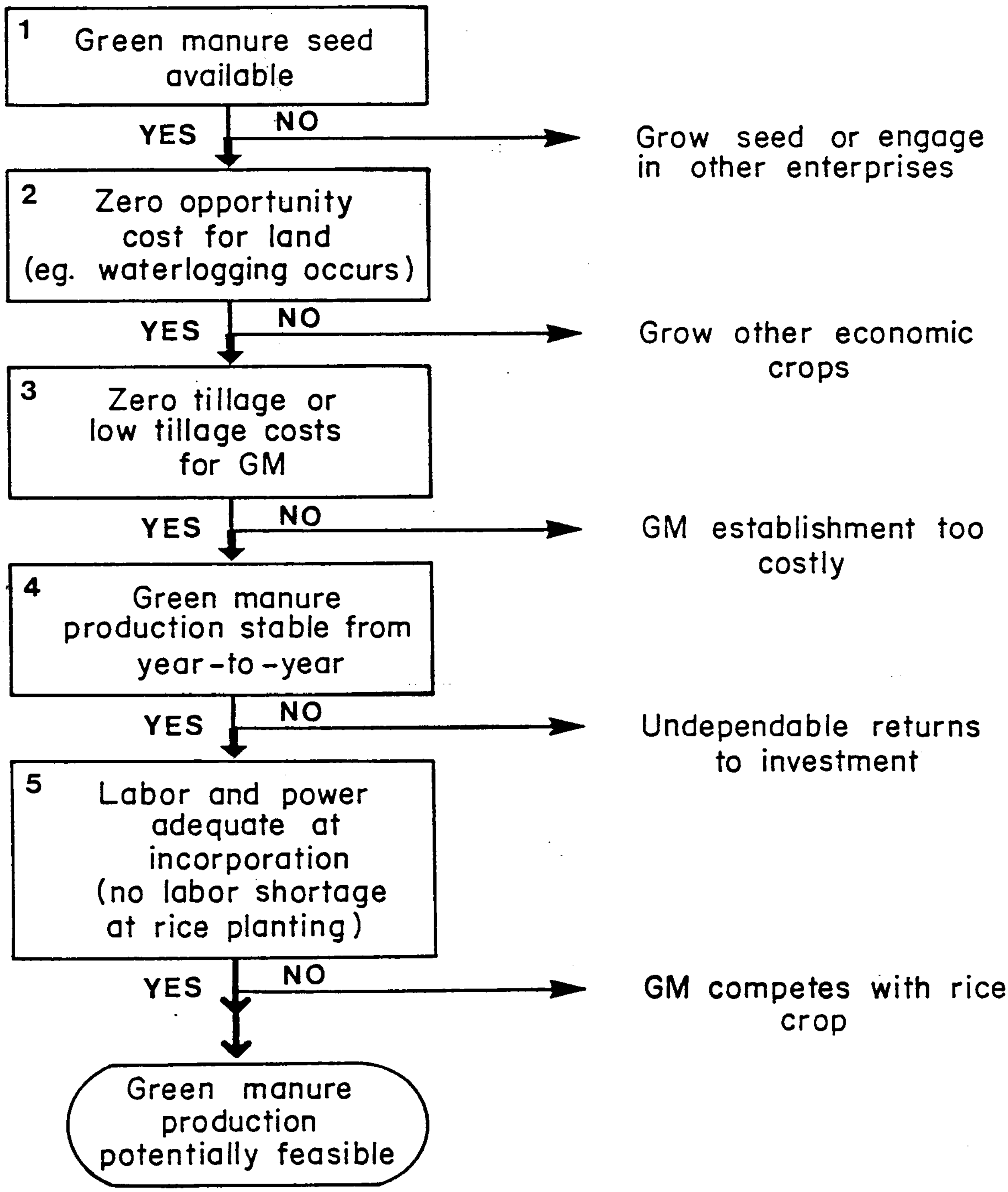

Figure 1. Decision tree of minimum necessary criteria for green manure production in a particular environment.

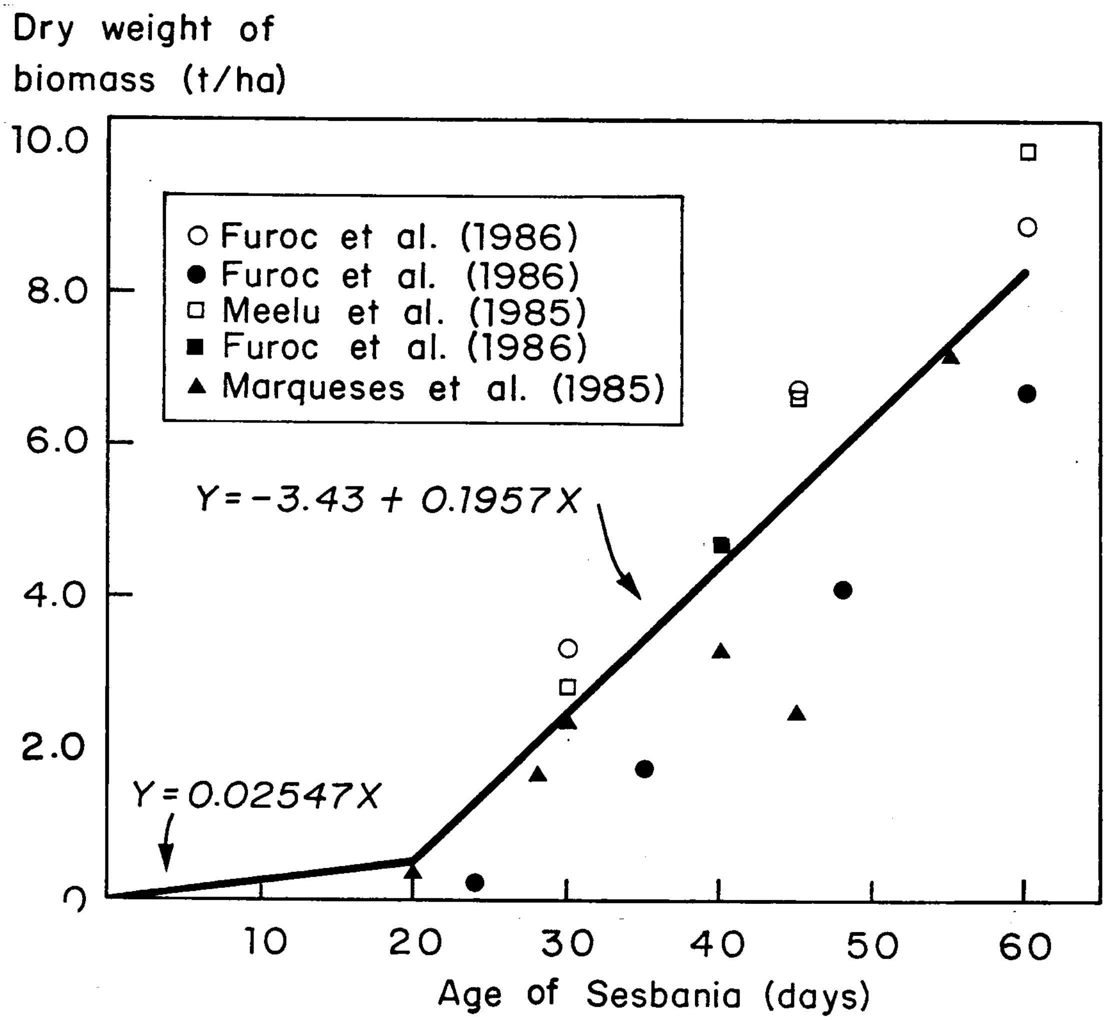

Figure 2. Biomass accumulation of <u>Sesbania rostrata</u> as a function of plant age under nonstress conditions.

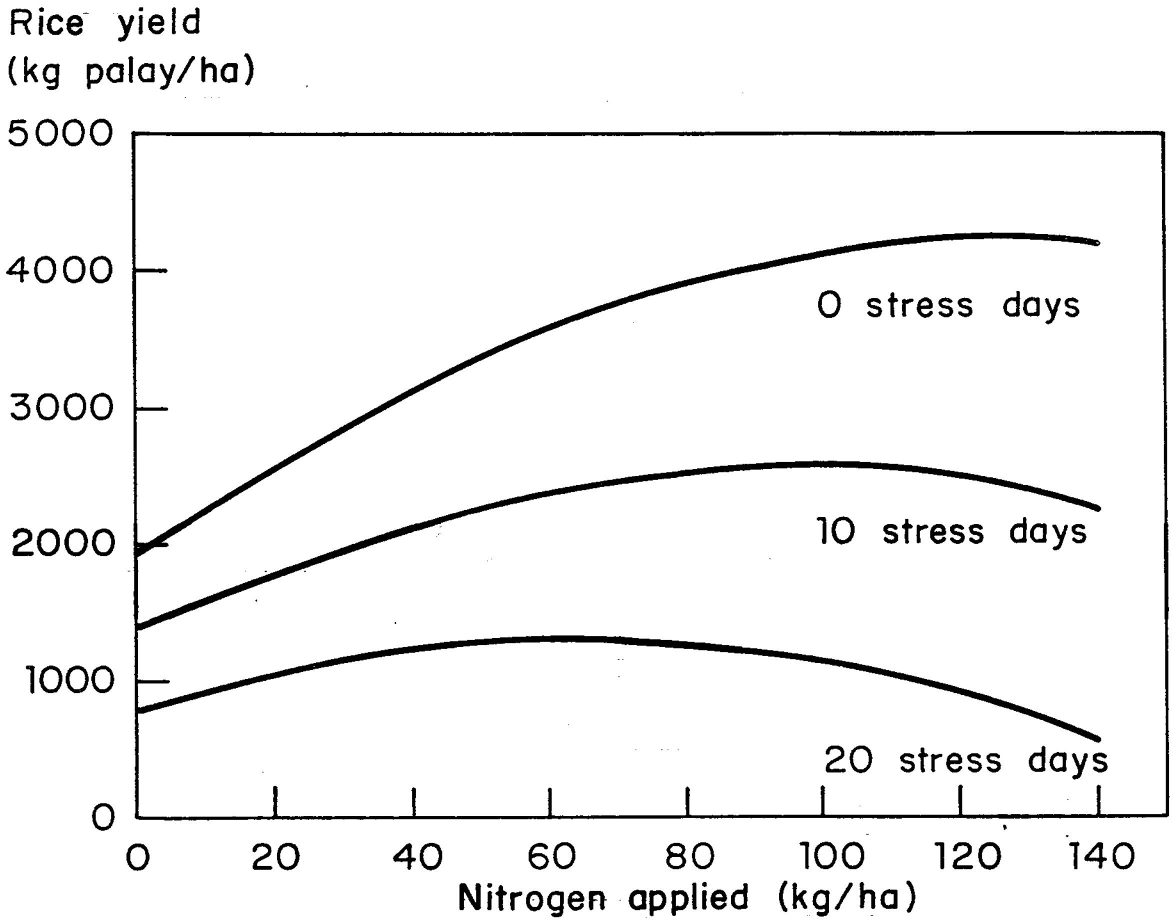

Figure 3. Rainfed rice grain yield as a function of inorganic N applied and number of stress days during the reproductive period (55 to 10 dbh) for farms in the central Philippines (Huysman, 1983).

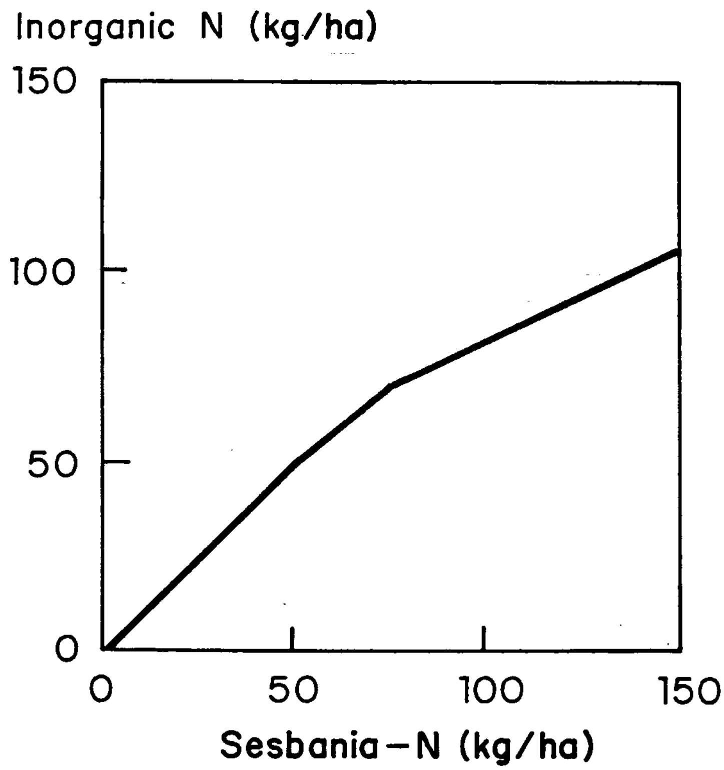

Figure 4. Functional relationship used to calculate inorganic N fertilizer equivalent of accumulated Sesbania N in the simulation of a Sesbania-rice cropping pattern.

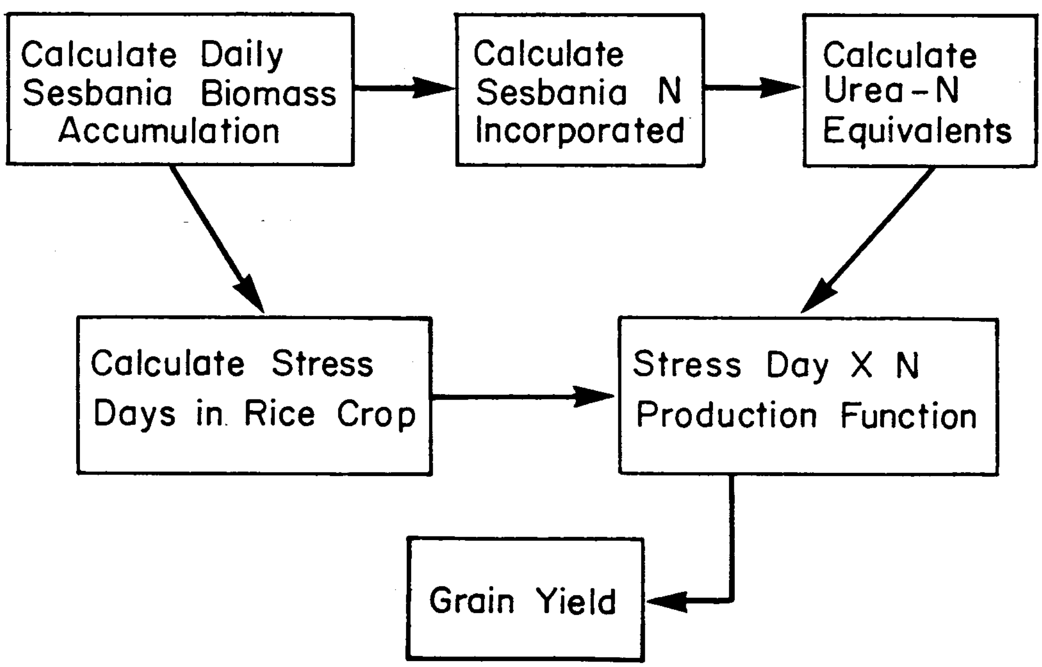

Figure 5. Simple flow diagram of the Sesbania-transplanted rice cropping system simulation model

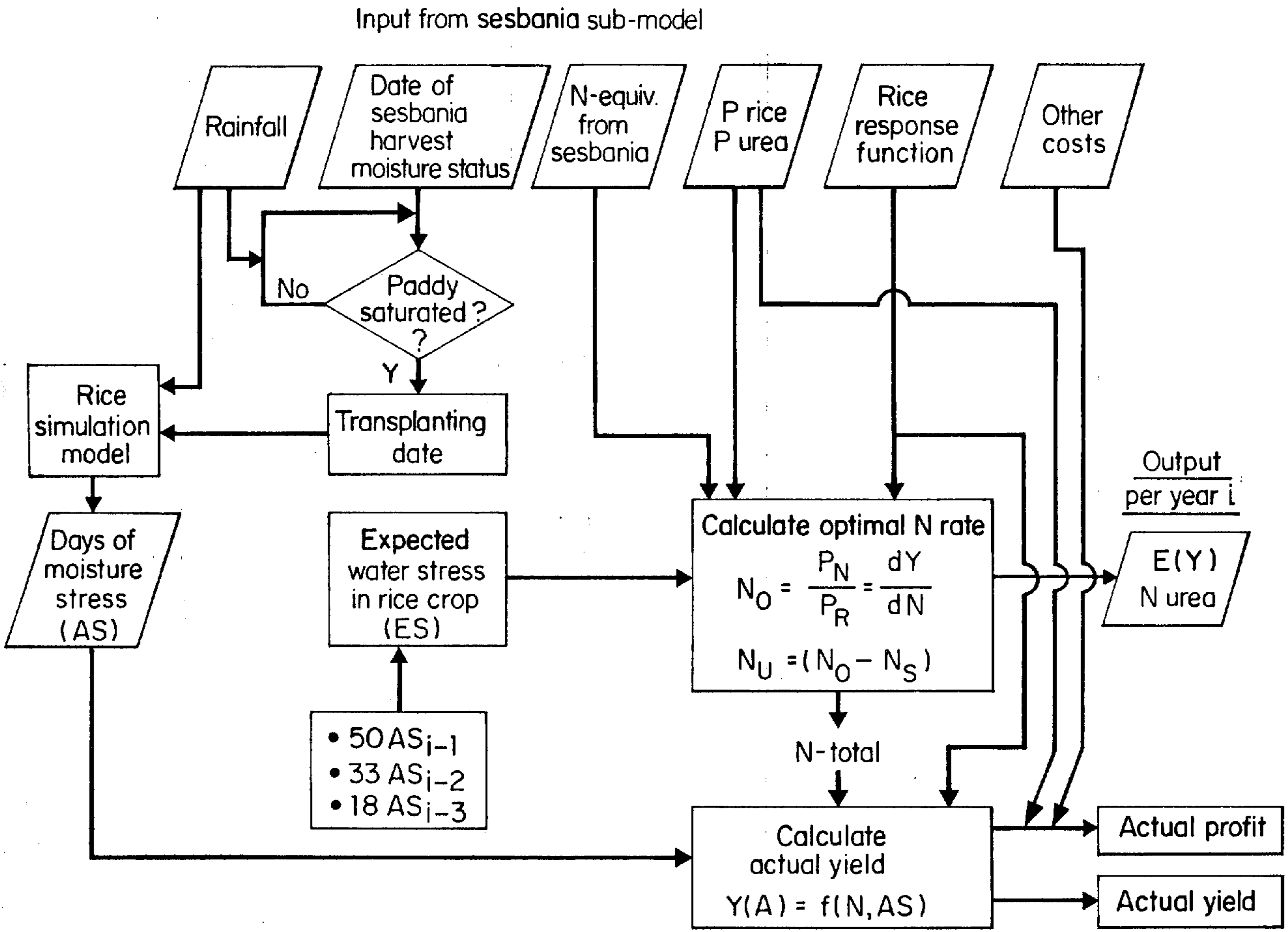

Fig. 6. Structure of sub-program to calculate inorganic N application, expected and actual rice yield.

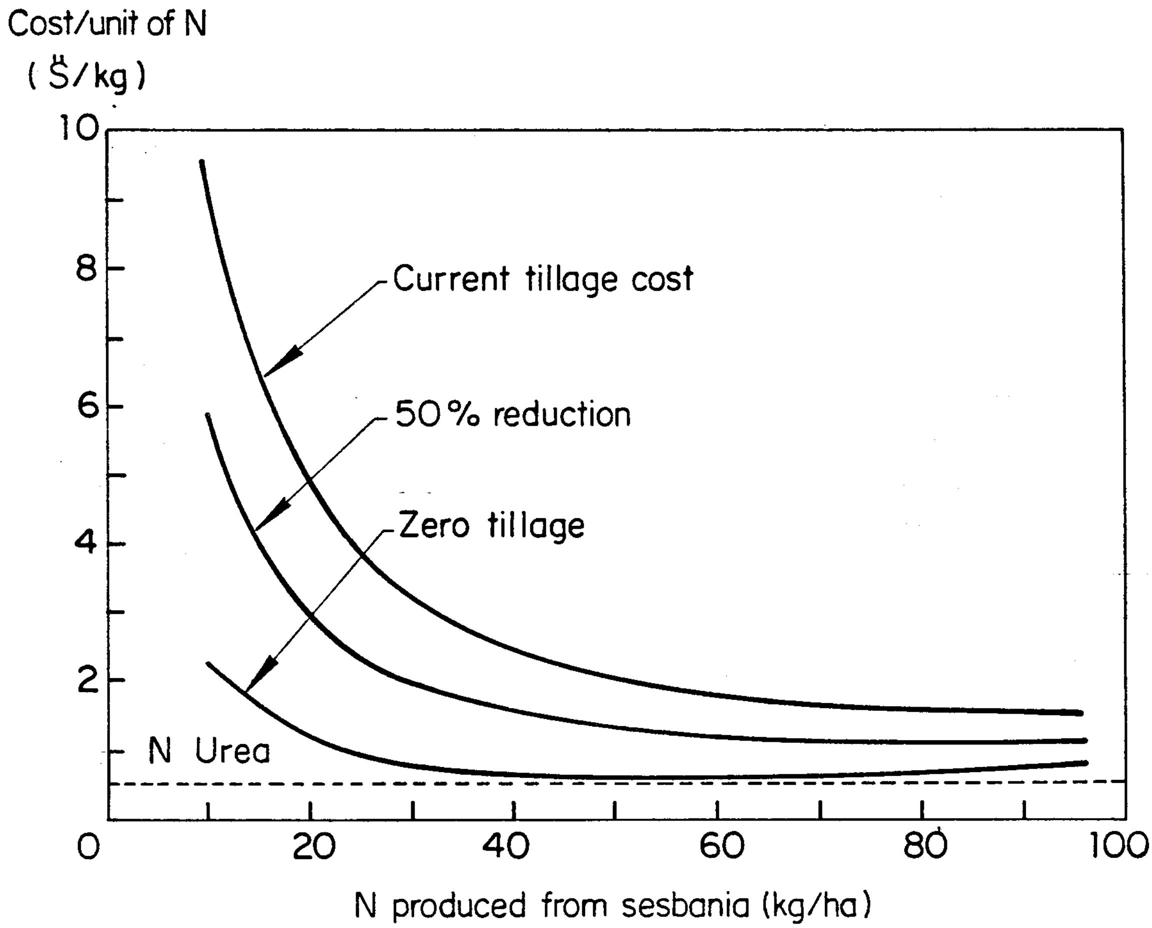

Figure 7. Relationship between cost per unit of N for Sesbania and N produced from Sesbania biomass.

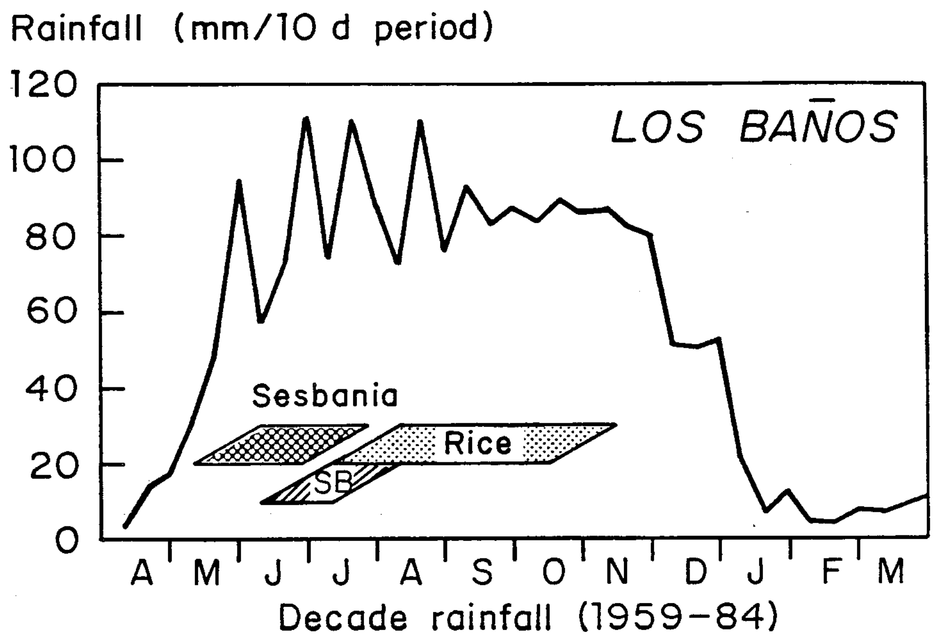

Figure 8. Timing of pre-rice green manure cultivation in a rainfed environment graphed against decade rainfall of 26 years (1959-84).

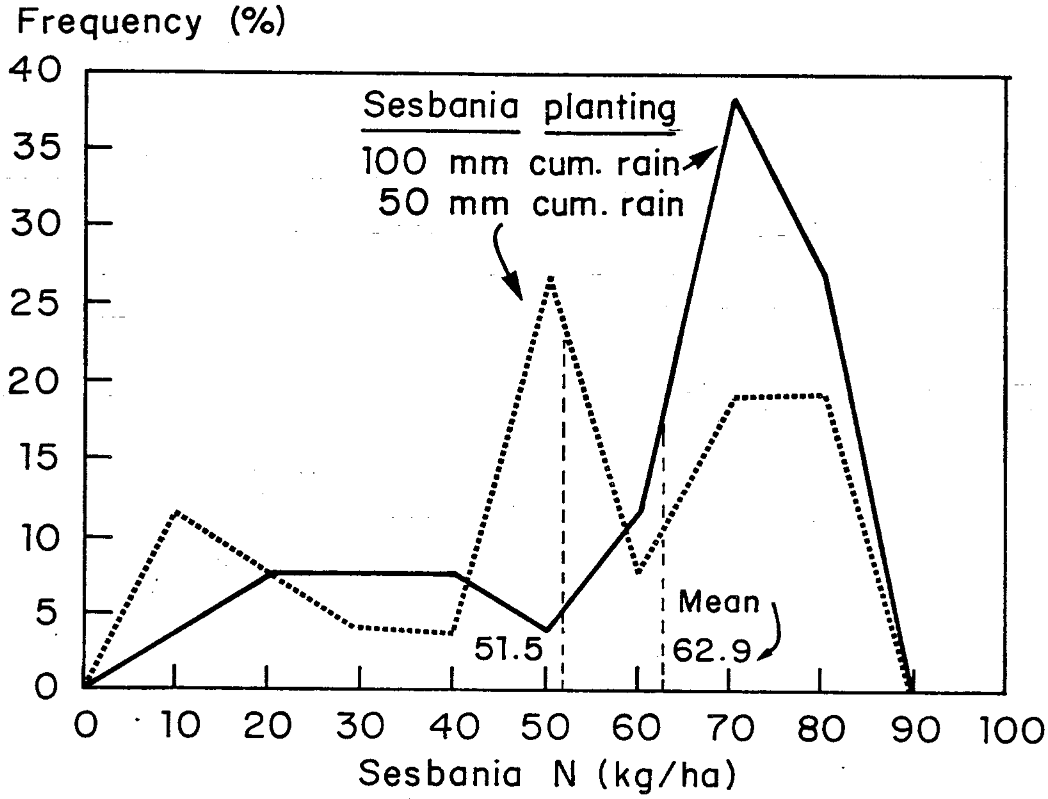

Figure 9. Frequency distribution of N yield of <u>Sesbania rostrata</u> simulated for a 26 year period at Los Baños, Philippines.

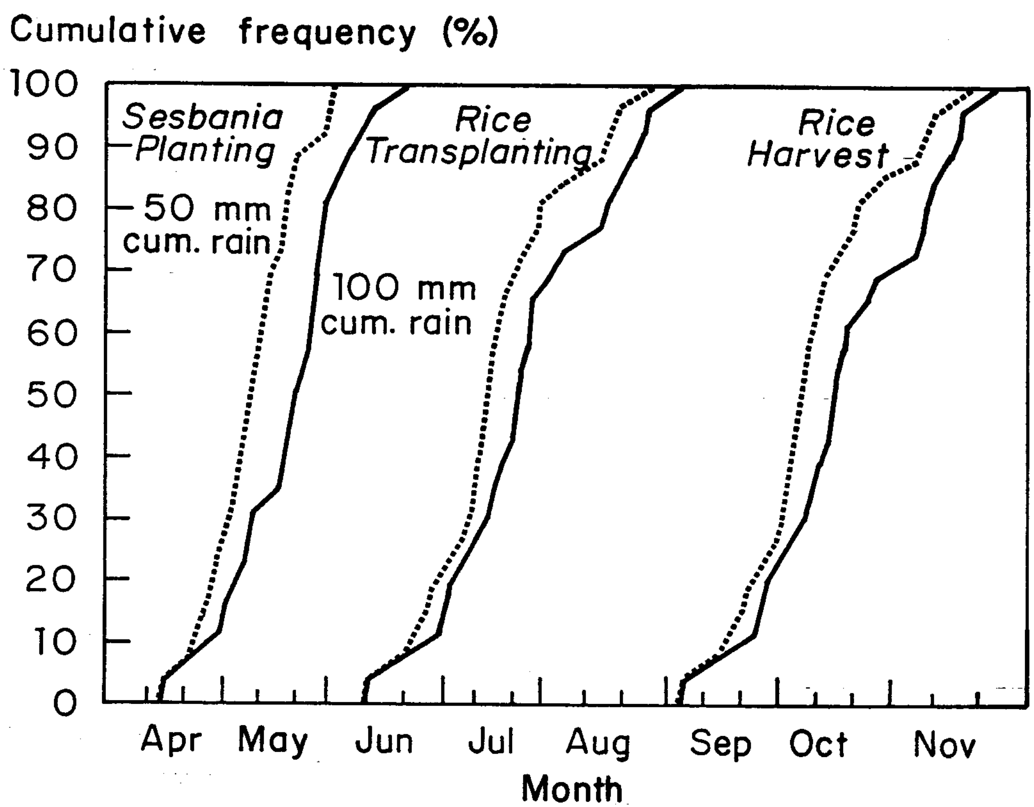

Figure 10. Longterm frequency of the dates of planting of <u>Sesbania rostrata</u> at Los Baños, Philippines simulated using criteria of 50mm or 100mm cumulative rainfall at the initiation of the dry-wet transition, and rice transplanting dates (cv. IR36) as a function of the presence of standing water after Sesbania incorporation. Based on 26 years daily rainfall data.

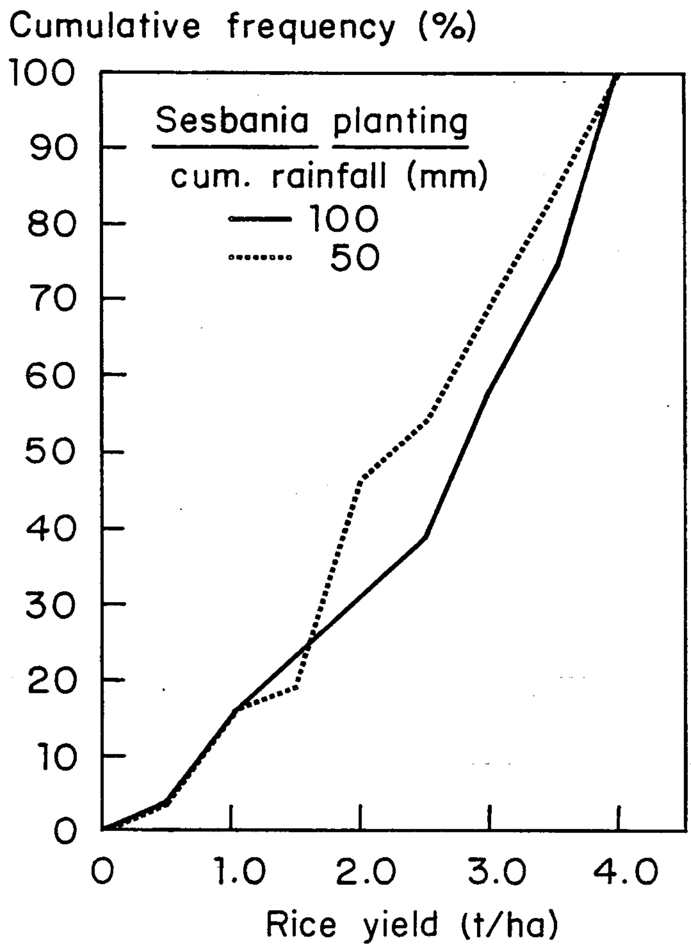

Figure 11. Cumulative frequency of rice grain yield following Sesbania rostrata, simulated for 26 years of rainfall and evaporation data, Los Baños, Philippines 1959-84. Sesbania-N yield and planting dates as in Figures 9 and 10.

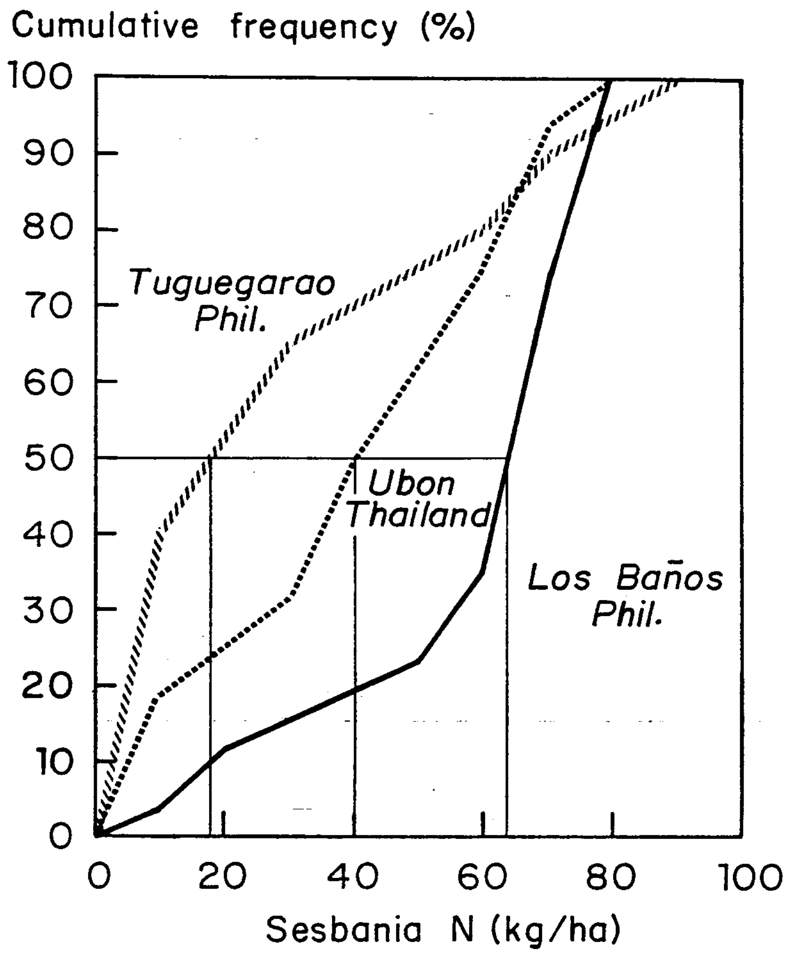

Figure 12. Cumulative frequency of simulated yield from Sesbania rostrata crops of 45 d duration planted with 100 mm total rainfall accumulation from April 1.

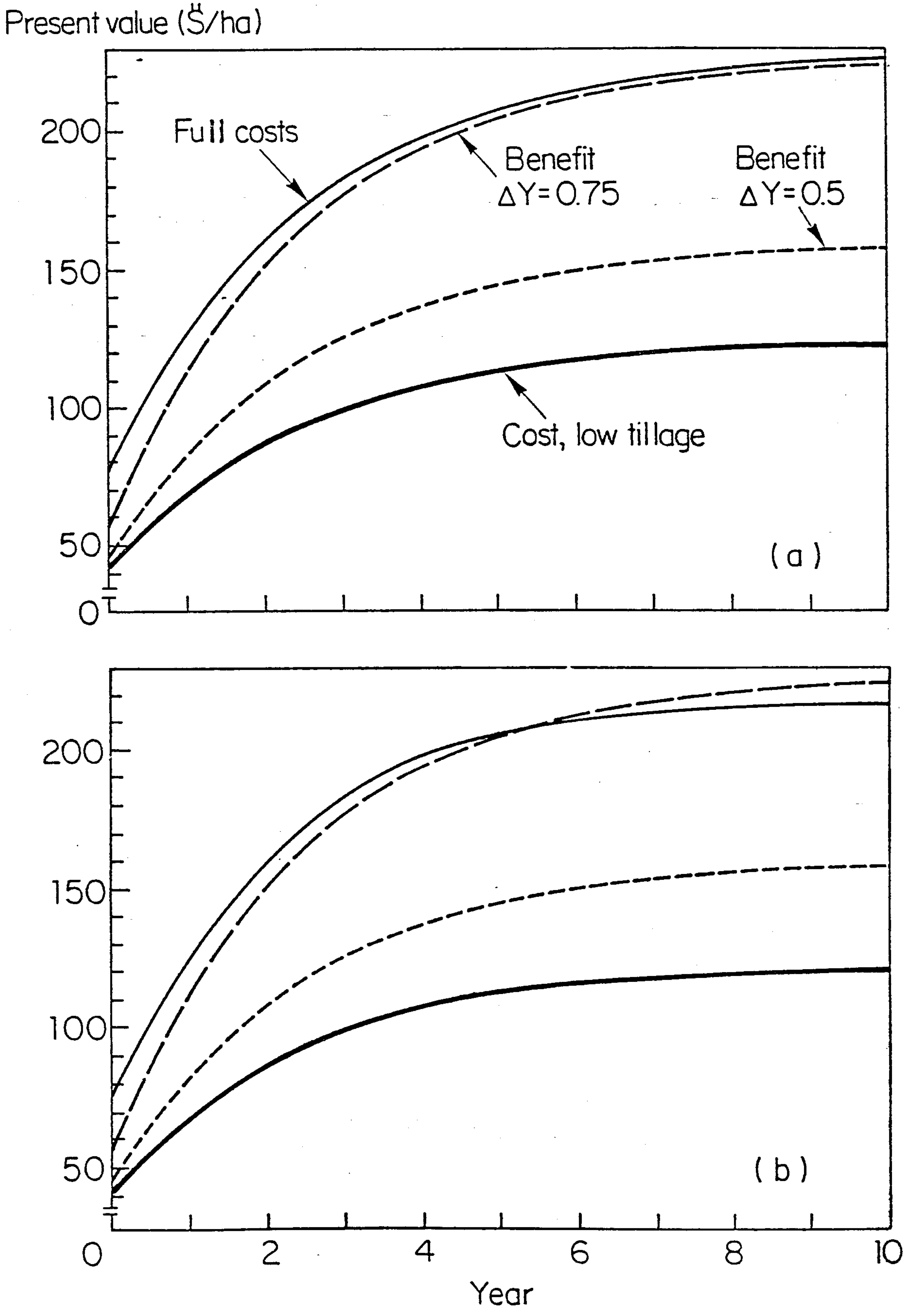

Fig. 13. Discounted benefit and costs from GM adoption, informal credit for sesbania grown each crop-season (a) and each second season (b).