熱帯における水稲の窒素吸収パターン

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Nitrogen Absorption Pattern of Rice Plant in the Tropics*

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Abstract : The amount of N in plants increased exponentially at the early growth stage ($y=ab^x$) and linearly at the middle and late growth stages ($y=a+bx$). The crossing point of the two equations coincided with the maximum tiller number stage.

Narrow spacing shortened the exponential phase. On the other hand, wide spacing and slow release fertilizer lengthened the exponential phase.

Parameter 'b' at the linear phase was not affected by spacing and rate of basal fertilizer. However, it varied with the kind of basal N and with soil chemical characteristics.

Sink size and potential sink size were correlated with the amount of N in the plant at the late spikelet initiation and flowering stages. However, contribution of N in the plant to sink formation varied with spacing and growth duration of varieties. This can be explained by the duration of the vegetative lag phase of the plant.
Key words : Growth duration, Nitrogen uptake, *Oryza sativa* L., Spacing, Yield component.

熱帯における水稲の窒素吸収パターン：和田源七，D.V. Aragones and R.C. Aragones (国際稲研究所)

要　旨：品種および栽培條件の差異が水稲の窒素吸収パターンおよび吸収窒素の Sink 生成に対する貢献度におよぼす影響を 1986 年雨季作と 1987 年乾季作で調査した．水稲体の窒素量の増加は生育初期には指数式 ($y=ab^x$) で，中後期には直線式 ($y=a+bx$) で，いずれの栽培條件でも表現しうる．両式の交点はほぼ最高分げつ期にあたる．高栽植密度は指数式の期間を短かくし，低栽植密度および緩効性肥料は長くした．直線式の勾配 'b' は基肥量の多小および栽植密度の高低による変化は非常に少なく，土壌の化学的性質および窒素肥料の種類に大きく影響された．窒素吸収の制限因子は生育初期では植物の窒素吸収能力であり，中後期では土壌中の有機態窒素の無機化速度とみられた．Sink および Potential sink は頴花分化終期および開花期の体内窒素量と正の相関関係が認められた．しかし，体内窒素量の Sink および Potential sink 生成に対する貢献度は品種および栽植密度によって異なる．このことは窒素吸収経過と Vegetative lag phase の長さとの関係により説明できる．
キーワード：窒素吸収，生育期間，栽植密度，収量構成要素，水稲．

Nitrogen is usually the most important nutrient applied in the soil and requires the most elaborate application technique. A great deal of work has been done to improve nitrogen (N) utilization through fertilizer, soil and water management [3,4,6,7,8,11,15]. Recent progress in these fields has been reviewed by some researchers ; in addition, N use efficiency of rice genotypes has been also discussed[4,16].

The remarkable increase in rice yield is attributed to high-yielding varieties that are highly responsive to N fertilizer that is applied in large quantities. Sometimes, the importance of the native fertility of paddy soil is neglected by the farmers who prefer to use large amounts of chemical fertilizers. However, the ratio of the amount of N derived from fertilizer to the amount of total N in the plants is less than 30%[15]. Moreover, farmers in developing countries cannot use large amount of fertilizer N due to its steadily increasing cost compared to rice price. Higher yields can be effected through improved utilization of soil N and increased contribution of N in the plant to yield. To do this, it is important to know the N absorption pattern of rice varieties grown under different cultural conditions as well as the contribution of plant N at different growth stages to yield and yield components. Particular attention must be given to sink size, a component that generally governs yield in the tropics.

Materials and Methods

Field experiments were carried out during

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Table 1. Chemical characteristics of the soil.

Site	pH		Org. C (%)	Total N (%)	C/N	CEC (meq·100 g^{-1})	Ammonification[a] (mg·100 g^{-1})	
	H_2O	KCl					Dry soil	Fresh soil
Field E	7.1	6.3	1.36	0.136	10.0	36.3	11.76	6.70
Field M	6.4	5.4	1.23	0.129	9.5	33.3	10.72	4.55

a : Incubation at 30°C for 4 weeks.

the 1986 wet season and 1987 dry season at E and M blocks (Maahas clay soil, Andaqueptic, Haplaquoll) of the International Rice Research Institute (IRRI) paddy field. The chemical properties of these fields and the experimental design are shown in Tables 1 and 2. Germinated seeds were sown in seedling trays (2 seeds/cm^3) and transplanted 14 days after seeding. Fertilizers were incorporated in the soil at about 10 cm depth two days before transplanting.

Plant samples were collected at weekly intervals until maturity. The amount of N in plants and NH_4-N in the plow layer were determined. Tiller count was done weekly to estimate the maximum tiller number stage. Yield and yield components were also determined. Sink size and potential sink size were calculated as follows :

Sink size = yield ÷ percentage of ripened grains

Potential sink size = sink size ÷ (1 − percentage of degenerated spikelets)

Table 2. The experimental design[a].

Rate of N[b]	Spacing (cm)		
0	20×10	20×20	20×30
6	20×10	20×20	20×30
6[c]	20×10	20×20	20×30
12	20×10	20×20	20×30

a : Varieties used-IR64 (110—115 days) and IR36892-163-1-2-2-1 (130 days).
Transplanted : 1986 WS—July 5 ; 1987 DS—Nov. 10, 1986.
b : Ammonium sulfate (g·m^{-2}) applied basally ; Four g·m^{-2} of P and K applied basally.
c : Meister 15 (Slow release fertilizer).

Results and Discussion

Nitrogen absorption pattern

The amount of NH_4-N in the soil tends to decrease exponentially after transplanting and became constant at very low levels in both dry and wet seasons (Fig. 1).

Nitrogen absorption patterns are shown in Figures 2-4. In both dry and wet seasons, the amount of N in the plant was closely related to the number of days after transplanting. Exponential equations ($y = ab^X$) were obtained during the early growth stage and

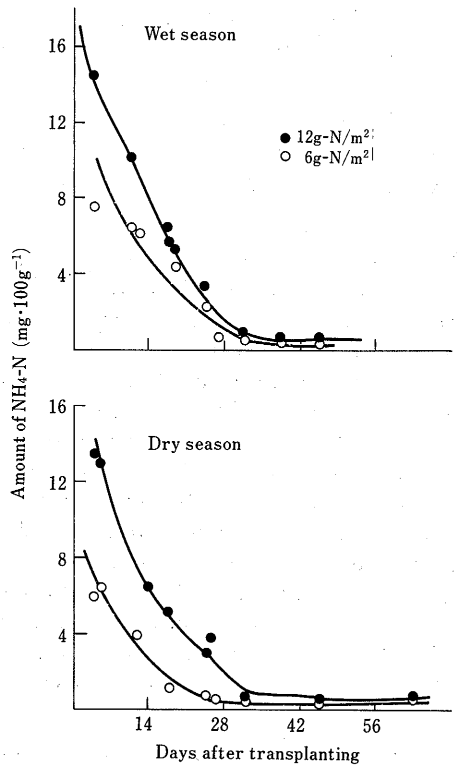

Fig. 1. Behavior of NH_4-N in plow layer (1986 WS, 1987 DS)

linear equations (y=a+bx) during the middle and late growth stages. There was no difference in N absorption pattern between short - and medium - duration varieties. Exponential equations existed only during the period when NH_4-N was found in the plow layer, while linear equations were observed during the period when NH_4-N in plow layer became constant at very low levels[9,11,12]. Earlier findings showed a similar trend of N absorption on accumulated effective thermal index (AETI)[10,11,12].

In the tropics, there is no great difference in temperature during the period from transplanting to maturity. Hence, the number of days after transplanting is equivalent to AETI in temperate areas.

The crossing point of the two equations, exponential and linear, coincided with the maximum tiller number stage which varied with cultural practices (Fig. 4). The rate of basal N did not affect the time of the maximum tiller number stage, whereas plant density, kind of fertilizers and cropping season

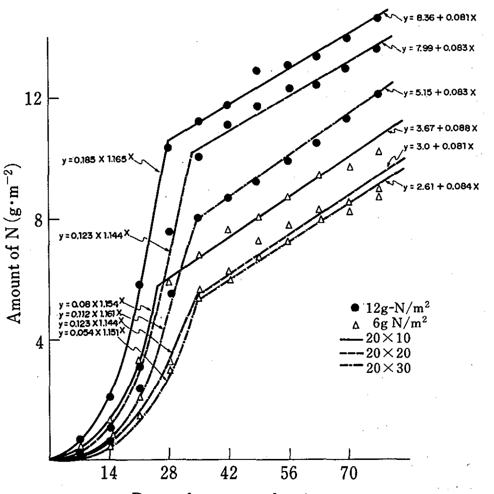

Fig. 2. Nitrogen absorption pattern of rice plant grown under different cultural practices (E, IR64, 1986 WS)

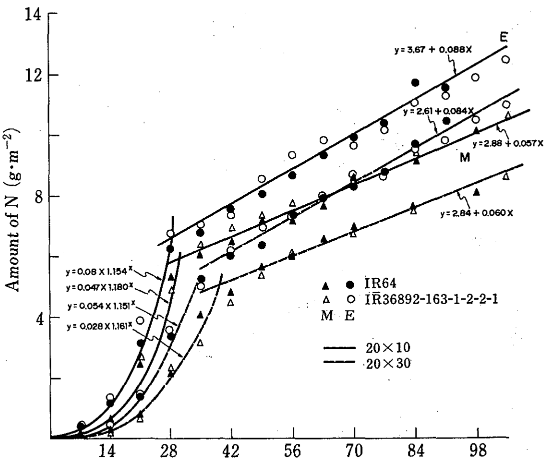

Fig. 3. Nitrogen absorption pattern of rice plant grown under different soils (1986 WS)
Note : M and E-Experimental fields

Table 3. Duration of exponential phase for N absorption.

Season		Field	Fertilizer	Spacing (cm)	Mean temperature at tillering stage (°C)	Duration[a] (days)
1986	WS	E	Ammonium sulfate (AS)	20×10	27.3	28
				20×30		35
			Meister	20×10		35
				20×30		40
		M	AS	20×10		28
				20×30		37
			Meister	20×10		35
				20×30		40
1987	DS	E	AS	20×10	23.4	35
				20×30		40
			Meister	20×10		42
				20×30		49

a : Number of days from transplanting.

affected the time of the maximum tiller number stage[11,15]. With narrow spacing and under the prevailing higher temperature during tillering stage, the maximum tiller number stage occurred earlier; under wider spacing and slow release fertilizer, the maximum tiller number stage occurred later. The exponential phase was shortened by narrow spacing and prevalent higher temperature during the tillering stage (Table 3). The rate of N absorption during the exponential phase was accelerated by narrow spacing and heavy basal N[11,12]. It was likewise affected by chemical characteristics such as rate of mineralization of soil organic N.

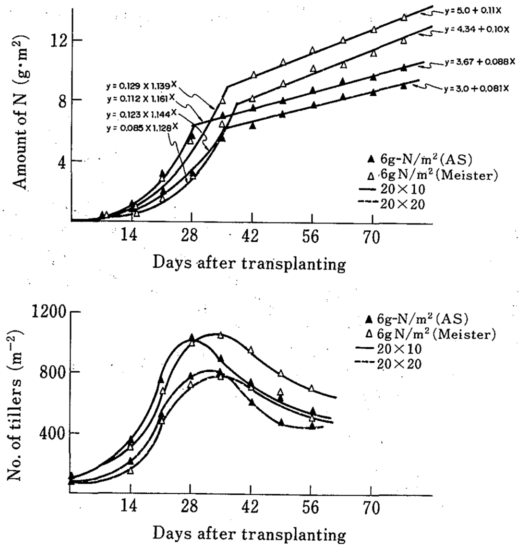

Fig. 4. Nitrogen absorption pattern and pattern of tillering of rice plant grown under different kinds of nitrogen fertilizer. (E, IR64, 1986 WS).
Note: AS, Ammonium sulfate

The panicle primordia initiation stage is observed almost on the same day in all the treatments in identical varieties within a cropping season[17]. Therefore, spacing largely affects the duration of the vegetative lag phase[17]. The duration of vegetative lag phase in turn affected the contribution of N in the plant to yield and yield components.

The absorption of soil N and the behavior of NH_4-N derived from basal and soil organic N strongly suggested that there are two kinds of soil organic N: the rapidly and slowly mineralizable forms. Recently, Ando and Shoji obtained the exponential equation for mineralization of soil organic N; it consists of two exponential equations for rapidly and slowly mineralizable soil organic N[2]. The former is largely absorbed by the plant at the early growth stage (exponential phase) and the lattter is largely absorbed at the middle and late growth stages (linear phase)[2,11,15].

Parameter 'b' in the linear equation (rate of N absorption) was scarcely affected by the rate of basal fertilizer and spacing. It was, however, affected by the soil chemical characteristics and the kind of fertilizers used[10]. Slow release fertilizer and higher rate of mineralization of soil organic N increased parameter 'b'. At the linear phase, there was little difference

Table 4. Amount of N ($g \cdot m^{-2}$) in plant from different origins.

Season	Field	Spacing (cm)	5 WAT[c] Basal N	5 WAT[c] Soil N[a] R	5 WAT[c] Soil N[a] S	Flowering Basal N	Flowering Soil N[a] R	Flowering Soil N[a] S
1986 WS	E	20×10	1.9	4.4	0.5	1.9	4.4	3.2
		20×20	1.7	3.8	0.4	1.8	3.8	3.2
		20×20[b]	—	3.2	0.3	—	3.2	3.1
	M	20×10	1.8	3.9	0.4	1.8	3.9	2.5
		20×20	1.7	3.0	0.3	1.8	3.0	2.5
		20×20[b]	—	2.2	0.2	—	2.2	2.2
1987 DS	E	20×10	1.7	4.0	0.4	1.7	4.0	3.0
		20×20	1.5	2.5	0.3	1.7	2.5	3.2
		20×20[b]	—	2.0	0.2	—	2.0	3.1

a: R: Rapidly mineralizable soil N, S: Slowly mineralizable soil N. The amounts of R and S are roughly estimated by the equation of mineralization of organic N (Ando and Shoji[2]).
b: No nitrogen.
c: 5 weeks after transplanting. Rate of basal N: $6g^{15}N \cdot m^{-2}$.

in the amout of N absorbed by plants grown in the same field but under different cultural practices. It was also reported that the amount of N absorbed at the middle and late growth stages closely correlated with the amount of slowly mineralized soil N[1].

Contribution of N from different origins absorbed at different growth stages is shown in Table 4. It is possible to increase the amount of N in the plant by increasing the absorption of N released from rapidly mineralizable soil organic N by cultural practices such as heavy basal N application and narrow spacing during the exponential phase[13,15]. However, there is a very limited chance to increase the absorption of soil N released from slowly mineralizable soil organic N by cultural practices during the linear phase. Therefore, it can be said that the limiting factor for N absorption is N absorption ability of plant during the exponential phase and mineralization rate of soil organic N during the linear phase[10,11,12,15,16]. During the linear phase, the plants can only increase N absorption by topdressing and by increasing N supply from the soil. Topdressing increases the rate of N absorption only during the period when NH_4-N derived from topdressed N stays in plow layer and then, the rate of N absorption in topdressed plot becomes similar to that in the plot which is not topdressed[14,15]. It can therefore be said that topdressing sometimes induces imbalance among yield components (relationship between sink and ripening) and decreases the yield as observed in temperate area. On the other hand, soils with higher mineralization rate of soil organic N (or high N soil fertility) keep the rate of N absorption constant at a high level and can make the plants absorb large amount of nitrogen without inducing any imbalance among yield components. Increasing the N soil fertility (N supply from soil) is a safer method than topdressing to increase the yield[15].

Slow release fertilizer can be used in increasing N supply during the linear phase instead of increasing N soil fertility. The effect of slow release fertilizer will be reported in detail later.

Contribution of N in plant to yield and yield components

There was a close relationship between potential sink size and amount of N in plant at the late stage of spikelet initiation. Likewise, sink size and the amount of N in plant at the late stage of spikelet initiation or at the flowering stage are highly correlated, as previous results showed[15]. However, differences in the contribution of N to sink size or potential sink size were apparent in IR64 and IR36892-163-1-2-2-1; the same was true for spacing (Table 5, Fig.5, 6)[16]. Compared with IR64,

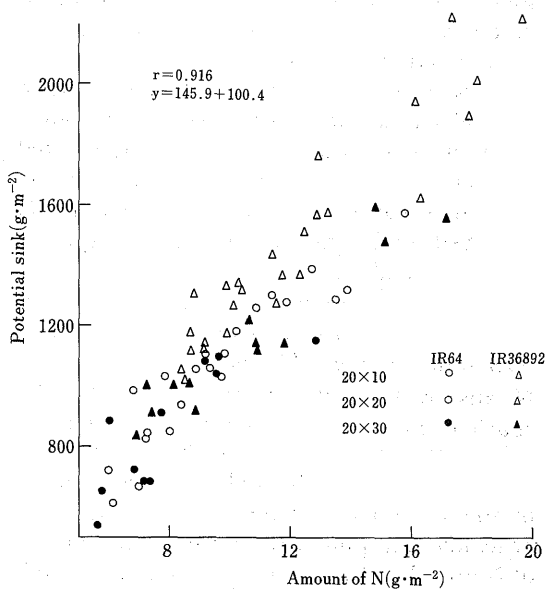

Fig. 5. Relationship between potential sink size and amount of N in plant at the late stage of spikelet initiation (1986 WS).

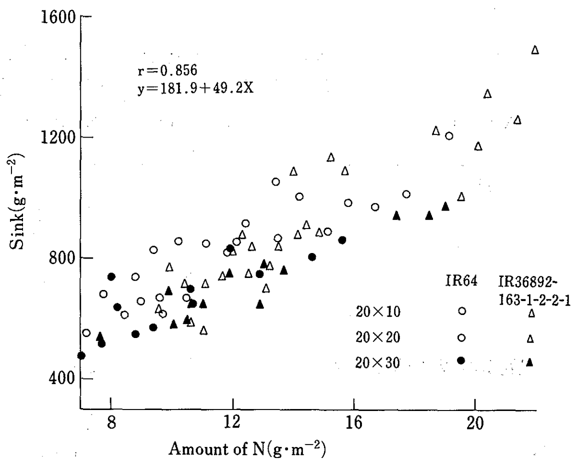

Fig. 6. Relationship between sink size and amount of N in plant at flowering stage (1986 WS)

IR36892-163-1-2-2-1 was characterized by a higher contribution of N to potential sink at the late stage of spikelet initiation. Furthermore, narrow spacing promotes higher contribution of N in plant at the late stage of spikelet initiation particularly in IR64.

This phenomenon can be explained by the relationship between the maximum tiller number stage and panicle primordia initiation stage, and the effect of N absorption at different growth stages on the spikelet differentiation.

It was reported earlier that the contribution of N absorbed after secondary rachis branch initiation stage to the number of differentiated spikelets became low and that after the late stage of spikelet initiation, the amount of N absorbed had little contribution to spikelet differentiation[5,15].

In IR64, the occurrence of panicle primordia initiation nearly coincided with maximum tiller number stage. Therefore, the amount of N absorbed by the plant was affected by spacing during the period from panicle primordia initiation stage to the late stage of spikelet initiation. This reflected the duration of the vegetative lag phase. The longer the vegetative lag phase, the smaller the amount of N absorbed by the plants during the period. Moreover, IR64 absorbed greater N during this period than did IR36892-163-1-2-2-1. During the same period, more N was absorbed with wide spacing than with narrow spacing.

On the other hand, the occurrence of the panicle primordia initiation in IR36892-163-1-2-2-1 was much later than the maximum tiller number stage. Hence, among plants grown under different spacings there was little difference in the amount of N absorbed by the plant during the period from panicle primordia initiation stage to the late stage of spikelet initiation. Narrow spacing was more effective in increasing contribution of N to sink formation in early maturing varieties.

There was little varietal difference in the N-sink relationship between IR64 and IR36892-163-1-2-2-1 because of the large number of degenerated spikelets in IR36892-163-1-2-2-1. Differences in contribution of N in plant to sink size at the late stage of spikelet initiation and at the flowering stage among fertilizer plots and between narrow and wide spacings in IR64 were noted (Table 5).

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Table 5. Effect of spacing and N level on the contribution to sink (1986 WS).

Variety	N level (g•m⁻²)	Spacing (cm)	Vegetative lag phase (days)	PS*/N***	S**/N***
IR64	0	20×10	10	96	79
		20×20	5	85	70
		20×30	−1	77	66
	6	20×10	10	100	76
		20×20	5	97	73
		20×30	−2	90	70
IR36892-163-1-2-2-1	0	20×10	31	115	76
		20×20	26	117	77
		20×30	20	123	77
	6	20×10	31	117	76
		20×20	26	115	75
		20×30	20	115	78

PS* : Potential sink size ; S** : Sink size ; N*** : Amount of N in plant at flowering stage.

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