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The Relationship between the Root Growth Analysis and the Growth Analysis in *Lolium multiflorum* Lam*

Yukio KUJIRA** and Mikio KANDA
(Institute for Agricultural Research, Tohoku University, Sendai 980)
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The growth analysis, introduced by GREGORY[4] and BRIGGS, KIDD and WEST[1], and developed by WATSON[18,19] and his collaborates, was considered to be only a means of analysing the plant growth from the point of view confined to the carbon part of the whole dry weight complex.

In this growth analysis, the relative growth rate (RGR) of a plant or plant population used to be split into derivates, that is, the net assimilation rate (NAR) and leaf area ratio (LAR). However, if it were possible, it would be desirable to take the concepts for uptake of mineral nutrients by roots on plant growth process as has been stated by EVANS[3].

We also considered that it was more essential to analyze the plant growth not only from the responses of above ground organs of plant to various spatial environmental conditions, but also from the processes of mineral uptake by roots at the same time.

Various root characteristics, including physiological activity in roots, which governed uptake of water and mineral nutrients and the top-root interrelations should be, in a way, introduced into the analysis of plant growth processes as the parameters, and the influence of environmental factors on them must be verified.

In the present paper, we discussed the relationships between the derivates which composed the root growth analysis and the growth functions by which the growth analysis was constituted.

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** Present Address: Faculty of Education, Kanazawa University, Kanazawa 920.

Materials and Methods

Two cultivars of Italian ryegrass, *Lolium multiflorum* Lam., i.e., *L. multiflorum* var. mammoth B for erect type, mammoth A for weeping type, were used for the experimental materials.

The experiments were carried out in a glasshouse at the Inst. Agr. Res., Tohoku University from May to August in 1976. About 3 weeks after sowing, May 28, young seedlings, about 10 cm in plant height, were transplanted in the opaque plastic boxes, 40×21×21 cm in size, filled with HEWITT's[5] nutrient solution. As the treatments, three planting densities, 3×3 cm, 6×6 cm, 9×9 cm, and two nutrient levels, NO_3-N: 10 ppm and 50 ppm, were employed in the experiments. The cultural solution, adjusted to pH 6.2 by dill.-H_2SO_4, was renewed every one week over the experimental period. Samplings were performed every two weeks.

The outermost plants of two lines in the culture boxes for the 3×3 cm and 6×6 cm plots, one line for the 9×9 cm plot, were rejected from the sample materials to avoid the sampling error caused by the border effect.

Whole dry weight, top dry weight, root dry weight, plant height, leaf area, number of tillers, number of roots, maximum root length, and α-naphtylamine (α-NA) oxidizing activity in roots were measured. SAKAI and YOSHIDA's[15] method was adopted for the α-NA oxidizing activity in roots. Attached roots of three plants of each treatment plot were soaked in the flasks filled with the reagent. After 24 hours incubation in the constant temperature of 25°C, the absorbancy of the samples were measured with the spectrophotometer at the wave length of 510 nm. The values of URA (URA=Ra/Pw), RAR (RAR=1/Ra·dPw/dt), RWR (RWR=Rw/Pw), were calculated by the procedure proposed by KUJIRA and KANDA which described in the previous paper[10]. Where, Pw, Rw, Ra, are showed plant dry weight, root dry weight, α-NA oxidizing activity in roots per hour, respectively.

Results and Discussion

WELBANK[20] has ever discussed the relationship between the size and the average rate of nitrogen absorption (R_N) by calculating the specific absorption rate for nitrogen on the basis of root dry weight (A_N) and the root weight ratio (RWR). He reported that the amount of absorbing "Machinery" was parallel to the root dry weight, though this was likely to be only approximately true, and most of variation in R_N was caused by difference in A_N.

Recently many workers have examined the possibility that a constant functional balance can exist between root and shoot systems despite varying external conditions. DAVIDSON[2] has investigated the functional relationship between the size and activity of shoot and those of root system, and proposed that the relationship could be represented by

Root Mass×Rate (absorption) $\propto$ Leaf Mass×Rate (photosynthesis).

HUNT and BURNETT[6], HUNT[7], HUNT, STRIBLY and READ[8] have tested this experimentally with their data of *Lolium perenne* L. and *Trifolium repens* L.. They reorganized the DAVIDSON's expression into

Root Mass/Leaf Mass $\propto$ 1/(Rateabsorption/Rate photosynthesis)

and they have interpretated above expression in the following from

Rw/Sw $\propto$ 1/(SAR/USR) or

Mass Ratio $\propto$ 1/Activity Ratio,

where R_W and S_W are the root dry weight and shoot dry weight, respectively.

THORNLEY[16] has pointed out that the above mentioned expressions are unnecessarily complicated, and that those are completely equivalent to the following such similer equation,

$$\triangle M=f_M\cdot\triangle W,$$

where $\triangle W$ is the increment of total dry weight during the period of time $\triangle t$, $\triangle M$ is the corresponding increment in weight of the element M (M could be a single element, a group elements, a single compound, or a group of compounds). $\triangle M$ is a fraction of total increment $\triangle W$, and f_M denotes the fraction.

Up to the minute, RICHARD[12], RICHARD *et al.*[13] discussed the top-root interactions and RICHARD, GROUBAN and COLLINS[14] also examined the relationship between the increment in plant nitrogen ($\triangle N$) and the increment in plant dry weight ($\triangle W$) with the fruiting tomato plants.

We had tried to discuss in the previous paper[9,10] that the plant growth process must be analyzed through the medium of the top-root interrelationship and the physiological activity in root system, and had pointed out the evidence that the top-root relationship might be closely connected with the root behavior and the physiological activity in roots.

We also have proposed a new idea of "Root Growth Analysis" analogous to the former growth analysis, by introducing the concept of the relative activity in roots into the analysis, and showed that the relative growth rate of plant (RPGR) could be split into three derivates, i.e., unit root activity (URA), root weight ratio (RWR) and root assimilation rate (RAR)[10].

The relationship between $\overline{URA}$ and $\overline{LAR}$ was showed in Fig. 1 and Table 1. Positive correlations between $\overline{URA}$'s and $\overline{LAR}$'s were recognized irrespective of cultivars, plant densities, and nutrient levels as far as the experiment concerned. As a rule, the value of coefficient of regression of $\overline{LAR}$ to $\overline{URA}$ in the NO_3-N: 10 ppm plots were smaller than those in the NO_3-N: 50 ppm plots. Physiological activity in roots might exert positively influence on the expansion of leaf area on which the photosynthesis of the plants depends so that the increasing $\overline{URA}$ brought about the increase in $\overline{LAR}$.

Fig. 2 and Table 2 showed the relation-

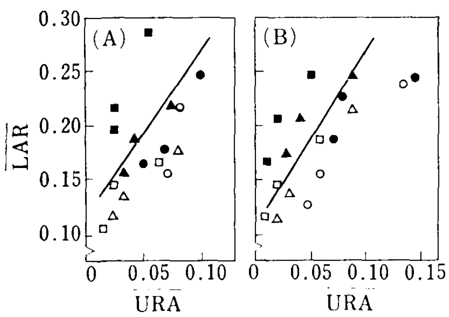

Fig. 1. Relation between $\overline{URA}$ and $\overline{LAR}$.
A and B are the Italian ryegrass mammoth A and B.
●, ▲, ■, are 3×3 cm, 6×6 cm, 9×9 cm planting densities in NC_3-N: 50ppm nutrient level.
○, △, □, are 3×3 cm, 6×6 cm, 9×9 cm planting densities in NC_3-N: 10 ppm nutrient level.

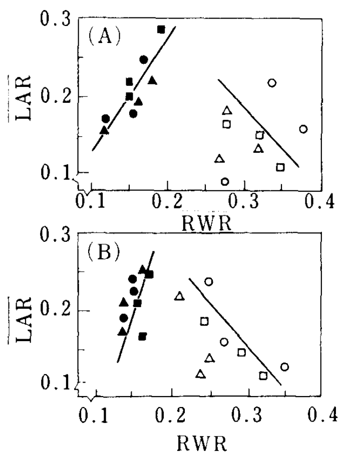

Fig. 2. Relation between $\overline{RWR}$ and $\overline{LAR}$. Simbols in figure are the same as shown in Fig. 1.

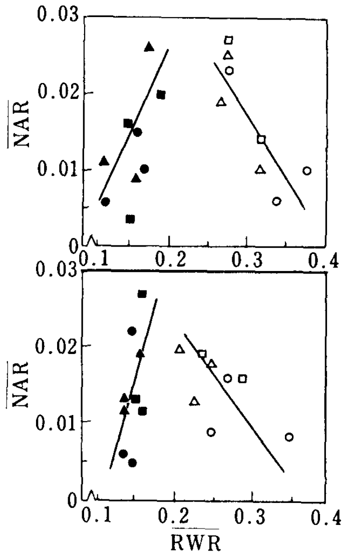

Fig. 3. Relation between $\overline{RWR}$ and $\overline{NAR}$. Simbols in figure are the same as shown in Fig. 1.

Table 1. Regression coefficient ($y=\beta_0+\beta_1x$), correlation coefficient (r), between $\overline{URA}$ and $\overline{LAR}$.

		(A)			(B)		
		β_0	β_1	r	β_0	β_1	r
●	N-3	0.10	1.19	0.986	0.18	0.39	0.728
▲	N-6	0.14	1.07	0.945	0.16	1.05	0.960
■	N-9	0.17	2.00	0.977	0.16	1.85	0.961
○	L-3	—	—	—	0.09	1.02	0.985
△	L-6	0.11	0.94	0.984	0.09	1.40	0.998
□	L-9	0.11	1.00	0.866	0.11	1.29	0.969

ships between $\overline{RWR}$ and $\overline{LAR}$. The RWR's indicated the positive correlation to the $\overline{LAR}$'s in the 50 ppm-N plots, and the correlations, on the contrary, were negative in the level of 10 ppm-N plots. The parameter b of the regression line was a positive value and the regression line showed the appearance of rising by degrees toward the right hand side of the abscissa in the 50 ppm-N nutrient level plots. The calculated regression coefficient b in the 10 ppm-N nutrient level plots, on the other hand, showed the negative value, and the regression line fell gradually toward the right hand side of the abscissa with the advance of plant growth stage.

The relationship between $\overline{RWR}$ and $\overline{NAR}$ was showed in Fig. 3 and Table 3. The circumstance that the negative correlation between $\overline{RWR}$ and $\overline{NAR}$ in the 10 ppm-N nutrient level plots was turned into the positive one in the 50 ppm-N nutrient level, was the same that in the case of the above described relationship between $\overline{RWR}$ and $\overline{LAR}$. There were the tendency that the regression line which showed the relationship between $\overline{RWR}$ and $\overline{LAR}$, $\overline{RWR}$ and $\overline{NAR}$ were moved down to the left hand side in the 50 ppm-N nutrient level as the plant growth was advanced. Because the $\overline{RWR}$'s values were decreased in the 50 ppm-N nutrient level[10], and the $\overline{LAR}$'s and $\overline{NAR}$'s values were decreased (Fig. 4) too

Table 2. Regression coefficient ($y=\beta_0+\beta_1 x$), correlation coefficient (r), between $\overline{RWR}$ and $\overline{LAR}$.

		(A)			(B)		
		β_0	β_1	r	β_0	β_1	r
●	N-3	0.018	1.214	0.737	−0.440	4.500	0.982
▲	N-6	0.042	0.964	0.982	−0.190	2.750	0.904
■	N-9	−0.090	2.000	0.977	—	—	—
○	L-3	—0.115	0.816	0.631	0.360	−0.679	−0.728
△	L-6	—	—	—	0.698	—2.308	−0.908
□	L-9	0.409	−0.838	−0.963	0.400	−0.867	−0.998

Table 3. Regression coefficient ($y=\beta_0+\beta_1 x$), Correlation coefficient (r), between $\overline{RWR}$ and $\overline{NAR}$.

		(A)			(B)		
		β_0	β_1	r	β_0	β_1	r
●	N-3	−0.008	0.121	0.717	−0.100	0.750	0.454
▲	N-6	−0.016	0.207	0.681	−0.051	0.450	0.866
■	N-9	−0.090	2.000	0.977	−0.085	0.650	0.447
○	L-3	0.060	−0.142	−0.805	0.021	−0.036	−0.435
△	L-6	0.086	−0.236	−0.826	0.039	−0.092	−0.533
□	L-9	—	—	—	—	—	—

with the advance of growth stage. There were the tendency that the regression line in the 10 ppm-N nutrient level were moved down to the right hand side, on the contrary, with the advance of growth stage. The $\overline{RWR}$'s value was increased in the 10 ppm-N nutrient level, because the root growth was promoted in this nutrient level[9].

It was recognized that the root growth would be influenced by the nutrient levels and the $\overline{RWR}$'s value would be determined, in the results, in both cases. It was considered that the $\overline{RWR}$'s would have an important meaning against the dry matter productions.

The relationship between $\overline{URA}$ and $\overline{NAR}$ was the same as that in case of above descrived relationship between $\overline{URA}$ and $\overline{LAR}$. There were not constant relationships between $\overline{RAR}$ and $\overline{LAR}$, $\overline{RAR}$ and $\overline{NAR}$, respectively. It would be necessary to think the meanings of the $\overline{RAR}$'s value more clearely. These relationships between $\overline{RWR}$ and $\overline{NAR}$, $\overline{RWR}$ and $\overline{LAR}$ were showed as a model in Fig. 5 in the lump.

In a young stage of growth (point I), RWR's value was increased with the advance of plant growth, for the physiological activity in roots (α-NA oxidizing activity) was kept high in the 10 ppm-N level[10]. When the plant growth would be advanced to the point II, if the nutrient level would be increased (50 ppm-N), the increment of RWR's value would be stopped and LAR's and NAR's values would be increased. Then the point (II) would be able to shift to the another regression line in the 50 ppm-N nutrient level. So, the point was marked down (III).

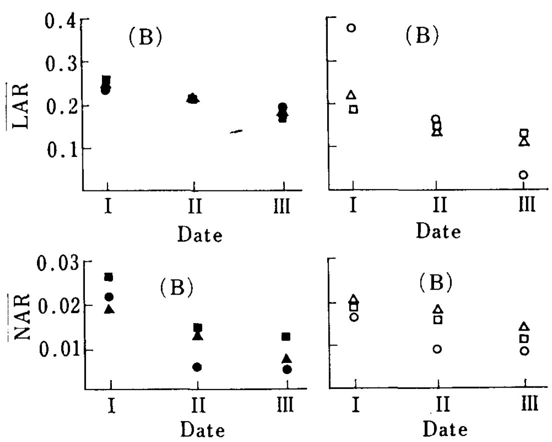

Fig. 4. Changes in $\overline{LAR}$ and $\overline{NAR}$.
I: Jul. 5~Jul. 20, II: Jul. 20~Jul. 30, III: Jul. 30~Aug. 13.
Simbols in figure are the same as shown in Fig. 1.

The growth was advanced in the con-

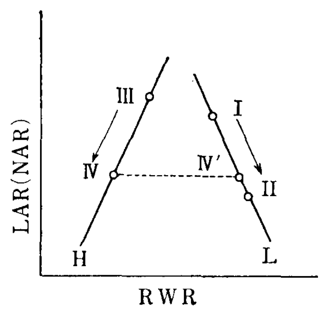

Fig. 5. Relations between RWR and LAR (NAR).
H and L are 50 ppm-N and 10 ppm-N nutrient level, respectively.

dition of 50 ppm-N nutrient level from the point III to the point IV. In this period, the RWR's, NAR's, LAR's would be decreased. Then, if the nutrient level would be decreased (10 ppm-N) at the point IV, the RWR's would be increased, and the point IV would be able to shift to the point IV′ on the 10 ppm nutrient regression line. It was considered that the time to change the nutrient level would be variable by the differences of the plant species, soil conditions, cultural season, of course.

In the previous report[11], we made clear that when the nutrient level was changed in the course of the growth period, the top-root relationship was changed elastically parallel with the change in nutrient level. It was considered that the physiological activity in roots would be kept high during the long period of growth stage, and the top-root balance would be kept suitably by making this artificial repetition at the nutrient level, so that the plant would be grown normally. We recognized that this model might be expressed the cultivation technique carried out experimentally and theoretically.

Above mentioned facts were seemed to be very important and interesting phenomenon to think over the cultural management of growing crops.

The hypothesis on the top-root relationship introduced by DAVIDSON[2] and developed by HUNT and BURNETT[6] and THORNLEY[17] have given us a clue for further approach to the better understanding of a plant growth. The method of root growth analysis proposed in the previous paper[10] have incorporated the physiological activity and top-root relationship as the growth parameters in its procedure. The root growth analysis, as a matter of course, will not a method to be confronted with the former growth analysis. It was recognized that the derivatives composed the root growth analysis and the growth analysis were interdependent mutuality in substance. We want to examine in the various nutrient levels, and discuss about the problems, in the future.

Summary

The cultivars of Italian ryegrass, *Lolium multiflorum* Lam, were used for the experimental materials. As the treatments, two nutrient levels and three planting densities, were employed in the experiments. We discussed the competition among individual plants with special reference to the functional relationship of the derivatives that compose the equation of the root growth analysis to the growth functions commonly used in the so-called growth analysis.

The positive correlations were observed between $\overline{\mathrm{URA}}$ and $\overline{\mathrm{LAR}}$ (Fig. 1), and between $\overline{\mathrm{URA}}$ and $\overline{\mathrm{NAR}}$. There were the positivie correlations in the 50 ppm-N nutrient level, and negative correlations in the 10 ppm-N nutrient level, between $\overline{\mathrm{RWR}}$ and $\overline{\mathrm{LAR}}$, between $\overline{\mathrm{RWR}}$ and $\overline{\mathrm{NAR}}$. It was considered that the derivatives composed the root growth analysis and the growth analysis were interdependent mutuality in substance. These relationships were showed as a model (Fig. 5) in the lump, and we discussed in relation to the cultivation technique carried out experimentally. It will be necessary to examine and discuss about the problems in the conditions of many nutrient levels, in the future.

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* In Japanese with English Summary

〔和 文 摘 要〕

Root Growth Analysis と Growth Analysis の関連性—イタリアン・ライグラス（*Lolium multiflorum* Lam.）の場合—

鯨 幸 夫・神 田 巳季男
（東北大学・農学研究所）

前報では，地下部生理活性の指標の一つとして，根の α-NA 酸化力を定量し，かつ，乾物生産の分配率をも考慮した形で，個体の生長を解析するという考え方を提起し，Root Growth Analysis と呼んだ．この中で，Root Activity/Rw を URA (Unit Root Activity), Rw/Pw を RWR (Root Weight Ratio), (1/Root activity)·(dPw/dt) を RAR (Root assimilation Rate) と定義した．（ここで，Root activity とは，α-NA 酸化量・hr^{-1}・個体$^{-1}$ のことである．）

今回は，これらの各要素と，生長解析法の要素である LAR, NAR との相関関係を調べ，かつ，栽培上の施肥技術との関係についても，若干の検討を加えた．$\overline{URA}$ と $\overline{LAR}$ (Fig. 1) との間には，正の相関関係が認められ，$\overline{URA}$ と $\overline{NAR}$ との間にも同様の関係が認められた．根の生理活性 (URA) は，地上部の光合成器官の生長と密接な関係があることが考察された．$\overline{RWR}$ と $\overline{LAR}$ (Fig. 2), $\overline{RWR}$ と $\overline{NAR}$ (Fig. 3) の関係は，培地 NO_3-N 50 ppm 区では正の相関関係が，培地 10 ppm 区では，負の相関関係が認められた．培地養分条件の違いによる，この相関関係の違いは，作物栽培上の施肥量，施肥時期などの問題とも関係があるものと考えられる．しかし，Root Growth Analysis と Growth Analysis との関連性，それに，栽培技術との関係を明確にするためには，未だ資料が不足しており，今後，種々の材料，多くの培地条件での実験によって検討を加えていきたい．