バレイショの根の乾物重,形態,長さおよび活力におよぼす施肥量の影響

誌名	日本作物學會紀事
ISSN	00111848
巻/号	574
掲載ページ	p. 759-764
発行年月	1988年12月

Japan. Jour. Crop Sci. 57(4) : 759—764 (1988)

The Effects of Fertilizer Rates on Dry Weight, Morphology, Length and Activity in Potato Root*

Kazuto IWAMA
(*Faculty of Education, Mie University, Kamihama 1515, Tsu 514, Japan*)
Received April 25, 1988

Abstract : Knowledge of the fertilizer effect on the roots of potato plants is surprisingly limited and not definitive. In order to obtain more detailed information, root dry weight (DW), root length, root morphology and root activity were investigated under field conditions at different fertilizer rates (0, 75, 150 and 300 kg/ha in each component of N, P_2O_5 and K_2O). The roots were sampled 28 days and 56 days after sprouting with a monolith of 5 cm in width, 30 cm in length and 30 cm in depth. Root activity was identified by root respiration rate per unit root length (ULRR).

The ratios of lateral root length to total (nodal+lateral) root length and of root length to root DW were relatively constant regardless of the fertilizer rates. The root length showed similar changes such as root DW, depending on the fertilizer rates. The increases of root DW and root length were suspended and the decay of the roots started earlier at the lower fertilized plot. In addition, ULRR increased significantly with the increase of the fertilizer rates at both sampling times. Its differences were much larger at 56 Days. These results suggested that an increase of the fertilizer rates would result in the increased nutrient absorption ability of the roots especially after the initial flowering stage, depending mostly on the differences in root activity per unit root mass.
Key words : Fertilizer rates, Potato, Root activity, Root dry weight, Root length, Root morphology.

バレイショの根の乾物重，形態，長さおよび活力におよぼす施肥量の影響：岩間和人（三重大学教育学部）

要　旨：施肥量がバレイショの根の生長におよぼす影響についての研究はきわめて少なく，またその結果が一致していない．そこで，施肥量の異なる（窒素，リン酸，加里のそれぞれについて 0，75，150 および 300 kg/ha）圃場条件下で，根乾物重（根重），根長，分枝根長/根長比（分枝根長比），根長/根重比および根長当り根呼吸速度を，萌芽後 28 日目と 56 日目に調査した．根の採取は鉄製のモノリス枠（幅 5 cm，長さ 30 cm，深さ 30 cm）を用いて行ない，根呼吸速度は前報[3]と同様の手法で調査した．

分枝根長比および根長/根重比に対する処理の影響は概して小さかった（第 3 表，第 2 図）．このため，根重と根長の処理に対する反応はほぼ類似し，施肥量が少ないと根重および根長の増加が抑制され，また根の枯死が早まった（第 2 表，第 4 表）．さらに，根長当り根呼吸速度にも処理間で有意な差異が認められた．両調査時期とも多肥区ほど高い値を示したが，特に 56 日目でその差異が顕著であった（第 5 表）．以上のことから，施肥量の増加にともない根の養分吸収能力が増加すること，これは開花始め以前では主として根量の差異に，またこれ以降では主として単位根量当りの根活力の差異に起因することが示唆された（第 3 図）．
キーワード：根長，施肥量，根活力，根乾物重，根形態，バレイショ．

For systematic management of potato growth, it is very important to clarify the response of the plant to the fertilizer applications. However, knowledge of the roots which directly promote nutrient absorption is surprisingly limited and not definitive. Asfary et al[1]. reported that fertilizer N (0 and 150 kg/ha) had no effect on the root length in their 2-year field experiments. On the other hand, Sommerfeldt and Knutson[10] reported that the root dry weight (DW) increased at intermediate rates (67—135 kg/ha of N) in a pot experiment. In our previous experiment[5], the root DW was the largest at the highest rate (240 kg/ha of N, 360 kg/ha of P_2O_5 and 240 kg/ha of K_2O) under the field conditions with 3 varieties.

One purpose of the present experiment was to confirm our previous results. Another aim was to attain a better understanding of fertilizer effects on the roots ; i.e. the root morphology and the root activity. For these purposes, root DW, root length, ratios of lateral root length to total (nodal+lateral) root length and of root length to root DW, as well as root respiration rate were investigated. The experiments were conducted under the field conditions where fertilizers were applied at four different rates.

* The outline of this paper was presented at the 186th meeting of the Crop Science Society of Japan, October 1988.

Materials and Method

The experiment was done in 1987 at the Institute for Experimental Farming, Faculty of Agriculture, Mie University (Tsu city ; 35°N, 136°E). Four varieties (early maturity ; Dansyakuimo and Hatsufubuki, late maturity ; Norin No. 1 and Konafubuki) were used. Their certified seed tubers (about 100—150 g per piece) were bisected, chitted for a month and planted on March 7 at four fertilizer rates (0, 75, 150 and 300 kg/ha in each component of N, P_2O_5 and K_2O). Fertilizers were applied one day before planting 10 cm beneath the soil surface and within a 20 cm wide stripe of the row. Seed tubers were planted 5 cm beneath the soil surface. Mulching of polyvinyl chloride sheet was done just after planting.

A split-plot randomized block with two replications was used. Each main plot for the fertilizer treatments consisted of one row of 75 cm width and 13.5 m length, which was divided into four subplots to test the four varieties. Each subplot consisted of 15 hills with 22 cm in hill distance. The main plots were arranged in the order of the fertilizer rates so as to minimize the plant competition between the differing fertilizer treatments.

The experimental site was prepared 2 years before specifically for the root investigations. The original soil of clay loam was excavated and changed to sandy loam which contained less amount of plant residues, to a 60 cm depth. The potato cultivation had been done for three seasons before the present experiment was undertaken. In these experiments, the roots could not extend below 60 cm where a hard soil pan existed ; more than 90% of the roots concentrated within the depth of 0- to 30- cm.

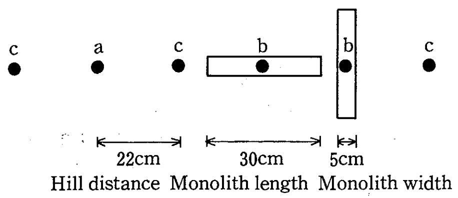

Fig. 1. Sampling portions of the monolith in a row at each plot.
Note. ●; Center of a hill.
a ; Sample hill for root respiration rate measurement,
b ; Sample hill for root monolith excavation,
c ; Border hill.

The 70% sprouting stage was reached between April 4 and 10, depending on the varieties. Bud pickings were done on April 15 to adjust into 2 stems per hill. Root samplings were done 2 times ; i.e. during May 1—8, just before the initial flowering stage, and during May 29 — June 5. The number of days after sprouting (Days) averaged over four varieties were 28 Days at the first sampling and 56 Days at the second. At each sampling, as shown in Fig. 1, one hill was excavated to measure the root respiration rate using the same procedure described in the previous report[3]. From the adjacent hills, two soil monoliths (5 cm in width, 30 cm in length and 30 cm in depth per each monolith) were sampled to observe root morphology and to measure the amount of roots. Each monolith was divided into 2 sections (0—15 cm and 15—30 cm), put into vinyl bags and stored at 5°C until processing. The roots were washed with an apparatus devised by the author to remove soil and other plant residues, collected on a wire sieve (0.7 mm mesh opening), and stored in a 5:5:90 mixture of formalin, acetic acid and alcohol (FAA) to prevent degradation. Their length was measured by the method described by Tennant[11], and the weight was determined after being ovendried at 80°C for 48 hrs. Although the root weight ovendried after FAA-fixation was about 10% lesser than those ovendried immediately after washing in the previous test, it was described simply as the root DW in this report.

Analyses of variance were performed on the root characters measured. Since the interactions between the fertilizer rates and the varieties were not significant at 5% level in their characters, the average values of the four varieties were used to interpret the fertilizer effects.

Meteorological data during the months from the planting to the harvest (June 15) recorded at the Institute for Experimental Farming, Faculty of Agriculture, Mie University, were listed in Table 1.

Results and Discussion

1. *The root DW*

The effect of the fertilizer rates on the root

DW is shown in Table 2. During the growth until 28 Days, the root DW increase was significantly depressed at the unfertilized plot. The differences among the other plots were, however, small and not significant. During the growth from 28 Days to 56 Days, the root DW decreased at the unfertilized and the low-fertilized plots, while increased at the higher fertilized plots. As a result, the differences in the root DW became apparent not only between the unfertilized plot and the fertilized plots but also among the fertilized plots at 56 Days.

These results indicate that nutritional deficiency in the soil will depress the root DW increase. The amount of nutrients stored in the seed tuber seemed insufficient for the early root DW increase. However, a relatively small amount of fertilizer application, less than 75 kg/ha of each N, P_2O_5 and K_2O in the present soil, will be sufficient to increase the normal root DW before the initial flowering stage. Thereafter, however, the higher fertilizer rate will be needed to maintain the root DW increase. At a lower fertilizer rate, earlier suspension of the root DW increase will occur and root decay will start earlier.

The present results agree well with our previous results[5]. It may be noted, however, that the root DW differences relating to the fertilizer rates were relatively small compared with those relating to the varieties and the year and cropping seasons reported by the authors[3,4]. It may be due to the facts that these factors affect the root DW increase during the period before the initial flowering stage, when the root DW increase is the largest, while the fertilizer rates mainly affect the root DW increase thereafter.

When the effect of the fertilizer rates on the root DW was compared between different soil depths (Table 2), the effect was greater in the depth of 0- to 15- cm of both sample times. The differences in the depth of 15- to 30- cm were relatively small and not significant. Since the fertilizers were applied in the depth of 10 cm, the present results indicate that the root DW differences due to differing fertilizer rates would occur especially within the portion where the fertilizers were applied. This agrees with the early observation by Weaver[13]. At the depth of 15- to 30- cm of the most heavily fertilized plot, root DW increased during the period from 28 Days to 56 Days. This indicates a movement of the fertilizers from the area of application to deeper soil as a result of leachings of rainfall.

Sommerfeldt and Knutson[10] reported the inhibition of the root DW increase at the high fertilizer rate (269 kg/ha of N) in a pot experiment. The present data, however, clearly showed that there was no inhibition of the root DW increase at the highest rate (300 kg/ha of each N, P_2O_5 and K_2O). It may be due to the facts that the experiment was conducted under the field conditions with adequate rainfall and that the fertilizers were applied within the relatively wide stripe.

Table 1. Daily solar radiation (cal/cm²/day), precipitation (mm), and daily maximum and minimum temperature (°C) during the months from the planting to the harvesting.

Month	Solar radiation	Precipitation	Temperature	
			Max.	Min.
March	221	146	11.5	3.5
April	348	72	17.6	8.0
May	342	155	22.2	13.0
June	390	120	26.8	17.9

Table 2. Effect of fertilizer rates on root dry weight (g/m²) at 2 sample times.

Fertilizer rates[1)]	28 days after sprouting Soil depth (cm)			56 days after sprouting Soil depth (cm)		
	0—15	15—30	0—30	0—15	15—30	0—30
0	9.87 a[2)]	5.84 a	15.71 a	8.48 a	5.10 a	13.58 a
75	15.21 b	6.54 a	21.75 b	13.21 b	5.32 a	18.53 b
150	14.77 b	6.03 a	20.80 b	15.38 b	5.74 a	21.12 bc
300	14.95 b	6.47 a	21.42 b	15.08 b	7.83 a	22.92 c

1) Fertilizer rates (kg/ha, each of N, P_2O_5 and K_2O).
2) Values followed by the same letter are not significantly different at 5% level (Duncan's Multiple Range Test).

2. *The root morphology and the root length*

To clarify the effect of the fertilizer rates on a root morphology, the length of the nodal roots and the lateral roots was separately measured. The identification of the lateral roots or the nodal roots was made by eye. In the previous experiment[2] using two late varieties, the mean diameters of the nodal and lateral roots measured during the tuber bulking period were 1.036 mm (SD=0.360 mm) and 0.276 mm (SD=0.086 mm), respectively. It indicated that the differences in thickness between the nodal roots and the lateral roots were relatively clear. As shown in Table 3, the ratio of the lateral root length to the total root length (lateral root ratio) differed between the depth of 0- to 15- cm and 15- to 30- cm. It was lower in the surface layer. On the other hand, it showed similar values regardless of the fertilizer rates within each depth with the exception of the unfertilized plot at 28 Days, where the ratio was significantly lower compared with the others. These results indicate that the effect of the fertilizer rates on the lateral root ratio is rather small. The extension or the decay of the nodal roots seemed to be parallel to those of the lateral roots.

The ratio of the root length to the root DW (root length ratio) coincided with the lateral root ratio, as shown in Fig. 2. Changes in the root length ratio caused by the fertilizer rates were relatively small. As a result, the similar changes in the root length relating to the fertilizer rates as those in the root DW were observed (Table 4.) Asfary et al.[1] reported no effect of N fertilizer on the potato root length. The present results, however, clearly showed that the root length was significantly smaller in the unfertilized plot compared with the fertilized plots at 28 Days. In addition, it was larger at the higher fertilized plot at 56 Days. Asfary's result seems to be due to insufficient root recovery. In their data the root length was constant during the period from 2 weeks after sprouting until the harvest. The observations of Lesczynski and Tanner[9], and the authors[6], however, indicated that the potato root length increased at least until the initial flowering stage.

3. *The root activity*

The effect of the different fertilizer rates on the root respiration rate per unit root length (ULRR) is shown in Table 5. ULRR in-

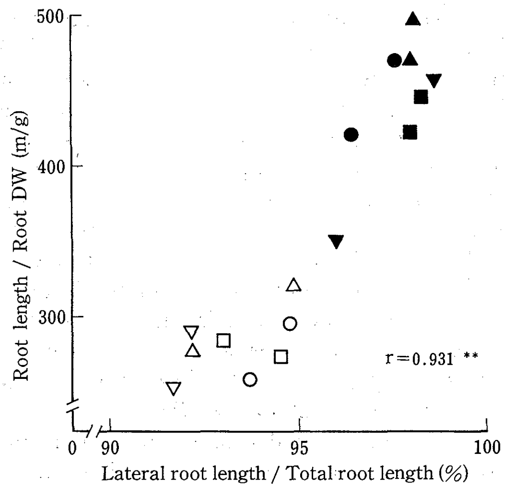

Fig. 2. Relationship between the ratios of lateral root length to total (nodal+lateral) root length, and root length to root dry weight in the depths of 0- to 15- cm and 15- to 30- cm at 2 sample times.
Note: Fertilizer rates (kg/ha, each of N, P_2O_5 and K_2O) ; ▽▼ ; 0, △▲ ; 75, ○● ; 150, □■ ; 300. The open and closed symbols indicate the depths of 0- to 15- cm and 15- to 30- cm, respectively.

Table 3. Effect of fertillizer rates on the ratio of lateral root length to total (nodal+lateral) root length (%) at 2 sample times.

Fertilizer rates[1]	28 days after sprouting Soil depth (cm)			56 days after sprouting Soil depth (cm)		
	0—15	15—30	0—30	0—15	15—30	0—30
0	91.7 a[1]	96.0 a	93.5 a	92.2 a	98.6 a	95.4 a
75	94.9 b	98.0 a	96.2 b	92.2 a	98.1 b	94.7 a
150	94.8 b	96.4 a	95.4 b	93.7 a	97.6 c	95.2 a
300	94.5 b	98.0 a	95.9 b	93.0 a	98.3 ab	95.5 a

1) The meanings of the numbers and the letters are the same as those shown in Table 2.

Table 4. Effect of fertilizer rates on root length (km/m^2) at 2 sample times.

Fertilizer rates[1)]	28 days after sprouting Soil depth (cm)			56 days after sprouting Soil depth (cm)		
	0—15	15—30	0—30	0—15	15—30	0—30
0	2.47 a[1)]	1.95 a	4.42 a	2.45 a	2.36 a	4.81 a
75	4.88 c	3.08 a	7.96 b	3.62 b	2.60 a	6.22 b
150	4.34 bc	2.47 a	6.81 b	3.83 b	2.66 ab	6.49 bc
300	4.11 b	2.83 a	6.93 b	4.19 b	3.50 b	7.68 c

1) The meanings of the numbers and the letters are the same as those shown in Table 2.

creased significantly with the increase of the fertilizer rate at both sampling times. However, the differences among the treatments were much larger at 56 Days. It resulted from the smaller reduction of ULRR after 28 Days in the higher fertilized plot. These results agree well with those reported by Lee and Ota[8)], where the retardation of the rice root activity by N deficiency was relatively small before the reduction division stage, thereafter it became clear. Kishitani and Shibles[7)] pointed out that the reduction of the root respiration rate per unit root DW as regards overall plant progress would be due to the reduction of the percentage of the new roots. In the present experiment the new root growth continued until the later stage in the higher fertilized plot. Tsuno and Yamaguchi[12)] indicated that the root respiration rate per unit root DW related well with the nitrogen content in the roots. It may be considered, therefore, that the soil nutrient deficiency progressed after the initial flowering stage in the lower fertilized plot restricted new root growth, and probably decreased severely the nitrogen content in the roots, resulting in the larger reduction of ULRR.

Since the ability of the roots to absorb soil nutrients is considered to depend on both the amount of the roots and their root activity per unit root mass, the total root respiration rate per unit soil area (TRR) can be calculated from the values of ULRR and the root length. Comparing the effects of the fertilizer rates on TRR, ULRR and the root length (Fig. 3), the fertilizer effect on the root length was much greater than that on ULRR at 28 Days. Thus, the differences in TRR among the fertilizer rates depended mainly on those in the root length. At 56 Days, however, since the fertilizer effect on ULRR increased, the differences in TRR among the fertilizer rates became

Table 5. Effect of fertilizer rates on root respiration rate per unit root length ($mgO_2/km/h$) at 2 sample times.

Fertilizer rates[1)]	Days after sprouting 28	56
0	3.23 a[1)]	1.22 a
75	3.35 a	1.97 b
150	3.72 b	2.37 c
300	3.92 c	2.69 d

1) The meanings of the numbers and the letters are the same as those shown in Table 2.

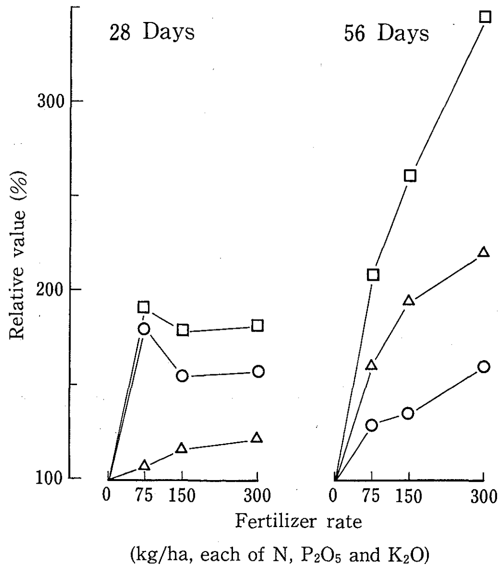

Fig. 3. Relative values of root length, root respiration rate per unit root length (ULRR) and total root respiration rate per unit soil area (TRR) at different fertilizer rates on the basis of the values at unfertililzed plot.

Note. ○ ; root length, △ ; ULRR, □ ; TRR.

much larger. It depended more largely on those in ULRR than those in the root length.

The present results lead to the conclusion that the fertilizer rates affect the amount of the roots, but the effect is relatively small. However, the root activity per unit root mass is also affected by the fertilizer rates especially after the initial flowering stage. As a result, it is suggested that there will be large differences in the nutrient absorption ability of the roots during the tuber bulking period as regards the fertilizer rates, depending mostly on the differences in the root activity per unit root mass.

Acknowledgements

I wish to express my gratitude to Dr. Y. Kono of Nagoya University and Dr. S. Tachibana of Mie University for their valuable advice, and also to Mr. H. Nakano of Mie University for his technical support. I would like to thank to Mr. M. Uchiyama and Mr. K. Yamashita for their helps with data collection. The seed tubers were kindly supplied from the Hokkaido National Agricultural Experiment Station.

References

1. Asfary, A. F., A. Wild and P. M. Harris 1983. Growth, mineral nutrition and water use by potato crops. J. Agric. Sci. (Camb.) 100 : 87—101.
2. Iwama, K. 1981. Studies on the root system in potato plants. Dr. Thesis, Hokkaido University. 7—24.
3. ——— 1988. Difference in root growth of potato plants among years and cropping seasons. Japan. J. Crop Sci. 57 : 346—354.
4. ———, K. Nakaseko, K. Gotoh, S. Nishibe and Y. Umemura 1979. Varietal differences in root system and its relationship with shoot development and tuber yield. Japan. J. Crop Sci. 48 : 403—408*.
5. ———, ———, ——— and ——— 1981. Responses of potato root systems to levels of fertilizer and shading treatment. Mem. of Fac. Agric. Hokkaido Univ. 12 : 176—182*.
6. ———, Y. Kusu, K. Nakaseko, K. Gotoh and S. Nishibe 1983. Root distribution pattern in potato plants. Potato Sci. 3 : 57—64*.
7. Kishitani, S. and R. Shibles 1986. Respiration rates of soybean cultivars. Crop Sci. 26 : 580—583.
8. Lee, J. H. and Y. Ota 1971. The role of root system of rice plant in relation to the physiological and morphological characteristics of aerial parts. V. The effects of nitrogen level and placing position of the fertilizer on the characteristics of root and aerial parts. Proc. Crop. Sci. Soc. Japan 40 : 217—222*.
9. Lesczynski, D. B. and C. B. Tanner 1976. Seasonal variation of root distribution of irrigated, field-grown Russet Burbank potatoes. Am. Potato J. 53 : 69—78.
10. Sommerfeldt, T. G. and K. W. Knutson 1968. Greenhouse study of early potato growth response to soil temperature, bulk density and nitrogen fertilizer. Am. Potato J. 45 : 231—237.
11. Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63 : 995—1001.
12. Tsuno, Y. and T. Yamaguchi 1987. Relationships between respiratory rate of root and temperature modulated photosynthesis in rice plant and the factors concerning the respiratory rate of root. Japan. J. Crop Sci. 56 : 536—546*.
13. Weaver, J.E. 1926. Root Development of Field Crops. McGraw-Hill Book Compaoy, New York. 240—246.

* In Japanese with English summary.