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土壌水分特性及び様々な程度の土壌水分ストレスに対するナスの根系生育パターン及び水分吸収率

Root Growth Pattern and Water Extraction Rate of Eggplant as Affected by Soil Moisture Characteristics and Different Levels of Soil Moisture Stress

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Introduction

The soil, the plant and the atmosphere are all components of a physically verified dynamic system in which various flow processes occur interdependently like a links in a chain. In this system soil water tends to move from soil mass to the root surfaces, then through the plant in the atmosphere, along the gradient of decreasing water potential (Oswal, 1996). The rate of flow is determined by the magnitude of the potential gradient and the resistance to water movement in the continuum. Water potential is highest in the soil, and decreases along the transpiration path.

Water extraction by the plant root is a dynamically changing process. These dynamic patterns of soil water extraction infer the interaction between rooting characteristics and hydraulic properties of soil. The nature of this interaction and relative importance of root factors and soil characteristics are still not well explained. Gardner (1964) suggested that water extraction pattern is mostly sensitive to relative root distribution as well as soil hydraulic properties. Root growth of plant is chiefly affected by soil factors like hydraulic properties, soil moisture content, as well as some other environmental factors. Soil moisture content directly affects root growth. Deficiency of soil moisture content usually brings about a reduction in or cessation of root growth, and little or no root growth occurs in dry soil. This inhibits water and mineral absorption. Eggplant is a higher water consumptive vegetable. It requires a lot of water for higher production. So, the soil moisture stress on eggplant can restrict the productivity not just in those areas classified as arid or semiarid, but in any area in which the evaporative demand greatly exceeds rainfall during the growing period. Some attempts to relate roots and moisture characteristics parameters in water uptake (Gardner, 1964; Nimah and Hanks, 1973a and b; Hasegawa and Yoshida, 1982; van Bavel et. al., 1984) have been made. But theoretical prediction often does not agree with experimental results. Therefore, detailed measurements of soils and root parameters in the field experiments are necessary for a better understanding of the various factors and for improving analysis of the root-soil flow system. So, it is necessary to formulate a comprehensive method that can predict the rate and distribution of soil moisture extraction by eggplant roots, while the soil water reserves in the root zone are depleting.

Objectives:

To optimize the management and utilization of soil moisture, more detailed knowledge is necessary. So, the aim of this study is -

1. To know the root growth pattern of eggplant at different soil moisture stress and recovery,
2. To know the extraction rate as affected by soil moisture characteristics and root factors of the plant.
3. To test the sensitivity of the simulated root water absorption model *HM2001* using field data.

Model Selection:

For measuring water extraction rate of eggplant at different stress levels, a mathematical model (HM2001) developed by Hara and Miyamoto (2001) has been selected. According to the model, ***Qmax*** is the water extraction rate at infinite power while ***Q*** is the actual water extraction rate i.e. ET rate. The Model (HM2001) is as follows

$$Q\max = 2*\pi*L*F2(v)*g(Ks,m,\alpha)*\frac{1}{|h(c)|^\wedge\frac{3m+2}{2(1-m)}}$$

Where L is the root length in cm, and

$$F2(a,b) = \frac{b^2-a^2}{b^2*Ln\frac{c}{a}-\frac{c^2-a^2}{2}},$$

$$p=\frac{b}{a},$$

$$v=\frac{1}{p^2}=\frac{\pi*a^2*L}{\pi*b^2*L}=RootVolumeDensity,$$

$$\frac{b}{a}=p=\frac{1}{\sqrt{v}},$$

Now

$$F2(v)=\frac{1-v}{Ln(\frac{1+\sqrt{v}}{2\sqrt{v}})-\frac{1}{2}\{(\frac{\sqrt{v}+1}{2})^2-v\}},$$

and

$$g(Ks,m,\alpha)=\frac{Ks*(1-m)*m}{(\frac{3}{2}+\frac{1}{m})*\alpha^\wedge(\frac{m+4}{2(1-m)})}$$

Where a is root radius, b is cylinder radius and c=(a+b)/2. Ks is hydraulic conductivity, h(c) is the soil water suction and m, n, and α are constants for the specific soil obtained from water retention curve where m=1-1/n.

Materials and Methods

Plant and soil culture

Pot experiments were conducted in the glasshouse at the Iwate University campus, Morioka (North-eastern Japan), during the summer 2000 using root grafted eggplant (*Solanum melongena* L. cv. *senryo ni go*). Eggplant var. *tonashimu* was used for rootstock while var. *senryo ni go* was for scion purposes. The successfully raising grafted, healthy, and uniformly vegetative growing seedling was selected for the experiment purposes. The selected seedlings of 20 to 25 cm in height were transplanted to the pot made of poly vinyl chloride. The pot was 50 cm in height and 25 cm in inner diameter in which 22.5 L volcanic ash soil was used up to 45 cm height for the eggplant growing purposes. The soil was previously well incorporated with mixed granular fertilizer of 1:1:1 for N, P, and K @ 50 g/20 L soil as maintenance dose along with 10 g lime/20 L soil. The experiments were lasted for 84 days after transplanting (DAT) in the pot.

Experimental design and moisture stress treatment array

A completely randomized design composing four treatments with three replications was followed for the both years. Thirty six pots with test plant were used for plant parameter and another 4 pots for soil parameter measurements. In both the experiments, the soil moisture stress treatment was sequenced as T0 (Control)- irrigated at pot capacity level once per week; T1 (Short-term repetitive)- irrigated at pot capacity level once per two weeks; T2 (Long-term repetitive)- irrigated at pot capacity level once per four weeks; and T3 (Prolonged severe)- no irrigation during the whole growing period up to harvest. Pot capacity condition was considered as the upper most limit for plant available soil water for this stress experiment. It is important to note that the pot was irrigated to raise its soil moisture status up to pot capacity level just replenishing the total amount of water lost by evapotranspiration after each wetting and drying cycles. The soil moisture content at pot capacity level was tested in this study on the basis of watering the pot at saturation level and then the moisture was allowed for depletion to the pot soil up to its water holding capacity level against gravitational force.

Soil water content and soil water suction measurement

The four pots with test plants applying four different treatments were used for soil water measurement with Time Domain Reflectrometry (TDR) sensor. The measurement was monitored during whole growing period at every 30 minutes interval at 15-20 cm and 30-35 cm pot soil depth. The data was collected through data logger CR10x with multiplexer AM416 (Model: Campbell Scientific Inc., USA). The soil water suction was estimated from the relationship between soil water suction and volumetric water content obtained with a pressure plate apparatus, using undisturbed core samples collected from the pot at different depths for the retention curve.

Root parameters

The roots in each pot were collected through careful washing the soils from root mass on a sieve, and finally washed with ultrasonic cleaner to remove the fine particles adsorbed with root mass. The fresh root weight was recorded just after gently blotted and subsequently its root volume was measured with water displacing method using a 500 mL measuring cylinder and a burette. The total root length was measured by Newman method (1966).

Results and Discussion

Volumetric Water Content (VWC)

Volumetric water content (cm^3 cm^{-3}) of the pot soil during entire experimental period was monitored at 15-20 cm and 30-35 cm pot soil layer with TDR sensor. The **Figure 1** showed the changing of soil moisture status with time under different soil moisture treatment. At the beginning of experiment, all the pots were maintain at similar soil moisture status As the time progress, significant variation in soil moisture content was observed at different pots due to different irrigation frequency, and evapotranspiration. The initial water content was about 0.52 cm^3 cm^{-3} but at the end of the irrigation cycle, it was around 0.20 cm^3 cm^{-3} after the end of 2nd study cycle for T0 and 0.16 cm^3 cm^{-3} for T1, T2 and T3 pot, respectively. Only slight variation in water content was observed in between two layers of 15-20 and 30-35 cm in all the pots. Reduction in water content in both layers was almost similar except for T0 and T1.

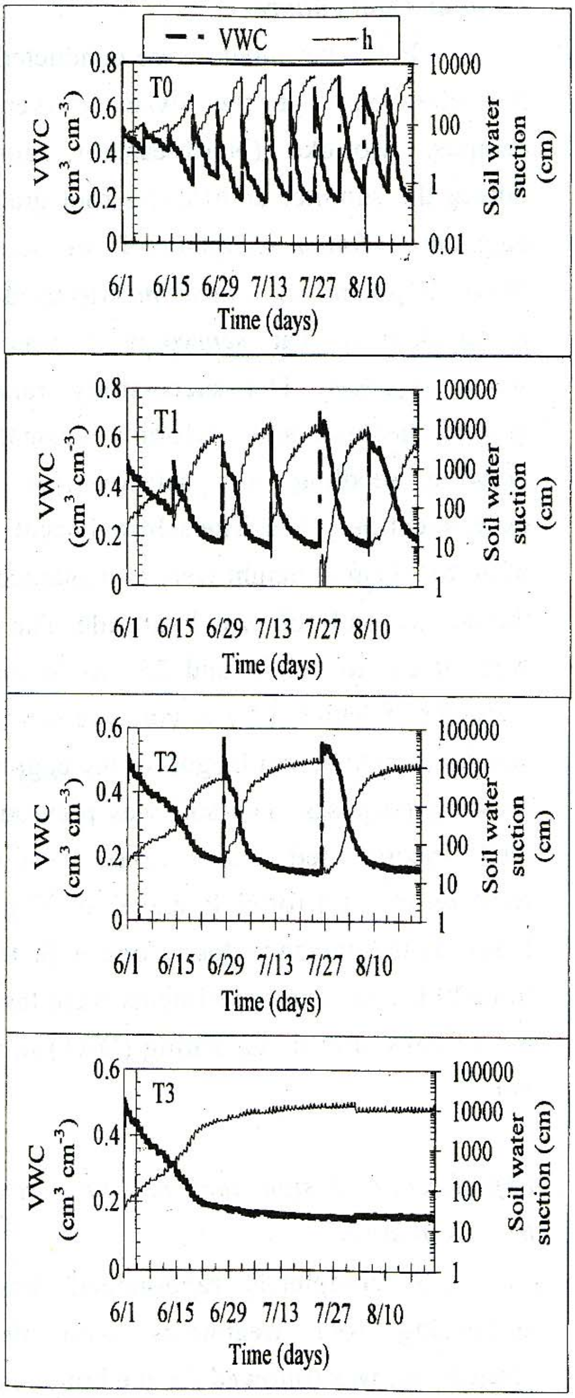


Figure 1. Volumetric water content and its corresponding soil water suction at 15 cm depth of pot under different soil moisture stress (Year-1).

Soil Water Suction

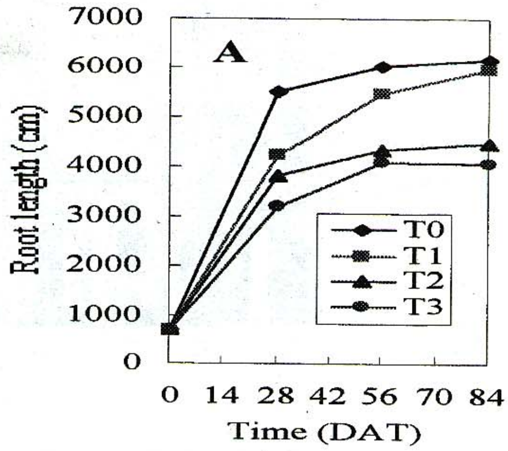
The soil water suction (cm) in pot soil under different moisture treatments was presented in **Figure 1**. The changes in soil water suction in different pot soil layers were conspicuous. Soil water suction was higher while the pot was wet and gradually decreased with decreasing soil moisture content. During study period, no significant difference in soil water suction was appeared between 15-20 cm and 30-35 cm layers. The lower value of soil water suction was observed in T3 pot which experienced with severe soil moisture stress

Root Parameters

Root Length and Root Volume

Total root length of eggplant measured at various times of experimental period under different treatment was shown in **Figure 2A**. Dramatic increase in root length was found in all plants within 28 DAT of 1st study cycle. The rate of increase in total root length was higher in the 1st study cycle and little increase was in remaining period of 84 days experiment. T0 plant produced root length very much compared with other identical stressed plants. But for T1 plant which received water two weeks interval continued to increase during its whole growing period but lower than T0. T2 and T3 plant increased its total root length but not satisfactorily during their latter period.

Root volume for Year-1 experiment was presented as 3-D bar diagram in **Figure 2B**. It distinctly reflected that soil water stress affected on root volume in the plant subjected to different levels of stress at various times of growing period.



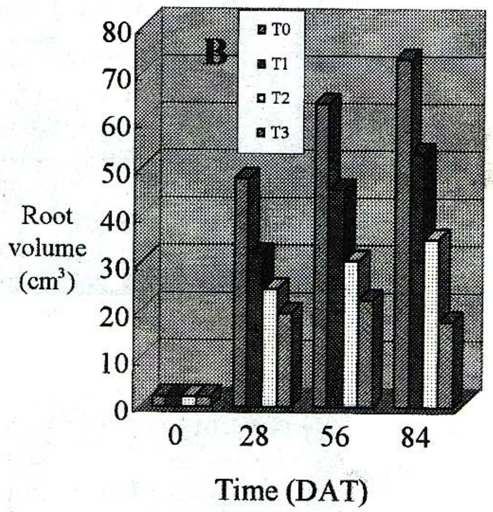


Figure 2. Root length and root volume of eggplant under different soil moisture stress.

Rooting Density

Root volume density (RVD) of 3-layer soil depth conducted in pot experiment was demonstrated in **Figure 3**. A, B and C indicate 3 layer RVD for 28, 56 and 84 DAT. The results showed that stress manifested the rooting density during various time of experimental period. The RVD of different plants varied with depth and time along with stress.

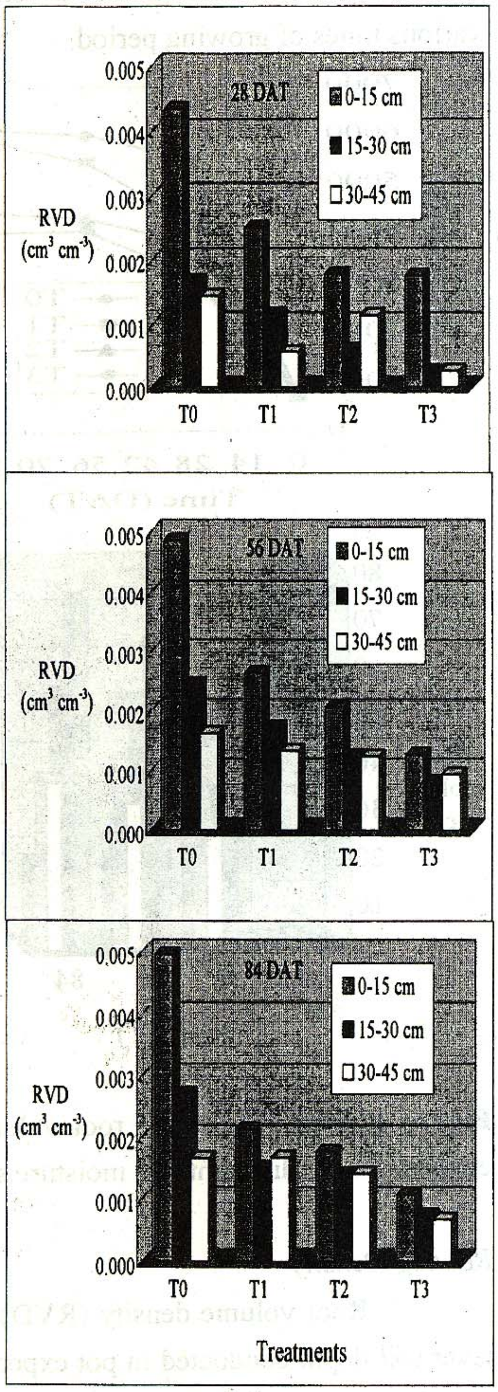


Figure 3. RVD of eggplants under different soil moisture stress.

intensity and duration. T0 plant showed highest RVD in all the layers among the plants while T3 showed the lowest.

Evapotranspiration (ET) Pattern

Relative evapotranspiration pattern in eggplant pot under varying soil moisture stress was presented in **Figure 4**. It is important to note that moisture loss due to

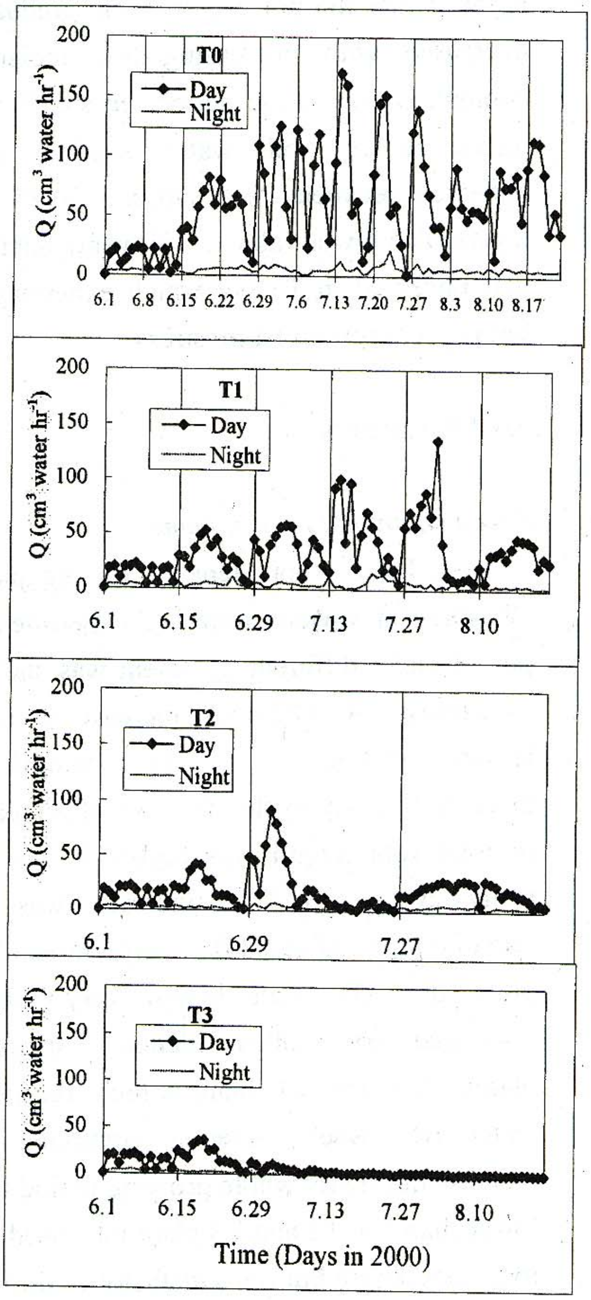


Figure 4. Evapotranspiration rate of eggplant for different soil moisture stress.

evapotranspiration was considered for actual extraction rate by plant roots i.e. Q. The result showed the relative pattern of ET rate per hour of different irrigation frequency in the respective pot. Initially soil water loss by ET was low but it increased as the time progressed. The ET rate continued to increase with the plant growth increased. But in contrast, moisture stress inhibited the ET for T1, T2 and T3 pot in comparison to T0.

Simulated Water Absorption Rate (Qmax) and Its Sensitivity Test

The simulated results of water absorption by plant roots using the model HM2001 have been presented in **Figure 5 (A, B, C, and D)** for T0, T1, T2 and T3 plant, respectively. The simulated Qmax for T0 plant was apparently very big at very high soil moisture content. The big value for Qmax was due to higher soil water content after irrigation. Initially Qmax was quite good but later its value was excessively high especially after 56 DAT. It is interesting that the model HM2001 showed good agreement during soil drying period. Qmax was mostly dependent on soil hydraulic properties like VWC, hydraulic conductivity (Ks) as well as on root factors. The simulated result for T1, and T2 plant **(Figure 5B**, and **C)** showed that the extration increased as the soil water content increased along with root factors. It also showed that Qmax decreased with decreased soil water content. In the Figure **5A, B,** and **C**, Qmax increased after adding water in the pot and began to decrease during drying period. Qmax for T3 plant that experienced severe stress showed continuous decline during drying period **(Figure 5D)**. The volumetric water content. was monitored three times a day and its corresponding Q/Qmax (ratio) was

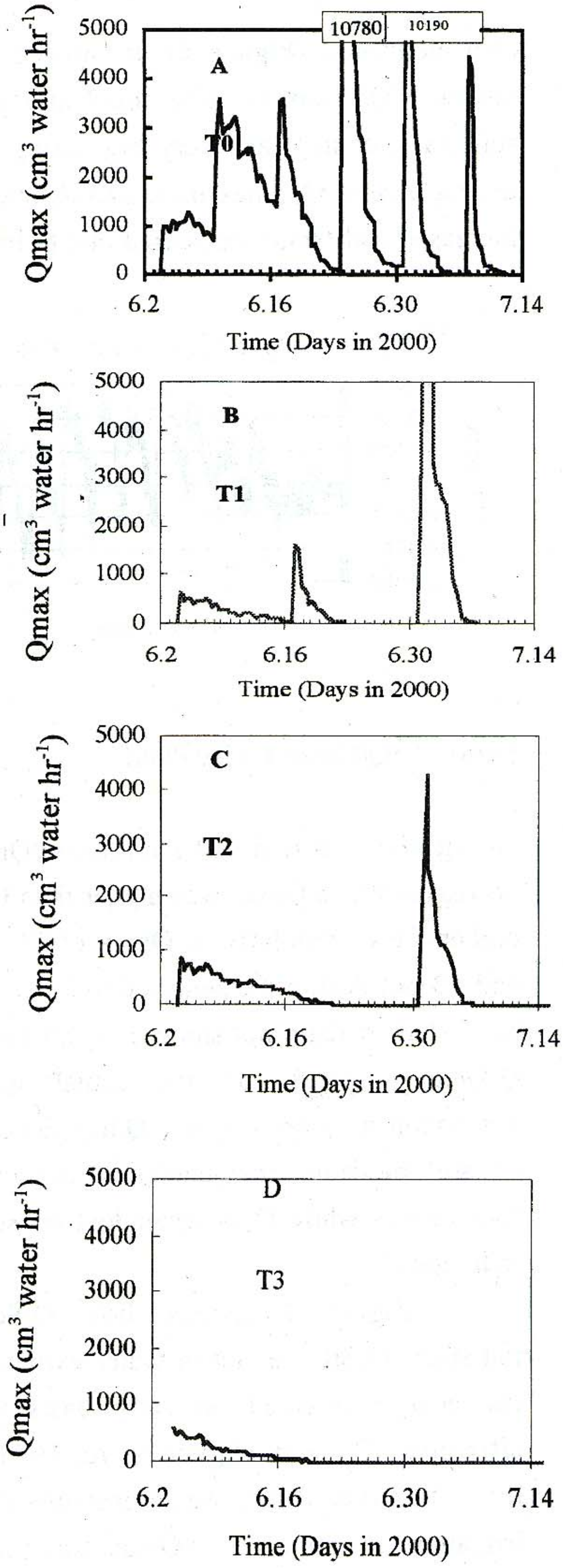


Figure 5. Simulated Qmax for eggplant under different soil moisture stress.

also monitored (**Figure 6**). It showed that the ratio Q/Qmax is quite small at higher soil water content and very big during soil drying period. Q/Qmax increased as the ET increased and Qmax decreased due to lower

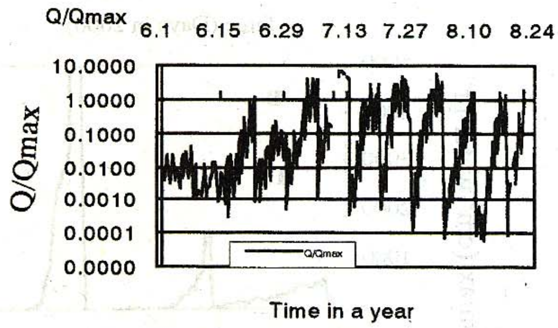


Figure 6. Q/Qmax for T0 Plant

during drying period and the ratio Q/Qmax decreased while Qmax was higher than Q at higher VWC. Similarly, Q/Qmax of T1, T2, and T3 pot during the study period has also been studied (data not shown). In all cases, Q/Qmax depends on the actual water absorption by plant (Q) and Qmax depends on soil moisture characteristics and plant root factors while Q is dependent on solar radiation.

Figure 7 showed how Q/Solar radiation (Q/SR) i.e. actual water extraction per energy received on daily basis was affected by Q/Qmax. **Figure 7A** for T0 plant, it was observed that Q was higher just after irrigation. In this time, Q/Qmax was lower and Q/Qmax began to increase while Q/SR was showed higher and almost constant. At well-watered conditions, Q/SR is chiefly dependent on solar radiation whereas Q/Qmax on Q. As the time proceeds, the Q/SR showed decreasing tendency but still Q/Qmax increased and lastly it showed flat. The flat shaped Q/Qmax is an important feature during drying period. It might be due to decreased Q in the latter period. Furthermore, the intercept point between Q/SR and Q/Qmax might be a good indicator for Q/Qmax value. As we assume that Qmax is always greater than Q. So, Q/Qmax should always be less than one (1.0). In this case, the intercept point might be an estimated indicator for the sensitivity of Q/Qmax. Similarly, **Figure 7B and 7C**

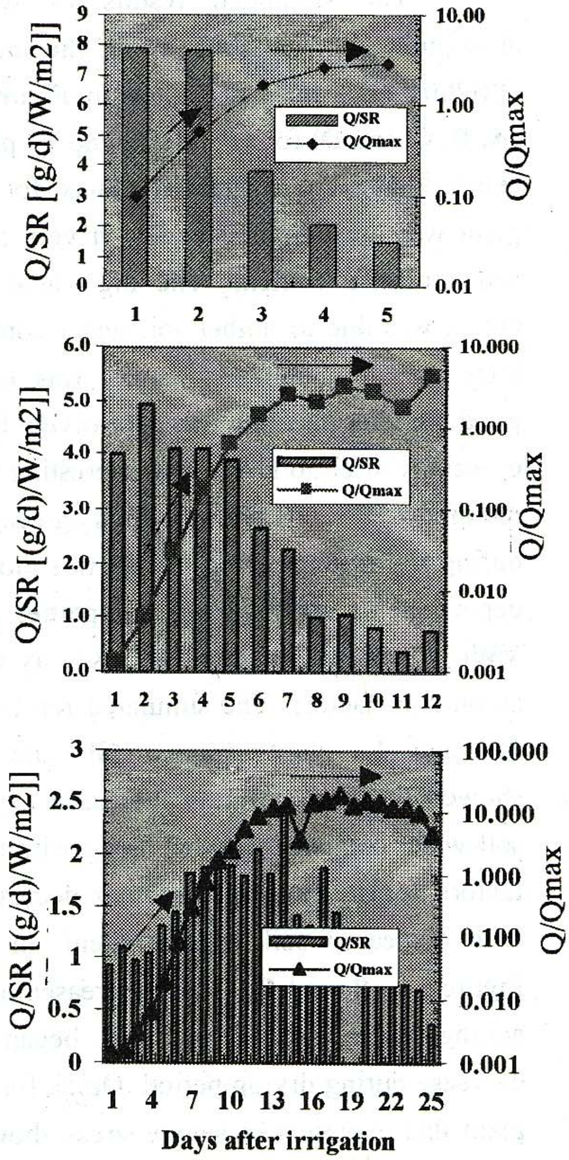


Figure 7. Relationship between Q/SR and Q/Qmax for T0, T1 and T2 plants.

showed that T1 and T2 plant also had a consistent feature between Q/SR and Q/Qmax. Increasing tendency of Q/Qmax after applying irrigation and then almost steady state during latter period was also the characteristics for T1 and T2 plant. It is important to note that in the latter drying period Q/Qmax value showed exceptionally higher than unity. It might be possibly due to some uncertain values of plant and soil parameters.

Higher ET by higher rooting density was characterized by non-stressed plants while decreased and lower ET with lower rooting density was observed in stressed plants. Water stress and plant aging reduced the growth of roots and thus reduced the ability of a root system to extract water from soils. The present findings indicated that the soil moisture stress adversely affect on the root growth and water extraction rate of eggplant. The adverse effect was highest in the severe stress followed by repetitive long-term and repetitive short-term in comparison to less-stressed plant. So, sufficient soil moisture should be maintained during vegetative and reproductive stage for securing higher yield and production.

The ratio of water extraction rates per solar energy received (Q/SR) were maintained constant at sufficient moisture and Q was sufficiently smaller than Qmax whereas Q/SR decreased day by day while Q approached near to Qmax that indicates the applicability of the model HM2001 in estimating the theoretical maximum of water extraction rate of eggplant. Therefore, it may be suggested that the developed model HM2001 may be a useful tool for studying root water extraction at variable soil moisture stress conditions although the model itself should be further revised through comparison between results of experiments and the theory.

References

Gardner, W. R. 1964. Relation of root distribution to water uptake and availability. Agron. J. **56**: 41-45.

Hara, M. and Miyamoto, K. 2001. Estimation of absorption rate of a cylindrical sink from surrounding materials which diffusivity is nonlinear on the assumption of the quasi-steady condition. SICE (Sensing Instrument Control Engineering). Tohoku-Branch Academic Meeting No. 194-13. pp 1-15.

Hasegawa, S. and Yoshida, S. 1982. Water uptake by dryland rice root system during soil drying cycle. Soil Sci. Plant Nutr. **28**: 191-204.

Nimah, M. N. and Hanks, R. J. 1973a. Model for estimating soil water, plant and atmospheric interrelations, I. Description and sensitivity. Soil Sci. Soc. Am. Proc. **37**: 522-527.

Nimah, M. N. and Hanks, R. J. 1973b. Model for estimating soil water, plant and atmospheric interrelations, II. Field test for model. Soil Sci. Soc. Am. Proc. **37**: 528-531.

Newman E, I. 1966a. A method of estimating the total length of root in a sample. J. Appl. Ecol. **3**: 139-145

Oswal, M. C. 1996. Soil Physics. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi. pp 155.

Van Bavel, C. H. M. , Lascano, R. J. and Stroosnijder, L. 1984. Test and analysis of a model of water use by sorghum. Soil Sci. **137**. 443- 456.

＜和文抄録＞

土壌水分特性及び様々な程度の土壌水分ストレスに対するナスの根系生育パターン及び水分吸収率

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ナス（穂木：千両２号、台木：トナシムの接木ナス）を直径25cm、深さ50cmのポット中の火山灰土壌（岩手大学附属滝沢農場の作土）に移植した。試料数は３反復とした。はじめ土壌を充分な湿潤状態（ポット容水量）にしたのち、灌漑間隔（T0：１週間、T1：２週間、T2：４週間、T3：無灌漑）を変えることにより４レベルの水ストレス状態を与え、12週間測定した。毎日6：00，12：00，18：00に1g単位で重量測定し，減量を蒸発散量とした。２週間ごとにポットを分解して根の形態（姿、体積、根長)、重量等を測定した。別途にTDR、熱電対、日射計により土壌水分量・温度、気温、湿度、日射量を連続測定した。土壌の保水特性、飽和透水係数を測定し、パラメータから不飽和透水係数を推定した。水ストレスレベルごとに根系生育状況の関係が得られた。一方、土壌の水分供給能力に関する原・宮本の公式HM2001により、達成可能な最大値 Q_{max}[g/s]を計算し、測定された蒸発散量 ET[g/s]との比を求めた。土壌がある程度以上湿潤で水分供給能力が大きい時には蒸発散量はほぼ日射量により規定され、土壌が乾燥して土壌の水分供給能力が小さくなると蒸発散量は土壌の水分供給能力に規定されることが示され、公式HM2001は定性的には有用であるといえる。しかし、得られた ET/Q_{max}の値は１を大きく超えることがしばしばあり、植物・土壌に関するパラメータの値及びモデルの詳細についてはさらに改善を要する。