TROPICAL AGRICULTURIST, VOL. 156, 2006 & 2007

LEAF GAS EXCHANGE CHARACTERISTICS AND LEAF AND PETIOLE NUTRIENT CONCENTRATION OF FIELD GROWING POTATO VARIETIES

H. HEMAL FONSEKA[1] AND R.M. FONSEKA[2]
[1] Horticultural Crop Research and Development Institute, Gannoruwa, Peradeniya
[2] Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

ABSTRACT

Three field grown potato varieties namely, Irish Cobbler, May Queen, and Dejima were used to measure the net photosynthetic rate (Np), transpiration rate (T), and stomatal resistant (Rs) by using a portable photosynthetic system (LI-6200 Primer, LICOR Inc. USA). The measurements were taken from the most distal leaflet of third and fourth leaves below the terminal bud of sixteen plants per each variety at three growth stages. Nitrogen (N) and potassium (K) content of leaves and petioles were also measured. The mean Np of three potato varieties aeross the three growth stages ranged from 16 to 25 µmol CO_2 m^{-2} sec^{-1}. The variety Dejima, which had a uniform vertical leaf distribution, maintained a higher Np at the vegetative and early tuber bulking stages, and a higher T value. This variety showed yield advantage of about 24% over the other two varieties. The variety May Queen gave the lowest tuber yield and showed mean Rs of 46% showing an inverse relationship with Np. The productive structure of the potato varieties showed close relationship with dry matter production. The Np, N, and K concentrations in the leaves and petioles at the early tuber bulking stage and the canopy architecture could be useful parameters in predicting the yield potential of potato.

KEY WORDS: Net Photosynthetic Rate, Nutrient Content, Potato, Stomatal resistant, Transpiration, Tuber dry matter yield

INTRODUCTION

Crop yield is a function of several physiological processes and morphological characters of the plant. Among these physiological processes photosynthesis and transpiration play a vital role in determining crop productivity and are regulated mainly through stomatal conductance (Wallace et al., 1972; Sun-Ben Ku et al.,

1977; Dwelle et al., 1981). Nutrient status of leaf tissues, especially nitrogen and potassium is closely associated with transpiration and stomatal conductance and has greater effect in determining the photosynthetic rate (Zelitch, 1969; Argen, 1985; Barton, 1989) and plant productivity.

The yield differences observed among potato (*Solanum tuberosum*) varieties may, therefore, be related to the variations in photosynthetic rates, transpiration rates, stomatal resistance and nutrient status of the leaves. However, studies carried out to examine the relationship between final tuber yield of potato and the aforesaid physiological processes involved in the yield forming process, have been limited to the warm climates under field grown conditions (Chapman and Loomis, 1952 ; Cieply, 1976; Dwelle et al., 1981). Furthermore, such studies carried out on other field crops such as rice, soybean, wheat and cassava have produced contradicting results. Cieply (1976) concluded that the photosynthetic rate could be utilized as a physiological criterion in predicting higher yield while Dwelle et al. (1981) reported of high seasonal variabilities in the correlations between tuber yield and diffusive resistance, stomatal conductance, and photosynthesis, and concluded that those measurements appear to have limited value. The inconclusive nature of the previous studies and the scarcity of information on the subject warrant further investigations. Therefore, the present study was carried out to analyze the yield variation in terms of photosynthetic, transpiration, stomatal resistance, and nitrogen and potassium status of leaves and petioles and to evaluate the inter-relationship between these parameters among different potato genotypes.

MATERIALS AND METHODS

Three potato (*Solanum tuberosum*) varieties namely, Irish Cobbler, May Queen, and Dejima, were planted in an experimental field of the Faculty of the Agriculture, Kagawa University, Japan, in March 1993. Seed tubers were cut into pieces of 30-50 g each and planted on ridges at a spacing of 66 cm x 30 cm and fertilized at the rate of 101 kg N, 212 kg P_2O_5 and 98 kg K_2O per ha. The net photosynthetic rate (Np), transpiration rate (T) and stomatal resistance (Rs) of the

distal leaflet of the third and forth leaves below the terminal bud were measured in sixteen plants per variety (32 measurement in total) at 22 (early vegetative growth), 40 (early tuber bulking stage), and 49 (tuber bulking stage) days after emergence (DAE) using a portable photosynthesis system (LI- 6200 Primer, LI-COR Inc. USA). At 30 DAE, the per cent light distribution at different heights of the canopy was measured using a Relative Community Illuminometer (NS-II, Sanshine Co., Japan). The above ground plant parts were sampled at the same height and dry weights were recorded. Photosynthesis and light measurements were made between 10.00 am and 12.00 noon. In addition, at each sampling, tuber dry matter yield (Yd) was also recorded. Recently matured leaves including the 3rd and 4th leaves were sampled, dried at 65 °C, and finely ground after recording the fresh weight and the leaf area. The nitrogen and potassium content of the samples, replicated four times, were determined using CHN Corder (Yanagi Moto Co., Japan) and flame photometry, respectively, with appropriate standards. Data were statistically subjected to analysis of variance (ANOVA) and means were separated using the Duncan's multiple range test (DMRT).

RESULTS AND DISCUSSION

Net photosynthesis, transpiration, stomatal resistant and tuber yield

The seasonal values of Np, T and Rs reached to a peak value at 40 DAE followed by a decline at 49 DAE. The variety Dejima recorded the highest Np and T values when compared to other varieties tested, at 22 and 40 DAE, followed by a rapid decline at 49 DAE. At all growth stages the variety May Queen had the highest Rs compared to other two varieties.

The ANOVA revealed that the Np, T and Rs varied significantly at all growth stages, depending on the potato variety. . The seasonal means of Np of the three potato cultivars ranged from 16 to 25 μmol CO_2 m^{-2} sec^{-1}. The potato variety Dejima, which produced a higher tuber yield than the other two cultivars (Table 1) also maintained a higher rate of Np (25 μmol CO_2 m^{-2} sec^{-1}), which was 31 and 36% higher than those of Irish Cobbler and May Queen, respectively. The tuber yield advantage of Dejima over Irish Cobbler and May Queen was 13 and 35%, respectively.

Table 1. Change in photosynthesis, transpiration and stomatal resistant of potato varieties (means of 3rd and 4th leaves) observed during three growth stages.

Growth stage	Variety	Photosynthesis ($\mu mol\ m^{-2}\ sec^{-1}$)	Transpiration ($\mu mol\ m^{-2}\ sec^{-1}$)	Stomatal Resistance ($sec\ cm^{-2}$)
I+	Irish Cobbler	16.5 b*	6.7 b	1.68 b
	May Queen	19.3 b	4.2 c	2.88 a
	Dejima	31.7 a	9.4 a	0.62 c
II	Irish Cobbler	22.2 b	6.2 b	0.77 a
	May Queen	22.4 b	6.0 b	0.83 a
	Dejima	33.4 a	8.5 a	0.51 b
III	Irish Cobbler	12.9 a	4.9 a	2.63 b
	May Queen	6.2 b	3.4 c	4.67 a
	Dejima	9.1 a	4.3 b	2.91 b

*: Within a growth stage, values followed by the same letter are not significantly different at P= 0.05; +: I: 22, II: 40, III: 49 days after emergence, respectively.

The mean T, across the respective growth stages, observed in the potato variety Dejima (7.4 $\mu mol\ m^{-2}\ sec^{-1}$) was 20 and 39 % higher than those of varieties Irish Cobbler and May Queen, respectively. In contrast, Rs of variety Dejima was the lowest while the Rs of the variety May Queen was 52% higher than that of variety Dejima and 39% higher than the variety Irish Cobbler.

Nitrogen per unit leaf area (SLN), potassium per unit leaf (SLK) and petiole potassium content (PK)

The seasonal trends of SLN, SLK and PK are illustrated in Figure 1. Similar to the trend observed for Np (Table 1), the SLN, too, reached to a peak at 40 DAE in all the potato varieties tested. The SLK and PK declined sharply as the season progressed. This decline in PK in the varieties Irish Cobbler and Dejima was more pronounced than that of May Queen. The potato variety Dejima had a higher PK when compared to May Queen at latter stages of growth. The variety Dejima showed higher levels of nutrients as well as higher final tuber yield when compared to other two varieties (Table 2).

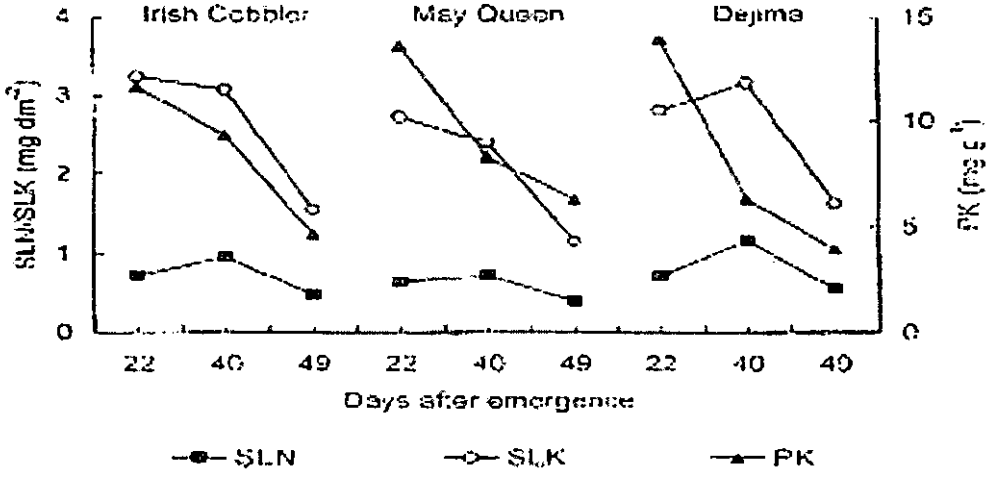

Figure 1. Seasonal Variation in leaf nitrogen per unit area (SLN), leaf potassium per unit leaf area (SLK) and petiole potassium content (PK) of three potato varieties

Table 2. Seasonal means of leaf nitrogen per unit area (SLN), leaf potassium per unit area (SLK), petiole potassium (PK) and tuber yield (at 49 days after emergence) of three potato varieties.

Variety	SLN ($mg\ dm^{-2}$)	SLK ($mg\ dm^{-2}$)	PK ($mg\ g^{-1}$)	Tuber Yield ($g\ plant^{-1}$)
Irish Cobbler	0.73	2.72	8.49	56.6
May Queen	0.72	2.15	8.05	42.7
Dejima	0.85	2.71	9.39	65.3

Light and dry matter distribution within the canopy

The relative light distribution and the light distribution in the canopy at 30 DAE are illustrated in Figure 2. In the case of variety Irish Cobbler and May Queen, the leaf dry matter distribution concentrated at a plant height of 20 cm to 40 cm whereas a relatively uniform distribution of leaf dry matter was observed in the variety Dejima. The leaf cluster at the top of the canopies of Irish Cobbler and May Queen imposed a barrier for light penetration to the deeper layers. Light distribution pattern in the potato variety Dejima revealed that more incident light had penetrated to the deeper layers of the canopy.

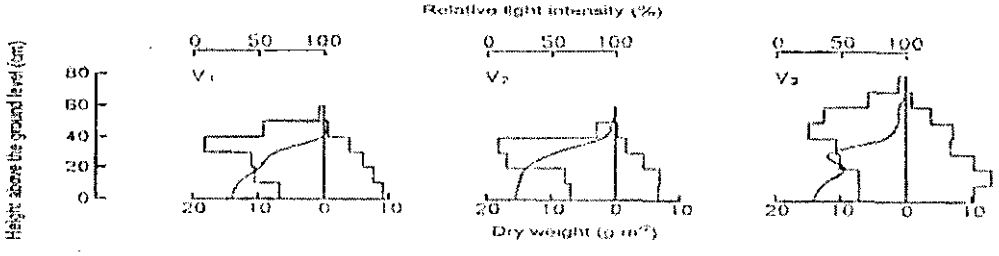

Figure 2. Difference in productive structure of thee potato varieties at 30 DAE (V1 – Irish Cobbler, V2 – May Queen, V3 – Dejima; Left – leaf blade, Right – stem+petiole)

The correlation between the measured parameters across three growth stages is shown in the Table 3. A significant positive correlation ($p<0.05$) was observed among Np, SLN and SLK. The Rs, showed a negative correlated with Np, T, SLN, and SLK. However, the correlation between PK and other characters were weak, except with SLK ($r = 0.861^{**}$). Transpiration (T) did not show a significant correlation ($p>0.05$) with any of the measured parameters

Table 3. Pooled correlation between photosynthesis (Np), transpiration (T), stomatal resistant (Rs), nitrogen per unit leaf area (SLN), potassium per unit leaf area (SLK) and petiole potassium (PK) of three potato varieties.

	Ts	Rs	SLN	SLK	PK
Np	0.451	0.893**	0.849*	0.769*	0.579*
T		0.357	0.073	0.328	0.377
Rs			0.823**	0.794	0.448
SLN				0.886**	0.660
SLK					0.861**

**, *: Significant at p=0.01 and p=0.05 level, respectively.

A significant varietal effect and significant differences among most of the measured parameters qualify their importance and potential value as criteria in varietal discrimination (Cieply, 1976; Dwelle et al., Guptha, 1992). The photosynthesis rates observed in the present study were comparable to those previously reported for potato (Chapman and Loomis, 1952; Barton, 1981; Dwelle et al.,1981; Peter et al., 1988). As reported in many studies (Sun-Ben ku et al.,1977; Dwelle et al., 1981; Leach et al., 1992), the inverse relationship of Rs with Np and T were observed in the present study, too. As the season progressed, the Rs increased, while Np and T showed marked decline at the end of the growing

season. The lower Rs of the potato variety Dejima may have caused Np and T to be higher than those of varieties May Queen and Irish Cobbler.

The nitrogen content per unit leaf area of a plant reflects the assimilation capacity (Np), as the ultimate carbon dioxide fixing enzyme (Rubisco) constitutes a large proportion of N in the leaves (Argen, 1985; Sinclair and Horie, 1989). Shortage of this enzyme often limits photosynthesis. The higher correlation observed between SLN and Np in this study confirms the above phenomenon. Potassium, which is reported to be involved in stimulating translocation of assimilates from synthetic tissues to the storage tissues (Marschner, 1986), influences the CO_2 flux to the intercellular space of leaf by regulating stomatal movement. The lower Rs of potato varieties Dejima and Irish Cobbler observed at the tuber bulking stage could be interpreted in favor of a higher SLK.

During the formation of storage organs the carbohydrates supplied to the roots decreases and thus, the root activity and nutrient uptake generally decreases (Marschner, 1986). This would result in a sharp decline in the mineral nutrient content of vegetative parts of a plant due to remobilization. The growing sink demand would aggravate the situation further. This phenomena was observed in the present study where N and K concentrations in the leaf and petioles of potato plant decreased simultaneously after the early tuber bulking stage. This declining trend observed conforms the results of Moorby (1986) where N, P and K concentration was found to decrease in the foliage after tuberization as the developing tuber become the dominant sink. Marschner (1986) reported that, K induced source limitation is more likely in tuber crops when compared to that of N. According to Spanner (1958), Hartt (1970) and Addiscott (1976), these changes in K concentration during the growing season may be a measure of the translocation capacity of the phloem. Moreover, Holm and Nylund (1978) hypothesized that the changes in the nutrient content, P and K in particular, as a function of the translocation capacity of the sink strength of developing tubers, where K was selected as the best variable associated with variation in potato yield. In the case of variety Dejima and Irish Cobbler, the Np observed at tuber bulking stage was associated with a higher SLN and SLK, indicating a higher source activity (Marschner, 1986) and thereby higher productivity. Hence, the K level in the leaves and petioles of these two varieties may be a good indicator of productivity. Haeder et al. (1973) found that a much higher proportion of ^{14}C labeled photosynthates was trans located from leaves to the tuber in plants with higher K concentration

in the vegetative part, especially in leaves. In contrast to varieties Dejima and Irish Cobler, low SLN, SLK and PK of the variety May Queen may have led to an early exhaustion of N and K in the vegetative shoots due to early tuber formation. This may be one of the reasons for early leaf senescence observed in this variety (Fonseka et al., 1996). The early depletion (source limitation) of N and K in the leaves of variety May Queenmay have not permitted in meeting the demand of developing tubers adequately, resulting in early termination of tuber growth and lower final yield. The nutrients supplied from the source leaves can also be one of the main limiting factors for tuber yield. The results of this study also reveal that, there is a possibility to predict yield potential on the basis of the changes of N and K levels in the leaves and petioles at early tuber bulking stage of potato. However, Bot et al. (1986) showed that N and K contents in plant decline sharply during the growing season, and even if regular measurement are made, prediction of optimum N and K concentration needs precise knowledge of what the ideal concentration is at a particular time of the season.

Results of the present study also indicated that Np and nutrient concentrations and the canopy architecture play a significant role in determining the productivity of a potato variety. The uniform vertical distribution of leaves observed for photosynthesis would have resulted in increase in total dry matter productivity. When compared to the variety Dejima, the leaf dry matter distribution of the vaireity Irish Cobbler was concentrated to middle layers of the plant whereas in case of May Queen leaves were concentrated at the top layers. This arrangement of leaves in the canopies of variety Irish Cobbler and May Queen prevented light penetration to deeper layers resulting in lower dry matter production. The combination of efficient canopy architecture, higher Np, and higher nutrient levels in leaves and petiole may have resulted in higher yielding ability in the potato variety Dejima over the other two tested varieties.

CONCLUSION

The potato genotypes with higher net photosynthetic rates together with persistent supply and adequate pool of mineral nutrient in the vegetative parts, will have better ability to synthesise and trans locate dry matter in response to the increasing sink demand. These physiological traits along with better canopy architecture could be useful criteria for the selection and breeding of high yielding potato genotypes. Moreover, the rate at which P and K levels decline may indicate the yield potential of a particular genotype.

REFERENCES

Addiscot, T.M. 1976. Nutrient concentration and interaction in young leaves of potato plants growing with and without tubers. Annals of Botany. 40:65-72.

Argen, G.I. 1985 Theory for growth of plants derived from the nitrogen productivity concept . Physiologia Plantarían. 64:17-28.

Barton, W.G. 1989. The potato. 3rd edition. Longman Sci. & Tech. New York. 84-154.

Bot, L.J., D.J. Pilbeam and E.A. Kirkby. 1994. Plant mineral nutrition in crop production. In Mechanisms of plant growth and improved productivity. Modern approaches. Ed . A.S. Basra. Marcel Dekker Inc. New York. 33-67.

Chapman , H.W. and W.E. Loomis. 1952. Photosynthesis in the potato under field condition. Plant Physiology. 28:703-716.

Cieply, J. 1976. The productivity of photosynthesis of several varieties of spring barley and potatoes as an index of their fertility (Abstr Reports, Academy in Agriculture in Karakow, Poland.

Dwelle, R.B., G.E. Kleinkof, R.K. Steinhorst, J.J. Pavek and P.J. Hurley. 1981. The influence of physiological process on tuber yield of potato Clones *(Solanum tuberosum* L.): Stomatal diffusive resistance, stomatal conductance, gross photosynthetic rate, leaf canopy, tissue nutrient levels, and tuber enzyme activities. Potato Research. 24: 33-47.

Fonseka, H.D., K. Asanuma, A. Kusutani, A.K. Ghosh and K. Ueda. 1996. Growth and yield of potato cultivars in spring cropping. I. plant morphology, growth, assimilate partitioning and yield under two planting densities. Japanese Journal of Crop Science. 65: 269-279.

Guptha, U.S. 1992. Crop Improvement: Physiological Attributes. West view Press, Colorado, USA. 17-55.

Haeder, H.E., K. Mangal and Foster. 1973. The effect of potassium on translocation of photosynthates and yield pattern of potato plants. Journal of the Science of Food and Agriculture. 24: 1479-1487.

Hartt, C.E. 1970. Effect of potassium deficiency upon translocation of 14C in detached blades of sugarcane. Plant Physiology. 45: 183-187.

Holm, D.G., and R.E. Nylund. 1978. Use of mineral element content of potato petioles for predicting yield potential. American Potato Journal. 55; 291-305.

Leach, J.E., K.J. Parkinson and T. Woodhead. 1992. Photosynthesis, respiration and evaporation of afield grown potato crop. Annals of Applied Biology. 101: 377-390.

Marschner, H. 1986. Mineral nutrition of higher plants. Academic Press, London.115-267

Moorby, J. 1968. The influence of carbohydrate and mineral nutrient supply on the growth of potato tuber. Annals of Botany. 32: 117-138.

Peter, J., V. Cerny and L. Hkuska. 1988. Yield formation in the main field crops. Longman Sci. & Trch., New York. 268-296.

Sinclair, T.R. and T. Horie. 1989. Leaf nitrogen, photosynthesis and crop radiation use efficiency: A review. Crop Science. 29: 90-98.

Spanner, D.C. 1958. The translocation of sugar in sieve tuber. J.Exp.Bot.9: 332-342.

Sun-Ben Ku, E.E. Gerald and C.B. Tanner. 1977. Effect of light, carbon dioxide and temperature and photosynthesis, oxygen inhibition of photosynthesis and transpiration in *Solanum tuberosum* L. Plant Physiology. 59: 868-872.

Wallace, D. H., J.L. Ozbun. and P. N. Munger. 1972. Physiological genetics of crop yield. Advances in Agronomy. 24:97-146.

Zelitch, I. 1969. Stomatal control. Ann. Rev. Plant Physiology. 20: 329-350.