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Nitrogen Distribution and Uptake Efficiency Traits of Potato under Different Nitrogen Regimes

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Abstract: Nitrogen distribution in different plant organs, dry matter production and tuber yield have been studied in spring cropping potato (*Solanum tuberosum* L.) for three N levels (N_0 = control, N_1 = 101 kg ha^{-1} and N_2 = 202 kg ha^{-1}) and two cultivars (May Queen and Dejima). Higher levels of N (N_2) produced higher amount of dry matter but yield was higher in N_1 treatment in both cultivars. Higher levels of N substantially increased the plant N concentration and the amount of N uptake to different plant organs was also increased. The average uptake rate up to 50 DAE was 1.81, 3.21 and 4.98 kg ha^{-1} day^{-1} in May Queen and 1.99, 3.64 and 5.17 kg ha^{-1} day^{-1} in Dejima for N_0, N_1 and N_2 treatments respectively. N uptake in different plant organs showed significant positive correlation among each other and total uptake and total dry matter production but not with total yield. Total uptake and total dry matter production also showed highly significant correlation in two cultivars. The C/N ratio decreased as fertilizer N increased throughout the season but it was increased with time. C/N ratio showed significant positive correlation with total N uptake and total dry matter but not with yield. Nitrogen uptake efficiency (NUE) by the whole plant (NUE_p) and tuber (NUE_{tu}) was relatively higher in N_1 treatment than N_2. In N_1 treatment, the peak values of NUE_p and NUE_{tu} were 62 and 33% in May Queen and 68 and 31% in Dejima but in N_2 treatment the values of NUE_p were 65% in both cultivars and that of NUE_{tu} were 17 and 16% in May Queen and Dejima respectively.

Key words: C/N ratio, Nitrogen uptake efficiency, Potato (*Solanum tuberosum* L.), Tuber yield

Introduction

Nitrogen is the major nutrient element as the plants require it in large amount. The amount of N uptake by different plant organs varied within the genotypes and the uptake efficiency is influenced by the amount of N applied and many other factors. The amount of nutrient uptake by potato crop is needed to plan fertilization in order to obtain the highest profit without damaging the environment or the tuber quality. N stress can affect the growth of individual plant organs and also the N partitioning to each organ. Still there is controversy with the environmental control of biomass partitioning. The partitioning of biomass has been related to the ratio of total carbon to total nitrogen (C/N) within plants (Reynolds and Thornley, 1982). Others assume that partitioning depend on the availability and uptake of carbon and (or) nitrogen (Agren and Ingestad, 1987; Wilson, 1988; Thornley, 1991; Dewar, 1993). Total dry matter production is the sum of the total product of individual organs. So individual plant organs have a substantial contribution for the increased production of total dry matter and total uptake. Many works have been done to know the effect of N fertilizer on growth, yield and N uptake (Gunasena and Harris, 1968; Dyson and Watson, 1971; Allen and Scott, 1980; Tyler *et al*., 1983; Millard and Marshall, 1986; Westermann *et al*., 1988; Biemond and Vos, 1992; Vos and Biemond, 1992; Joern and Vitosh, 1995). But detailed N distribution pattern within different plant organs, their interrelationship and C/N ratio throughout the season on potato is still insufficient. That is why we studied more accurately the plant organs N distribution pattern, its uptake and use efficiency, C/N ratio, dry matter production and yield in response to N supply.

Materials and Methods

The experiment was conducted in spring 1997 in the experimental field of Faculty of Agriculture, Kagawa University. Treatment consisted of three levels of nitrogen where, N_0 = control, N_1 = 101 kg N ha^{-1} (recommended rate), N_2 = 202 kg N ha^{-1} and two potato cultivars May Queen and Dejima where May Queen is leafy type and Dejima is stemmy type (Fonseka and Asanuma, 1996). Design of the experiment was split plot design with three replications. Fertilizers N were applied according to the treatments over the ridge and mixed well to the soil just before planting. P_2O_5 and K_2O at the rate of 98 kg and 212 kg ha^{-1} were also applied. About 50g seed tubers were planted over the ridge by hand with a spacing of 30 cm between the plant and 66cm in ridge. Six destructive harvests were made starting from 10 DAE (days after emergence). All plant organs were separated into main stem (MS), main stem laminae (MSL), main stem petiole (MSP), branch (Br), branch leaf (BrL), stolon, tuber and root. For yield determination, 10 plants per replication were harvested and total yield marketable yield (>50 g), yield components and dry weight of tubers were recorded. Plant samples were dried at 70°C for 96 hours and fresh and dry weight of each organs were recorded. Samples were finely ground and total N and C was determined by CHN Corder (Yanagimoto Co., Japan). Nitrogen accumulation was calculated by multiplying % N with dry matter produced (g plant^{-1}) divided by 100 and total uptake was calculated by the summation of individual organs accumulation. Plant tissue fertilizer N uptake efficiency (NUE) is the percent of applied fertilizer N that is recovered in the plant tissue. The fertilizer NUE was calculated by (Ni-Nc)100/Nf, where Ni and Nf were the N uptake by the plants and N fertilizer applied for N treatment and Nc was the N uptake by the plant on the control treatment, respectively (Westermann *et al*., 1988). All statistical analyses were performed by software MSTAT-C package (Michigan State University, USA).

Results

Dry matter production and tuber yield: The effects of N on dry matter production throughout the growing season and tuber yield at final harvest are shown in Table 1. Both N_1 and N_2 treatment significantly increased the total dry matter in both cultivars but there was no significant interaction between the treatment. Higher rates of N produced higher amount of dry matter in both cultivars, it was 41% higher in May Queen and 43% higher in Dejima over control at 60 DAE. The total dry matter production trends were nearly similar in N_1 and N_2 treatments. In N_1 treatment, it was 37% higher in May Queen and 39% higher in Dejima over control at 60 DAE. But N_0 treatment always showed slower rate of dry matter accumulation throughout the season resulting lower amount of dry matter production. Like dry matter production fertilizer had

Table 1: Effect of nitrogen on dry matter production throughout the season and final tuber yield of two potato cultivars at three nitrogen levels

		Dry matter production (g $plant^{-1}$)						Tuber yield (ton ha^{-1})	
Cultivars	N levels	10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	60 DAE	Total	Marketable
May Queen	N0	1.98a	9.37b	26.74b	63.92b	101.00b	111.19b	28.26c	17.18c
	N1	2.23a	13.2ab	43.74a	95.04a	142.02a	152.35a	37.71a	27.11a
	N2	3.12a	15.18a	49.5a	100.85a	143.22a	156.48a	32.59b	23.35b
Dejima	N0	1.76a	8.9b	21.81b	51.63b	90.76b	111.19b	24.19b	21.95c
	N1	2.19a	14.32a	39.33a	82.57a	127.16a	154.99a	32.63a	30.47a
	N2	2.33a	14.34a	38.48a	82.81a	129.68a	159.01a	30.62a	27.36b

*: Figures with the same letter(s) within the collumn do not differ significantly at 5% level (DMRT)

Table 2: Seasonal trend of whole plant total N uptake (kg ha^{-1}) of two potato cultivars

Cultivars	N levels	10 DAE	20 DAE	30 DAE	40 DAE	50 DAE	50 DAE
May Queen	N0	5.85c*	23.93c	48.08c	69.35c	78.06c	74.30c
	N1	7.46b	36.78b	102.64b	131.63b	135.66b	130.25b
	N2	10.97a	49.78a	136.74a	189.76a	209.98a	166.42a
Dejima	N0	5.19b	24.19c	48.85c	81.30c	84.48c	90.80c
	N1	7.35a	48.15b	105.39b	148.39b	152.86b	150.07b
	N2	8.28a	50.28a	118.48a	181.82a	215.07a	185.56a

*: Figures with the same letter(s) within the collumn do not differ signficantly at 5% level (DMRT)

Table 3: Relationship between different plant organs N uptake, total plant N uptake and total dry matter production of two potato cultivars (n = 18)

Plant organs	May Queen		Dejima	
	Total N uptake	Total dry matter	Tota N uptake	Total dry matter
MS	0.923**	0.571*	0.848**	0.477*
MS laminae	0.818**	0.444ns	0.683**	0.373ns
MS petiole	0.756**	0.297ns	0.611**	0.190ns
Branch	0.904**	0.613**	0.914**	0.619**
Br. Leaf	0.934**	0.760**	0.949**	0.770**
Tuber	0.793**	0.981**	0.768**	0.982**
Total uptake		0.829**		0.856**

ns, *, **: not signifcant, significant at 0.05 and 0.01 levels respectively

Table 4: The internal correlation of N uptake by different plant organs of two potato cuitvars (n = 18)

	My Queen					Dejima				
	MSL	MSP	Br	BrL	Tu	MSL	MSP	Br	BrL	Tu
MS	0.888**	0.890**	0.939**	0.871**	0.535*	0.810**	0.859**	0.915**	0.818**	0.339ns
MSL		0.491*	0.729**	0.656**	0.340ns		0.909**	0.618**	0.506*	0.208ns
MSP			0.748**	0.653**	0.228ns			0.667**	0.509*	0.033ns
Br				0.963**	0.608**				0.960*	0.519*
BrL					0.762**					0.702**

ns, *, **: not significant, significant at 0.05 and 0.01 levels respectively

significant effect on tuber yield too. Higher rates of N did not produced higher yield. Total yield and marketable tuber yield were higher in N_1 treatments in both cultivars (Table 1).

N Content: The percentage of total nitrogen (%N) of different plant organs are shown in Fig. 1. N_2 treatments substantially increased the N concentration in all plant organs throughout the season in both cultivars. N concentration in main stems showed gradual decrease with time. N_2 plants contained higher levels of N during all stages of growth. N_1 plants slightly lower than N_2 but N_0 plants always possessed the lowest levels of N. Main stems laminae N showed upward trends up to 30 DAE then decreased with time. N_0 plants always showed lower values. Main stems petiole N decreased up to 40 DAE then remain nearly similar and the trends were higher in higher levels of N treatments. Branches contained slightly higher levels of N than MS. The trend was initially increased in N_2 treatment and then gradually decreased with time. Among the plant organs N level was the highest in branch leaf and it was the lowest in tuber. N_2 plants contained higher levels of N, N_1 plants contained moderate levels but N_0 contained lower levels of N throughout the season.

Total and Tuber N Uptake: Like N content, total N uptake by potato plants were also increased by N levels (Table 2). N_0 plants always accumulated lower amount of N in all stages of growth and the maximum uptake was attained at 50 DAE in May Queen and 60 DAE in Dejima. The average accumulation rate for N_0 plants between 10 to 50 DAE was 1.81 and 1.99 kg ha^{-1} day^{-1} in Dejima. N_2 plants accumulated significantly higher amount of N throughout the season in both cultivars. Maximum uptake was

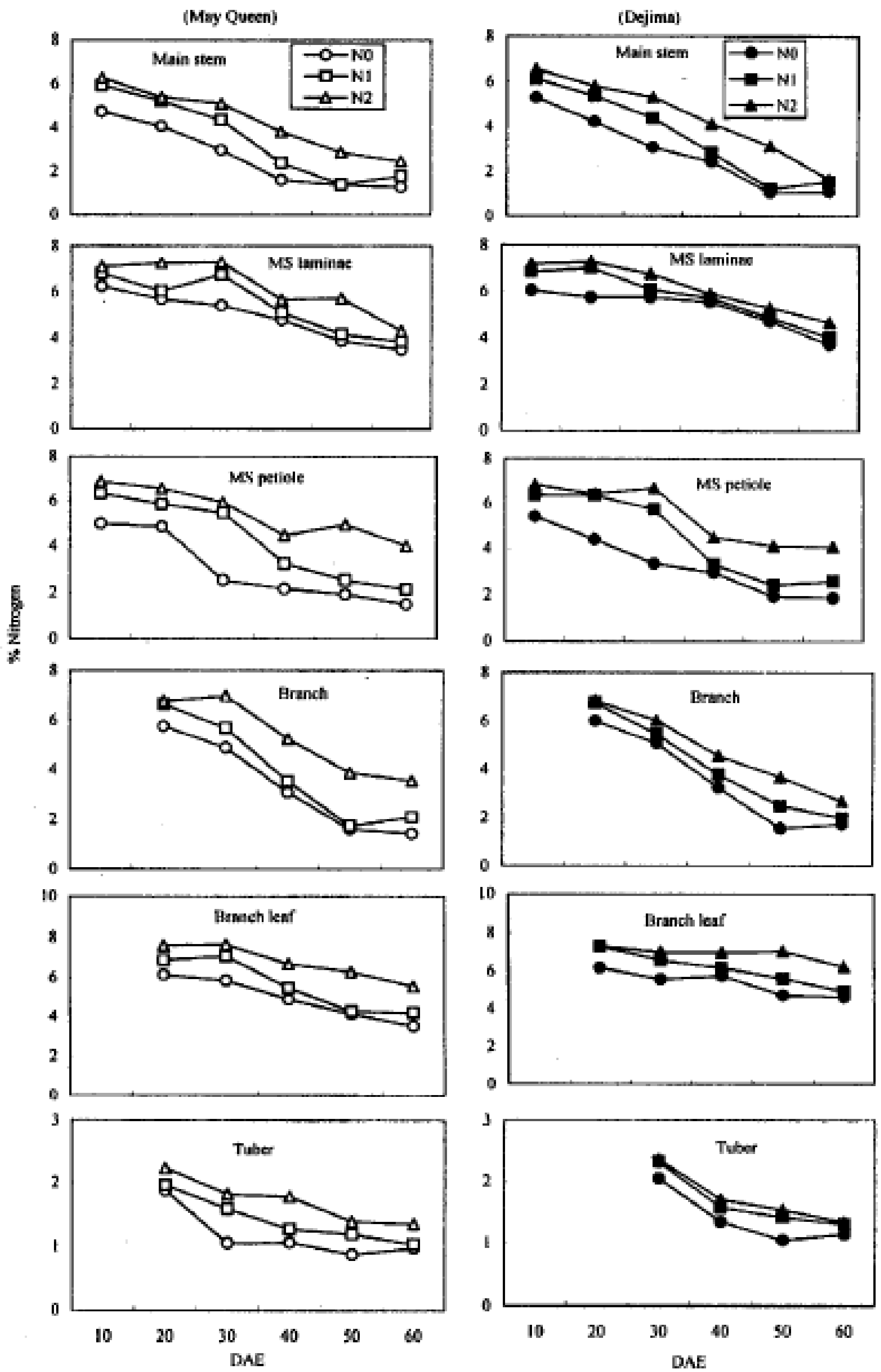

Fig. 1: Seasonal trend of N distribution to different plant organs of two potato cultivars at three N levels

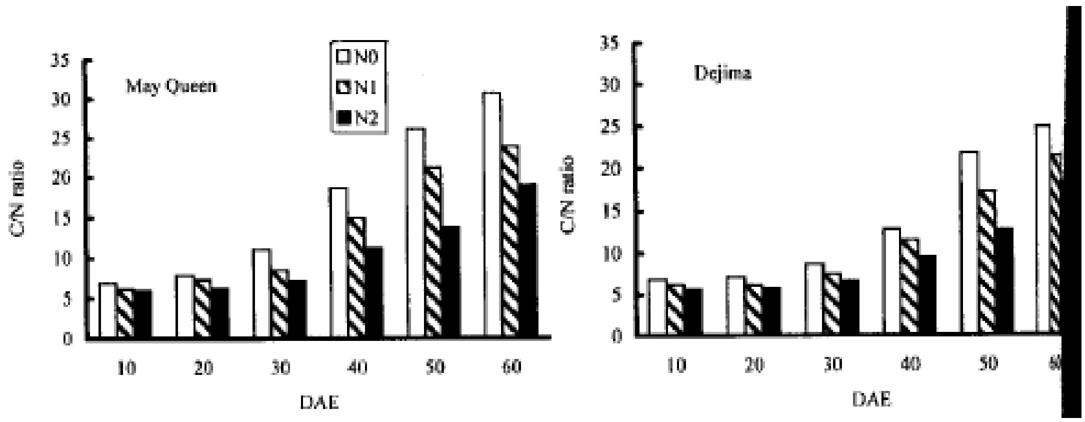

Fig. 2: C/N ratio of the whole plant during the growing season at three N levels of two potato cultivars

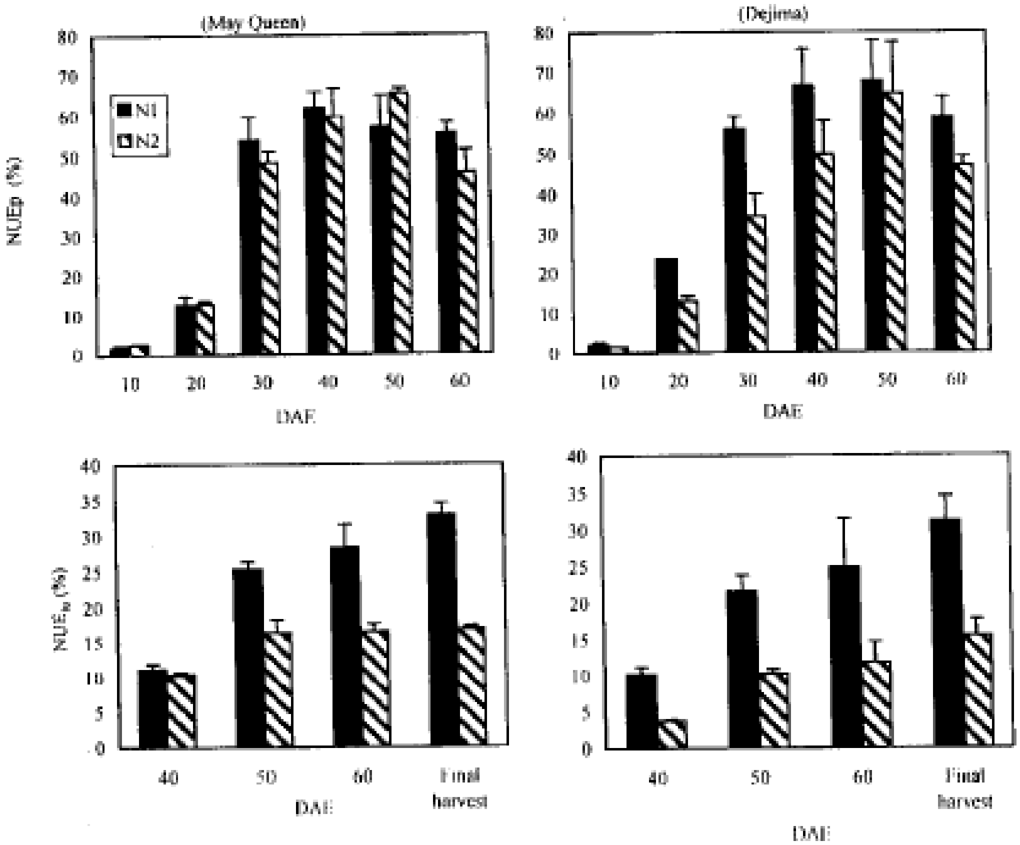

Fig. 3: Effect of fertilizer nitrogen on fertilizer nitrogen, uptake efficiency of the whole plant (NUE_p) and tuber (NUE_{tu}) throught the season of two potato cultivars. Upper for whole plant and lower for tuber. Bars represents standard error

attained at 50 DAE in both cultivars and the amount was 209.98 kg ha^{-1} for May Queen and 215.07 kg ha^{-1} for Dejima. The average uptake rate between 10 and 50 DAE was 4.98 kg ha^{-1} day^{-1} in May Queen and 5.17 kg ha^{-1} day^{-1} in Dejima. But N_1 plants accumulated slightly lower amount of N than N_2 treatment. Maximum uptake was attained at 50 DAE and the value was 135.66 kg ha^{-1} in May Queen and 152.86 kg ha^{-1} in Dejima. The average uptake rate was 3.21 kg ha^{-1} day^{-1} and 3.64 kg ha^{-1} day^{-1} in May Queen and Dejima respectively.

C/N Ratio: The total carbon to nitrogen (C/N) ratio of the whole plant throughout the growing season are presented in Fig. 2. C/N ratio of plants tends to increase with time. Increasing N fertilization decreased the C/N ratio of plants. N_o plants always showed the higher C/N ratio. C/N ratio of whole plant showed significant positive correlation to total N uptake and total dry matter production but not with yield in both cultivars, although data are not shown.

Nitrogen uptake efficiency (NUE): Nitrogen uptake efficiency (%) by the whole plants (NUE_p) at 20 DAE was 12.7 and 23.7% in May Queen and Dejima respectively and peaked at 40 DAE in May Queen (61.7%) and 50 DAE in Dejima (67.7%) in N_1 treated plants (Fig. 3). But in N_2 plants, NUE_p increased from 12.8 to 65% in May Queen and 12.9 to 65% in Dejima between 20 to 50 DAE. Average NUE over 20 to 60 DAE were 48 and 55% in May Queen and Dejima respectively in N_1 treatments. But in N_2 treatments those were 46 and 42% in May Queen and Dejima respectively. So, the higher levels of N decreased the NUE in both cultivars. NUE by the tuber (NUE_{tu}) was also decreased by N_2 treatment in both cultivars and reached the maximum at final harvest and the value was 32.97, 31.15% in N_1 treatment and 16.87, 15.47% in N_2 treatment for May Queen and Dejima respectively.

The relationship between N uptake in different plant organs and total N uptake and total dry matter production are presented in Table 3. Two cultivars showed similarity in correlations. Only exception was in MS laminae and MS petiole, where the relationship with total dry matter was not significant. Total N uptake and total dry matter of the cultivars showed strong positive correlated with each other and the value was 0.829 and 0.856 in May Queen and Dejima respectively. Different plant organs showed highly significant positive correlation to each other, only exception was in tubers at early stages where the value was not significant (Table 4).

Discussion

Applied nitrogen significantly affected dry matter production and tuber yield for both cultivars. Tuber yield for both cultivars were more increased by N_1 treatments compared to N_0 and N_2 treatments. Additional available N (N_2) treatments produced the higher amount of dry matter in both cultivars but did not produce higher yield. This might be due to the higher vegetative growth rather than tuber growth and early maturity of the cultivars. This result agrees well with the report of Allen and Scott (1980). The pattern of change of N to different organs was almost identical for plants receiving no added N fertilizer and those receiving N fertilizer. The N distribution to different organs were increased by the increased supply of N as similar reported by Dyson and Watson (1971). The total N concentration to different organs showed similarity like the treatments i.e., $N_2 > N_1 > N_0$. In major cases, plant organs N content decreased on time i.e. plant N content decreased on plant age, except in MS laminae and branch, where initially increased and thereafter decreased gradually. Among the different organs BrL contained the highest N levels up to the later stage of growth. It was due to the newly developed leaves on the branch than the leaves on the main stem at later stage. N concentration in the tuber initially differ too much among the treatments but in the final harvest N content in the tuber did not differ much for the treatments in both cultivars. There is considerable evidence that N% of dry matter in the tubers remain substantially constant from an early stage of their growth (Yamaguchi *et al*., 1960; Moorby, 1968; Soltanpour, 1969). The considerable difference in N uptake by N fertilized and unfertilized plants was observed in this study. Total N uptake increased by plant age and reached the peak at 50 DAE. This was primarily due to the increased dry matter production on plant age. But after 50 DAE, N uptake did not increase due to senescence of leaves and it was decreased in the concentration of plant N. N uptake by the tubers reached its maximum at the final harvest. Total N uptake by whole plant gradually increased and reached the maximum at 50 DAE and then decreased but N uptake by tuber reached the maximum at final harvest. Higher rates of N treatments increased the uptake rates in both cultivars. The peak NUE_p for May Queen and Dejima was 61.7 and 67.7% respectively in N_1 treatments. In N_2 treatment peak value was equal (65%) for both cultivars. In contrast NUE obtained 57% for 202 kg ha^{-1} and 39% for 270 kg ha^{-1} N application in another experiment of potato (Tyler *et al*., 1983). The peak NUE_{tu} reached at the end of the season and the value was double in N_1 treatment (33 and 31% in May Queen and Dejima) than N_2 treatments (17 and 16% in May Queen and Dejima). These results agree with the report of Joern and Vitosh (1995) having 52% for whole plant at onset of senescence and 32% for tubers at final harvest. The C/N ratio of the whole plant decreased as fertilizer N rates increased. N fertilization increased the plant N much higher than that of carbon in the plant. C/N ratio also increased over plant age in both cultivars and treatments. C/N ratio of the plant showed significant positive correlation to total N uptake and total dry matter production but not with yield. Because, higher rates of N (N_2) did not produced higher yield in this experiment.

N uptake by each organ showed significant positive correlation to each other. Relation was poor with tubers at early stage of growth but at the later stage it was highly significant. At the early stage the relation was poor due to the insufficient amount of the tuber. That is, plant organ maintained relationship for the production of each organ during the growth and development. The total dry matter production and total uptake of N also showed highly significant correlations.

Plant organ based N study helps the plant breeders, especially it represents the actual amount and distribution pattern of N in different plant organs and the uptake efficiency. The analysis of different organs N separately gives the value more accurate than the values obtained from total plant organs together for the calculation of total uptake.

Fertilizer recommendations for potato production are available from research and extension personnel in nearly all potato growing areas. But data presented here shows that the response of potato plant to the available nutrient supply is an important determinant for accurate fertilizer recommendation. It also suggest that N fertilizer recommendations should be developed for cultivars depending on dry matter production, yield, fertilizer uptake efficiency and also on the growing conditions. This type of information may also be used by the plant breeder to develop cultivars with improved production and fertilizer use efficiencies.

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