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Potential Productivity of Intensively Irrigated Potatoes in the Low Country Regosol Belt of Sri Lanka

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ABSTRACT. A field experiment was conducted, at the Agricultural Research Station Kalpitiya (8^0 N lat, 0-5 m asl) during 1988/89 Maha season (October to February) to identify suitable fertilizer and irrigation practices which favour potato production under warm condition and sandy soils in the area. The experiment was designed to test the effects of high levels of N and irrigation at frequent intervals on tuber yield of variety "Desiree".

Increasing N from o - 160 kg/ha improved tuber yields by 35% but further increases up to 320 kg/ha reduced it, mainly due to lower tuber number/plant. Tuber yield was not influenced significantly by the frequency of N application. Application of 25 mm/day of irrigation water with a hose pipe to simulate farm practice had no effect on yield compared with the application of 15 mm/day (10 mm in the morning and 5 mm in the evening) with drip irrigation. However the maximum tuber yield recorded in the experiment (16 mt/ha) was far below the potential yield of the variety when grown under favourable conditions. The canopy cover even under the optimum combination of treatments, did not exceed 75% and the highest LAI recorded was 1.6. This suggests that the low productivity was associated with sub-optimal leaf development.

The likely explanation of poor leaf growth and hence the size of the photosynthetic system was low leaf water status brought about by a combination of a high evaporative demand and inadequately developed root system. Therefore a second field trial was conducted at the University of Reading research farm at Sonning, UK to analyze the impact of varieties Cara and Wilja by artificial shading and soil compaction on tissue water status and the resulting crop productivity of the potato crop.

A relationship was observed between the rate of transpiration and leaf water potential which was dependant upon ground cover, root length, density distribution and soil water potential profile.

INTRODUCTION

Since the introduction of the potato cultivation to the Kalpitiya area in 1980, yield have been low with highly seasonal and site variations. The low nutrient and water holding capacity of the sandy soils and the adverse weather conditions which prevail in the area, necessitate frequent application of irrigation and fertilizer in heavy doses. However, in a series of experiments conducted in Kalpitiya, N, P and K rates up to 400 kg/ha failed to improve th tuber yields appreciably (Kuruppuarachchi, 1986). It has been shown that the effect of irrigation on fertilizer use may be influenced by numerous factors, such as type of nutrient, it's placement in the soil profile, timing of application and the capacity of the crop to extract nutrients from the soil (Harris, 1978).

It was suspected that frequent application of irrigation water in large quantities might deplete the soluble nutrients beyond the extraction zone of the poorly rooted potato crop. Therefore an experiment was conducted at Kalpitiya during 1988/89 *Maha* season to test the effects of level and frequency of application of N and irrigation. N levels between 0 and 320 kg/ha were compared under the controlled application of water with a drip irrigation system at the rate of 15 mm per day against the conventional overhead irrigation practiced in the area at the rate of 25 mm/day, and application of basal and 4 top dressings of N against conventional application of basal and one top dressing. Although a slight response to applied N was observed, the highest yield obtained (at 160 kg/ha N) was far below the potential yield of the variety when grown under favourable conditions. the canopy cover, even under the optimum combination of treatments did not exceed 75% and the highest leaf area index (LAI) recorded was 1.6 suggesting that low productivity is due to an ability of plants to develop a larger leaf area. Gander and Tanner (1976) stated that leaf growth of potato is severely inhibited at leaf water potentials approaching -4 to -5 bars. Epstein and Grant (1973) have shown that after periods of moderate stress stomata did not reopen for 48 hours. Therefore it is clear that the consequence of an inadequate water supply and resulting dehydration are severe. Therefore the likely explanation of poor leaf growth and hence the size of the photosynthetic system under Kalpitiya conditions is low leaf water status brought about by a combination of a high evaporative demand and a poor rooting system. Tuber yield has been increased upto 20% by shading the potato crop during its early growth stages with *Ipil Ipil (L. leucocephala)* plants grown in 3 m avenues under Kalpitiya conditions (Kuruppuarachchi, 1988). In addition the photosynthetic efficiency of the crop canopy is particularly sensitive to plant water status, since stomata tend to close at high water potentials. Therefore the impact of varieties, soil physical conditions and artificial shading on tissue water status and resulting crop productivity of the potato were analysed in the second field trial conducted at. Reading in england, to work out the Techniques which are to be applied in Sri Lanka.

The proposition that the flow of liquid water through a plant (during transpiration) may be described by an Ohm's law analogy (Van der Hornet, 1948 and Gardner, 1960) has been the topic of several recent reports. For simple soil plant model, in which water moves from the soil through roots' and stem' to the leaf'; from which all transpiration occurs, the flux of water may be written,

$$E \doteq \frac{\psi_s - \psi_1}{R_{p+s}}$$

Where, E is the transpiration rate

ψ_s is the soil water potential

ψ_1 is the leaf water potential

R_{p+s} is the total resistance offered by the soil flow pathway.

There is substantial agreement (Newman, 1969, Weatherley, 1976 and Lawler and Lake, 1976) that a major resistance to water flow probably occurs within the root system. The resistance to flow within the root system is associated mainly with the radial pathway from epidermis to xylem, with axial resistance being generally small. Hence the resistance offered by a root system would be expected to vary inversely with the overall length of the root system. Also the large and controlling resistance may occur in dry soil within the soil volume that immediately surrounds the individual root.

Rooting density parameters; rates of transpiration, water potentials, plant resistance and resulting dry matter production examined in the present experiment for two potato varieties with distinct differences in rooting behaviour, grown under conditions which led to different rooting densities (by artificial compaction of the soil) and atmospheric demand (artificial shading).

MATERIALS AND METHODS

Experiment 1

This experiment was conducted at Kalpitiya (8^0N and 1 - 5 m amsl)in the North Western coastal belt of Sri Lanka. The soil classified as a Regosol (De Alwis and Panabokke, 1973), contained 90 -98% fine coarse sand with a pH of 6.5, organic matter of 0.4%; P (Olsen) of 2.5 ppm, exchangeable K of 0.04 ppm; ec of 0.01 m.mho/cm; available water capacity of 7% (by volume), and bulk density of 1.56 g/cm^3. The climate of the area is characterised by high day temperatures (27^0C) throughout the year with a biannually distributed rainfall. Weather data during the experimental period are presented in Table 1 and the analysis of irrigation water is given in Table 2.

Five levels of N (0, 40, 80, 160, 320 kg/ha) were applied at two frequencies (basal plus one top dressing at 4 weeks after planting (WAP) and basal plus 4 top dressings at 2 WAP) under two irrigation practices; *i.e.* application of 25 mm/day of irrigation with a hose pipe (to simulate farm practice) and application of 15 mm/day (10 mm in the morning and 5 mm in the evening) by drip irrigation (Wimpee's low pressure gravity fed biwall system with emitter discharge of 0.5 1/ha). Irrigation was not done when the rainfall during the previous 24 hours exceeded 10 mm. Total irrigation of 150 cm and 90 mm were applied in the overhead and drip irrigation treatments respectively.

The experiment was conducted as split-split plot design with three replications; irrigation treatments were the main plots, frequency N applications were sub-plots and N levels formed the sub-sub plots with 6 m x 2 m in size. Crop spacing was 50 cm x 30 cm. N was applied in the form of urea (46% N); and K and P were applied at the rate of 200 kg/ha half the amount at planting and rest at 4 WAP.

Table 1. Average air temperature, pan evaporation and rainfall during the experimental period.

Month		Air temperature °C max.	Air temperature °C min.	Pan evap. mm/day	Total rain mm
Nov.	0 – 10	30.5	24.0	5.0	132.5
	11 – 20	30.0	24.0	3.8	33.5
	21 – 30	31.5	21.0	3.5	–
Dec.	0 – 10	30.0	22.5	3.3	24.0
	11 – 20	30.0	23.0	4.0	14.0
	21 – 31	30.5	24.0	4.1	22.0
Jan.	0 – 10	30.0	23.5	5.2	41.5
	11 – 20	29.0	23.5	5.8	13.5
	21 – 31	30.0	20.5	5.0	–

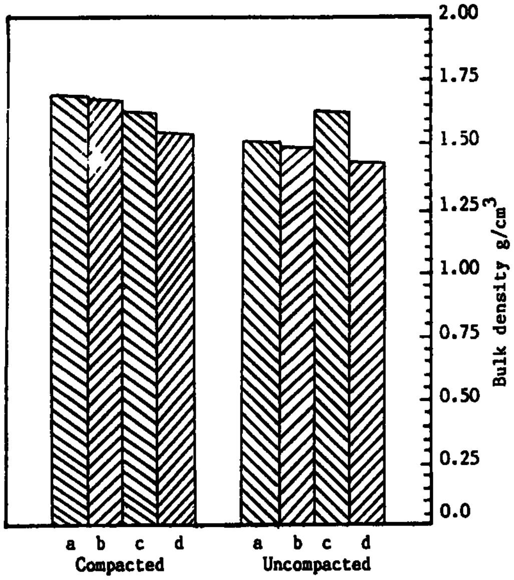
Table 2. Chemical analysis of irrigation water.

pH at 25°C	– 7.85
ec. at 25°C, Ms/cm	– 425.00
total dissolved solids, mg/l	– 40.00
chloride (as cl), mg/l	– 40.00
ammonia (as NH_3), mg/l	– 2.80
phosphate (as P), mg/l	– 2.40
nitrate (as N), mg/l	– 9.60
potassium (as K), mg/l	– 11.00
total nitrogen (as N), Mg/l	– 11.50

Experiment 2

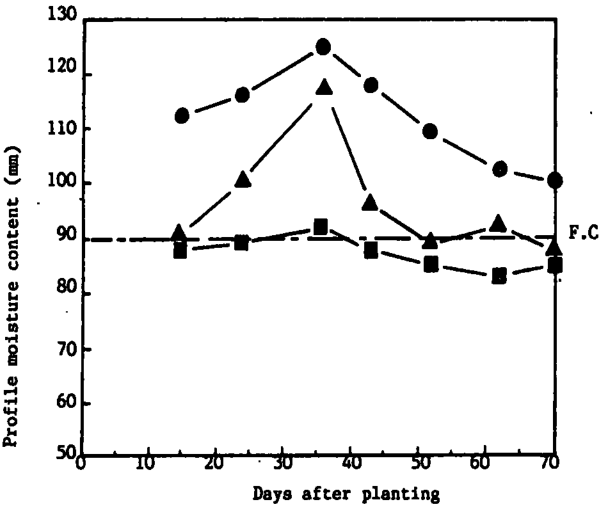
Cara (a main crop variety) and Wilja (a second early maturing potato variety) were grown in the University of Reading research farm. Uniform sized, presprouted seed potatoes were sown at a spacing of 50 cm x 50 cm on 10th April 1989. The soil was a loamy sand. The crop was grown under exceptionally dry conditions, with less than 70 mm of rain falling during the experimental period, and the crop was irrigated on the 19th and 20th of June, applying 15 mm of irrigation each day with a trickle irrigation system.

Experiment was laid out as a randomized complete block design with low replicates. The plot size was 2 m x 10 m. N, P, K were applied at the rate of 200 kg/ha. Compaction treatment was imposed using two passes of a tractor. Bulk densities were measured in both compacted and uncompacted plots upto 55 cm depth as shown in Figure 1. Emergence was recorded daily from 10 days after planting (DAP). During early stages of crop growth weeds were removed manually from the plots to reduce water loss from the surface soil layers. When all the plots reached 80% emergence, artificial shading was imposed using black polythene strips designed to cover 50% of the plot area. Measurement of volumetric moisture content were made using a 'Wallingford' neutron probe. Growth analysis was done at 14 day intervals commencing from 15th May. Total N content were determined in all the components at every harvest. Ground cover was measured at weekly interval using a 5 cm by 10 cm grid. Samples for root growth were taken every two weeks, Cylinders of soil (10 cm depth by 10 cm diameter) containing roots were removed from four depths, 0 – 15, 15 – 25, 25 – 35 and 35 – 55 cm. Roots were washed out of the soil and the samples were measured for root length using the line intersection technique, (Newman, 1966). Pressure chamber was used in this experiment to measure the leaf water potential, and the soil water potential were measured using the 'Filter paper method' (Hamblin, 1981). The rate of transpiration was estimated from measurements of stomatal conductance, leaf – air vapour pressure deficit and leaf area index (Black *et al.*, 1985). Stomatal conductance was measured using a diffusion porometer (Delta – T Device, Cambridge).



a - 0 - 15cm b - 15 - 25cm
c - 25 - 35cm d - 25 - 55cm

Fig.1. Bulk density.



● Overhead irri.
▲ Drip irri.
■ Bare land

Fig.2. Profile moisture content (to 100cm depth)

RESULTS AND DISCUSSION

Experiment 1

Profile moisture content related to irrigation regime

Figure 2 shows the profile moisture contents measured over the growing period, under the two irrigation systems compared with the moisture content in unirrigated bare land. The neutron probe data were collected about one hour after irrigation at each sampling date. The data shows that with overhead irrigation, about 10 – 15 mm of water moved down the profile after each irrigation while with drip irrigation the downward movement of water was minimal.

Yield parameters at harvest

Total tuber yield gradually increased with increase in N level and the highest yield was recorded with 160 N kg/ha. However further increases in N had a negative effect on total tuber yield (Table 3). Marketable yield too followed a similar trend. The increase in tuber yield was attributed mainly to the higher tuber number/plant. However percentage diseased tubers at harvest increased with the increasing N levels. A significant interaction between irrigation and N level was recorded for total tuber yield. Figure 3 shows the response to n with methods of irrigation. When these curves are extrapolated back, the curves for overhead and drip irrigation meet the X axis at – 200 and – 120 kg/ha of N respectively. This is an indication of the amount of N available to the amount of N available to the crop from sources other than fertilizer. Since the nutrient holding capacity of Regosols is considered to be negligible and the organic matter content extremely low (0.4%), the only major source of additional N was the irrigation water, which contained 11.5 N mg/l. Thus the amount of N supplied through irrigation water was calculated to be 165 and 100 kg/ha in overhead and drip irrigation respectively, and the difference, between this calculated amounts and the amounts estimated by extrapolation (20 – 35 kg/ha) could be attributed to contribution from other sources such as organic matter.

Growth parameters

Crop emergence was unaffected by the treatments. Other growth characters such as LAI, plant height, stem number were significantly influenced by N (Table 4). After emergence, interception of solar radiation by the crop is dependant upon canopy cover. Figure 4 shows

Table 3. Effect of Level and Frequency of N and method of irrigation on Yield Parameters.

Treatment	Total tuber yield t/ha	Marketable yield t/ha	Total tuber number/m^2	% Diseased tubers
Irrigation (I)				
Overhead	13.98	10.05	66.13	2.00
Drip	13.52	9.75	63.06	1.30
Frequency of N				
Basal + 1 t.d.	14.37	10.47	66.63	1.93
Basal + 4 t.d.	13.23	9.32	62.56	1.48
Level of N (kg/ha)				
0	11.94	8.27	61.75	1.23
40	12.22	8.80	60.83	1.46
80	14.14	10.50	63.66	1.32
160	16.42	11.98	71.91	2.01
320	14.02	9.95	64.83	2.65
I	n.s	n.s	n.s	n.s
T	n.s	n.s	n.s	n.s
N	*	*	*	*
N x I	*	n.s	n.s	n.s
N x T	n.s	n.s	n.s	n.s
I x T	n.s	n.s	n.s	n.s
N x T x I	n.s	n.s	n.s	n.s

* significant at 0.05% level, n.s. not significant at 0.05%

Table 4. Effect of level and frequency of N and irrigation on growth parameters.

Treatment	Emergence (%) at 2 WAP	% Canopy at 9 WAP	LAI at 9 WAP	Plant Height (cm) at 9 WAP
Irrigation (I)				
Overhead	79.3	63.3	1.00	35.8
Drip	87.2	70.2	1.19	45.8
Frequency of N				
Basal + 1 t.d.	85.7	65.7	1.08	41.2
Basal + 4 t.d.	81.0	68.1	1.11	40.4
Level of N kg/ha				
0	83.8	60.3	0.84	36.0
40	85.1	64.3	0.95	40.0
80	79.7	64.2	0.95	41.2
160	86.4	76.1	1.39	45.0
320	81.9	69.0	1.34	41.8
I	n.s	n.s	n.s	n.s
T	n.s	n.s	n.s	n.s
N	n.s	*	*	*
I x T	n.s	n.s	n.s	n.s
I x N	n.s	n.s	n.s	*
N x T	n.s	n.s	n.s	*
N x T x I	n.s	n.s	n.s	n.s

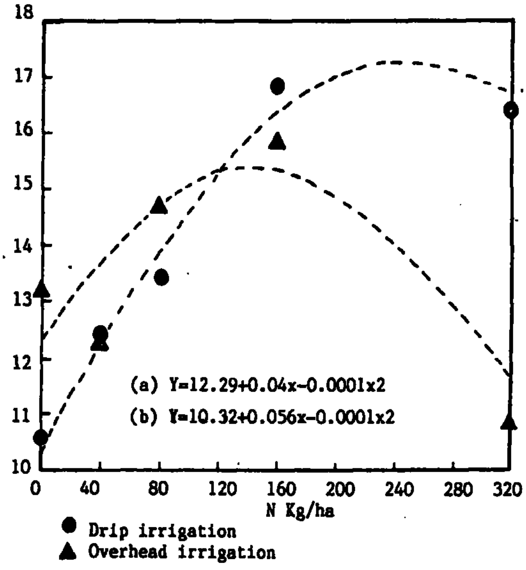


Fig.3. Relationship between total tuber yield and N levels for two irrigation methods.

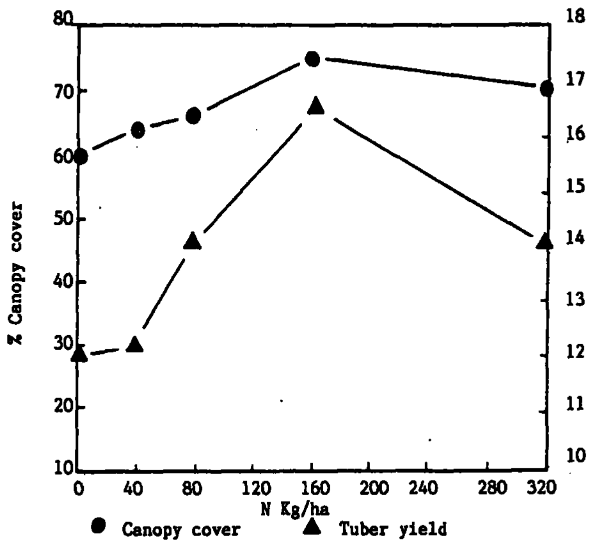


Fig.4. Maximum canopy cover as influenced by the level of N. (Average for two irrigation)

the influence of N on the maximum canopy cover obtained and tuber yield at 9 WAP. The highest tuber yield and canopy cover were recorded at 160 kg/ha, and further increase in N levels led to reduction in both canopy cover and tuber yield. Figure 5 illustrates the change in canopy cover with time with the application of 0 and 160 N kg/ha. The canopy duration (value equivalent to the number of weeks of full canopy cover) was estimated as 4.42 and 3.34 respectively for 160 and 0 N kg/ha, and this implies that under prevailing conditions the tuber yield was proportional to the canopy cover duration.

However, tuber yield showed no response to splitting N application under Kalpitiya conditions; and this may be due to the masking effect of N supplied through irrigation water. The tuber yields increased with N upto about 300 kg/ha of total available N and then decreased with further additions. There was evidence that this behaviour was independent of the method of irrigation suggesting that leaching of N had no significant influence on the productivity of potato under Kalpitiya conditions.

Burstall and Harris (1982) determined a linear relationship between canopy cover and intercepted radiation. the improved interception of light energy resulted in higher total and tuber dry-matter (Allen and Scott, 1980). In addition a quick crop cover should also favour soil cooling, providing more suitable environment for tuberization in warm conditions (Midmore, 1984).

Therefore, it can be concluded from this study that irrigation and fertilizer has only limited scope for yield improvement under Kalpitiya conditions; and there were evidence that changing crop architecture, to achieve the maximum canopy cover to improve the conversion efficiency of light energy to dry-matter, might be useful in improving the productivity of the potato crop.

Experiment 2

Dry-matter production inrelation to light interception

It has been shown that when water is not limiting, tuber yield is directly related to the total amount of radiation intercepted by the crop canopy (Allen and Scott, 1980). Therefor the potential yield of the crop will be fixed by the light energy received /unit area and how much of

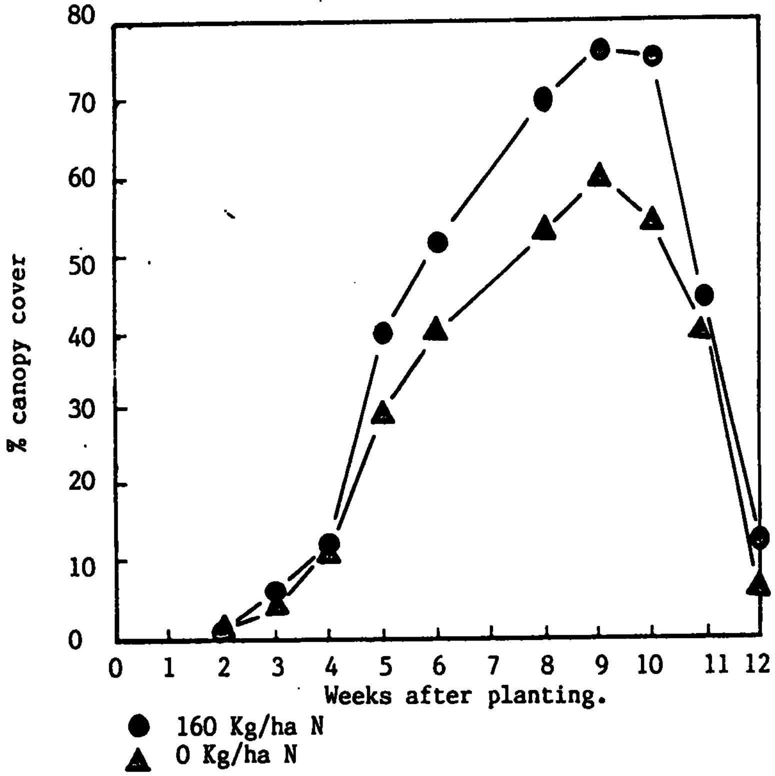


Fig.5. Change in canopy cover with time at 0 and 160 Kg/ha N.

this radiation is intercepted by the crop canopy. This in turn will depend upon the rate at which the canopy expands early in the season and for how long the canopy can be maintained. Figure 6 shows the percent ground cover against time for all treatment combinations. Shaded plots achieved maximum ground cover earlier compared with unshaded plots, and compacted plots lagged behind the uncompacted plots virtually from emergence. the amount of radiation intercepted by the crop was calculated by summing the amounts of incident radiation which was received each week multiplied by corresponding fractional ground cover. Total dry-matter production was plotted against cumulative intercepted radiation for shaded and unshaded treatments of varieties Cara and Wilja (Figure 7). The conversion coefficient (gradient of the lines) varied from 0.80 g/MJ (unshaded Cara) to 1.49 g/MJ (shaded Wilja).

Dry-matter production inrelation to water use:

Both total and tuber dry-matter have been reported to be linearly related to transpiration in potatoes (Tanner, 1981). Figure 8 shows that there is an linear relationship between water use (cumulative evapotranspiration, ET) and the total dry-matter yield. Table 5 shows the water use efficiencies ranged from 2.35 g dry-matter/kg ET (for shaded compacted) to 6.01 g/kg ET (for open uncompacted) when the total water use and the dry-matter production over the whole season was considered. There was no significant influence of shading or variety on the overall water use efficiency.

This variation may be explained by differences in partitioning of ET between transpiration (T) and evaporation from soil surface (E). Plots with least ground cover might be expected to loose proportionally more water through E, with a consequent reduction in water use efficiency when expressed on an ET basis. The evaporation from soil surface might be regarded as negligible during periods of complete ground cover. When the water use efficiency of the treatments during full canopy was considered, variety Wilja recorded higher water use efficiency (6.52 and 6.34 g/kg transpiration for shaded and open treatments respectively) than the variety Cara (4.67 and 5.24 g/kg transpiration respectively for shaded and open treatments).

Water relations

Evaporation of water vapour from the stomatal cavity was calculated from the diffusion porometer data. The canopy evaporation was found

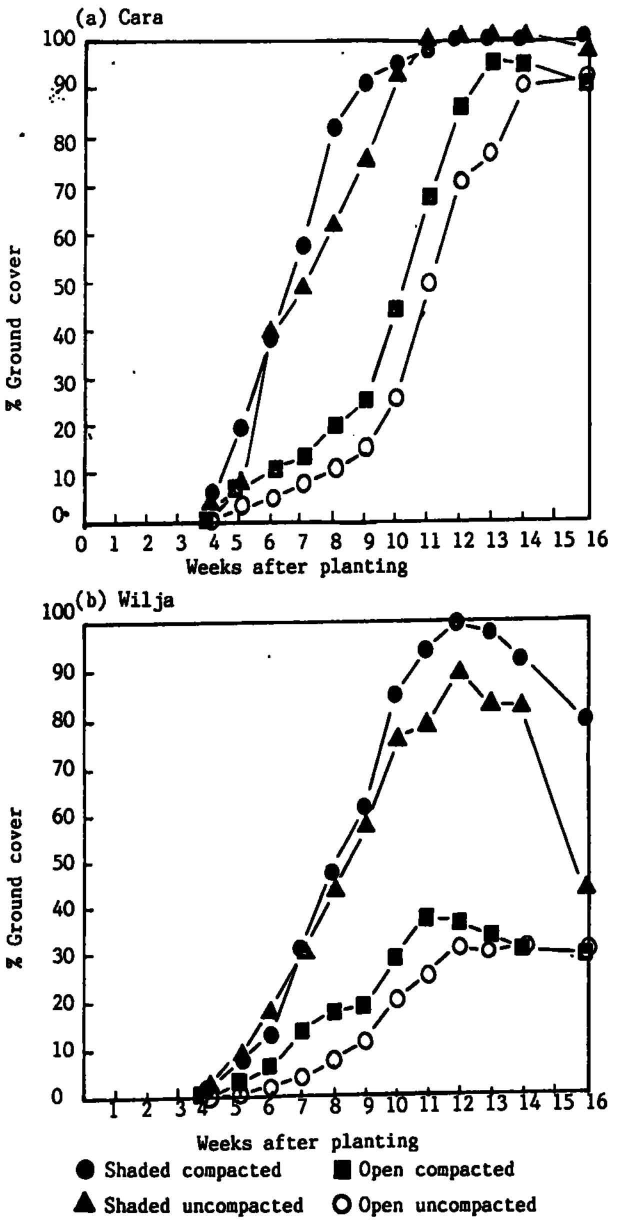
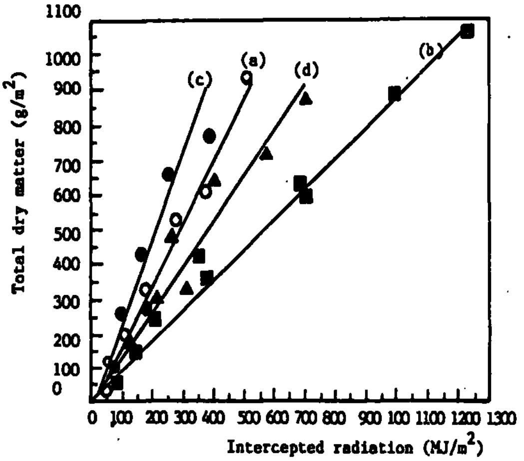
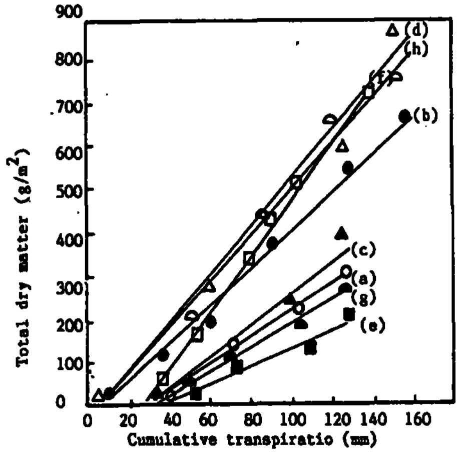


Fig.6. Ground cover against time.



(a) Y=34.6+1.28X(R^2=0.97) Cara shaded ○
(b) Y=49.3+0.80X(R^2=0.99) Cara open ■
(c) Y=34.9+1.49X(R^2=0.97) Wilja shaded ●
(d) Y=42.9+0.97X(R^2=0.95) Wilja 0pen ▲

Fig.7. Intercepted radiation against total dry matter.



(a) Cara shaded compacted ○
(b) Cara shaded uncompacted ●
(c) Cara open compacted ▲
(d) Cara open uncompacted △
(e) Wilja shaded compacted ■
(f) Wilja shaded uncompacted □
(g) Wilja open compacted
(h) Wilja open uncompacted

Fig.8. Total dry matter production against cumulative transpiration.

to be significantly reduced in compacted plots throughout the growth period (Table 6). It would be expected that canopy evaporation to be greater in uncompacted plots due to higher ground cover in these plots. Eavis and Taylor (1979), showed that transpiration rates of soybeans, increased linearly with leaf area in wet soils, and decreased linearly as soil water content decreased. Figure 9 shows the effect of LAI and soil water potential on transpiration rates of the varieties Cara and Wilja under compacted open and uncompacted shaded conditions. Although transpiration tend to increase with leaf area, it was observed that it depends on other factors such as soil water potential. The Ohms Law analogue, suggests that transpiration will be related to leaf water potential. Figure 10, pooling data from all treatments, shows that, as expected fast transpiration rates were associated with low leaf water potentials. The solid line shows the prediction, based on previous experiments at Sonning (Grime, 1987) of the relationship between transpiration and leaf water potential that would be obtained in the absence of soil water stress. This line was calculated from knowledge of the resistance per unit length of root for the variety Cara (obtained from past experiments at Sonning) and the overall length of the root system (C. 5 km/m^2 for Cara in this experiment). It appears that, for a given leaf water potential, the predicted transpiration rate for a freely transpiring crop is close to the maximum rate observed. Most of the data in Figure 10 falls below the solid line indicating that for most of the season there was substantial water stress. The dashed line shows, in principle how soil drying may effect the relation between transpiration and leaf water potential. First, there will be non-zero intercept on the X axis the intercept being a measure of the 'effective' soil water potential. Second, the slope of the line might decrease, as a consequence of increased resistance to water flow through soil with low hydraulic conductivity.

The work to date has led to the hypothesis that the principle reason for low potato yields at Kalpitiya peninsula is poor canopy development as a result of tissue water stress induced by a large evaporative demand. In principle therefore, yields might be increased by two different strategies;

a) Reducing tissue water stress, and thereby increasing the leaf area produced per plant.

or

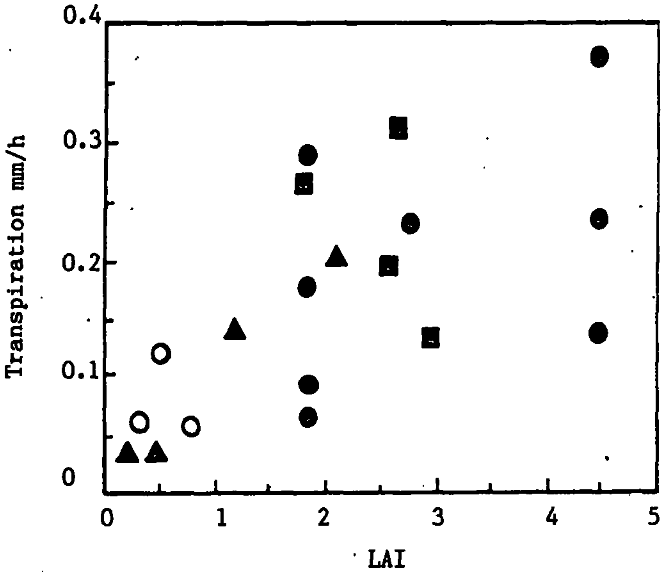


Fig.9. (a) Effect of LAI on canopy transpiration

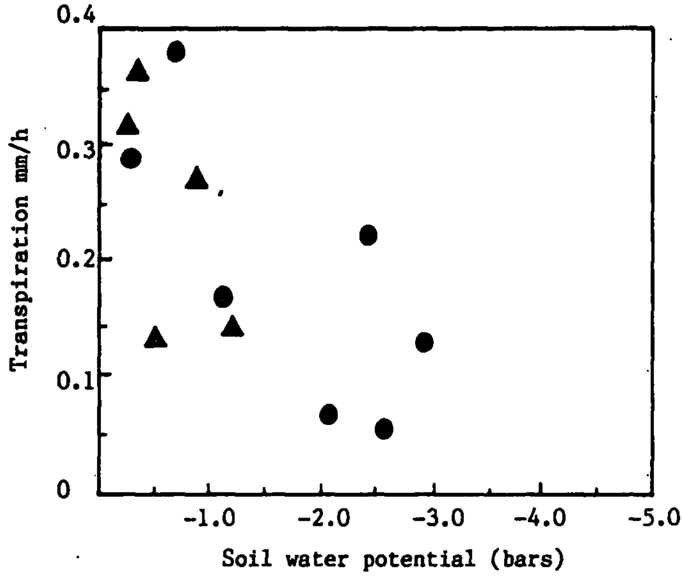


Fig.9. (b) Effect of soil water potential on canopy transpiration.

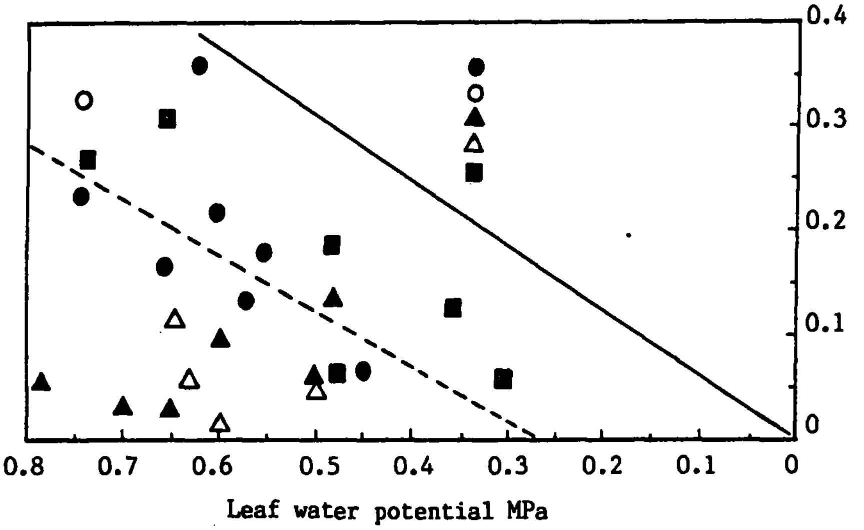


Fig.10. Effect of leaf water potential on the rate of transpiration.

Table 5. Water use efficiency

Treatment	Over the whole season Cara	Over the whole season Wilja	At full canopy cover Cara	At full canopy cover Wilja
Shaded compacted	2.78	2.09	3.25	–
Shaded uncompacted	4.98	6.19	4.67	6.52
Open compacted	3.50	2.64	4.76	–
Open uncompacted	6.24	5.79	5.24	6.34

Table 6. Canopy transpiration rate (mm/h)

	Cara				Wilja			
	Shaded		Open		Shaded		Open	
W.A.P.	C	U	C	U	C	U	C	U
5	.015	.175	.037	107	–	–	–	–
6	.002	.074	.014	.062	.003	.036	.005	.028
7	.009	.013	–	.030	.002	.034	.004	.034
8	.069	.230	.032	.157	.030	.270	.061	.182
9	.138	.231	.145	.305	.063	.316	.123	.260
12	.130	.373	.157	.400	.030	.135	.055	.173

C – Compacted
U – Uncompacted

b) Overcoming the problem of small leaf area per plant by reducing spacing to increase leaf area index.

In future experiments will be investigated these possibilities and tissue water stress may be alleviated by shading either artificially or by 'live' shade.

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