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Comparison of the growth of potato crops grown in autumn and spring in North Africa

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Summary

The relationships between intercepted solar radiation and dry matter production (total and tubers) were established for four cultivars of different maturity classes and using seed tubers of two physiological ages. The crops were grown in an autumn and a spring season in Tunisia. Radiation use efficiencies were lower in autumn than in spring and the quantity of intercepted radiation at tuber initiation was more than two times greater in autumn than in spring due to retarded tuberization in the autumn caused by the relatively high temperatures. In addition, tuber dry matter, number of stems per plant, tubers per stem and harvest indices were all lower in the autumn than in the spring season which explained why tuber yields in the spring season were higher than in the autumn.

Introduction

Potato crops in North Africa are mainly grown in two seasons; a spring crop grown from imported seed, and an autumn crop grown from seed tubers produced locally in the previous spring. Potatoes are neither grown in summer in the lowlands due to the high temperatures nor in winter in continental areas due to the risks of night frost in January. In some coastal areas a winter crop is planted around November with either imported or locally produced seed potatoes. In many parts of North Africa (Egypt, Morocco) the yield of this early crop is exported.

In Tunisia, where the work described here was carried out, about 240000 t of potatoes are produced annually on about 5000 ha in autumn, 2000 ha in winter and 8000 ha in spring. Yields on farms are lowest in the autumn (8–10 t ha^{-1}) and highest in the spring (15–20 t ha^{-1}), although experimental station yields of over 40 t ha^{-1} have been recorded in both seasons. The low yields in autumn compared with those of spring are only partly explained by the lower quality of the locally produced seed tubers which may have more tuber-borne pathogens and which may be physiologically younger than the seed imported from northern Europe used for the spring planting. The relatively long days and high temperatures at the initial stages of crop growth in autumn favour foliar development rather than tuber initiation and tuber growth (Steward et al., 1984; Bodlaender, 1963). Manipulation of the age of the seed tubers

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and the use of better adapted genotypes that tuberize well under high temperature conditions (Ewing et al., 1984) may partly overcome some of the problems associated with growing potatoes in the autumn.

The research described here was carried out to study the crop components affecting tuber dry matter production in the two contrasting seasons as influenced by cultivar and seed age. The work focussed mainly on the interception of photosynthetically active radiation (PAR), the efficiency with which intercepted PAR is converted into dry matter, and the distribution of dry matter to the foliage and the tubers. Good linear relations between intercepted solar radiation and dry matter production were found both under conditions of temperate climates (Allen & Scott, 1980) and under tropical highland conditions (Haverkort & Bicamumpaka, 1986; Haverkort & Rutayisire, 1986 and Haverkort & Harris, 1986, 1987). This approach provides the most concise way in which to present the data and the best way to compare the trials carried out in different seasons with a range of treatments.

Material and methods

Description of the climate. The experiments were carried out at Saïda in Tunisia (36° 50′ North, 9° 55′ East) located at an altitude of 328 m above sea level. Daylengths (Fig. 1) ranged from 13.5 hours at planting to 9.60 hours at crop maturity in the autumn and from 10.8 to 14.8 hours in spring. Figure 1 also shows the number of hours of bright sunshine as measured with a heliograph; cloudiness was more marked in winter from November to March (about 60 %) than in early autumn and late spring (about 30 %).

Daily global solar radiation was measured *in situ* with a distillation based Gunn-Bellani solar radiation integrator calibrated against a Kipp-thermopile solarimeter by

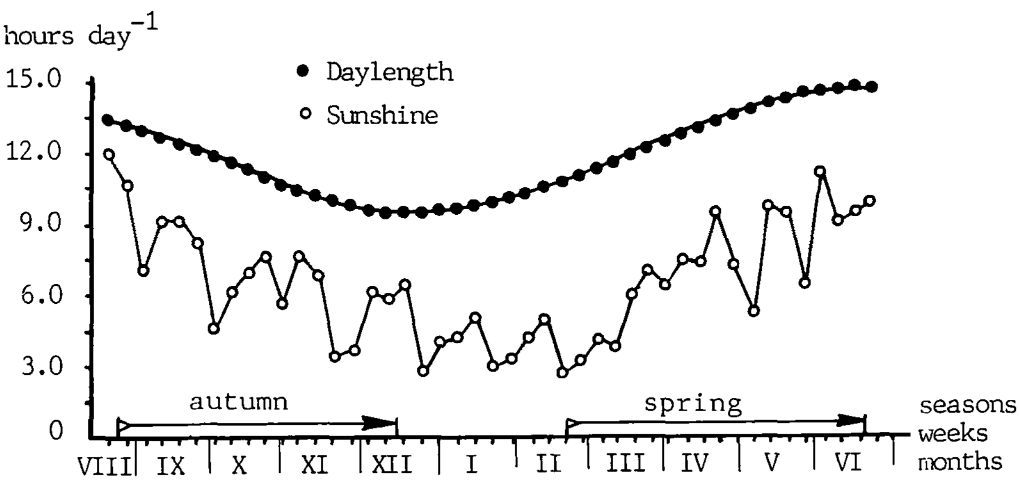

Fig. 1. Mean weekly values of daylength and number of hours of sunshine per day recorded at the trial site in autumn 1986 and spring 1987.

the National Meteorological Service. Photosynthetically active radiation (PAR) between 400 and 700 nm (Fig. 2) was taken to be 0.5 × global radiation (Monteith, 1972). The measured PAR approached potential PAR on cloudless days (Goudriaan & van Laar, 1978) and fell from about 14 to 5 MJ m^{-2} day^{-1} in the autumn season and increased from about 5 to 14 MJ m^{-2} day^{-1} in the spring season.

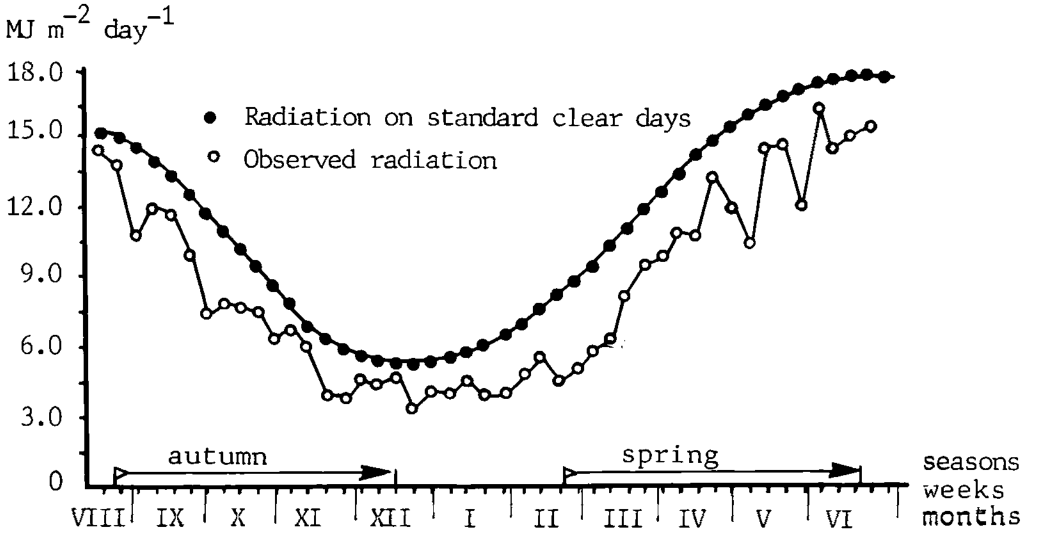

Fig. 2. Mean weekly values of photosynthetically active radiation on standard clear days and daily radiation recorded at the trial site in autumn 1986 and spring 1987.

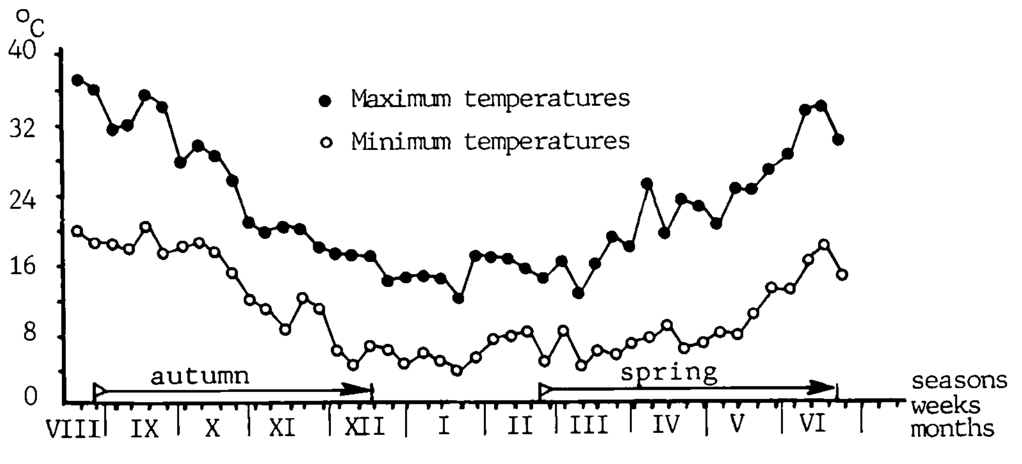

Fig. 3. Mean weekly maximum and minimum temperatures per day recorded at the trial site in autumn 1986 and spring 1987.

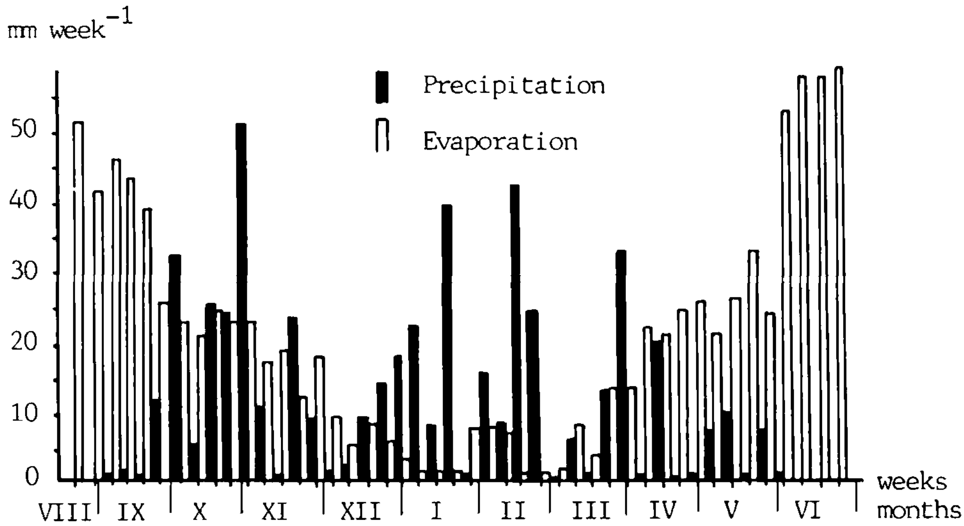

Fig. 4. Total weekly precipitation and open pan evaporation recorded at the trial site in autumn 1986 and spring 1987.

Daily maximum and minimum temperatures (Fig. 3) reflect the contrasting conditions of the two seasons with respect to daylength (Fig. 1), and radiation (Fig. 2); but temperatures limit the growing seasons to a greater extent. Minimum temperatures fell from 20 to 4 °C in autumn and rose to 20 °C again in the spring while maximum temperatures ranged between 10 and 35 °C.

Potato crops in North Africa are irrigated during most of crop growth. Precipitation deficits (Fig. 4) occur mainly at the beginning of the autumn season and at the end of the spring season. Total rainfall in the 1986 rainy season was over 450 mm for the two crops. To assure absence of drought stress, additional furrow irrigation was applied at 4–5 days intervals during dry periods.

Implementation of the field experiments. The field trials were planted with four cultivars: Atica (early), Claustar (mid-late), Désirée (late, long dormant period) and Spunta (mid late). The last cultivar is the one most widely grown in Tunisia and is reputed to perform well in both the spring and the autumn seasons. The seed for the 1986 autumn season was harvested in early June 1986 at Saïda and stored under ambient conditions (Fahem & Haverkort, 1987) to obtain 'old' seed, and for one month at 6 °C in a cold store to obtain 'young' seed. Seed tubers for the spring season were either imported (young seed) or locally produced in the previous spring and stored in the cold store (old seed). Degeneration of the local seed multiplied once in Tunisia was not serious as only an occasional PVY infected plant was observed.

The trials were planted in a completely randomized block design with 4 replicates. The plot size was 4 rows (3 m) × 30 plants (9 m). The plots were separated by a guard row of cv. Désirée. At planting 50 kg N (as ammonium nitrate), 180 kg P_2O (as super phosphate) and 200 kg K_2O (as potassium sulphate) were applied and another 50 kg of N was applied at the first hilling. These NPK applications were as recommended for potatoes on the deep loamy clays of the lower Medjerda valley.

Data collection. The proportion of ground covered with green foliage was estimated with the aid of a light metal frame, split into 80 squares, viewed directly from above. The dimensions of the frame were a multiple of the planting pattern: 75 cm × 90 cm. Two readings per plot were taken once a week. To calculate intercepted radiation per week, the proportion of ground cover (mean value of the two readings) was multiplied by the total observed PAR of that week as shown by Burstall & Harris (1983). Harvests took place every two weeks starting about two weeks after emergence. Fresh weight of foliage and tubers of 8 plants per plot were taken and samples dried at 105 °C for 40 hrs. The 'foliage' included leaves, stems, stolons and a few attached roots after lifting the plant. In all there were, five harvests. In the autumn, total dry matter was measured for the first three and in spring for the first four harvests. Thereafter foliage losses occurred due to leaf drop. Tuber dry matter was observed for the last four harvests.

Results and discussion

The ground was better covered with green foliage in the autumn than in the spring season (Fig. 5). Although the length of the growing season from planting to maturity was two weeks longer in the spring than in the autumn, a greater proportion of the ground was covered in the autumn resulting in a ground cover duration for old and young seed of 46.7 and 47.4 days respectively, whereas it was only 36.4 and 36.5 days in the spring. Ground cover duration was calculated as the cumulative values of the weekly (seven days) proportion of ground cover multiplied by seven. Its value in days per season shows to how many days of 100 % ground cover the observed ground cover throughout the season corresponds.

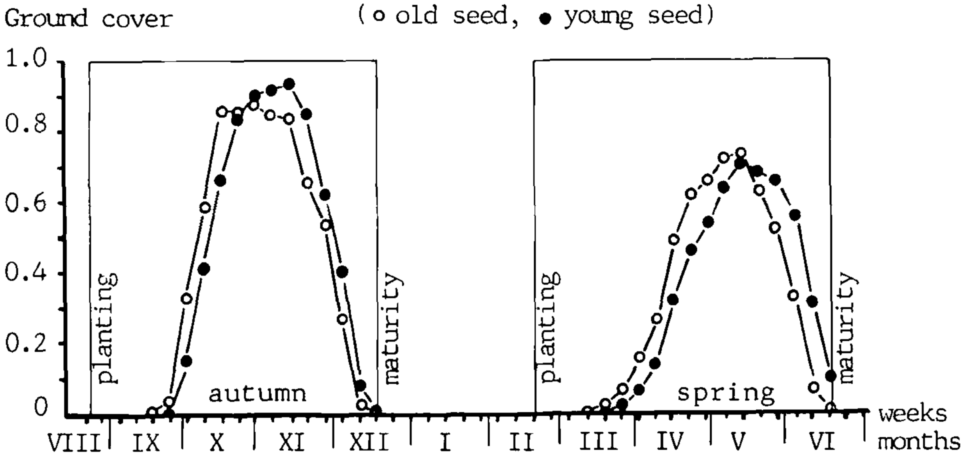

Fig. 5. Proportion of ground covered by leaves in the autumn 1986 and spring 1987 seasons, mean values of 4 cultivars.

The age of the seed tuber did not influence total ground cover duration but ground cover development was brought forward 9 days in the autumn and 18 days in the spring by using old seed tubers. The greater difference in spring was due to the greater difference in the physiological age of the seed and the delaying effect of low spring temperatures. Total PAR between planting and harvest was 866 MJ m^{-2} of which 336 MJ m^{-2} (about 40 %) was received before emergence in the autumn; in spring 1373 MJ m^{-2} was recorded of which only 150 MJ m^{-2} (about 10 %) was received between planting and emergence. The relatively low proportion of ground cover in the spring was compensated by the much higher radiation levels leading to higher amounts of intercepted PAR per week (Fig. 6). Maximum intercepted radiation (IR) in the autumn did not exceed 6 MJ m^{-2} day^{-1} while it exceeded 10 MJ m^{-2} day^{-1} in the spring. For the whole season, when averaged over all treatments, total intercepted PAR in spring was 457 MJ m^{-2} compared with 293 MJ m^{-2} in the autumn.

The relationships between IR and dry matter production were highly significantly linear, with $r > 0.99$ for all regression lines, both for total dry matter and tuber dry matter (Fig. 7). The physiological age of the seed had no effect on the relationship between intercepted PAR and total dry matter production in the autumn and spring crops. The radiation use efficiency (RUE) was 2.11 g per MJ PAR intercepted. RUE for tuber dry matter production were lower, 1.84 g MJ^{-1} in spring and 1.68 g MJ^{-1} in autumn, while tuber initiation started at much higher levels of intercepted radiation in autumn since tuber initiation in autumn took place at higher plant weights (Fig. 8). Apparent tuber initiation which took place at 88 g m^{-2} in spring and 214 g m^{-2} in autumn when planting physiologically younger seed was further retarded by the use of physiologically older seed tubers to 137 and 235 g m^{-2} respectively.

Figure 7 shows the Y-IR relationships for the means of the four cultivars used, whereas Table 1 gives the range of efficiencies calculated for the different cultivars (mean

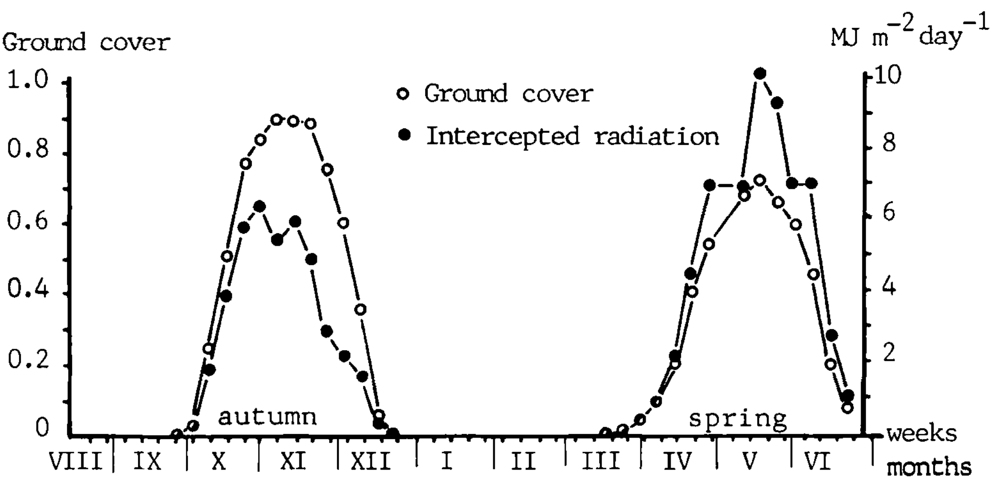

Fig. 6. Mean weekly values of the proportion of ground covered by leaves and intercepted radiation per day in the autumn 1986 and spring 1987 seasons, mean values of four cultivars and 2 seed ages.

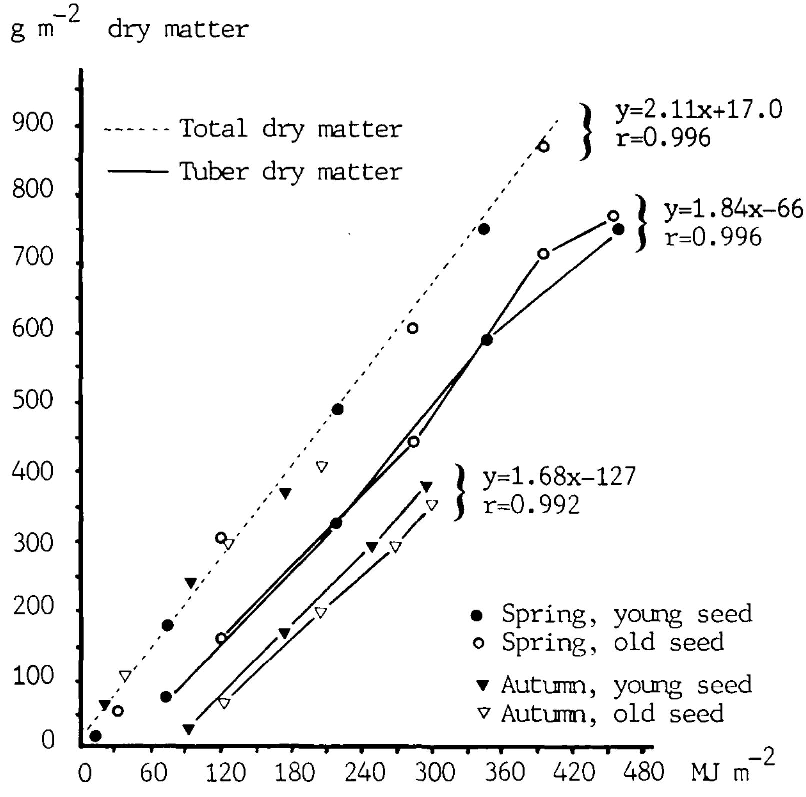

Fig. 7. Relationships between yields and intercepted radiation observed in the autumn 1986 and spring 1987 seasons, mean values of 4 cultivars (F^2_{12} = 4.9 for the slopes and F^2_{12} = 9.43 for the intercepts).

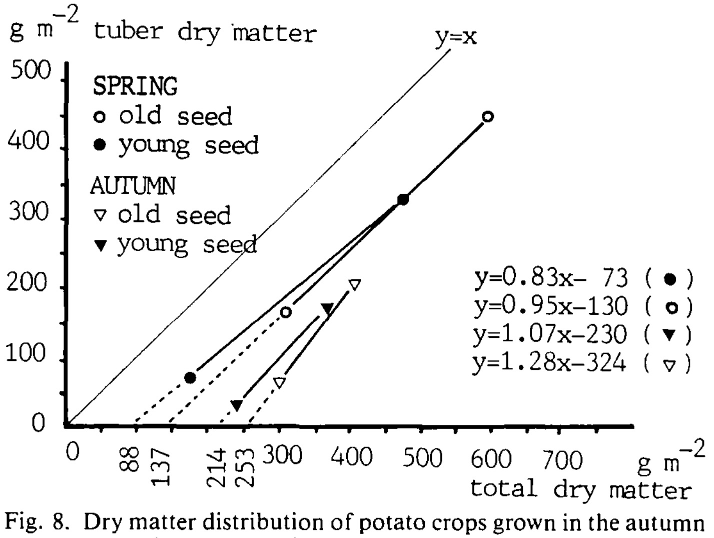

Fig. 8. Dry matter distribution of potato crops grown in the autumn 1986 and spring 1987 seasons, mean values of 4 cultivars at the second and third harvests.

Table 1. The effect of cultivar on radiation use efficiency (RUE in g MJ^{-1}) and on the quantity of intercepted radiation at tuber initiation (IR_{ti} in MJ m^{-2}). Values with different letters per row and all values of the column with mean data differ significantly ($P \leq 0.05$, F_{test}).

Season	Observation	Atica	Claustar	Désirée	Spunta	Weighted means
Autumn	RUE_{total}	1.79	1.95	2.23 ^{a}	1.67 ^{b}	1.91
Spring	RUE_{total}	2.04	2.13	2.22	2.24	2.14
Autumn	RUE_{tuber}	1.69 ^{a}	1.63	1.71	1.82 ^{b}	1.68
Spring	RUE_{tuber}	1.98 ^{a}	1.90 ^{a}	1.65 ^{b}	1.76 ^{b}	1.84
Autumn	IR_{ti}	77.1 ^{a}	50.7 ^{b}	93.0 ^{a}	94.8 ^{c}	75.6
Spring	IR_{ti}	33.4 ^{a}	51.8 ^{a}	23.5 ^{b}	7.85 ^{b}	35.9

values of the two seed ages). In the autumn RUE_{total} ranged from 1.67 g MJ^{-1} for Spunta to 2.23 g MJ^{-1} for Désirée. The relatively high value for Désirée may have been due to its late emergence wherebye it escaped the early autumn high temperatures. Differences of efficiencies were less marked in spring (2.02–2.24 g MJ^{-1}) and the mean values of the efficiencies of the four cultivars were higher in spring than in autumn both for total and for tuber dry matter production, due to the lower temperatures in spring which presumably reduced respiration rates and retarded leaf drop. The increased mean temperature and radiation levels between the last two sample harvests in spring may also have been responsible for the decrease in RUE_{tuber} (Fig. 7) and the relatively low RUE_{tuber} of 1.65 g MJ^{-1} for Désirée in spring (Table 1) due to its lateness. Similar decreases of efficiencies associated with higher temperatures and increased solar radiation were quantified for tropical highland conditions by Haverkort & Harris (1987). There is also a tendency ($r = 0.85$ in autumn and 0.65 in spring) for higher values of intercepted radiation at tuber initiation (IR_{ti}) to be associated with higher conversion coefficients between intercepted radiation and tuber dry matter production, in agreement with the findings of Haverkort & Harris (1986). However, the higher IR_{ti} value of 78.9 MJ m^{-2} in autumn compared with 29.1 MJ m^{-2} in spring was not associated with a higher efficiency because of the higher autumn temperatures. The efficiences of about 2 g MJ^{-1} (PAR) are not comparable to those found in northern Europe by MacKerron & Waister (1985) who reported 1.43–1.84 g MJ^{-1} (global radiation). In Tunisia radiation interception was measured differently which may account for the difference, while temperatures and solar radiation levels were higher which may have reduced efficiency rates. The higher proportion of direct solar radiation received compared to the cloudy, more diffuse light of northern Europe may have further reduced efficiency rates (Britton & Dodd, 1976).

In addition to different radiation use efficiencies, a number of crop characteristics differed between the autumn and the spring season (Table 2). Tuber dry matter content was 15.1 % in autumn but 20.2 % in spring. This led to fresh weight tuber yields in spring exceeding those in the autumn by only 50 % although dry matter production was 100 % higher in spring; 7.62 t ha^{-1} instead of 3.67 t ha^{-1}. Tuber dry matter content in autumn was reduced by increased age of the seed tuber (14.9 % instead of 15.3 %), which might be attributed to the shorter tuber bulking period of the crops grown from young seed and because crops from older seed tuberize earlier at higher

Table 2. Crop characteristics of the four cultivars at maturity; the harvest index was calculated as tuber yield at maturity divided by tuber yield at maturity plus highest observed foliage yield in the third or fourth harvest.

Season	Cultivar	Seed age	Final yield tubers fresh (t ha^{-1})	% dry matter	Final yield tubers dry (t ha^{-1})	Stems $plant^{-1}$	Tubers $plant^{-1}$	Tubers $stem^{-1}$	Harvest index
Autumn 1986	Spunta	young	27.2	15.1	4.11	2.19	2.99	1.37	0.62
		old	26.0	15.0	3.90	2.68	2.94	1.10	0.57
	Atica	young	22.3	15.0	3.34	1.84	3.02	1.64	0.66
		old	19.6	15.1	2.96	1.90	3.18	1.67	0.60
	Claustar	young	26.1	15.0	3.91	1.82	3.00	1.64	0.68
		old	25.4	13.8	3.51	2.13	2.96	1.39	0.63
	Désirée	young	25.0	16.0	4.00	2.44	2.82	1.16	0.58
		old	23.3	15.7	3.65	2.26	2.70	1.19	0.59
	$LSD_{0.05}$		2.9	0.3	0.49	0.43	0.27	0.22	0.09
	Mean data	young	25.2	15.3	3.84	2.07	2.96	1.45	0.64
	Mean data	old	23.6	14.9	3.51	2.24	2.95	1.34	0.60
Autumn 1986	Mean data		24.4	15.1	3.67	2.16	2.95	1.40	0.62
Spring 1987	Spunta	young	38.9	19.1	7.44	3.28	9.53	2.91	0.83
		old	33.7	19.2	6.48	3.50	12.16	3.47	0.83
	Atica	young	34.7	20.2	7.01	3.25	11.22	3.45	0.83
		old	36.3	19.5	7.07	3.78	16.72	4.42	0.86
	Claustar	young	41.7	18.6	7.76	2.44	11.09	4.55	0.80
		old	49.0	19.5	9.55	3.53	15.28	4.33	0.83
	Désirée	young	34.5	22.6	7.80	2.47	13.44	5.44	0.77
		old	33.9	22.9	7.76	4.50	14.09	3.13	0.80
	$LSD_{0.05}$		4.5	0.4	0.92	0.71	1.22	0.43	0.06
	Mean data	young	37.5	20.1	7.50	2.86	11.32	4.09	0.81
	Mean data	old	38.2	20.3	7.72	3.83	14.56	3.84	0.83
Spring 1987	Mean data		37.8	20.2	7.62	3.34	12.94	3.96	0.82

temperatures in autumn, which also causes reduced dry matter content (Haverkort & Harris, 1987; Ben Khedher & Ewing, 1985). The longer growing season at lower temperatures was probably responsible for the higher tuber dry matter content in spring. The number of stems per plant did not differ significantly between old and young seed in the autumn since both seed types were still relatively young. The numbers were significantly different in spring when the number per plant was 3.34 compared with 2.16 in the autumn, probably because of the increased physiological age of the seed. The number of tubers per plant was 4 times higher in spring mainly because of a higher number of tubers per main stem (3.96 in spring compared with 1.40 in autumn). In autumn, no stolons, or only very short ones were produced. These phenomena may have been caused by the rapid change from the long day-high temperature conditions to the short day-low temperature conditions which brought about tuber initiation and growth within a very short period, limiting stolon growth and preventing the initiation of a high number of tubers. As expected, harvest indices were higher in spring due to tuber initiation taking place at lower plant weights.

Conclusions

In these experiments spring was, overall, the best season for potato production in North Africa mainly because of the advantageous lag time in spring between solar radiation and temperatures and the disadvantageous lag in autumn. At similar daylength of 12 hours in autumn and spring, i.e. around the equinox on September 21 and March 21, the PAR was about 10 MJ m^{-2} day^{-1}, but the temperatures were much more favourable for potato crop growth in March, with maximum temperatures of 20 °C, than in September with maximum temperatures of 35 °C.

Conversion coefficients between intercepted radiation and total dry matter production (radiation use efficiencies) were 13 % higher in spring than in autumn. In spring, tuber initiation started at lower plant weights and lower levels of radiation interception, the spring value being less than half the autumn value, and led to higher harvest indices. Radiation use efficiencies hardly differed between cultivars in spring, but in autumn they ranged from 1.67 g MJ^{-1} (Spunta) to 2.35 g MJ^{-1} (Désirée). These differences were mainly attributed to an escape from the initial high temperatures (which cause losses through higher respiration rates) by late emergence. Although apparent tuber initiation in autumn at high levels of intercepted radiation was associated with higher conversion coefficients between intercepted radiation and tuber dry matter production, this advantage was offset by the lower harvest indices.

This study showed that the early cultivar, Atica, advantageous for marketing, did not make full use of the favourable period for potato crop growth and its yields were the lowest of the four cultivars tested in both seasons. The 1987 spring period was relatively cool and higher temperatures were recorded only towards the end of the season so that the potential of the early variety to escape from the consequences of high temperatures through earliness was not expressed. The three later cultivars performed equally well within each season. Physiologically older seed tubers were not an advantage in the autumn, especially with cultivars with a short dormant period, because of the higher temperatures encountered during the early stages of growth. In spring, older seed was only advantageous for the late cultivar Claustar which produced 10 t ha^{-1} tuber dry matter from the locally produced older seed compared with 7.76 t ha^{-1} from the imported seed; it also showed an escape from the higher temperatures encountered at the end of the spring.

The relationships between intercepted radiation and dry matter production and the distribution of dry matter between foliage and tubers, adequately described crop phenomena leading to tuber yield in the crops studied in the two contrasting seasons. The work showed that the unexplained, 'other factors than ground cover duration and proportion of light interception involved in tuber yield', (Levy et al., 1986) are the distribution of solar radiation throughout the growing season (Fig. 2), the influence of temperature on the conversion coefficient between PAR and dry matter production, the distribution of dry matter and, finally, tuber dry matter content.

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References

Allen, E. J. & R. K. Schott, 1980. An analysis of the growth of the potato crop. *Journal of agricultural Science, Cambridge* 94: 583–606.

Ben Khedher, M. & E. E. Ewing, 1985. Growth analysis of eleven potato cultivars grown in the greenhouse under long photoperiods with and without heat stress. *American Potato Journal* 62: 537–555.

Britton, C. M. & J. P. Dodd, 1976. Relationships of photosynthetically active radiation and short wave irradiance. *Agricultural Meteorology* 17: 1–7.

Burstall, L. & P. M. Harris, 1983. The estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *Journal of agricultural Science, Cambridge* 100: 241–244.

Ewing, E. E., M. Ben Khedher, E. J. Batutis & R. G. Snyder, 1984. Partitioning of dry matter in the potato implications for modelling. Abstracts 9th Triennal Conference European Association for Potato Research (Interlaken) 344–345.

Fahem, M. & A. J. Haverkort, 1987. Stockage de pommes de terre de consommation issues de la culture de saison en Tunisie. Abstracts 10th Triennal Conference European Association for Potato Research (Aalborg): 51–52.

Goudriaan, J. & H. H. van Laan, 1978. Calculations of daily totals of gross CO_2 assimilation of leaf canopies. *Netherlands Journal of agricultural Science* 26: 373–382.

Haverkort, A. J. & M. Bicamumpaka, 1986. Correlation between intercepted radiation and yield of potato crops infested by *Phytophthora infestans* in central Africa. *Netherlands Journal of Plant Pathology* 92: 239–247.

Haverkort, A. J. & C. Rutayisire, 1986. Utilisation des engrais chimiques sous conditions tropicales. 2. Effet de l'application d'azote, phosphore et potasse sur la relation entre la radiation interceptée et le rendement de la pomme de terre en Afrique centrale. *Potato Research* 29: 357–365.

Haverkort, A. J. & P. M. Harris, 1986. Conversion coefficients between intercepted solar radiation and tuber yields of potato crops under tropical highlands conditions. *Potato Research* 29: 529–533.

Haverkort, A. J. & P. M. Harris, 1987. A model for potato growth and yield under tropical highland conditions. *Agricultural and Forest Meteorology* 39: 271–282.

Levy, D., L. Livesku & D. E. van der Zaag, 1986. Double cropping of potatoes in a semi-arid environment; the association of ground cover with tuber yields. *Potato Research* 29: 437–449.

MacKerron, D. K. L. & P. D. Waister, 1985. A simple model of potato growth and yield, part 1: Model development and sensitivity analysis. *Agricultural and Forest Meteorology* 34: 241–252.

Monteith, J. L., 1972. Solar radiation and productivity in tropical ecosystems. *Journal of applied Ecology* 9: 447–466.

Steward, F. C., U. Moreno & W. M. Roca, 1981. Growth, form and composition of potato plants as affected by environment. Supplement to *Annals of Botany* 48: 45 pp.