GROWTH, DEVELOPMENT AND YIELD OF POTATOES

by

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TO MY PARENTS

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GROWTH, DEVELOPMENT AND YIELD OF POTATOES

ABSTRACT

Experiments were conducted in growth rooms to study the photoperiodic response of Pentland Crown. In field experiments the effects of sprouting techniques and the possibility of mixing of different physiologically aged tubers and a use of plant growth regulator, pp333 were studied. Sprout growth of the tubers used for planting was studied during storage. Light interception in the photosynthetically active range (PAR), was measured in the crop canopies. Relevant literature relating to the present investigation was briefly reviewed.

Tuberization in Pentland Crown was stimulated by relatively, short days, lower temperature and higher irradiance. pp333 allowed closer plant spacing (61 x 20cm) without any visible crowding effect, further it increased the allocation of assimilates to the tubers, which resulted in higher tuber yields and with a higher proportion of medium sized tubers.

Sprout growth was linearly related to the initial tuber weight and day degrees above $4^{\circ}C$ from dormancy break. Storing tubers in the cold before planting increased the sprout number and thus the proportion of main stems in the field. Time to reach 50% emergence was not reduced with increases in physiological age over 80 day degrees above $4^{\circ}C$. Cold (tubers stored at $3 \pm 1^{\circ}C$ until a day before planting) delayed tuber initiation but once the tuber had been initiated then the effect of physiological age disappeared and further tuber or overall plant growth or development was no more affected by the physiological age of the seed tuber. Yields from mixing different physiologically aged

tubers were not different from those expected.

The major factor affecting the growth of the crop was the water supply. The overall photosynthetic conversion effeciency of the canopy (g dry weight MJ^{-1} PAR intercepted) was 3.42g in 1980 in absence of any apparent water stress while in 1979 it was only 2.49g due to water stress.

INTRODUCTION

Crop canopy is basically a converter of solar energy to dry matter. Potato crop growth has been considered only in terms of leaf area index (LAI), leaf area duration and net assimilation rate. Crop growth rate for various agricultural crops has been found to be positively correlated to the light intercepted by the canopy (Biscoe and Gallagher, 1977; Williams et al., 1965). Published reports on light interception in potatoes are few (Scott and Wilcokson, 1978).

There appear to be a considerable genetic difference in the photoperiodic dependence of potatoes (Murti et al., 1975; Mendoza and Haynes, 1976). Potatoes are planted at different times in the field due to various reasons such as weather. It is accepted that there is a balance between growth of tubers and rest of the plant, anything which favours the growth of one will retard the growth of others (Moorby, 1978; Ivins and Bremner, 1965).

Varieties differ in their rates of sprout growth at a given temperature (Headford, 1962; Short and Shotton, 1970). Physiologically old seed has been found to increase tuber yield early in the season but the effect changed as the harvesting was delayed and in some cases it became negative (O'Brien and Allen, 1978; Allen et al., 1979) which was associated with lower LAI in the case of old seed, which may be overcome by manipulating spacing. Higher tuber yields have been reported by mixing early and late crop varieties (Schepers and Sibma, 1976), but the mixed product may be only useful for starch industry or other uses for which a mixed product is acceptable.

In this thesis response of Pentland Crown to photoperiod and irradiance is studied in Growth rooms. Effects of physiological age,

spacing, sprouting techniques, mixing of different physiologically aged tubers and pp333 (plant growth regulator, ICI) has been studied in the field by sequential harvests for crop growth analysis along with regular light measurements.

2. PHOTOPERIOD AND LIGHT

2.1 LITERATURE REVIEW

Effects of environment have long been recognised as among the most important factors influencing tuber formation by the potato plant (Garner and Allard, 1923; Bushnell, 1925; McClelland, 1928; Doroshenko et al., 1930; Arthur et al., 1930; Werner, 1940; Driver and Hawkes, 1943). There is almost general agreement that environmental factors which stimulate haulm growth also delay or inhibit tuberization.

2.1.1 Effects of photoperiod

There appear to be considerable genetic differences in the photoperiod dependence of potatoes. Schick (1931) observed that four German varieties showed little response to a reduction of photoperiods to 12 hours, while three South American varieties showed a very striking response. Different response to photoperiod, for the varieties Alpha and Eersteling has been reported by Bodlaender and Marinus (1969), and Murti et al., (1975) reported for the varieties Kufri Lauvlar, Kufri Jyoti, Kufri Jievan and SLB/Z 405 a . Mendoza and Haynes (1976) reported differences in critical day length among potato clones of three taxonomic groups: andigena; phureja; tuberosum.

The variety Kufri Sindhuri, previously grown at continuous light for 47 days did not form tubers for 60 days at 14 hours day length while only 11 short days (8 hours) were required for tubers to initiate (Murti and Banerjee, 1976a).

Murti et al., (1975) reported increase in tuber yields in varieties Kufri Lauvkar, Kufri Jyoti, Kufri Jeevan and SLB/Z 405a under short days compared to natural day length in summer (temperate climate).

Higher tuber yields under short days (8-10 hours) compared to long days (18 hours) have also been reported by some other workers, Gregory (1954), for the variety Kennebec; Chapman (1958), for Triumph; Okazawa and Chapman (1962) for Red McClure. In contrast to these, some workers have reported higher yields under long days (18 hours) compared to short days (12 hours), Borah (1959) for the variety Arran Pilot and Bodlaender and Marinus (1969) for Eersteling and Alpha.

Increase in tuber induction due to photoperiodism has been related to increase in levels of cytokinins (Langille and Forsline, 1974; Forsline and Langille, 1975), and decrease in levels of gibberellins (Okazawa, 1960; Railton and Wareing, 1973), with increase in short day cycles.

2.1.2 Effects of temperature

The effect of temperature is similar to that of photoperiod, higher temperature promoting vegetative growth and lower temperature stimulating tuberization. Plants of the variety Sebago previously grown under non inducing conditions gave higher tuber yields at 22/18 compared to 32/18°C (Menzel, 1980). Borah and Milthorpe (1962) reported decrease in the percentage of assimilates diverted to the tubers with increase in temperature and Gregory (1954) reported a decrease in tuber to top weight ratio with increase in temperature. Tuber initiation was induced by lowering the temperature to 7°C for about a week, in plants growing at 20/15 or 25/15°C (16 hours day length) by Burt (1964). Saha et al., (1974) reported an increase in tuber yield with decrease in only night temperature. Like photoperiod there is considerable variance among potato varieties in temperature dependence. With increase in night temperature from 20 to 30°C, reduction in tuber yield

was 80 and 75% for the varieties Kufri Jyoti and Kufri Chandramukhi respectively, while Kufri Sindhuri failed to form tubers at 30°C (Saha et al., 1974).

Optimum temperature requirement for any variety is influenced by other environmental factors such as photoperiod and irradiance. Gregory (1954) obtained higher tuber yields, at 17/17°C where day length was 8 hours and at 17/10°C where day length was 16 hours.

2.1.3 Effects of light

The influence of light on growth and yield of potatoes is determined by the irradiance level, its duration and quality of the light. Photosynthesis of a single leaf as well as of the canopy as a whole increases with increase in irradiance until an optimum is reached (Ku et al., 1977; Sale, 1974). Pohjahkallio (1951) reported change in top to tuber ratio in favour of top with decrease in irradiance. Borah (1959), reported a 68 to 77% decrease in tuber dry weight with decrease in irradiance by 45% in the variety Arran Pilot, in both the green house and field. Differences were higher in growth rooms, tuber weight per plant at 64 and 128 cal cm^{-2} d^{-1} was 1 and 14g respectively. Similar results were reported by Bodlaender (1963), in this experiment tuber initiation was delayed by 27 and 54 days with decrease in irradiance from 16000 to 8000 and 3000 lux respectively. Even in a region of high solar input (daily solar input averages 25-30 MJm^{-2}), Sale (1973) reported decrease in tuber number and increase in time between tuber initiation and maximum bulking rate, with increase in shading.

Experiments under controlled conditions provide very useful

information, but spectral photon distribution (SPD) may affect several aspects of plant growth and development (McLaren and Smith, 1978) and SPD is different for different light sources (McCree, 1972).

2.2 OBJECTIVES

There are considerable differences in response of various potato varieties to the environment (Chapter 2.1). Potatoes are planted at different times and so some photoperiodic and light treatments were given to the variety Pentland Crown to understand its response to the environment as this variety was to be used in a number of experiments in the field.

2.3 MATERIALS AND METHODS

Out of three, two (Experiments: GR1 and GR2) were carried out in growth rooms and third one in glasshouse (Experiment GH1). Potato variety Pentland Crown was used for all the experiments.

2.3.1 Experiment GR1

2.3.1.1 Preparation of pots and planting

Pots of 25cm diameter were washed thoroughly in hot water and filled with John Innes potting compost No.1 (details given in Appendix A). One mm nylon mesh was kept over the compost and apically sprouted tubers (details for seed source given in Appendix B) of uniform size were planted on top of the mesh to study tuber initiation and stolon growth periodically. Pots (individually) were covered with double polythene sheet white inside and black outside, with a hole for sprout to come out. Pots were kept in growth rooms at constant temperature of $15^{o}C$ and 16hrs photoperiod until emergence.

2.3.1.2 Treatments

After emergence on 12 Feb. 1979 pots were given photoperiodic treatment according to Table 2.3.1.1. In growth rooms (Saxhill), warm white fluorescent tubes were used as the source of light. Irradiance in photosynthetically active range (400 - 700nm) was maintained as 450 $UE m^{-2} S^{-1}$ (Photon fluence rate) on pot level (measured using quantum meters with cosine corrected sensor heads; lambda

instrument). Photoperiod: 16 hours day in case of long day (LD) and 10 hours day in case of short day (SD) and day-night temperatures of 20°/15°C was maintained. The temperature in the growth rooms were continuously recorded on thermographs, fluctuations being of the order of ±1°C.

2.3.1.3 Experimental design and practical details

Due to limitation in the number of growth rooms available, plants were treated as replicates and data was analysed as completely randomized design. Number of replicates used at different time are given in Table 2.3.1.2. Although there were 1-3 SEDs, depending upon the number of replications for different treatments (Table 2.3.1.2), but for simplification only one SED is shown which is for comparing the treatments with different number of replications.

After roots had grown to the bottom of the pot; 150ml of supplementary solution containing: 50g $(NH_4)_2SO_4$, 9.2g KNO_3 and 7.5g $NH_4H_2PO_4$ per litre was given every week (Burt, 1964). Plants were irrigated with ordinary tap water as and when required. Data on length of stolons, leaves of axillary branches and number of: stolons, leaves, axillary branches and tubers were recorded without harvesting. Tuber was judged when tip was swollen, twice the diameter of the actual stolon.

2.3.1.4 Growth Analysis

Due to fewer number of plants available only 2 growth analyses were carried out: 49 and 66 days after emergence.

Plants were stored in a cold room (4°C) until they could be dissected. The number of leaves per plant on main stem and axillary branches were counted separately, at the same time, the leaflets were removed from the petiole. Length of the main stem and the axillary branches measured and petiole and stems were combined for stem's dry weight. The leaf area was determined using the punch method, (Watson and Watson, 1953) as modified by Radley (1963), which involves taking discs of known diameter and dry weight was used instead of fresh.

Number of main and branched (defined in Appendix E) stolons, were removed, counted and their total length measured. Roots were difficult to separate from the peat and were not collected and roots which were attached to the stem and stolons were removed and discarded. Tubers were removed, riddled, counted and weighed before being sliced finely with a knife and dried. Dry weights were obtained by drying different parts separately in the oven at 85°C to constant weight.

2.3.2 Experiment GR2

2.3.2.1 Preparation of pots and planting

Same as described earlier, 2.3.1.1. except that tuber pieces weighing 7g (instead of whole tubers) with single eye were taken using a cork borer (same diameter in all the cases) and planted in moist sand 2cm deep at 15°C (Details for source of seed given in, Appendix C). After one week tuber pieces were selected for uniformity of sprout and planted on top of the mesh and covered with vermiculite before covering with double polythene sheet.

2.3.2.2 Treatments

This experiment was conducted during 1980 and there were 4 treatments: combinations of 2 photoperiods i.e. 16 hours (LD) and 10 hours (SD) and 2 irradiance levels (on pot level) i.e. 400 $UEM^{-2}S^{-1}$ (HI) and 290 $UEM^{-2}S^{-1}$ (LI) (400 - 700nm). Constant temperature of 15 $\pm$ 1°C was maintained. Rest same as described earlier, 2.3.1.2.

2.3.2.3 Experimental design and practical details

Same as described earlier, 2.3.1.3 but no data was recorded without growth analysis except tuber initiation and height of the main stem. Five plants per treatment were used for measuring height of the main stem. 5,7,3,4, and 3 plants were harvested for growth analyses carried out after 29, 41, 51, 66 and 81 days of emergence respectively.

2.3.2.4 Growth analysis

Same as described earlier, 2.3.1.4, but growth analyses were carried out at frequent intervals.

2.3.3. Experiment GH1

2.3.3.1. Preparation of pots and planting

Same as described earlier, 2.3.2.1, except that seed pieces (2.3.2.1) were planted in 17.5cm pots, 2cm deep in J.I. potting compost number 1. Pots were kept in green house where temperature varied from 10°C min. to 20°C max. Pots were not covered with any polythene sheet. Detail for source of seed is given in Appendix C.

2.3.3.2. Treatments

10 days after emergence (on, 11.4.1980), plants were selected for uniformity and were either left under natural glasshouse light or under, muslin, red or blue shades (Cinemoid filters were used for red and blue shades) in an unheated glasshouse. Air maximum and minimum temperature obtained from nearby meteorological station is given in Figure 3.3.2b. Transmittance (400 - 700nm) measured (2.3.1.2.) through the shades was 21.97, 33.10 and 32.67, percent for red, blue and muslin shades respectively. Spectral photon distribution measured using scanning spectroradiometer is given in Fig. 2.3.3.1. Phytochrome state was 0.56, 0.49 and 0.44 for muslin, red and blue shades respectively and 0.54 for natural glasshouse.

2.3.3.3. Experimental design and practical details

Due to number of limitations of shades, available, plants were used as replicates and data was analysed as completely randomized

design and there were three replicates. Only main stem length was measured without harvesting. Rest same as described earlier, 2.3.1.3.

2.3.3.4 Growth analysis

Same as described earlier, 2.3.1.4., but only one growth analysis was carried out.

Table 2.3.1.1.

Details of treatments

Treatment name	Detail
LD	Long days from emergence onward.
LS	17 long days from emergence onward, followed by short days.
LSL	17 long days from emergence onward, followed by 20 short days and then long days only.
SD	Short days from emergence onward.
SL1	17 short days from emergence onward, followed by long days.
SL2	37 short days from emergence onward, followed by long days.

Table 2.3.1.2. Number of replications for different treatments used for analysing data at different time.

Days after emergence	10, 13 and 18	23, 28, 31 and 35	45	49	66
Treatment					
LD	17	5	5	2	2
LS	-	12	8	3	5
LSL	-	-	4	2	2
SD	18	12	6	2	3
SL1	-	6	6	3	3
SL2	-	-	6	4	2

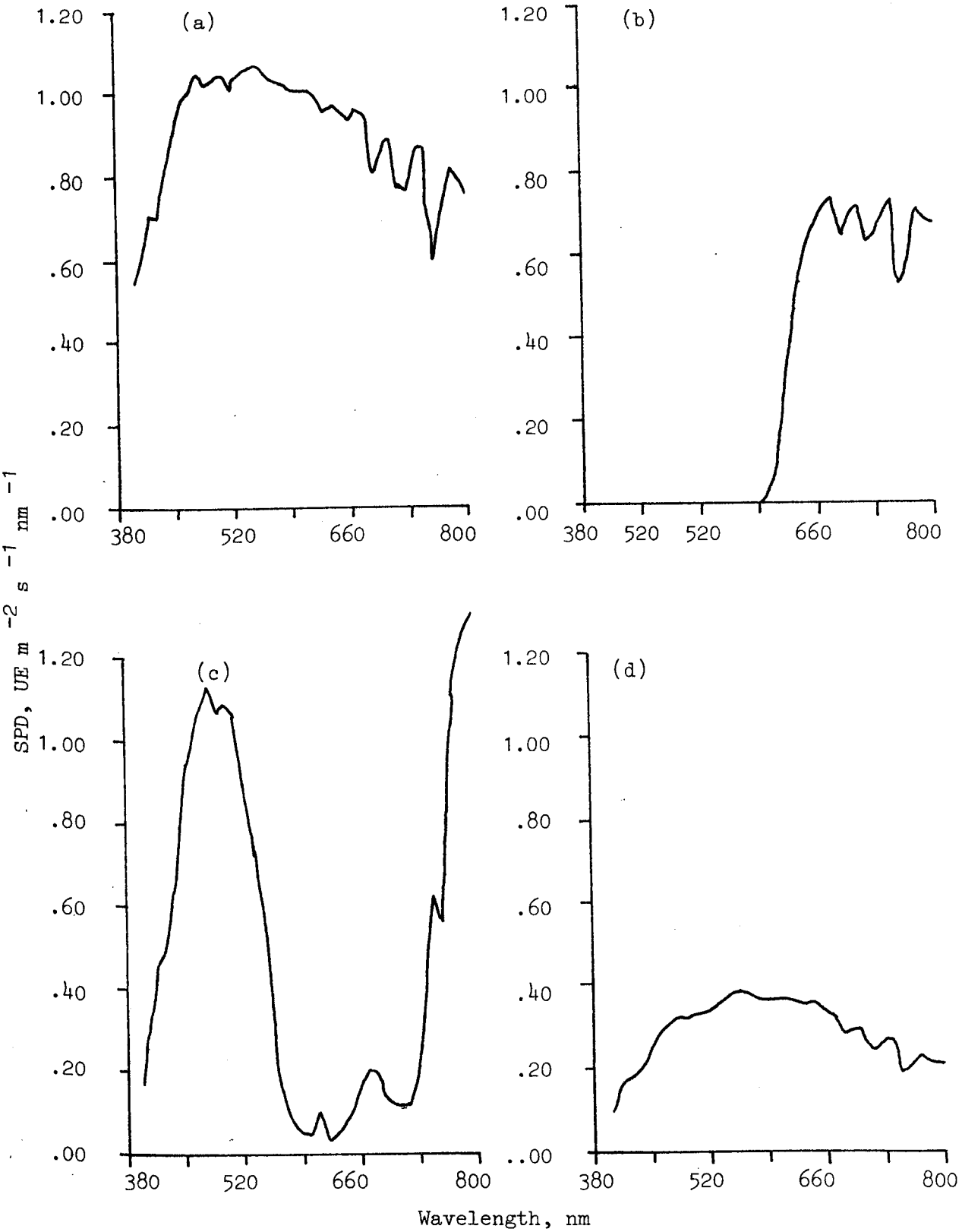


Figure 2.3.3.1 Spectral scan (400-800nm): (a), glasshouse (12=00); (b), red shade (12=40); (c), blue shade (12=30); (d), muslin shade (12=42), taken on 4th March 1980, with a scanning spectroradiometer.

2.4 RESULTS

2.4.1 Experiment GR1

2.4.1.1 Stolon

Length of the main and branch stolons (Appendix E) and their number is given in Figures 2.4.1.1. and 2.4.1.2. Stolon number and their length was not affected by the treatments until tuber initiation after which LD continued to produce more; main as well as branch stolons and their length was also more. Plants which had 17 short days in the beginning and then moved to LD (treatment, SL1) behaved like treatment LD and treatments LS and LSL like SD. Data for stolon weight is given in Table 2.4.1.2 and was higher in treatments LD and SL1.

2.4.1.2 Stem

Length of the main stem (data not presented) was not affected until few days after tuber initiation, after which plants in SD started diverting most of their assimilates to the developing tubers while in LD stem length was still increasing. Axillary branches, which started developing little before tuber initiation (Fig. 2.4.1.3) continued to develop and grow at faster rate in treatments LD and SL1, while in others rate was very low. Data for total stem weight is given in Table 2.4.1.1 which was higher in treatments LD and SL1.

2.4.1.3 Leaf

Due to shortage of number of plants for growth analysis it was

decided to count number of leaves and measure their length without harvesting. Internode length was not affected by any of the treatments thus number of leaves and their total length did not vary until tuber initiation after which LD plants had more leaves and their total length was also more. Number of leaves on axillary branches were more in treatments LD and SL1 and their total length was also more (Fig.2.4.1.4). Lower leaves from treatments: LD and SL1 started coming off after about 40 days of emergence, but they were still growing, while in others it started slightly later. Total leaf area after 49 and 66 days of emergence is given in Table 2.4.1.1. Specific leaf area and ratio of leaves to stem is also given in Table 2.4.1.1, and was lower in treatments LD and SL1. Thus leaves in these treatments were either thick or stored carbohydrates which were being diverted to tubers after tuber initiation in other treatments.

2.4.1.4 Tuber

Percentage of plants forming tubers is given in Figure 2.4.1.5. Plants which were only under LD did not initiate tubers until 66 days after emergence when the experiment was terminated, while all plants in case where they had only SD or given SD after 17 days of emergence formed tubers by the end of experiment, suggesting that tuber stimulating conditions have more effect if given few days after emergence, rather than straight from emergence onward. Data on number of tubers per plant is presented in Figure 2.4.1.5 and weight of tubers in Table 2.4.1.2. Although plants which were shifted to SD after 17 days of LD, initiated tuber but stimulus in the begining was not enough, as they had lower number of tubers, but by the end of experiment (66 days after emergence) they did not vary from the plants which were only under SD.

2.4.1.5 Total dry matter accumulation

It was observed that roots were more in treatments LD and SL1, but could not be separated, thus total dry weight presented (Table 2.4.1.1) is excluding roots. Percentage of assimilates out of total dry weight diverted to tubers were lowest in treatment SL1. It appears that LD given after 37 days of emergence (treatments: LSL and SL2) did not affect the assimilate distribution as indicated by the percentage of tubers out of total dry weight.

Table 2.4.1.1. The effects of photoperiod on some morphological characters of potato.

	Specific leaf area $dm^2\ g^{-1}$		Leaf area $dm^2 plant^{-1}$		Ratio of leaf to stem (wt basis)		Stem dry wt g $plant^{-1}$		Total dry wt g $plant^{-1}$	
Days after emergence	49	66	49	66	49	66	49	66	49	66
Treatment										
LD	2.18	1.91	40.3	63.2	1.45	1.26	12.85	26.19	32.6	61.4
LS	3.52	3.03	57.3	42.6	1.68	1.90	9.64	7.50	34.9	53.3
LSL	2.94	2.51	44.2	38.3	1.66	1.86	8.92	8.35	37.5	74.1
SD	3.64	3.71	48.0	41.8	2.10	2.19	6.30	5.17	43.4	52.0
SL1	2.39	2.04	45.8	55.7	1.34	1.41	14.68	19.60	39.2	63.7
SL2	3.41	2.48	40.8	29.5	1.61	2.51	7.94	4.74	43.6	73.7
SED	0.456	0.179	7.48	4.85	0.211	0.149	1.794	1.451	6.89	7.42

Table 2.4.1.2. The effects of photoperiod on dry weight of: (a) tuber, g plant^{-1}, (b) stolon, g plant^{-1}, and (c) percentage of tubers out of total dry weight.

	a		b		c	
Days after emergence	49	66	49	66	49	66
Treatment						
LD	0	0	1.16	2.15	-	-
LS	8.0	31.0	1.13	0.70	22.9	58.0
LSL	12.0	49.6	1.81	0.71	29.2	67.3
SD	23.2	35.0	0.68	0.56	53.5	64.8
SL1	3.3	14.8	1.65	1.75	8.0	21.5
SL2	22.8	56.1	0.62	0.63	46.6	76.5
SED	7.86	7.78	0.437	0.546	15.85	9.23

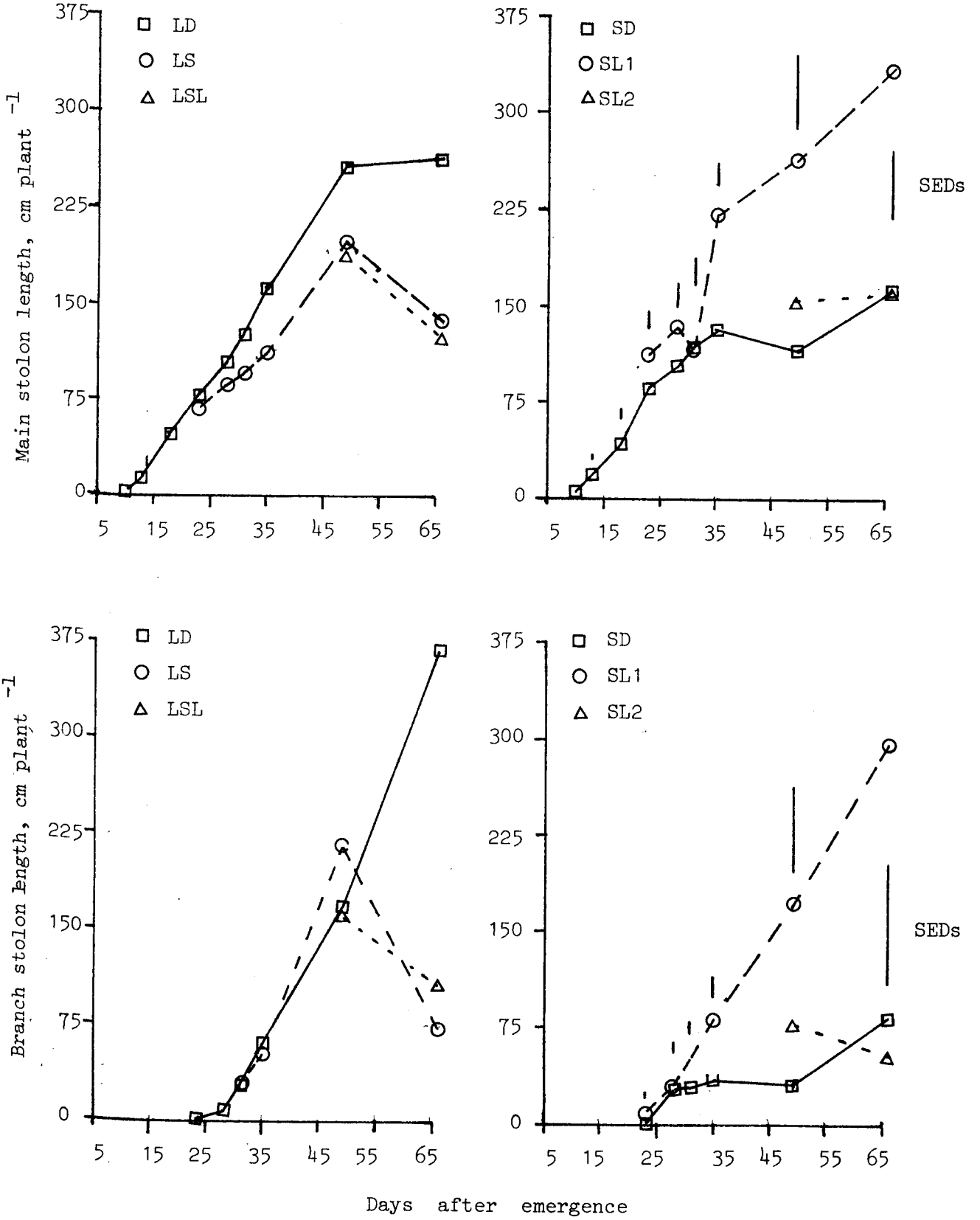


Figure 2.4.1.1 The effects of photoperiod on total length of the main and branch stolons.

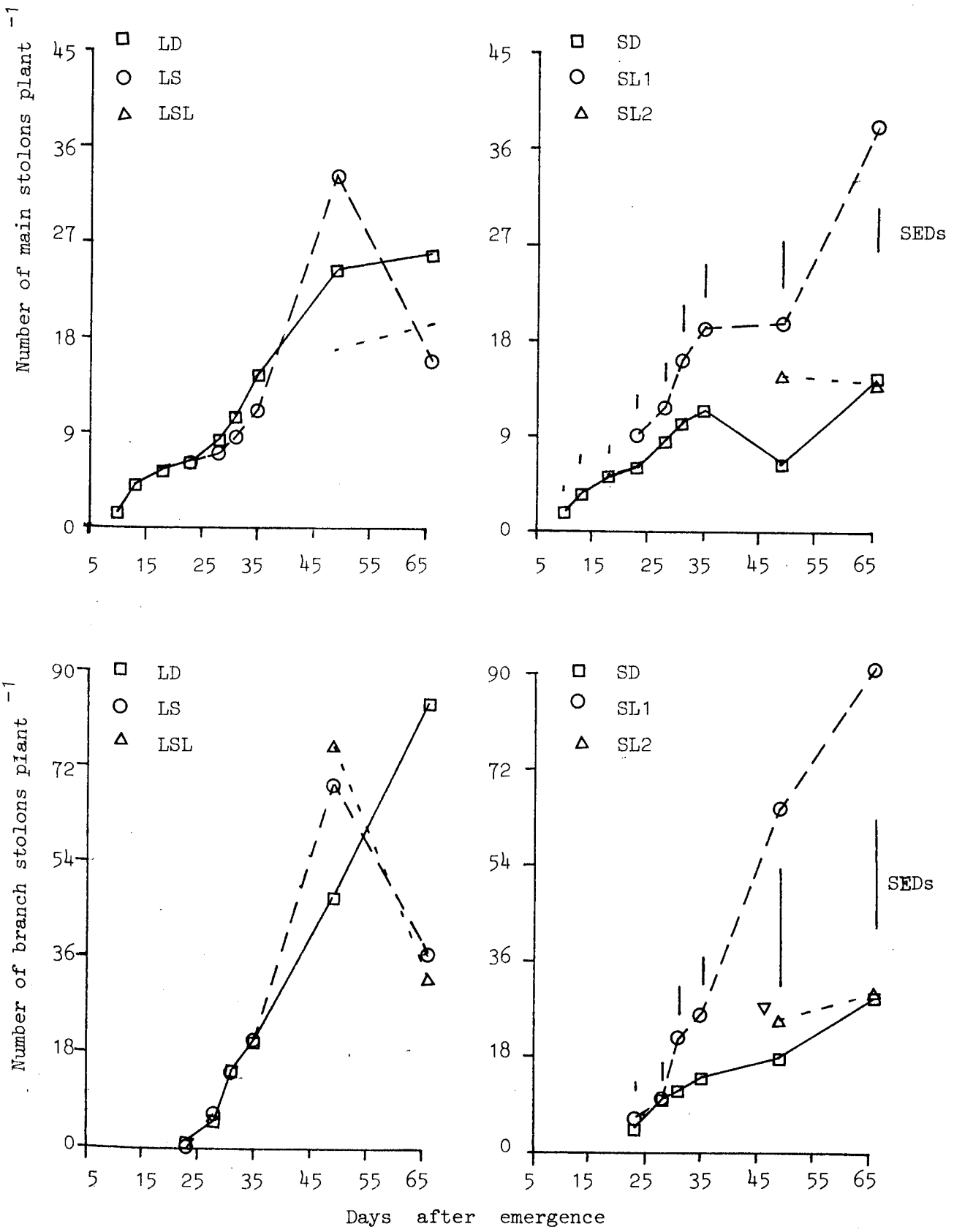


Figure 2.4.1.2 The effect of photoperiod on the number of main and branch stolons.

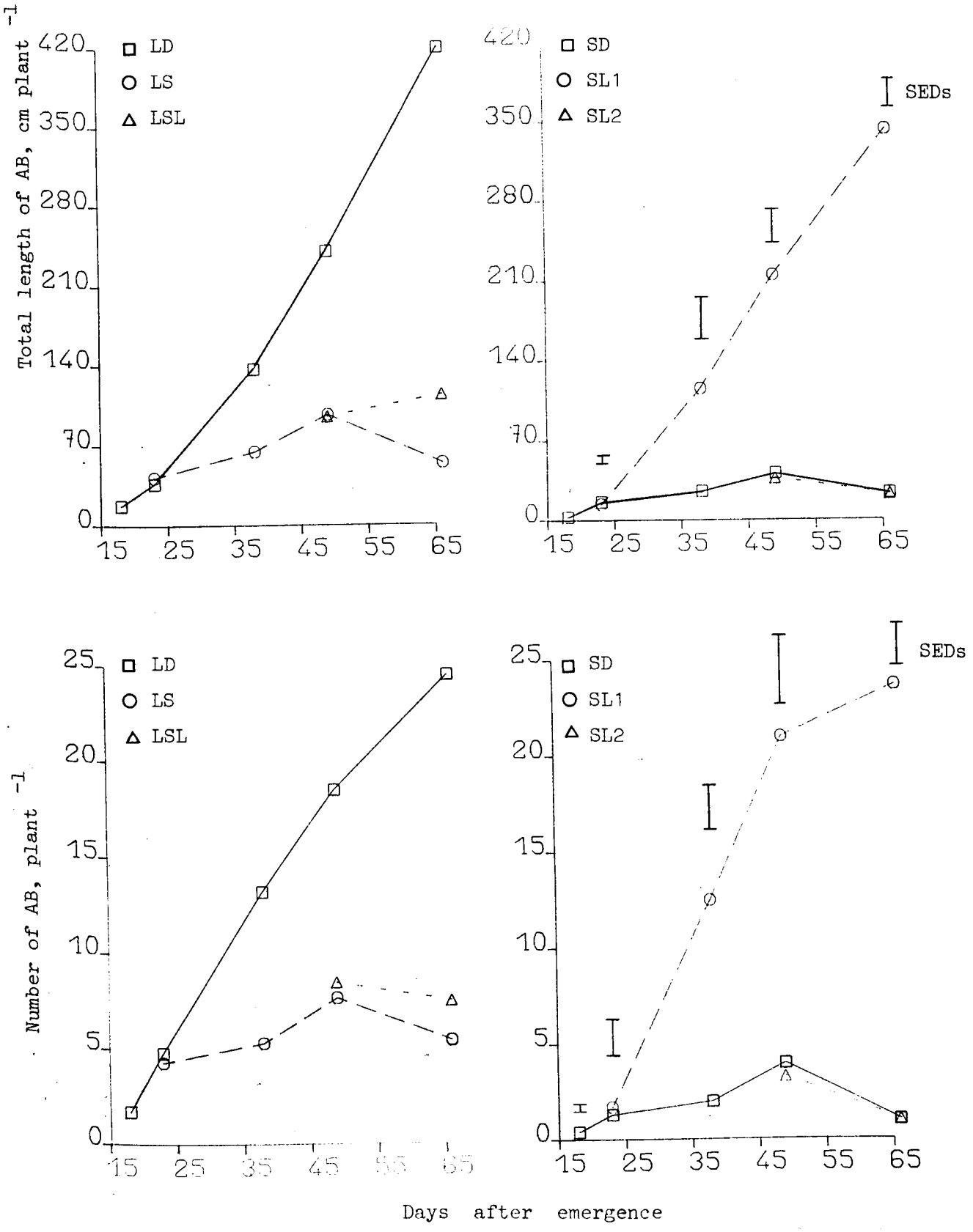


Figure 2.4.1.3 The effects of photoperiod on number and total length of the axillary branches (AB).

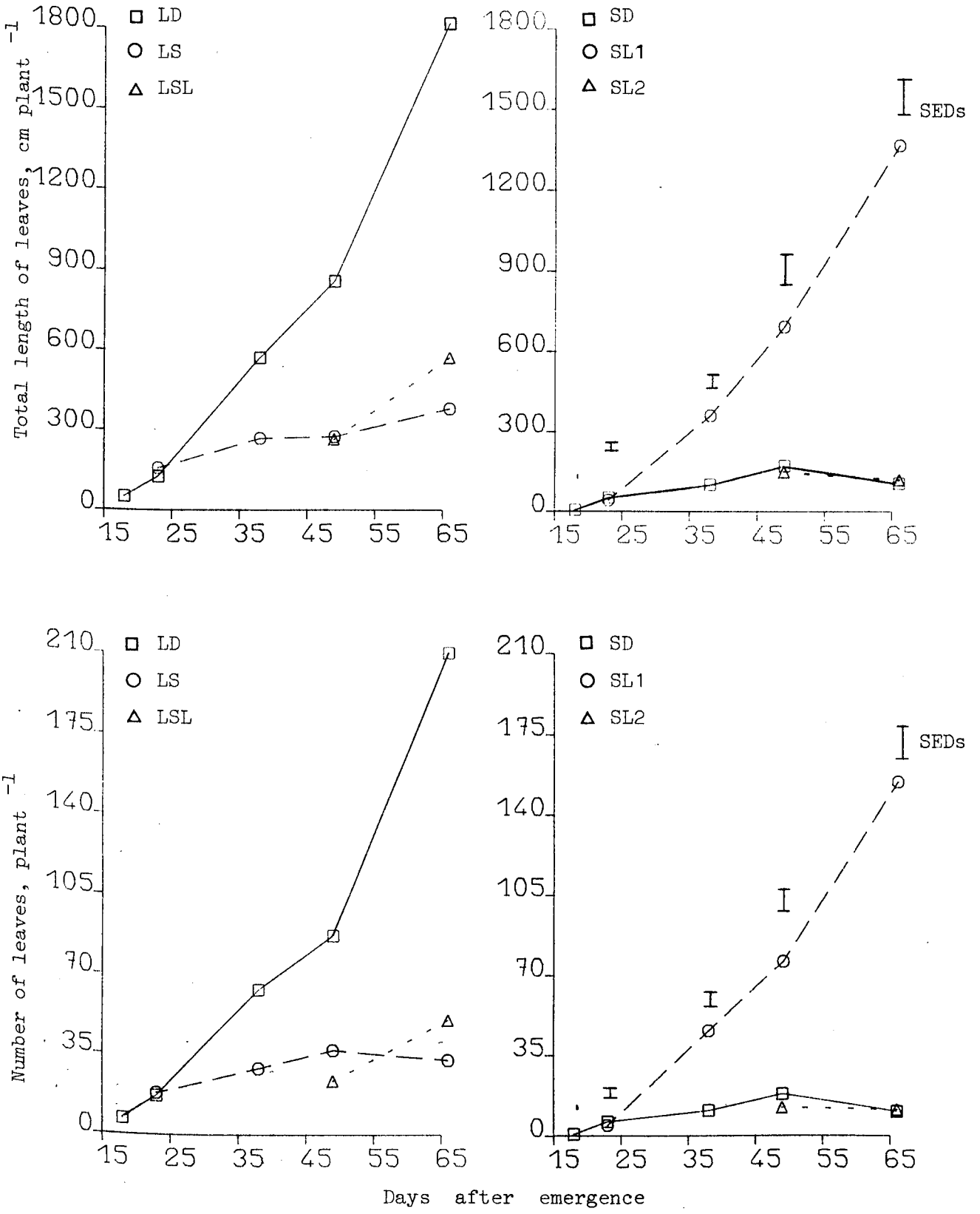


Figure 2.4.1.4 The effects of photoperiod on number and total length of the leaves contributed by axillary branches.

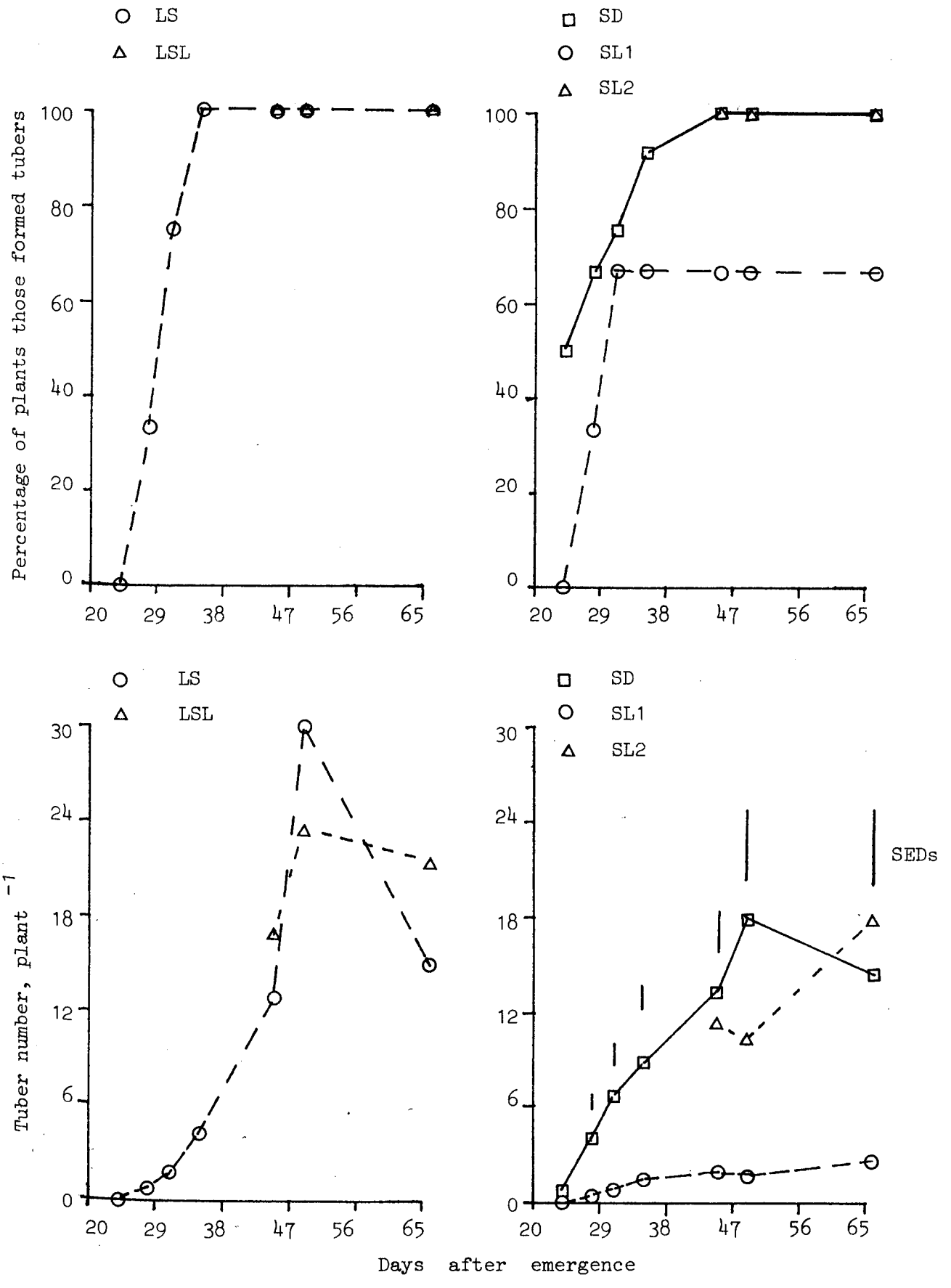


Figure 2.4.1.5 The effects of photoperiod on number of tubers and percentage of plants those formed tubers.

2.4.2 Experiment GR2

In general there was no interaction between photoperiod and irradiance levels except in few parameters of the plant growth, thus the results in general are presented as the effect of photoperiod and irradiance levels.

2.4.2.1 Stolon

Number of main stolons (average) went up to 19 plant^{-1} and was not affected by any of the treatments; irradiance did not affect their total length either. After tuber initiation growth of main stolons in SD was negligible while in LD they continued growing (Fig.2.4.2.1). Branch stolons started coming little before tuber initiation. HI increased the total number of branch stolons as well as their total length in LD while LI increased number and their total length in SD. Taking SD and LD together, HI increased slightly number of branch stolons as well as their total length (Figs.2.4.2.2 and 2.4.2.3). LD increased number of branch stolons and their total length was also more (Figs.2.4.2.2. and 2.4.2.3). Specific weight for main stolons went up to 2.4mg cm^{-1} of its length and of branch to 2.03 and was not affected by any of the treatments. Data for total stolon weight is presented in Fig. 2.4.2.4 and was much higher in LD, after tuber initiation. Stolon weight was also slightly higher in HI as compare to LI.

2.4.2.2 Stem

LI stimulated extension of the main stem (Fig.2.4.2.6) and little after tuber initiation (TI), effect was more in LD as SD almost stopped growing. Rate of appearing axillary branches (AB) in SD was slightly lower (Fig.2.4.2.8) and difference increased after TI. AB present in SD almost stopped growing after TI, thus at the time of final harvesting their average length was 11.52cm while in LD it was 21.25cm. Total length of AB; which is product of number of AB present and their average length, is presented in Figure 2.4.2.7 and was much higher in LD. Effect of irradiance on number of AB was variable; more AB were present in HI before TI, after that rate of appearance was higher in LI. Their total length was higher in LI (Fig.2.4.2.7). Data for total stem weight is presented in Figure 2.4.2.5. 51 days after emergence SD stopped diverting assimilates to the stems as their weight was almost constant, rate of stem growth in LD was very high after 41 days of emergence. Irradiance did not affect the total stem weight at all (Fig.2.4.2.5)

2.4.2.3 Leaf

Photoperiod did not affect the internode length and length of the main stem and total length of AB were higher in LD (Figs.2.4.2.6 and 2.4.2.7), thus no. of leaves present on the main as well as AB were higher in LD (Figure 2.4.2.9). Increase in stem length (Figs.2.4.2.6 and 2.4.2.7) due to LI was primarly due to extension of internode length, thus there was no difference in number of leaves due to irradiance. Leaf size in general was not affected by any of the treatments

and average leaf size for the leaves on main stem went up to 2.05dm^2. Total leaf area was much higher in LD especially after TI, while irradiance levels did not affect it (Figure 2.4.2.10). Leaves weight did not increase in proportional to leaf area thus resulted in difference in specific leaf area (Fig.2.4.2.11). Both LD and HI decreased specific leaf area, therefore they increased, either leaf thickness or cellular density or stored carbohydrates or combination of these factors. Effect of irradiance and photoperiod on net assimilation rate (NAR) is given in Figure 2.4.2.12; which shows that leaves were more efficient in producing dry matter in treatment HI. This may be explained by the fact that more photons were available per unit LA. Lower NAR in LD could be attributed to the mutual shading of the leaves due to higher LA. LD increased leaf to stem ratio in favour of stem especially after TI (Fig.2.4.2.13). Although irradiance did not affect the total stem weight (Fig.2.4.2.5) but leaf weight was higher in HI, which resulted higher leaf to stem ratio (Fig.2.4.2.13).

2.4.2.4 Tuber

Tuber initiation (TI) was examined by removing vermiculite, at intervals of 3 to 5 days. Irradiance did not affect TI in combination with SD, where plants initiated tubers after 32 days from emergence, but HI enhanced TI in LD where it was 38 days after emergence. Some of the plants under treatment combination of LD and LI intitiated tubers after 41 days of emergence but all plants did not have tubers even when harvested, 51 days after emergence, when 3 out of 4 plants had tubers. In general total number as well as their weight was much higher in SD (Fig.2.4.2.14). HI increased tuber number in LD but decreased in SD.

Tuber weight was increased under both photoperiods by HI but effect was more evident in LD.

2.4.2.5 Total dry matter accumulation

Roots could not be separated from the peat so total dry weight (TDW) presented in Figure 2.4.2.15 is without roots. LD increased TDW, which was affected in two ways: due to higher leaf area, they intercepted more photons and further they had more time for photosynthesis. Later in the season leaves started coming off the stem and were not included in TDW. HI also increased TDW primarily due to more number of photons available, which increased NAR also (Fig.2.4.2.12).

Little after tuber initiation there was no competition for assimilates between tubers and haulms in SD as indicated by the evidence that stolons stems and leaves, almost stopped importing assimilates (Figs.2.4.2.4; 2.4.2.5; 2.4.2.10; 2.4.2.11), which resulted in to a higher percentage of tubers out of TDW (Fig.2.4.2.16). HI also increased the proportion of tubers out of TDW (Fig.2.4.2.16). In SD effect was one way, as there was enough induction so percentage increase in tuber weight was due to higher quantity of assimilates available. In LD it might have affected in two ways: one by stimulating tuberization and another by making more assimilates, available.

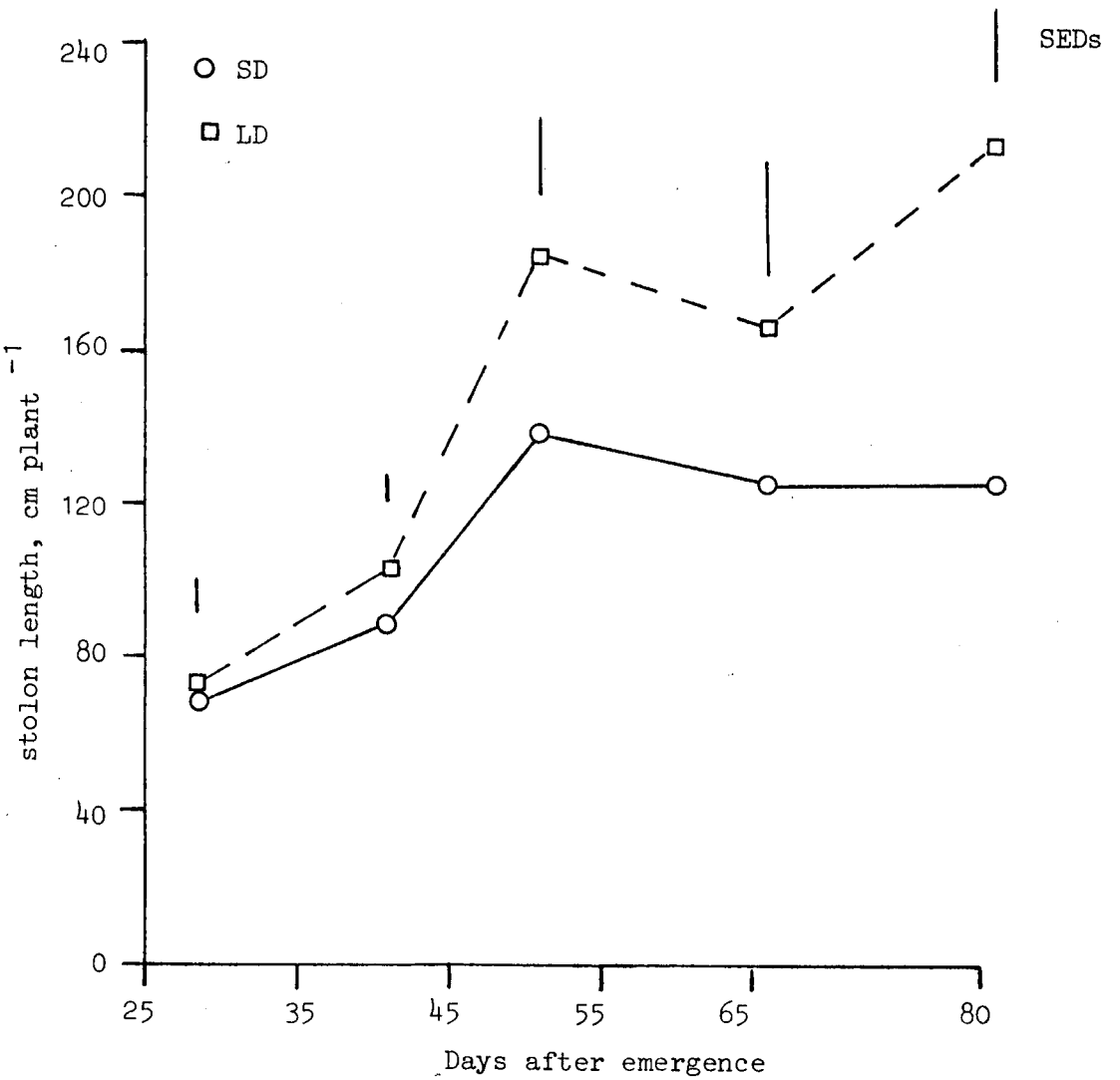


Figure 2.4.2.1 The effects of photoperiod on total length of the main stolons.

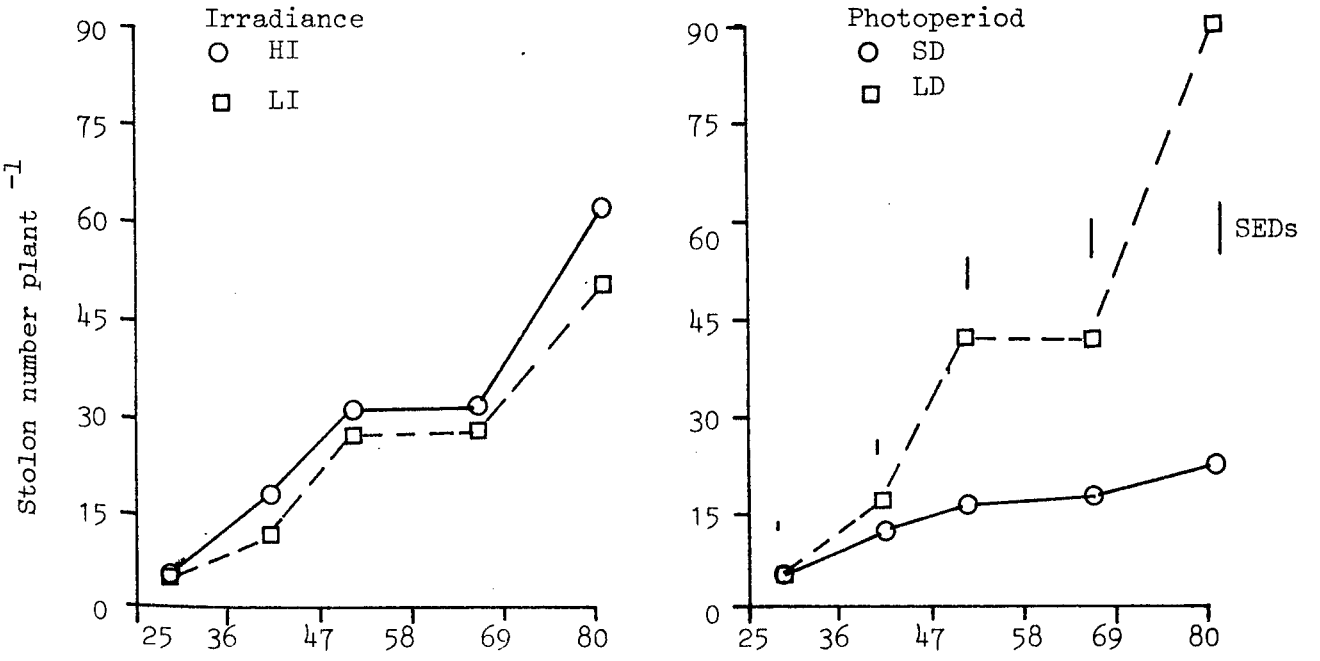


Figure 2.4.2.3 The effects of photoperiod and irradiance on number of branch stolons.

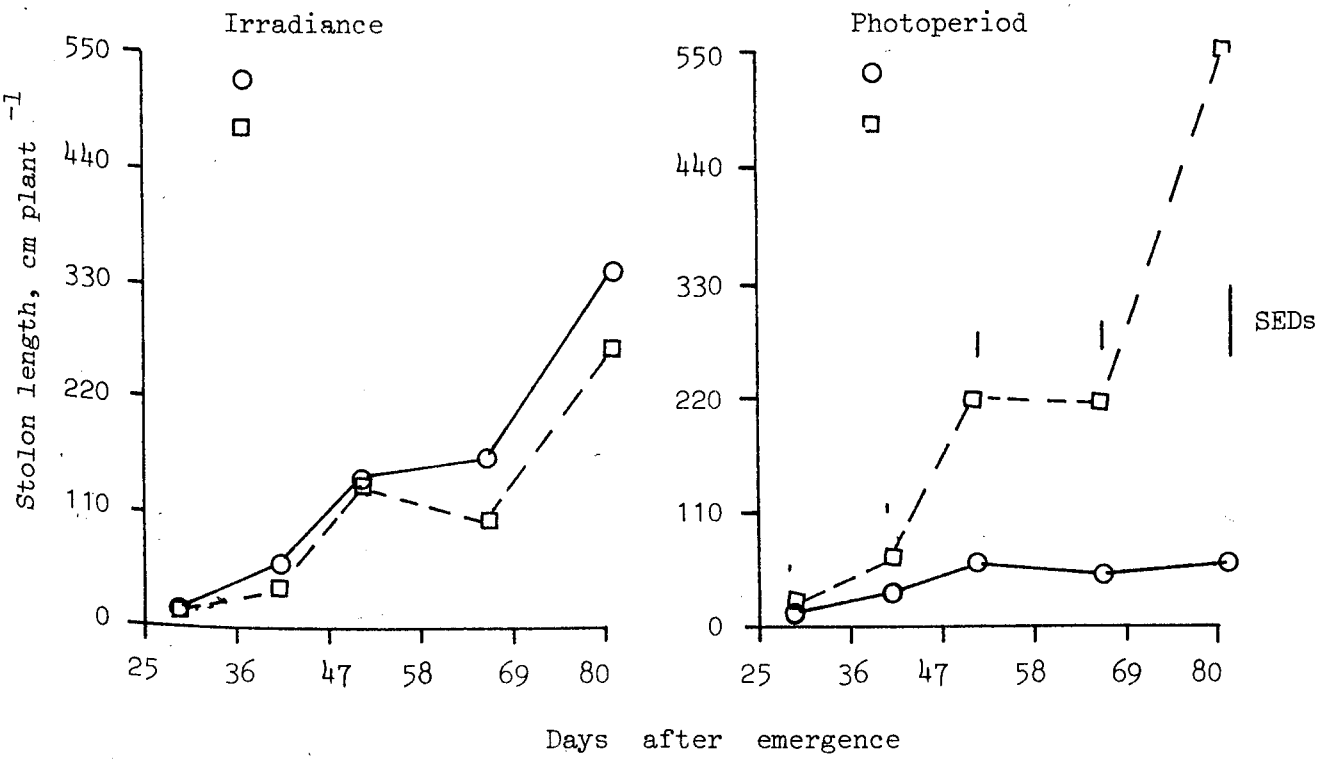


Figure 2.4.2.2 The effects of photoperiod and irradiance on total length of branch stolons.

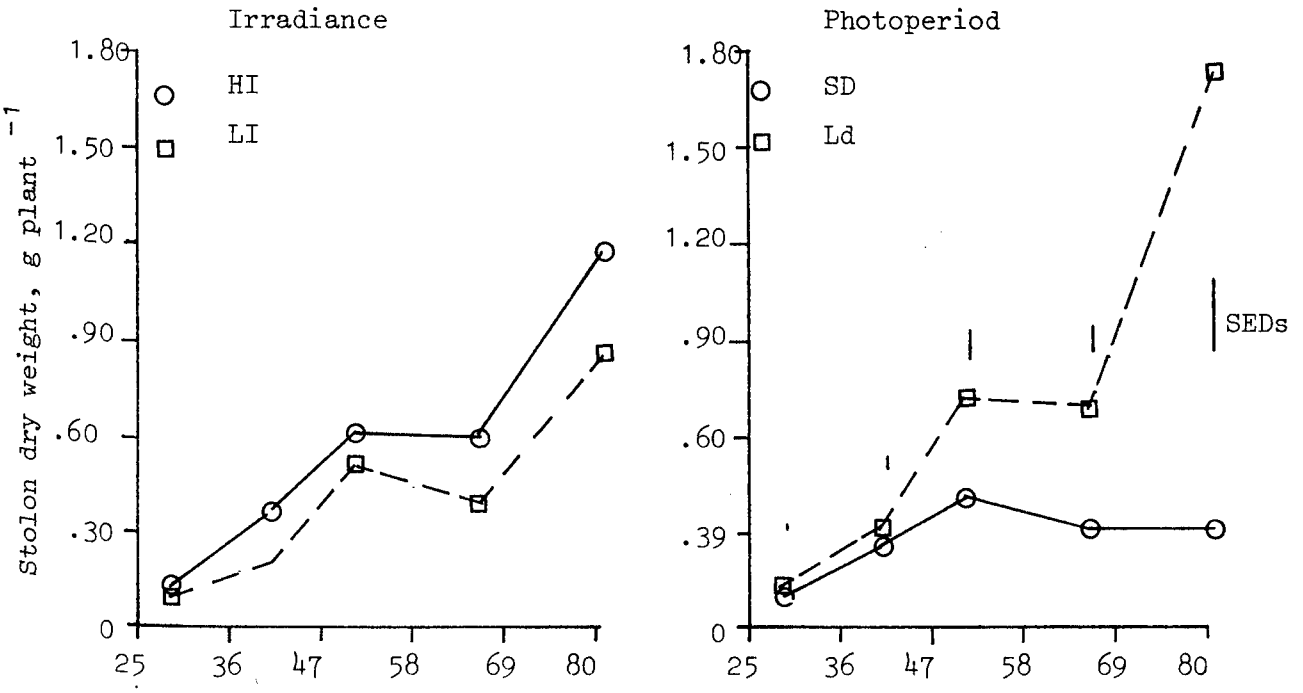


Figure 2.4.2.4 The effects of photoperiod and irradiance on total stolon dry weight.

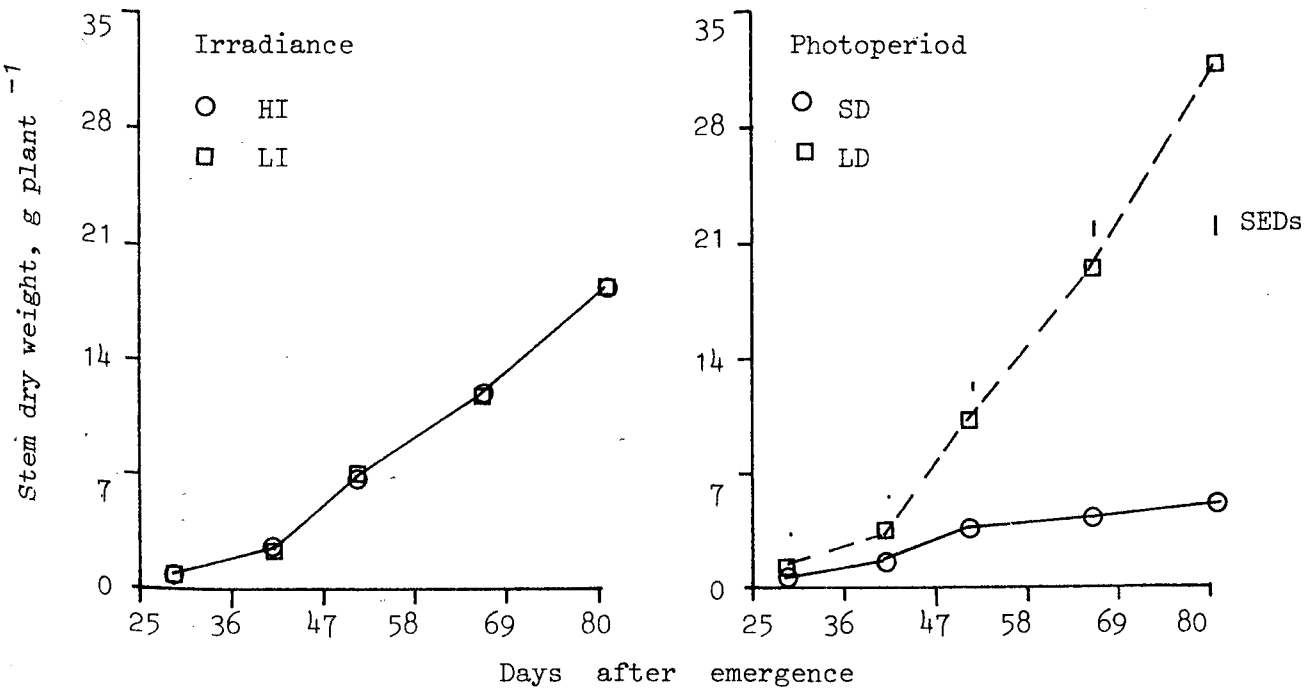


Figure 2.4.2.5 The effects of photoperiod and irradiance on total stem dry weight.

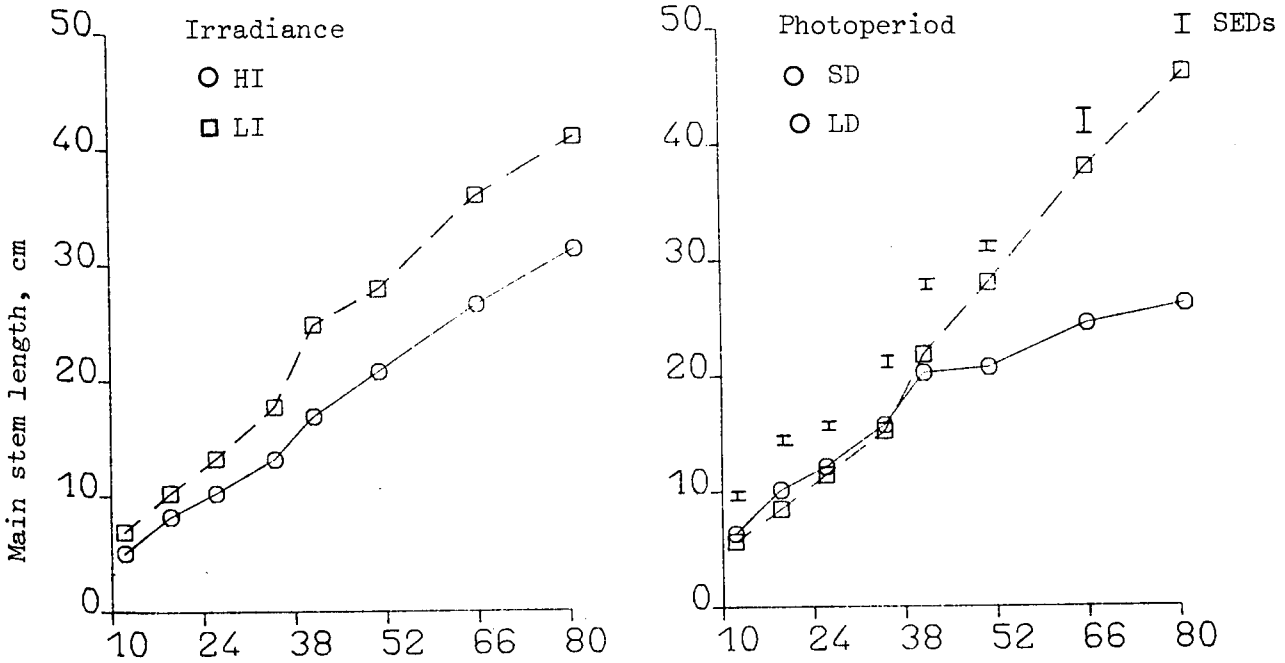


Figure 2.4.2.6 The effects of photoperiod and irradiance on main stem length.

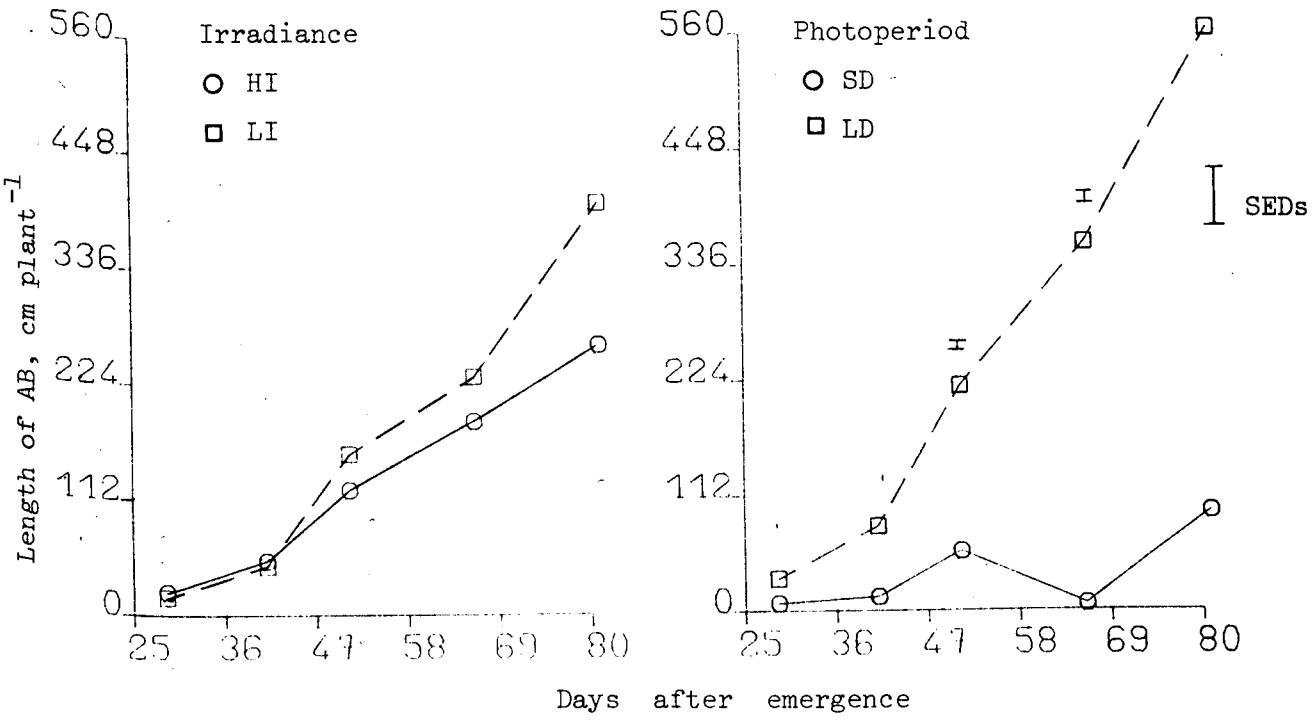


Figure 2.4.2.7 The effects of photoperiod and irradiance on total length of the axillary branches (AB).

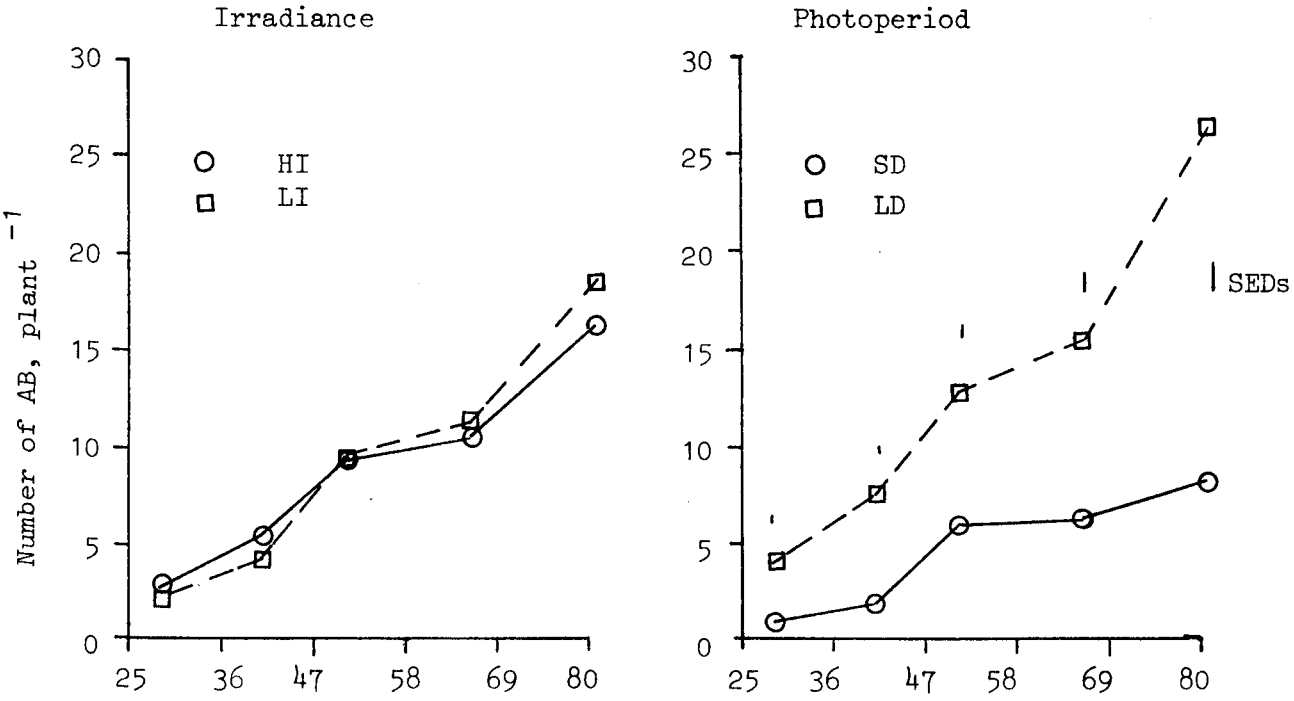


Figure 2.4.2.8 The effects of photoperiod and irradiance on the number of axillary branches (AB).

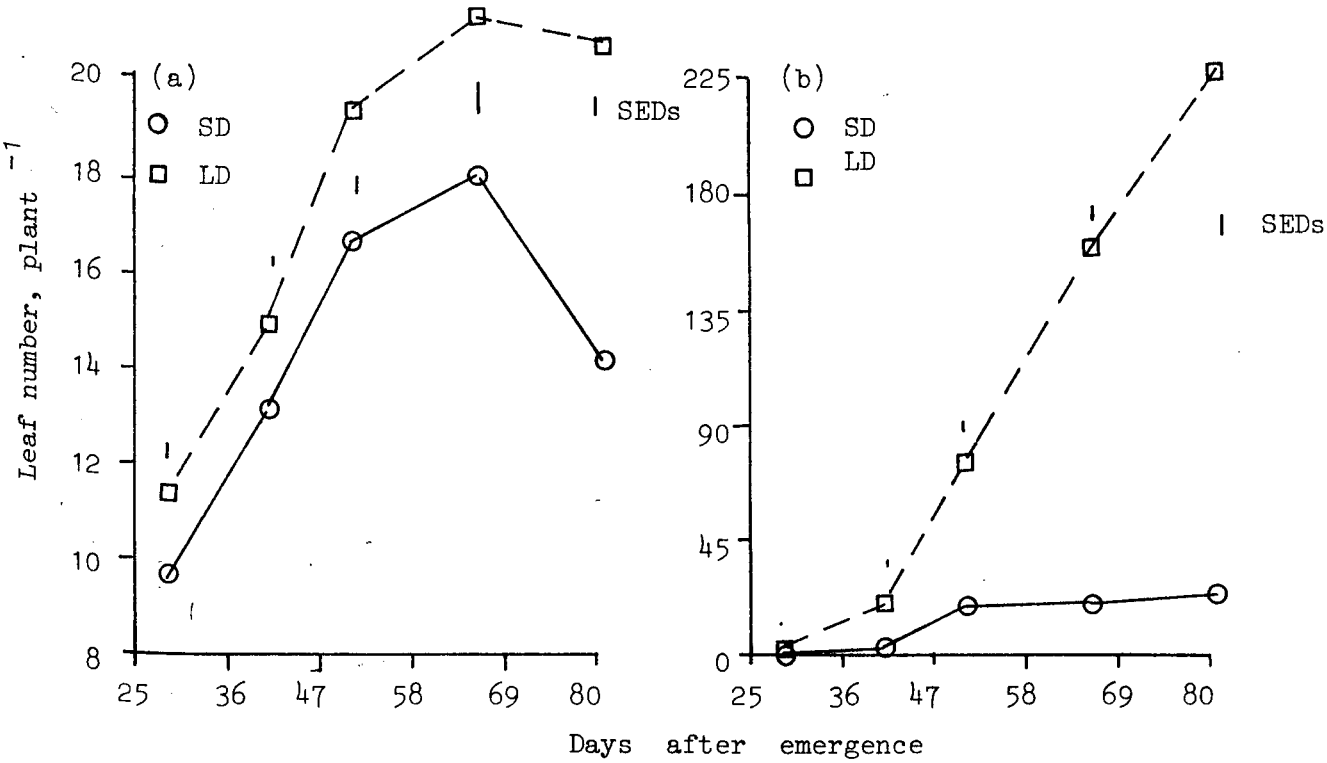


Figure 2.4.2.9 The effects of photoperiod on number of leaves coming from the main stem (a) and the axillary branches (b).

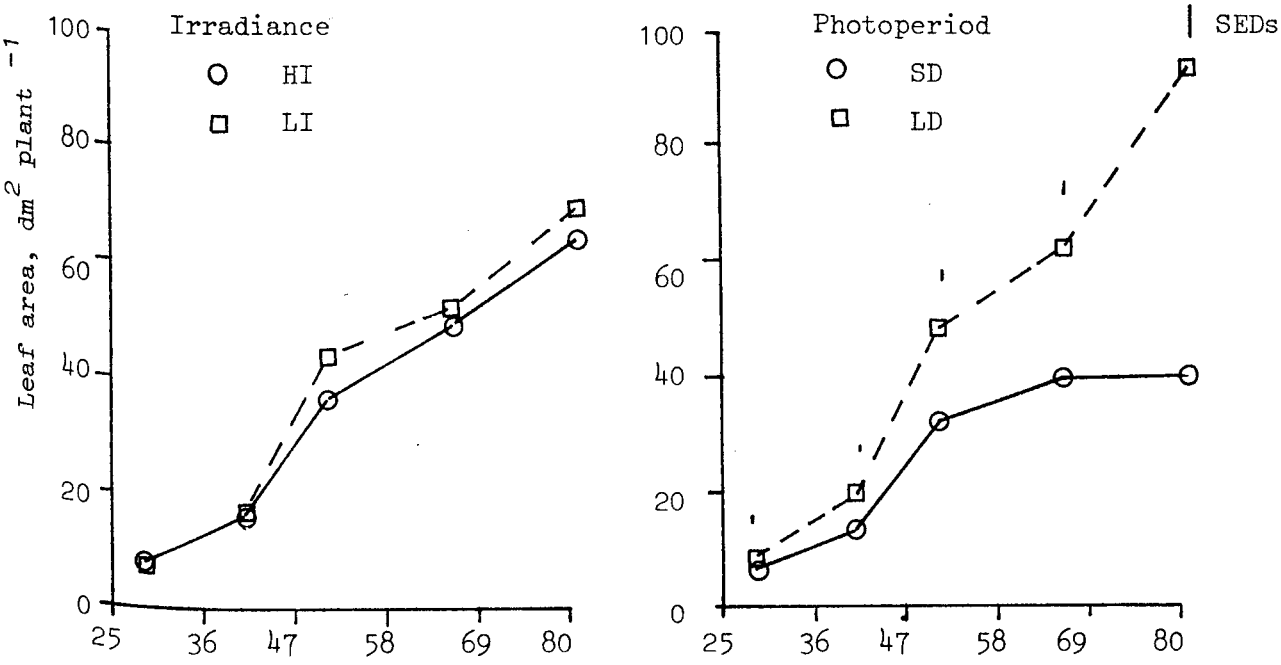


Figure 2.4.2.10 The effects of photoperiod and irrandiance on total leaf area.

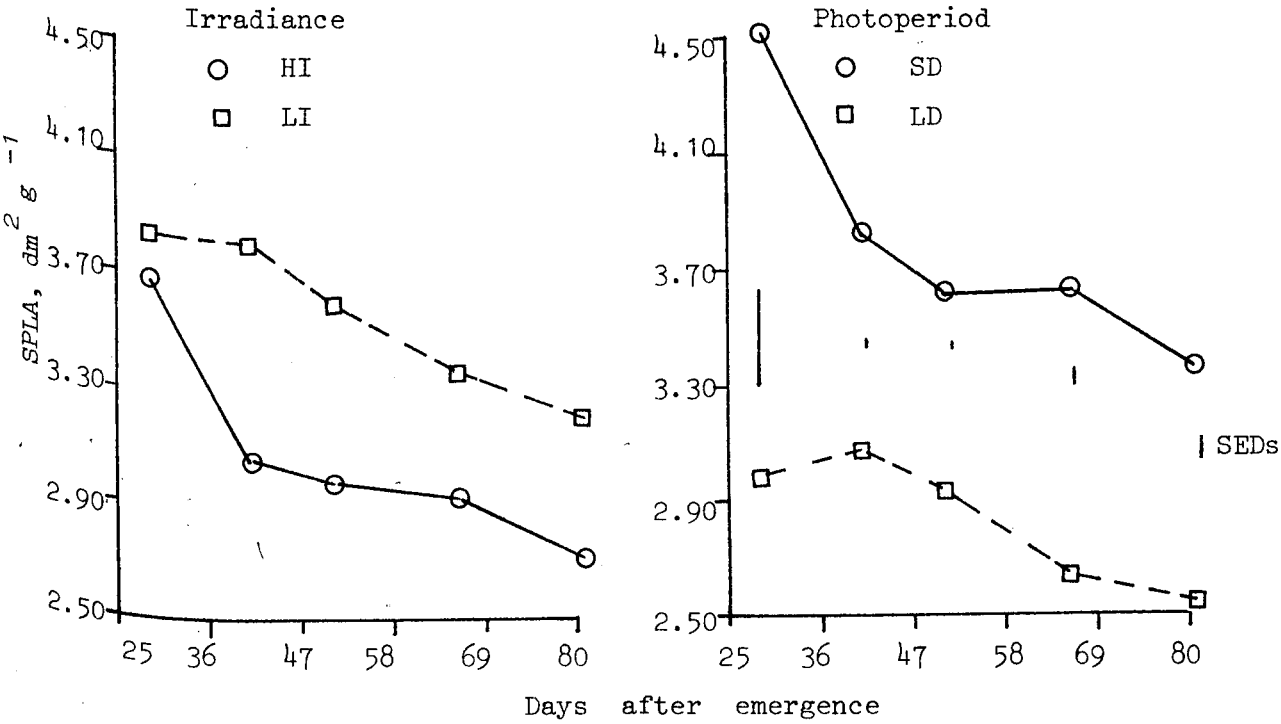


Figure 2.4.2.11 The effects of photoperiod and irradiance on specific leaf area (SPLA).

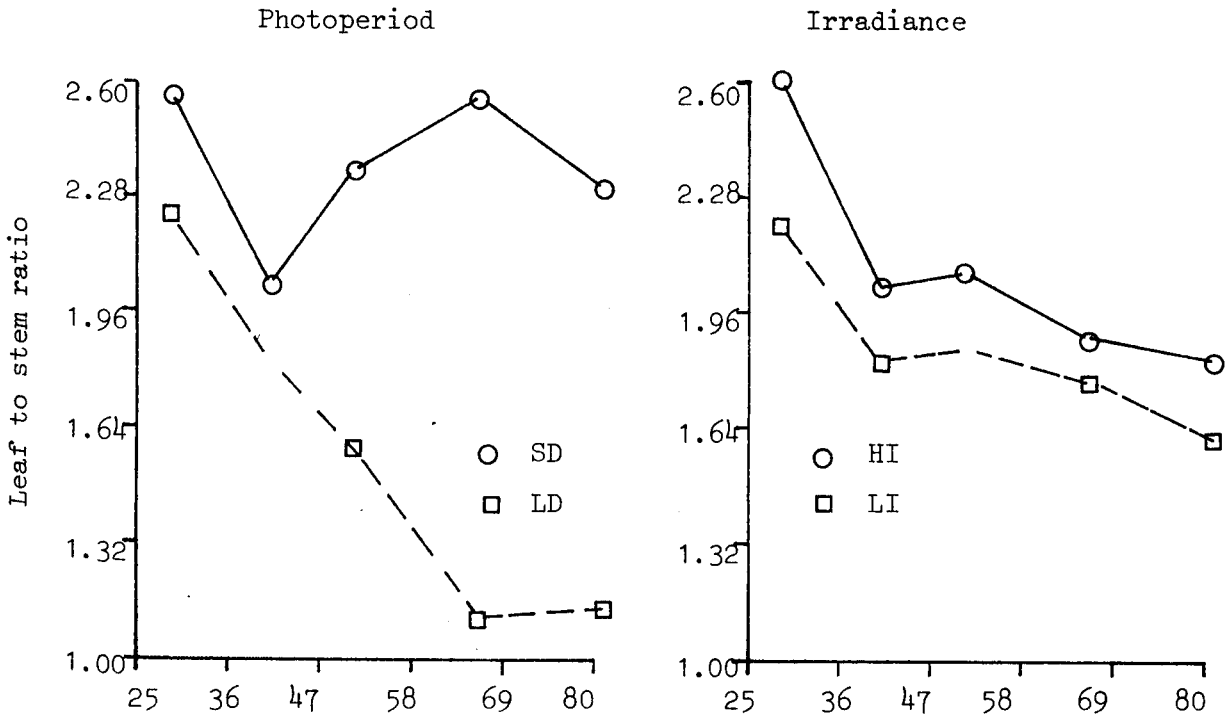


Figure 2.4.2.13 The effects of photoperiod and irradiance on leaf to stem ratio (dry weight basis).

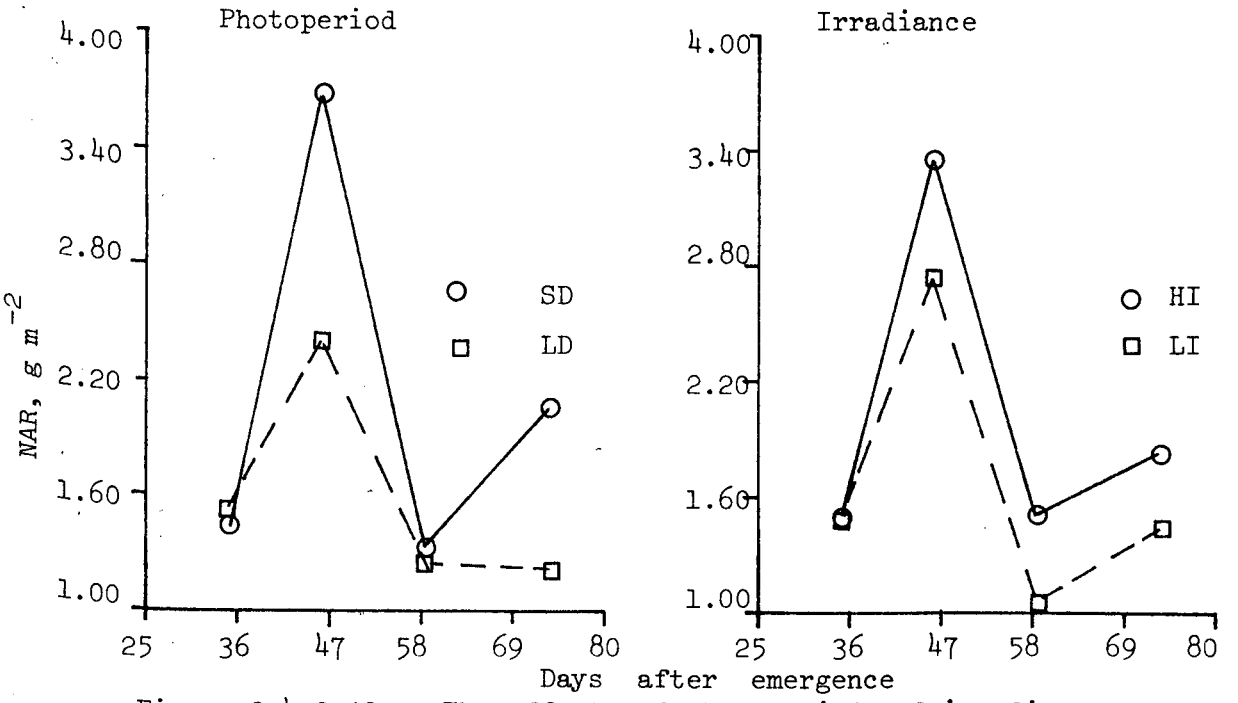


Figure 2.4.2.12 The effects of photoperiod and irradiance on net assimilation rate (NAR).

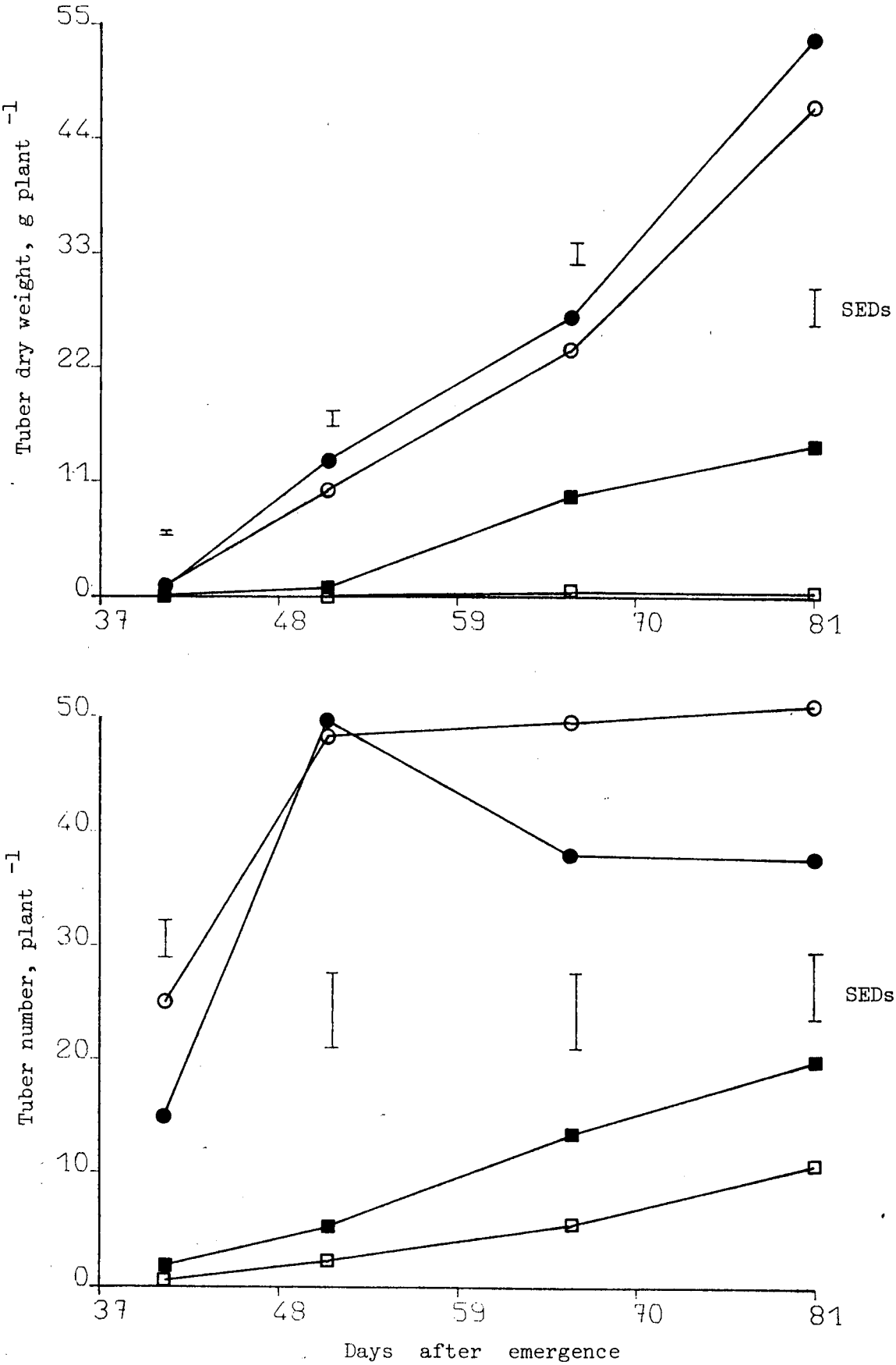


Figure 2.4.2.14 The effects of photoperiod and irradiance on tuber numbers and tuber dry weight.

Key: ○, SD; □, LD; closed symbols, HI; open symbols, LI

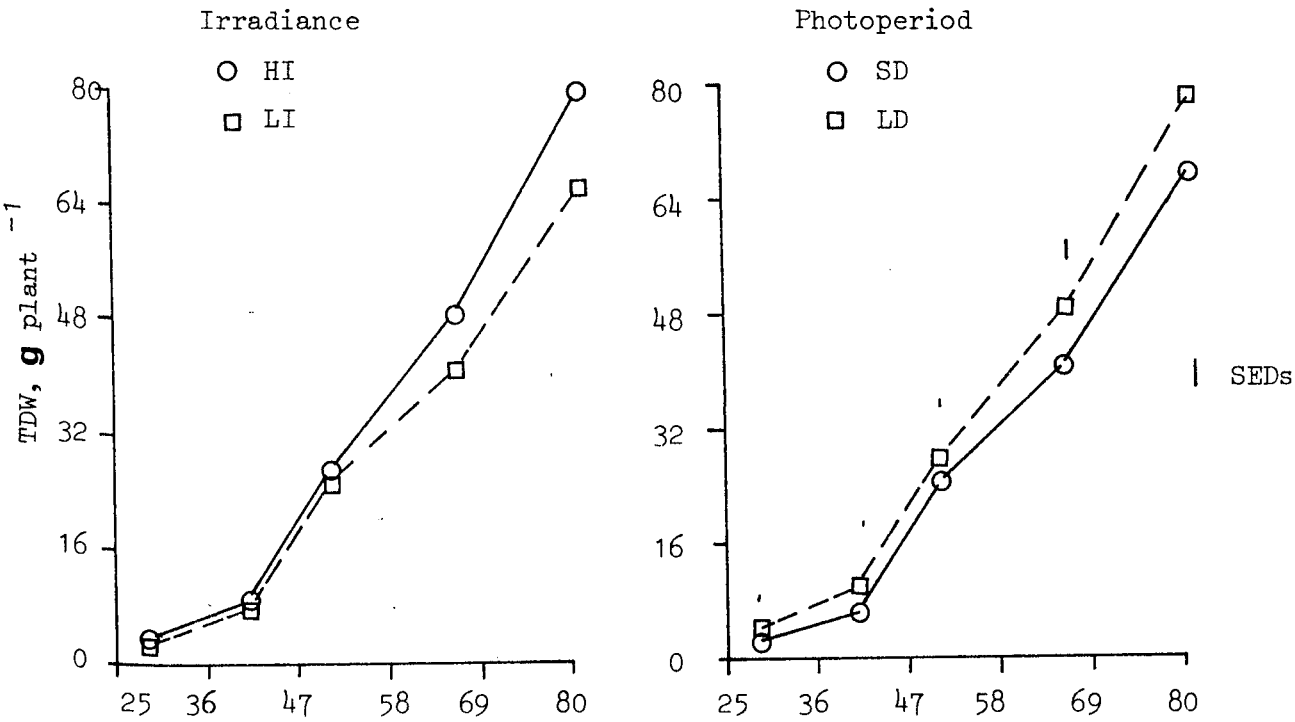


Figure 2.4.2.15 The effects of photoperiod and irradiance on total dry weight (TDW).

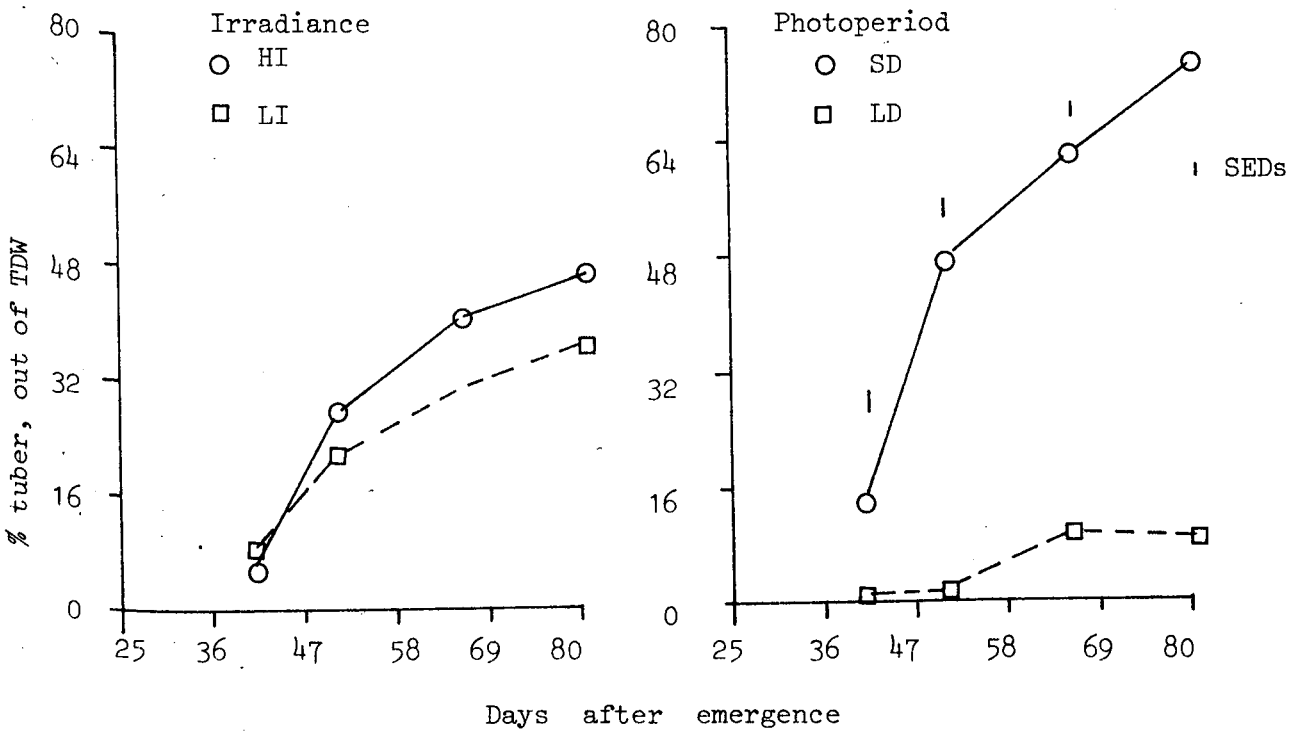


Figure 2.4.2.16 The effects of photoperiod and irradiance on percentages of tubers out of TDW.

2.4.3 Experiment GH1

Due to fewer number of replications there was more variation in the data.

2.4.3.1 Stolon

Number of main as well as branch stolons and their total length was higher in control (Table 2.4.3.1).

2.4.3.2 Stem

Length of the main stem is presented in Figure 2.4.3.1. All the three shades used stimulated stem extension and difference was visible even two days after moving them under the shades. Control had higher number of axillary branches and their total length was also more (Table 2.4.3.1), but difference was not significant due to variation in the data. Although plants were taller under shades but total stem weight was higher in control (Table 2.4.3.1).

2.4.3.3 Leaf

Increase in length of the main stem by shades was purely due to extension of internode, as there was no difference in total number of leaves (yellow or dead + green) recovered from the main stem (Table 2.4.3.1). No. of leaves present on axillary branches were higher in control and leaves were bigger in size in control and their total leaf area was also more (Table 2.4.3.1) increase in leaf weight was not in

proportion to the leaf area, resulting, differential values for specific leaf area. All shading increased specific leaf area (Table 2.4.3.1). Leaf appeared slightly thicker in control but were not measured.

2.4.3.4 Tuber

Plants under muslin shade did not form tubers at all, while in red shade there was only 1 tuber plant^{-1} as compared to control where there were 12.7 tubers plant^{-1}, tubers dry weight for red shade was negligible (2.7mg plant^{-1}), while in control and blue shades it was 1.42 and 0.4g plant^{-1} respectively (Table 2.4.3.1).

2.4.3.5 Total dry weight

Control had higher total dry weight (Table 2.4.3.1) and quantity reduced by shades was almost proportional to the number of photons transmitted through the respective shades. Percentage assimilates directed to the tubers were equal in control and blue shades.

Table 2.4.3.1. The effects of different type of shading on morphological characters and tubers, 49 days after emergence.

Treatment	control	muslin	Red	Blue	SED
No. of axillary branches (AB), Pl^{-1}	4.75	1.0	1.33	0.33	1.728
Total length of AB, cm pl^{-1}	22.7	6.4	5.8	2.2	7.73
No. of green leaves on main stem, pl^{-1}	13.25	11.67	11.67	9.33	1.214
No. of yellow or dead leaves coming from main stem, pl^{-1}	0.50	2.67	2.67	4.00	0.894
Average size of leaves coming from main stem(dm^2)	1.03	0.61	0.47	0.56	0.096
Specific leaf area, $dm^2 g^{-1}$	2.66	3.94	4.82	5.02	0.134
No. of main stolons, pl^{-1}	15.3	10.7	10.0	9.0	2.96
Length due to main stolons, cm pl^{-1}	57.1	24.6	17.9	21.1	17.48
No. of branch stolons, pl^{-1}	7.3	3.3	0.0	0.7	2.9
Length due to branch stolons, cm pl^{-1}	9.3	1.6	0.0	0.6	3.31
Tuber numbers, pl^{-1}	12.7	0.0	1.0	4.0	3.35
Tuber dry weight, g pl^{-1}	1.42	0.0	0.0027	0.40	0.304
Total dry weight, g pl^{-1}	10.57	3.91	3.16	2.97	1.035
Total stem weight, g pl^{-1}	3.18	1.62	1.63	1.32	0.39
Total stolon weight, g pl^{-1}	0.33	0.07	0.05	0.03	0.11
Percentage of tubers out of TDW	13.4	0.0	0.1	13.3	

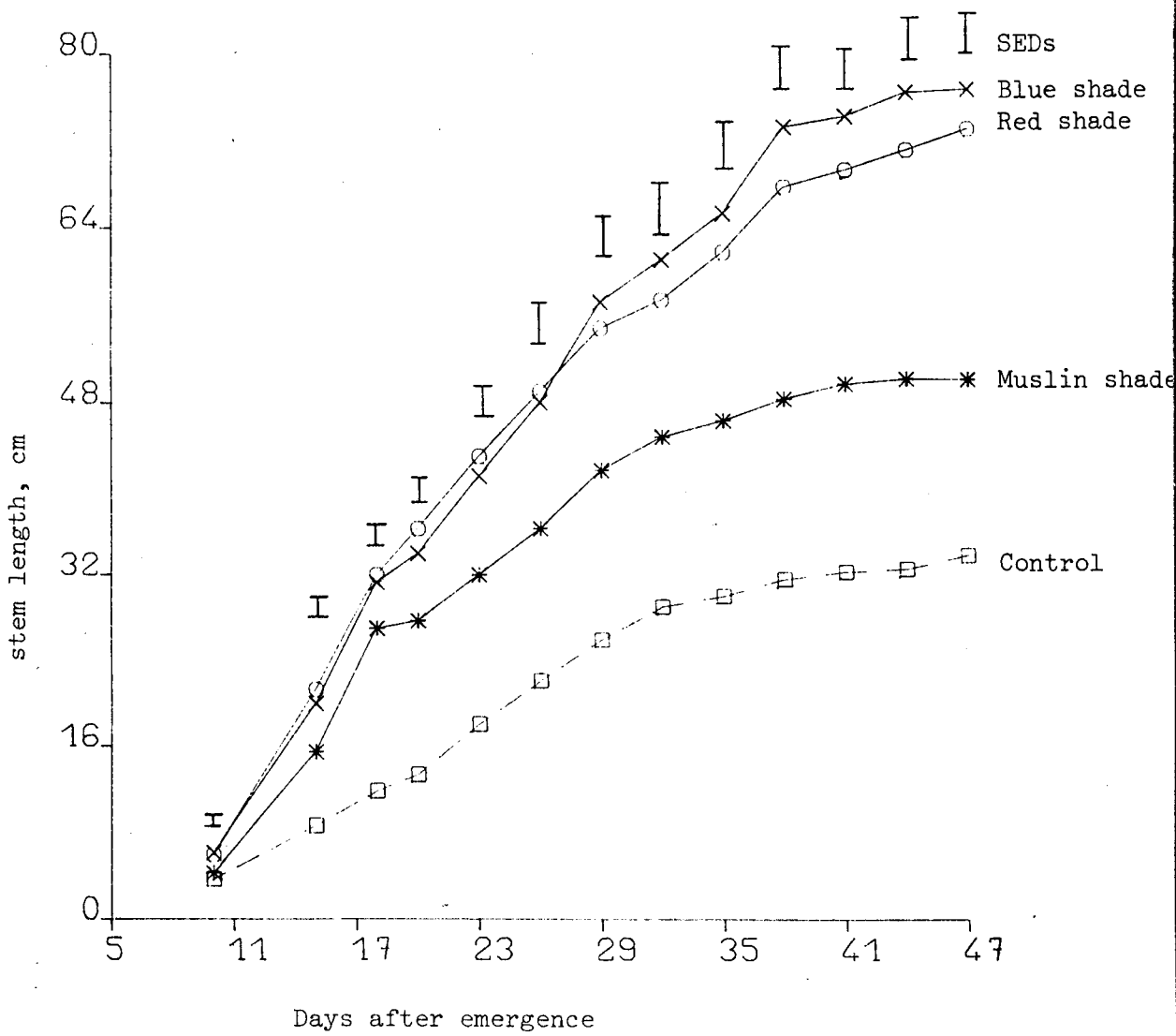


Figure 2.4.3.1 The effects of shading on main stem length.

DISCUSSION

There is general agreement between experiments: GR1 and GR2 that SD stimulated tuberization (even there were some sessile tubers) and decreased **haulm** growth after tuber initiation. In Experiment GR2 where growth analysis was done regularly, after 41 days of emergence there was no increase in length of stolons or stems and after 51 days of emergence there was only negligible growth of stolons, stems and leaves (in term of weight) so almost all the assimilates produced, were being directed to the tubers. It may be easy to explain this after understanding the theory of tuberization.

It has already been mentioned (Chapter 2.1.1) that lower levels of gibberellins and higher levels of cytokinins were detected in SD as compare to LD. Further exogenous application of gibberellins have been found to inhibit tuberization (Lovell and Booth, 1967; Hammes and Beyers, 1973; Menzel, 1980), on the other hand Palmer and Smith (1969, 1970) demonstrated the requirement for cytokinins in tuberization of excised stolons of Solanum tuberosum in vitro; similar results were obtained by Mauk and Langile (1978), using Ziatin riboside instead of kinetin. Wareing and Jennings (1980) found that endogenous Abscisic acid (ABA) supplied by the leaves was necessary for tuber development in Solanum andigena, but there was no significant difference in ABA content in diffusates from induced to non-induced leaves. Further more a non-induced leaf could induce tuberization when grafted on to an induced stem cuttings (Wareing and Jennings, loc. cit.). Supply of exogenous cytokinins plus ABA did not cause tuber formation in one-node cuttings from a non-induced plant of Solanum andigena (Wareing and Jennings, 1980). They argued that the clones of Solanum andigena, they

used have an obligate short-day requirement where as many cultivars of Solanum tuberosum have no absolute requirement for SD; but give a quantitative SD response. Thus it might be possible that a second factor was present in Solanum tuberosum independently of the photoperiodic pre-treatment. Thus it may now be concluded that the tuberization in potato is promoted with increase in ratio of cytokinins and unknown tuberization stimulus (UTS) to gibberellins. Production of the UTS has been suggested to be promoted by SD (Wareing, 1982).

Tuberization involves cell divisions in the sub-apical region of the stolon apex (Booth, 1963; Cutter, 1978). Cytokinins, have been suggested to inhibit apical meristem and promote cell division in the sub-apical region (Palmer and Smith, 1970); thus with increase in levels of UTS and cytokinins, tuber initiation occurred and with a further increase in number of short days, the ratio of cytokinins and UTS to gibberellins increased. This further stimulated cell division in the sub-apical region of the stolons and the apical meristem might have been inhibited to the extent that stem and stolons stopped growing and all assimilates produced by the leaves were directed to the tubers.

In Experiment GR1, after 35 days of emergence treatment LS had 3.64 tubers per plant and 85.7% of the plants had formed tubers, while in treatment SL1, there were only 1.5 tubers per plant and 66.7% of the plants had tubers; but both of them had equal number of short days by that time, with the difference that LS was given short day after 17 days of emergence and SL1 straight after emergence. Furthermore number of axillary branches, their total length, no. of leaves on axillary branches and length of stolon, all were higher in SL1 as compare to treatment LS. In an another treatment, LSL, which had 20 short day cycles but after, 17 days of emergence; tuber weight after

49 and 66 days of emergence was 23.2 and 35.00g plant^{-1} while in SL, it was 3.3 and 14.8g plant^{-1} respectively. Stem weight which is increased by non-inducing conditions was also higher in SL1 than LSL. Specific leaf area was lower in SL1. As we have seen earlier that effect of photoperiod is quantitative, thus difference of only 3 short day cycles cannot be the only reason, thus there must be some other factor affecting it.

Murti and Saha (1975), found that 20 SD cycles given immediately after emergence or 20 days after emergence, failed to initiate tubers, while 15 SD cycles were enough when given 40 or 60 days after emergence, where plants were kept in continuous light and harvested after 90 days of emergence. In an experiment where plants in addition to 7 old leaves had: 3 young (less than 3cm) terminal leaves or one young terminal leaf or without any terminal leaf. Tuber weight was highest where there was no young terminal leaf and lowest where there were three young terminal leaves (Hammes and Beyers, 1973).

Thus it follows that the ratio of production of cytokinins and UTS to gibberellins is more in old leaves compared to younger ones and obviously ratio of old to young leaves increases with age of the plant.

In case of treatment LD: in Experiment GR1, there was no tuberization until 66 days after emergence when this experiment was terminated, while in Experiment GR2 under higher irradiance level (40 0 UEM^{-2}S^{-1}, still lower than GR1), some tubers were recorded (10g plant^{-1}). This clearly shows that tuberization is favoured by lower temperature as in Experiment GR2, temperature was 15°C during day and night while in Experiment GR1 temperature was 20°C during day and 15°C night.

Results are in general agreement with privious workers (Gregory, 1956; Borah and Milthorpe, 1962; Slater, 1968; Saha et al., 1974; Menzel, 1980).

At lower irradiance level in experiment GR2 in combination with LD, tuber weight was 0.5g plant^{-1} after 81 days of emergence but at higher irradiance level in combination with LD tuber weight was 14.5g plant^{-1}. Similarly in experiment GH1 plants under muslin shade did not tuberize while plants growing in natural glass house attained 1.42g of tubers per plant (there was no difference in spectral photon distribution). Similar results in growth rooms were obtained by Borah (1959) in variety Arran Pilot (irradiance levels were 64 and 128 cal cm^{-2} day^{-1}). Either induction increased with increase in irradiance levels, or alternatively, tuber induction was already there and the additional assimilates available due to higher number of photons, were diverted to the tubers. Favouring the first hypothesis, analysis of endogenous hormones in Solanum andigena showed that low light intensity increased levels of acidic gibberellins in leaves of short day plants (Woolley and Wareing, 1972). Thus under higher light intensity ratio of cytokinins and UTS to gibberellins might have been higher, which resulted higher tuber weight.

Total dry matter produced was reduced by decrease in irradiance as earlier reported by (Pohjahkallio, 1951; Bodlaender, 1963; Sale, 1973; Borah, 1959). NAR was low in LD due to mutual shading and high in HI due to higher number of photons available for photosynthesis. Specific leaf area increased with decrease in irradiance levels; e.g. Experiment GR2 and GH1, and was higher in SD as compare to LD as found by Borah (1959). Ratio of leaves to stem (on weight basis) decreased in LD after tuber initiation, due to continuous growth of the stem.

With decrease in irradiance plant height was increased due to increase in internode length (e.g. compare treatments LI and HI in Experiment GR2 and muslin and control in Experiment GH1). Increase in stem length of potato due to decrease in radiation has also been reported earlier (Borah, 1959; Bodlaender, 1963) and may be related to higher amount of gibberellins produced under lower irradiance levels (Wolley and wareing, 1972). Length of the potato stem was also increased with decrease in phytochrome state. For example, in treatment blue and muslin shade in Experiment GH1, total radiation was the same, but plants were taller under blue shade where phytochrome state was lower than under muslin. Stimulatory response (length) of far red (>700nm) and inhibitory of red light (<700nm) is established in various crops (Imnoft et al., 1979; Jacques, 1968; Satter and Wetherall, 1968).

Effect of spectral photon distribution on tuberization is not quite clear from this experiment as total radiation was confounded with light quality. However blue light appears to have some stimulatory effect on tuberization as percentage of assimilates diverted to tubers were equal in plants grown under blue shades and natural glass house while irradiance was much less under blue shade. Further there was no tuberization in plants grown under muslin or red shade.

3. CHEMICAL CONTROL OF GROWTH

3.1 LITERATURE REVIEW

Environmental factors which stimulate haulm growth inhibit tuberization (Chapter 2.1). It is recognised that the growth of crop plants may be altered in several beneficial ways by the use of plant growth regulators (Wittwer, 1971; McLaren, 1982). There are several reports that application of gibberellic acid (GA) to the foliage stimulates haulm growth and delays or inhibits tuberization and that partially grown tubers may respond by ceasing to bulk and by growing out stolons (Hammes and Nel, 1975; Menzel, 1980; Murti and Banerjee, 1976b; Kushizaki and Hoshi, 1961; Lovell and Booth, 1967; Timm et al., 1960, 1962; Tizio, 1964; Dyson, 1965).

The inhibitory effect of GA on tuber formation has led to the experimental application of growth retardent such as 2-chloroethyltrimethyl ammonium chloride (CCC). When plants were either sprayed with CCC or they were watered with this substance, height as well as weight of aerial stems and leaf area were decreased (Krug, 1961; Dyson, 1965; Gunasena and Harris, 1969, 1971; Kumar and Wareing, 1974; Murti and Saha, 1975b), tuber weight was increased especially following CCC application (Dyson, 1965; Hammes and Nel, 1975; Menzel, 1980). If CCC was applied around tuber initiation (TI), then tuber numbers were increased (Gunasena and Harris, 1969; Gifford and Moorby, 1967).

The effect of CCC is greater under conditions, which stimulate haulm growth and decrease tuberization, such as long days, high temperatures and high nitrogen application. Menzel (1980) reported greater increase in tuber weight due to CCC application in plants growing at higher temperatures (32/18 or 32/28°C) compared to lower temperature (22/18°C). In a photoperiodic experiment, Hammes and Nel (1975)

reported greater increase in tuber weight due to CCC application in plants growing at 18 hours day length compared to 12 hours. The effect of CCC was more in favour of tubers when nitrogen was applied at higher rates (Gunasena and Harris, 1969).

The inhibitory effect of CCC on growth is transitory and decreases steadily over a period of 42 days (Krug, 1961). When CCC was used at the rates of 50ml, 790 or 3160ppm per pot before tuber initiation, rate of the stem growth was low for a period of 30 days following CCC application and tuber initiation was enhanced but final tuber weight was not affected (Dyson, 1965).

N-dimethyl aminosuccinamic acid (B9) had similar effects to those of CCC giving a general decrease in haulm growth (Dyson and Humphries, 1966) and tuber number and tuber growth were increased particularly in the period following its application but final tuber yield was not affected (Humphries and Dyson, 1967).

A more recently synthesised growth regulator, pp333 (Imperial Chemical Industries) has been shown to decrease culm length and increase seed yield in grasses (Hebblethwaite et al., 1982). Uptake of pp333 was largely from the soil via roots and activity, or at least the observed response was maintained over a long period. It was considered that the general response to pp333 was similar to that of CCC and B9 but the effect may stay for a longer time.

3.2 OBJECTIVES

The effects of pp333 on potatoes were investigated in order to determine whether haulm growth could be decreased without detrimental effects on tuber yields. A higher proportion of total plant dry matter in the tubers would provide the potential for increased productivity per unit area. Little is known about the reaction of the potato crop to pp333 and so in a preliminary way the time of application was investigated in single plots, with sequential harvests for crop growth analysis.

3.3 MATERIALS AND METHODS

The experiments were carried out on the University of Nottingham farm, at Sutton Bonington, over the two years, 1979 and 1980. In 1979, soil was sandy clay loam (Field 32) and in 1980, it was sandy loam (Field 10).

On receipt, seed (detail for seed source in Appendices B and C) of the variety Pentland Crown, was examined for disease etc. In 1979 seed was infected with Rhizoctonia solani Kuhu (Black scurf). All severely affected and deformed tubers were discarded and remaining tubers were arranged 'Apical' end uppermost in a single layer in chitting trays. Seed was then stored (Table 3.3.1) until planting and irradiance to avoid etiolation of the sprout during storage was 2.3 $\pm$ 0.4 UEM^{-2} S^{-1} (warm white fluorescent tubes), on top of the tubers. Relative humidity was 90 $\pm$ 4% at 4°C and 65 $\pm$ 4% at 12 and 8°C.

3.3.1 Experimental design and practical details

Treatment details are given in Table 3.3.1. Single application of pp333 @ 750g a.i. ha^{-1} was given as a spray, covering the whole plot equally i.e. plants and bare soil. There were no cultivations after planting and weeds were effectively controlled, using a mixture of paraquat and linuron at recommended dose, at about 5% emergence. Over the period when stems were emerging, number of stems were counted for 10 plants per plot, on every other day in the beginning, when stems were emerging at fast rate and on every 4 - 5 days later on, until no further increase took place. Data for rainfall, screen temperature and soil temperature at 10cm depth was obtained from a nearby meteorological

station, within one kilometre of the experimental site. Rainfall totalled for every five days is presented in Figure 3.3.1 and screen (max. and min.) and soil temperature at 10cm depth, both averaged for every 5 days are presented in Figures: 3.3.2(a,b) and 3.3.3(a,b) respectively.

Light interception in the photosynthetically active range (400 - 700nm) was measured in situ using Quantum meters (Lamda instruments) with remote cosine corrected sensor heads. Simultaneous readings were taken from above and below the crop canopy at randomly selected positions. Reflectance in the 400 - 700nm range was considered to be low (Scott et al., 1968) and relatively constant and consequently was not included in the readings. To decide, the number of readings per plot; in 1979, 40 readings per plot were taken for few plots of Experiment F1 and co-efficient of variation was worked out for all the 40 readings and then selecting randomly 5 and 10 out of 40 (Table 3.3.2).

It was decided to take 10 readings per plot. In order to minimise the influence of solar height, all readings were taken between 10.30 - 14.00 hours. Early in the season when ground was not covered completely; readings were taken around the plants and thus percentage light interception was adjusted for ground cover, measured using the grid.

The grid consisted of a rectangular metal frame, with strings, at 15cm spacings pulled tightly across the frame. Size of the frame was, 150 X 90 sq.cm to cover, 2 ridges. The ground cover was recorded by placing the grid at two places in a plot and looking downward.

Recommended plant protection measures were taken and crop stayed healthy during both years as far as insect pest and diseases were concerned.

3.3.2 Growth analysis

Seven growth analyses were carried out during both years. Sampling was frequent early in the season, to obtain an idea of earlier tuber growth. Each sample consisted of, 2 in 1979 and 4 in 1980, adjacent plants and care was taken that at least one guard plant was left between each sample. At each harvest foliage of the selected plants was cut off at soil level and then underground parts of the plants were lifted carefully, using a fork. All the tubers, however small, were recovered. Plants were stored in labelled polythene bags, at 4°C until dissected. No attempt was made to recover roots and those which were attached to the stems were removed and discarded. Laboratory procedure for growth analysis was the same as described in 2.3.1.4, except that stolons were not measured.

Early in the season the leaf and stem material from the whole sample were used in determining the dry matter content, but as sample size increased, a random sub-sample of 350g to 1.5Kg was taken depending on the size of sample.

3.3.3 Final harvesting

After complete senescing, guard plants on either side of the row were harvested with a fork, remaining plants, excluding guard rows were harvested with a tractor operated potato digger (Jonson), and then picked manually. Tubers were stored in labelled sacks in a cold room at 4°C, until passed through the riddle. Riddles available for grading large quantities of produce were slightly different from the one used for growth analyses. Records were made for the number and fresh weight

Table 3.3.1. Experimental details

	1979	1980
Pre-planting storage.	97 days at 4°C, followed by 13 days at 12°C and 22 days at 8°C.	90 days at 4°C, followed by 39 days at 12°C and 1 day at 8°C.
Planting date	1st May	15th April
Seed size	105.3 ± 1.31g	77.5 ± 1.26g
Plot size	5 rows of 6.56M each	8 rows of 7.20M each (control) 10 rows of 7.20M each (pp333)
Spacing	76X41cm	76X36cm (control) 61X20cm (pp333)
Treatments	There were 5 treatments: pp333 sprayed on; 5th June or 18th June or 2nd July or 16th July and control (no spray).	There were 2 treatments: pp333 sprayed on; 23rd May and control (no spray).
Fertilizer (All given before planting)	1318Kg ha^{-1} (15:15:15; $N:P_2O_5:K_2O$)	1318Kg ha^{-1} (15:15:15; $N:P_2O_5:K_2O$)
Dose of pp333	750g a.i. ha^{-1}	750g a.i. ha^{-1}

of tubers in each grade and a sub-sample of 350g to 4Kg was taken, depending upon the quantity of tubers in each grade, for dry weight.

Table 3.3.2. Mean percentage light interception before adjusting for ground cover and CV% on 21.6.79.

VARIETY		Pentland Crown		Record	
Replication	No. of readings	mean	CV%	mean	CV%
	40	86 ± 0.9	1	83.6 ± 1.78	2.13
1	10	84 ± 1.3	1.5	83.4 ± 2.77	3.33
	5	83 ± 1.3	1.5	82 ± 3.5	4.3
	40	83.2 ± 1.18	1.42	86.5 ± 0.86	0.996
2	10	84.7 ± 1.46	1.73	88.5 ± 0.92	1.06
	5	83.3 ± 2.6	3.12	86.76 ± 0.89	1.02

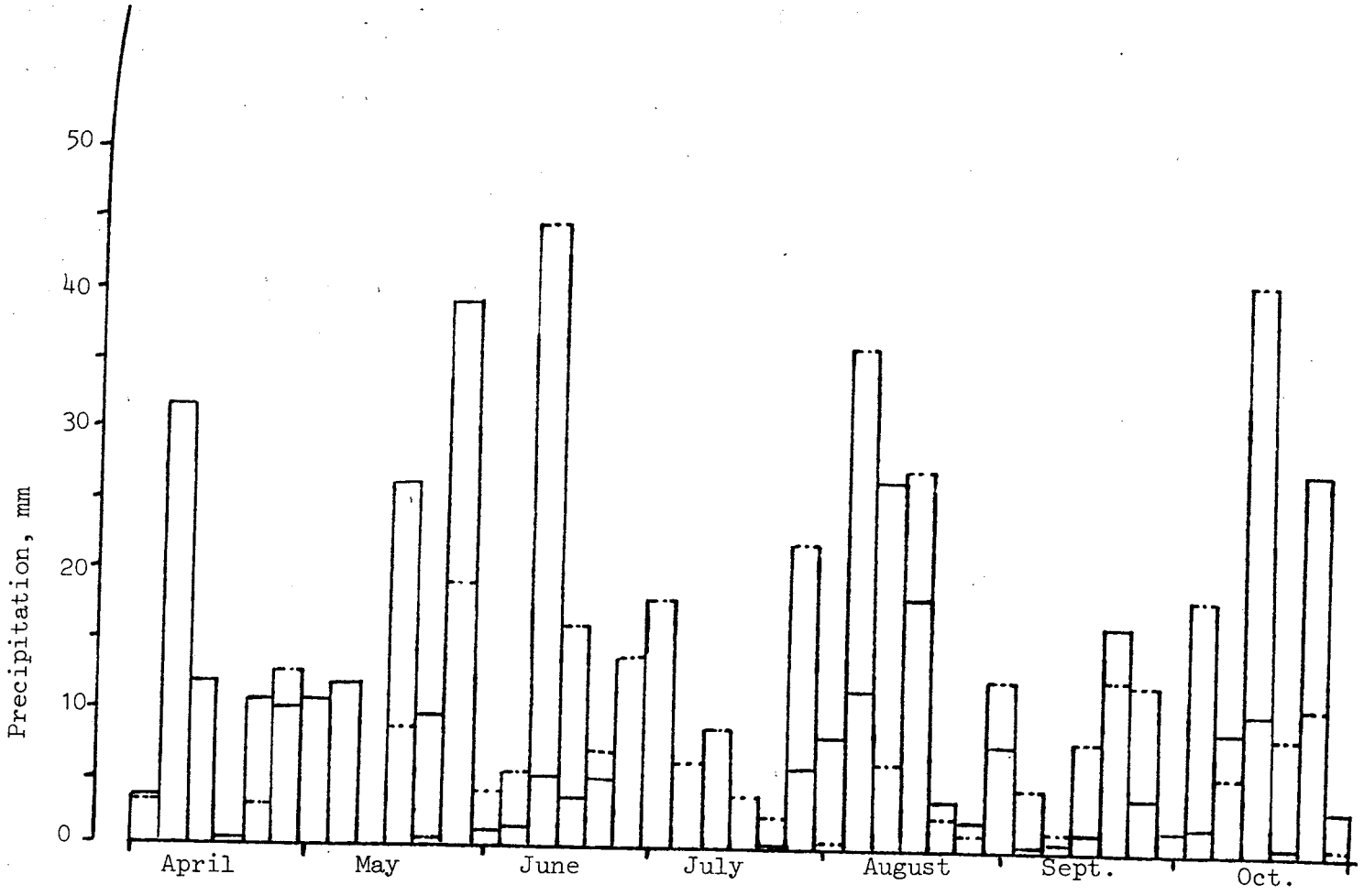


Figure 3.3.1 Rainfall (mm) totalled for every 5 days during 1979 (——) and 1980 (- - -).

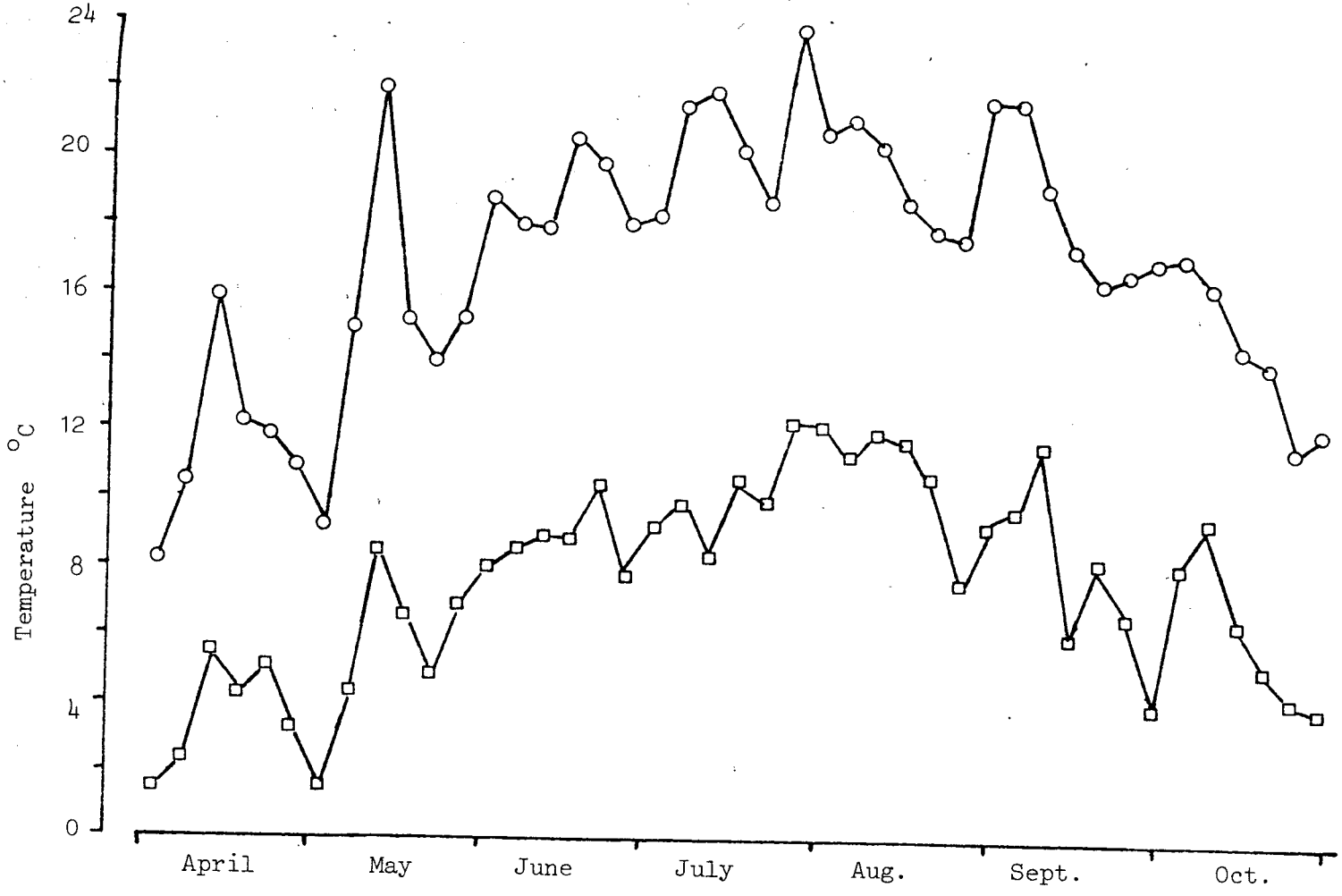


Figure 3.3.2 a Screen max (O) and min (□) temperature (°C) during 1979, averaged for every 5 days.

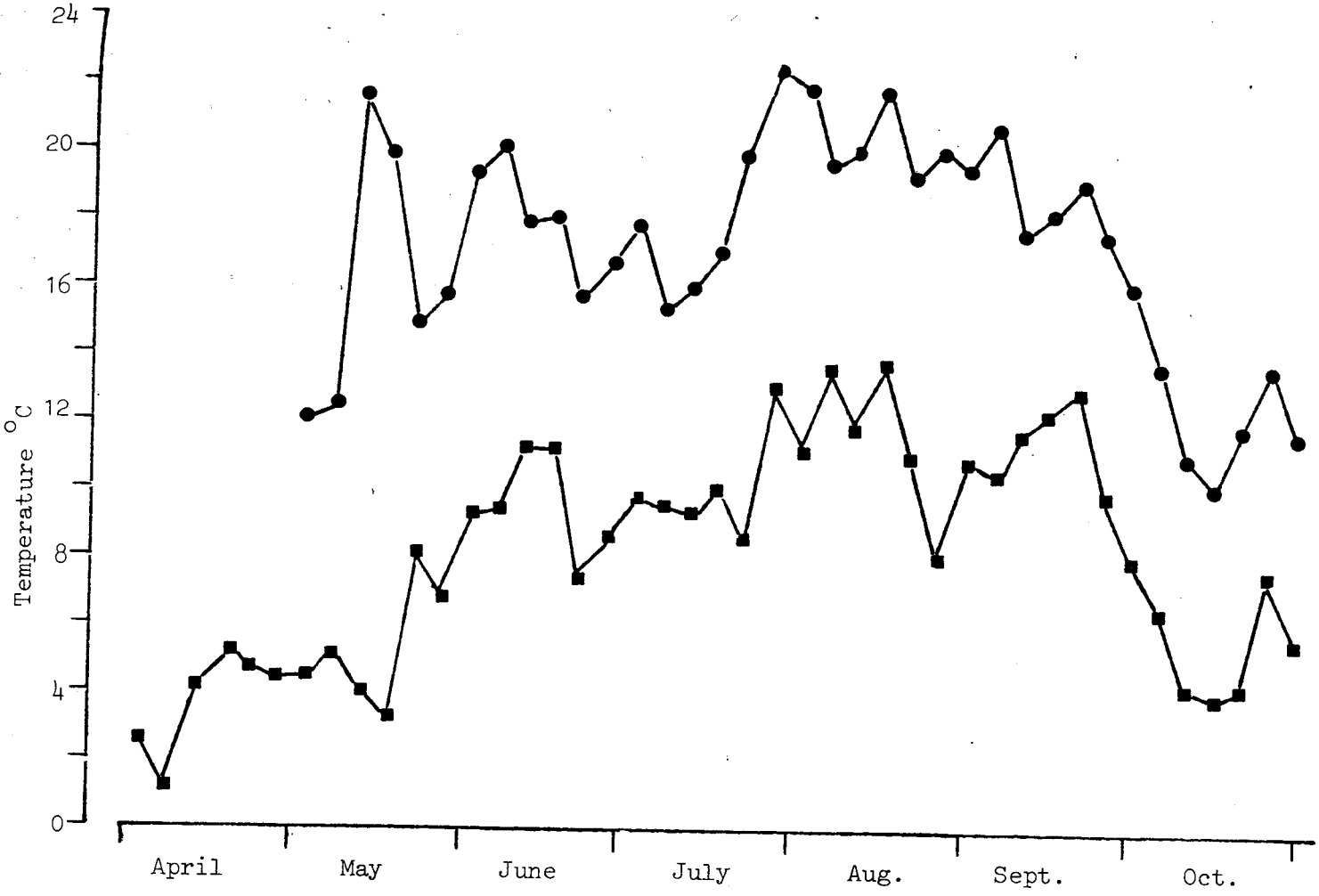


Figure 3.3.2b Screen max (●) and min (■) temperature (^{o}C) during 1980, averaged for every 5 days.

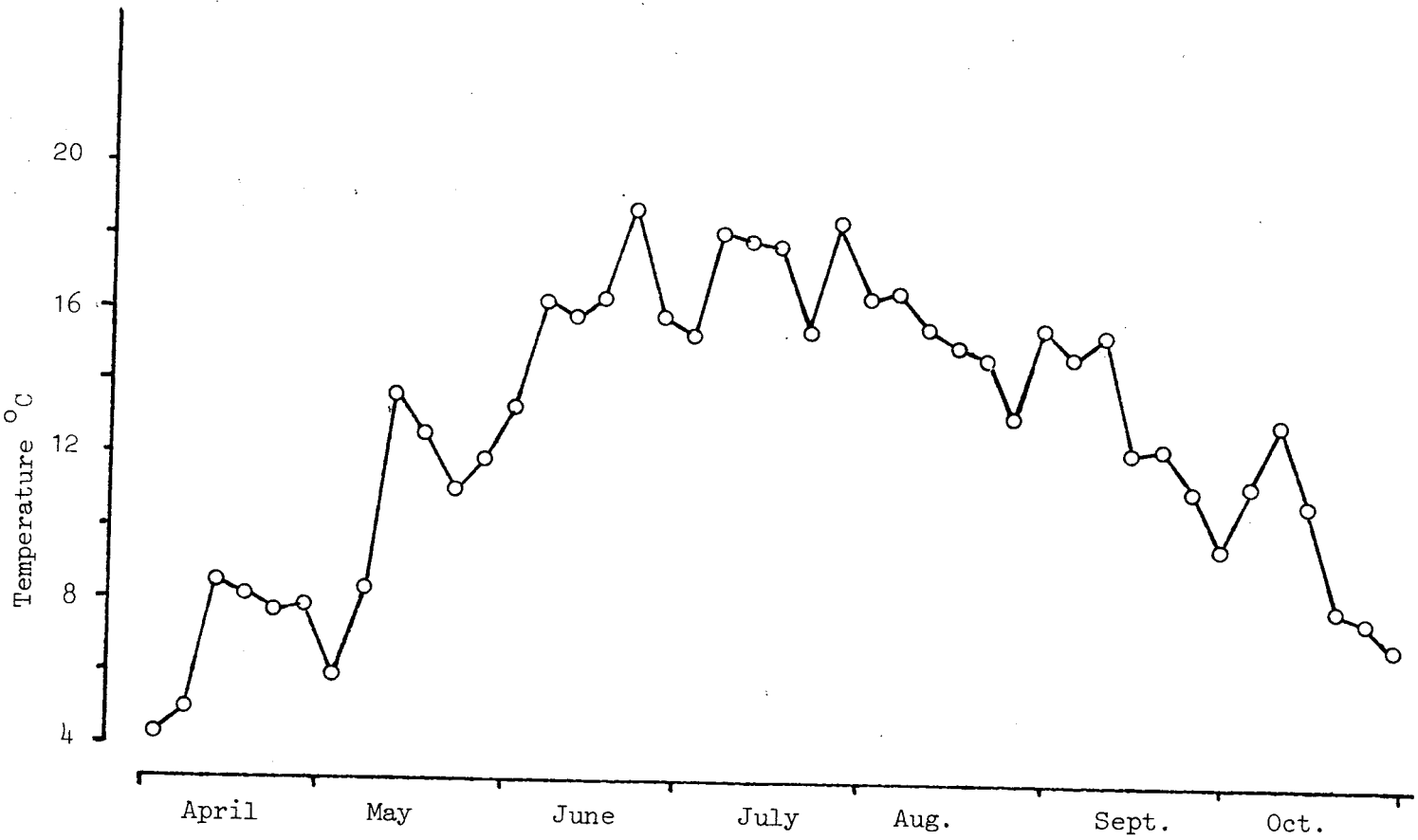


Figure 3.3.3a 9am soil temperature (°C) at 10cm depth during 1979, averaged for every 5 days.

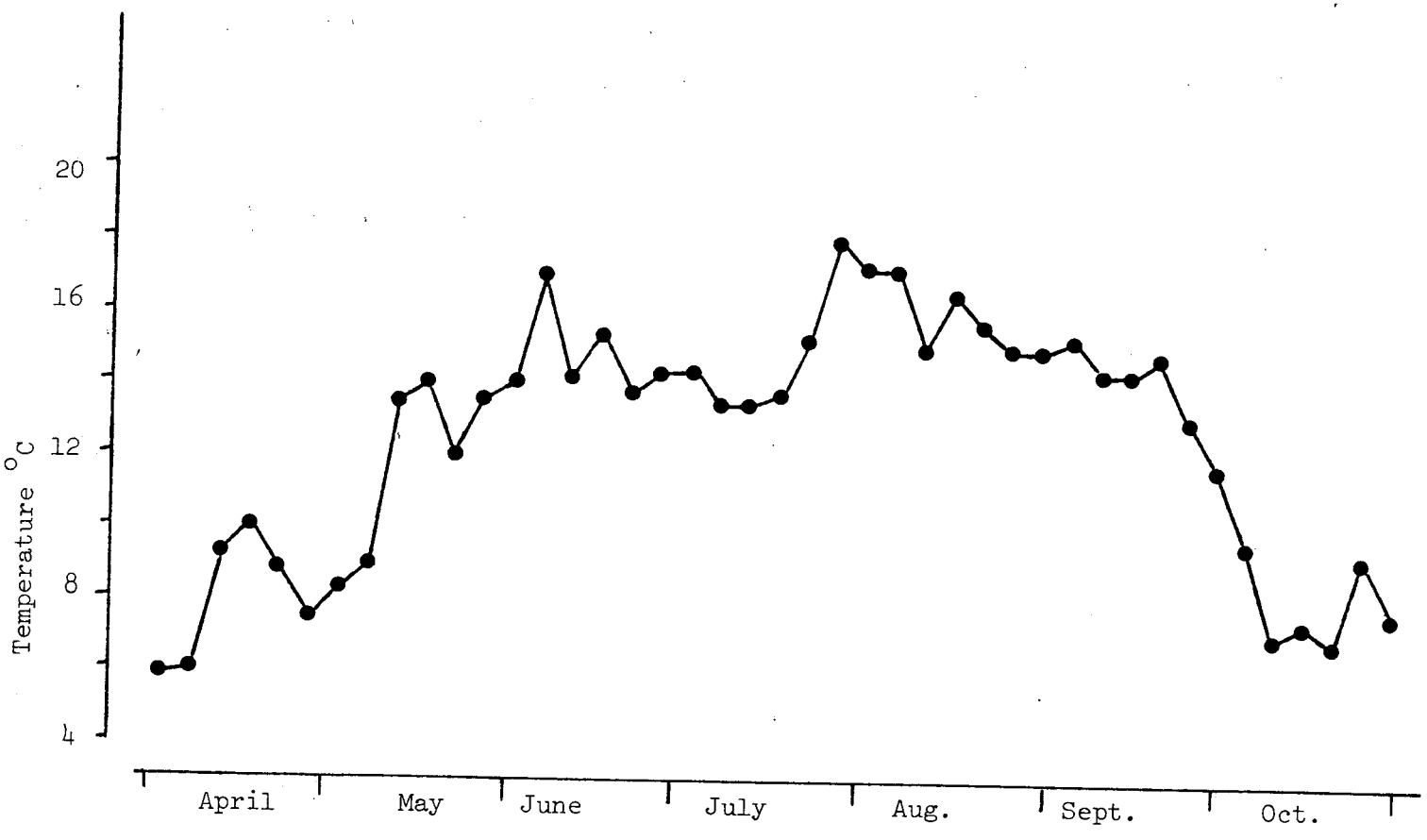


Figure 3.3.3b 9am soil temperature (°C) at 10cm depth during 1980, averaged for every 5 days.

3.4 RESULTS

Soil temperature, at 10cm depth and screen, max. and min. air temperature did not vary substantially between years (Figures 3.3.3(a,b) and 3.3.2(a,b)). However, rainfall (Fig.3.3.1) did differ between years with a noticeably dry period, in the months of June and July during 1979.

Depending upon the results of 1979, there were only 2 treatments in 1980 i.e. pp333 sprayed on 23rd May, 1980 and control, and a further treated plot was planted at closer spacings (61X20cm). General growth of the crop was more rapid in 1980, in the absence of a dry period.

3.4.1 Stolon and stem growth

Before tuber initiation, immediately after spraying the pp333, total dry weight of the stolons and total number of stolons were increased in treated plots. But the important result was that, when plant growth regulator was sprayed before tuber initiation, the percentage of stolons out of total dry weight was higher in treated plots, for example, after 44 days of planting, in case of G5 percentage of stolons out of total dry weight was 3.55 compared to 1.85 for control. Similarly in 1980, 48 days after planting the percentage of stolons out of total dry weight was 4.35, while in control it was 2.60.

No effect of pp333 was found on the number of stems, nor the axillary branches (AB), present. However, stem extension was decreased in both years in treated plants. Figure 3.4.1 shows that pp333 decreased the average length of the mainstems and the response was substantially greater in 1980, with adequate rainfall. Spraying at later dates also

affected stem height (1979), rather where spraying was done earlier in the season for example, G5, the rate of stem extension, later in the season was not much lower than control. This may be explained by lower uptake of the chemical due to dry weather. The pattern of pp333 effects on average internode length was similar to that for stem length (Fig.3.4.2), indicating that all internodes growing after application were shortened. In 1979, leaves for the last two growth analyses were not counted, thus average internode length could not be calculated. Data for total dry weight of above ground stems (AGS) is presented in Figure 3.4.3 and was reduced in both years by the growth regulator. Growth of under ground stem (UGS) was not affected, resulting in differential values for AGS to UGS ratio, on weight basis (Fig.3.4.4) and was higher in control in both years.

3.4.2 Leaf growth

Decrease in stem length was due to decrease in internode length, thus leaf number were not affected. During both years the foliage was a darker shade of green following uptake of pp333. The area of individual leaves was decreased by pp333 and the effect was more pronounced in 1980.

The growth of leaves in control plots was lower in 1979 compared to 1980 (Fig.3.4.5), and, in addition, uptake of pp333 may have been lower under the drier conditions.

Irrespective of time of application, in 1979, the pp333 - treated plants had a lower leaf area index since leaf area plant^{-1} was decreased and plant spacing was the same as the control. In treatment, G5, plants had a higher LAI than, G18, later in the season and plants started

growing out of its effect. Since leaf area per plant was expected to be decreased, the treated areas in 1980 were planted at closer spacing in order to utilise all the available aerial space, for comparison of productivity area^{-1}, under full canopy cover. Therefore, although the average leaf area was decreased by pp333, the leaf area index was similar to that of the control during the 1980 experiment, except at the peak, when control LAI went up to 5 and pp333-treated was 3.5. In 1980, pp333-treated plants senesced a few days earlier than the control, resulting in a more rapid decline in LAI.

Changes in leaf area reflect changes in leaf expansion in two dimensions but actual leaf growth occurs in three dimensions. Therefore, although pp333 decreased leaf area the differences in leaf dry weight were not in proportion, resulting in differential values for specific leaf area. Specific leaf area was decreased, in both years, by pp333 and the decrease was evident throughout the growing season (Fig.3.4.6). It appeared that pp333 had increased either leaf thickness, cellular density or stored carbohydrate, or a combination of these factors. In the case of G5 (1979), the effect on specific leaf area seems to diminish later in the season.

3.4.3 Light interception

Figure 3.4.7 shows that the proportion of PAR intercepted by the crop canopy was altered by pp333 treatment. In 1980, light interception was similar for control and pp333 treatments between 70 - 105 days after planting (middle of the growing season), during this period LAI was higher than 3.0 and light interception was independent of LAI at indices of more than 3.0. LAI hardly reached 3.0 in 1979 and consequently

treatment differences were evident throughout the growing season rather than at particular times.

3.4.4 Tuber growth and development

The effect on tuber number during 1979 was variable (Fig.3.4.8). G5 decreased tuber number, may be due to very low leaf area index at the time of tuber initiation. Although G18 slightly reduced LAI, but increase in availability of assimilates by decreasing the stem growth, increased tuber numbers. In 1980, tuber number in pp333-treated plot were affected in two ways: firstly, due to closer spacing, there was higher leaf area index at the time of tuber initiation, and secondly, due to retardation of stem growth more assimilates were available for tubers. Thus tuber numbers were increased severalfold (Fig.3.4.8). Since total light interception was not much different, although stem growth was reduced, but there were not enough assimilates available for all those tubers to grow, thus differences at final harvest were reduced.

In 1979, G18 increased tuber weight, early in the season by making more assimilates available. Since leaf area index was reduced by all the pp333 applications (1979), thus final tuber yield was higher in control (Fig.3.4.9). In 1980, pp333-treated plot was planted at closer spacing, thus total light intercepted by the canopy during the growing season was the same. If then total assimilates available were equal in both treatments, pp333 by reducing stem growth and making more assimilates available for tuber growth, resulted in 16% higher tuber yield $area^{-1}$ over control (Fig.3.4.9) at final harvesting.

Although total tuber yield is important, the distribution of tuber

sizes making up the total yield may also be of importance in practice. In both years, the pp333-treated crop had a higher proportion of tubers in the 35 - 60mm range than the control (Fig.3.4.10a,b).

3.4.5 Total dry matter accumulation

Roots were not collected and those present on stems or stolons were removed and discarded, thus total dry weight (TDW) presented is excluding roots. Later in the season (end of July) leaves started to fall off and were not collected from the ground. The TDW achieved in 1979 was substantially lower than in 1980, reflecting the lack of rapid growth during the dry period in June and July of 1979 (Fig.3.4.11). In 1979, pp333 at all times of application reduced TDW, since plants were shorter and took up less aerial space. In 1980, pp333 treatment was grown at closer spacing to determine if dry matter production area^{-1} could be increased. There was very little difference in dry weight m^{-2} with pp333 and closer spacing compared to the control (Fig.3.4.11). Although the growth regulator allowed closer spacing without visible crowding effects, inter-plant competition for water, nutrients and soil space may have influenced the crop performance.

Given that total dry matter production area^{-1} was slightly decreased (1979) or similar with closer spacing (1980) it was of obvious importance to determine the distribution of that dry matter since tuber yields are the commercial product. Figure 3.4.12 indicates that in both years there was a higher proportion of total dry weight allocated to the tubers in the pp333 treatment. The redistribution of dry weight was more evident earlier in the season, probably because tuber initiation occurred 4 - 5 days earlier with pp333.

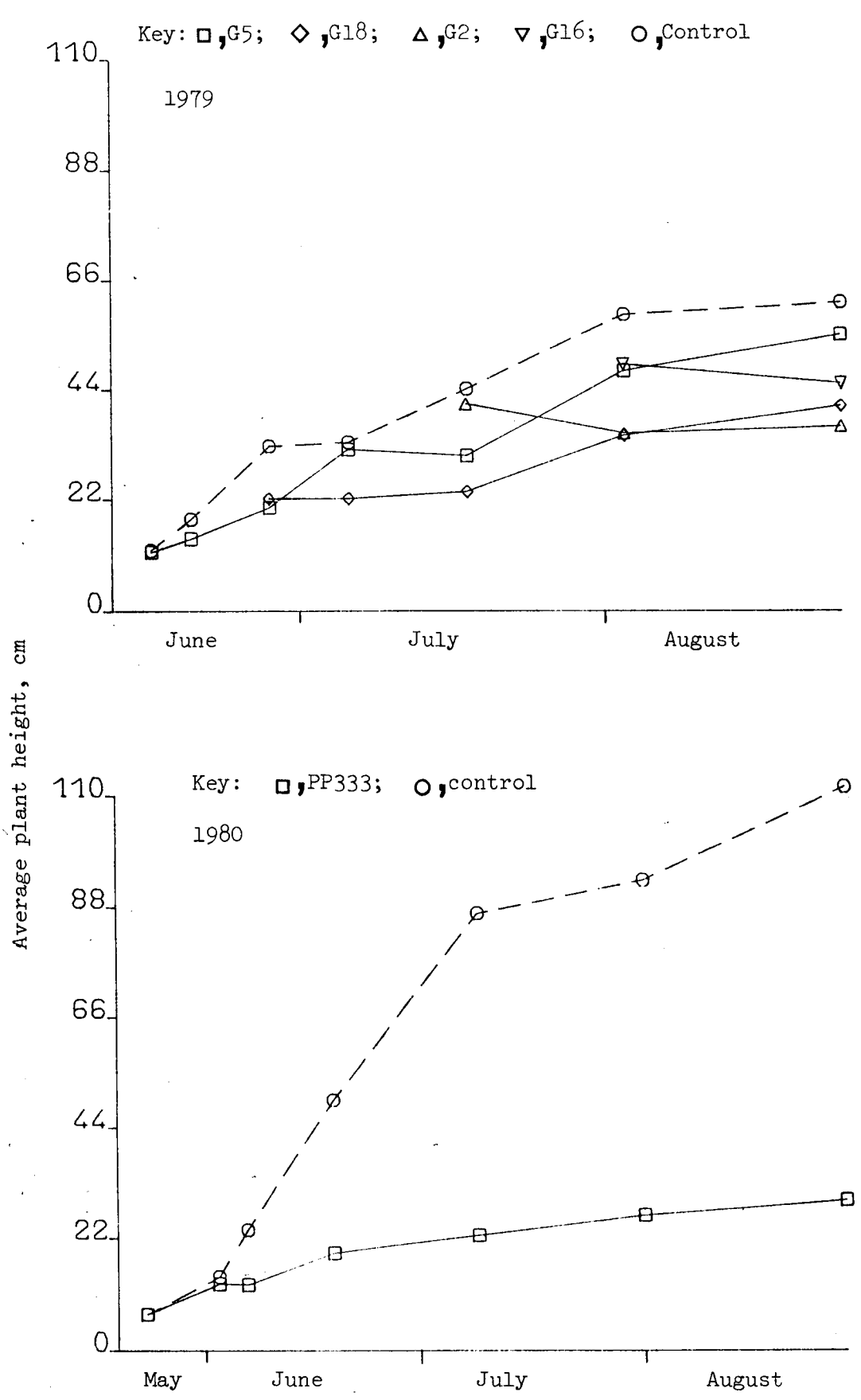


Figure 3.4.1 The effects of PP333 on average plant height.

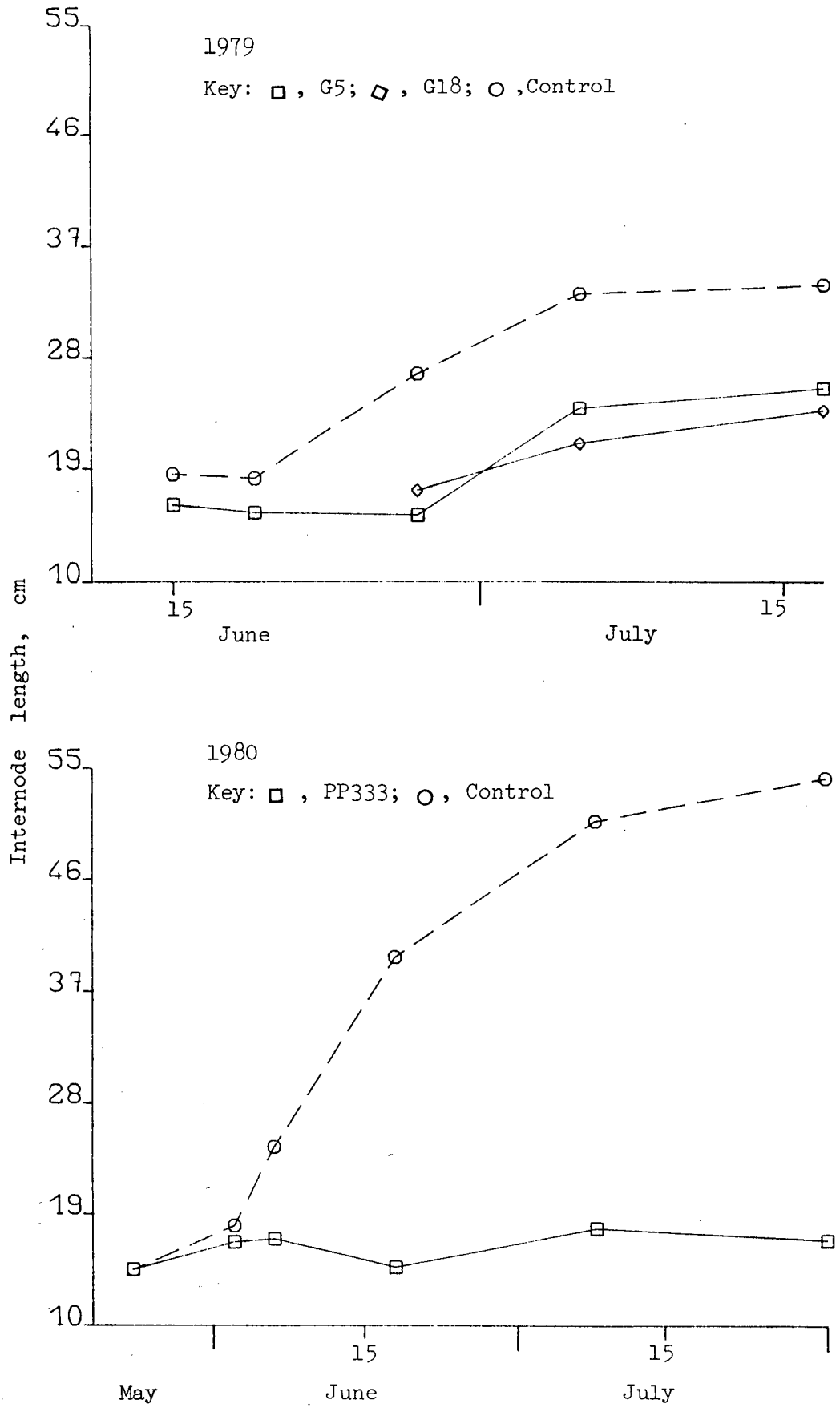


Figure 3.4.2 The effects of PP333 on average internode length (main stems only).

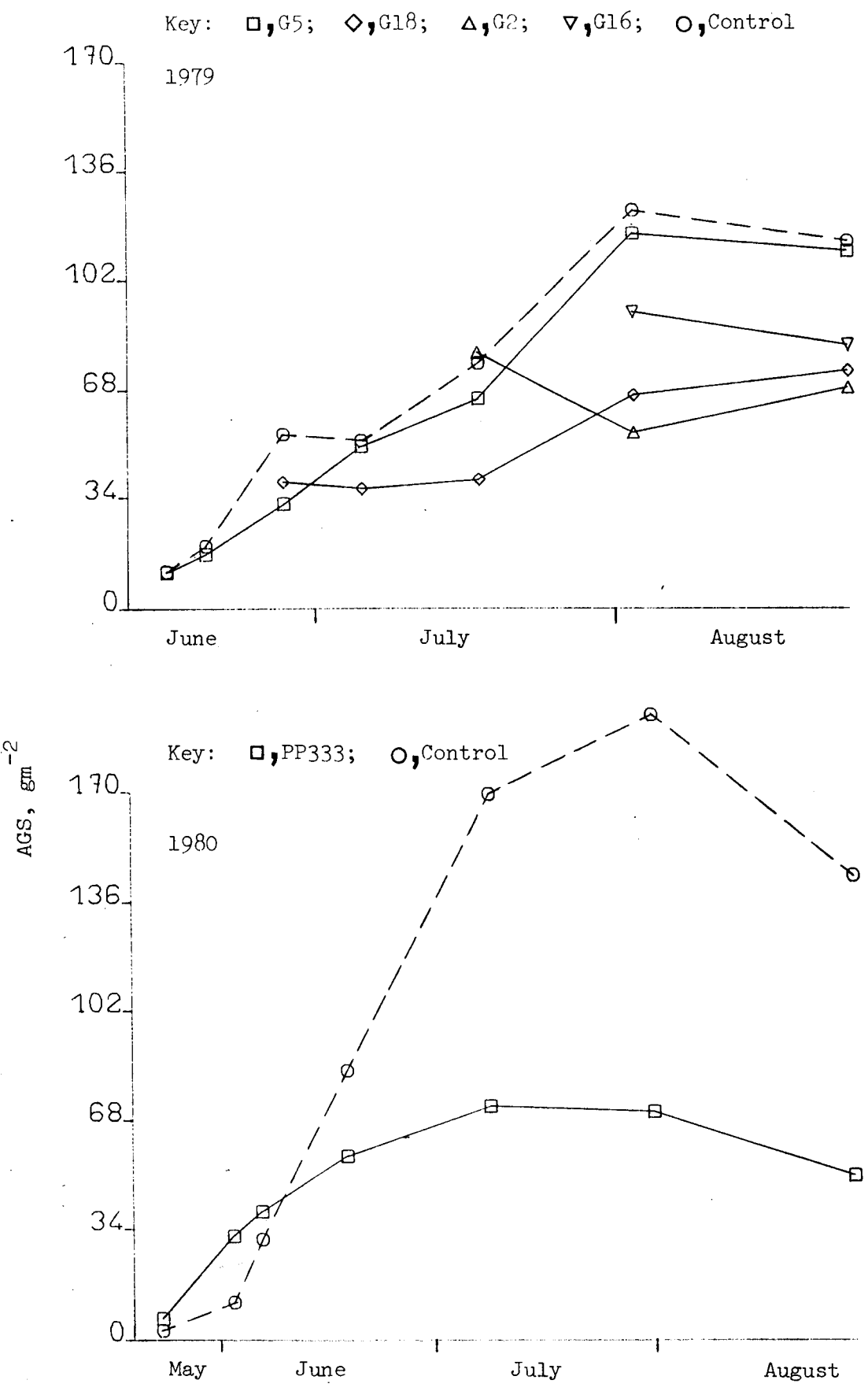


Figure 3.4.3 The effects of PP333 on dry weight of above ground stems (AGS).

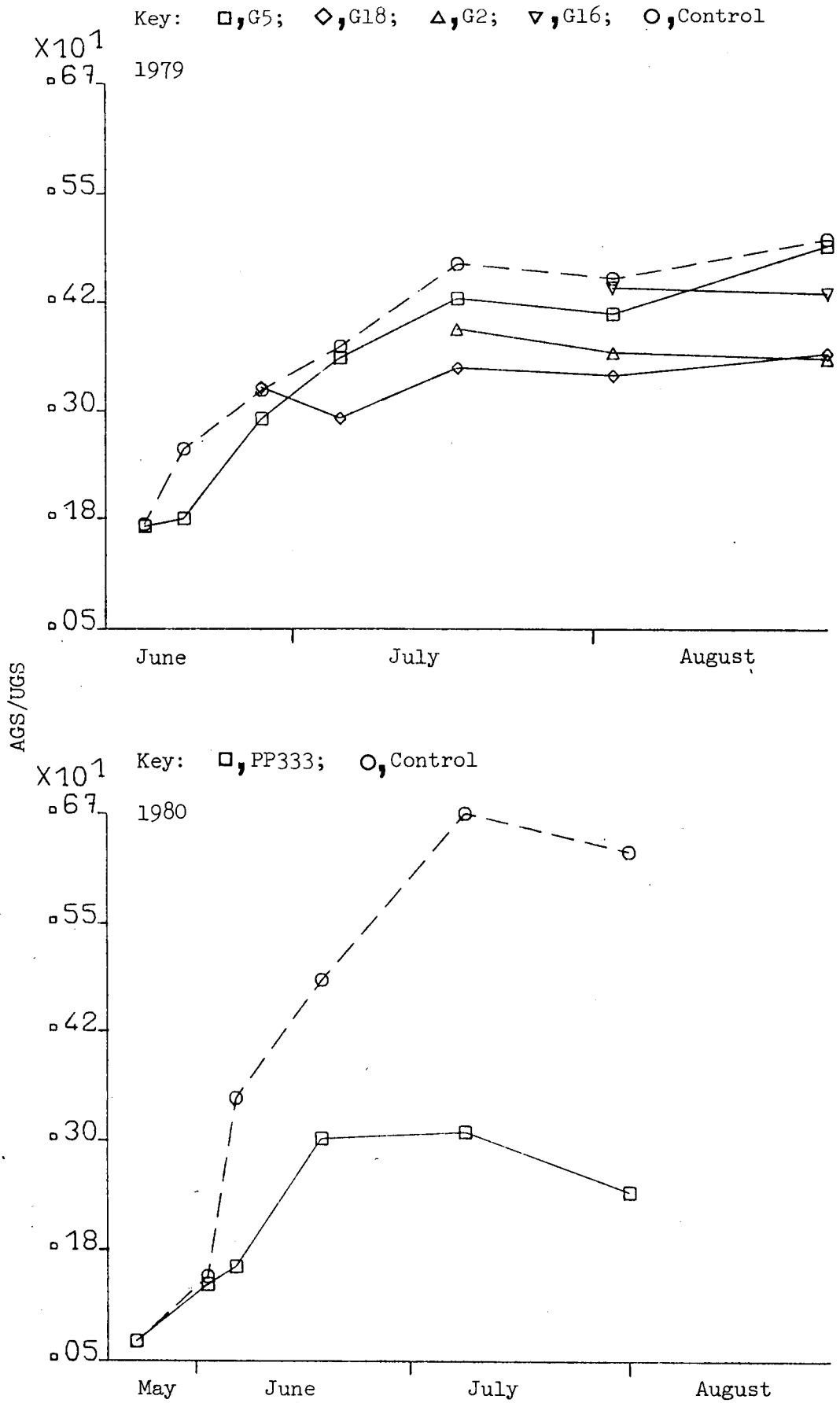
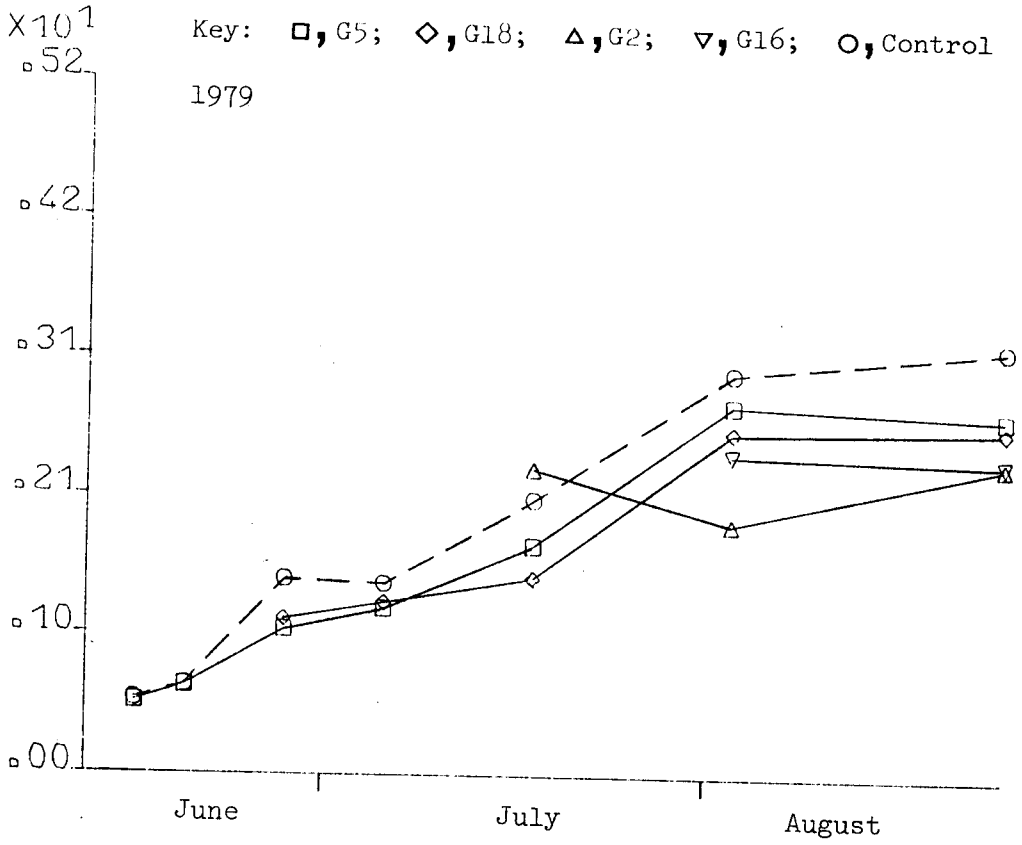


Figure 3.4.4 The effects of PP333 on the ratio of total above ground stem to total under ground stem (dry weight basis) (AGS/UGS).



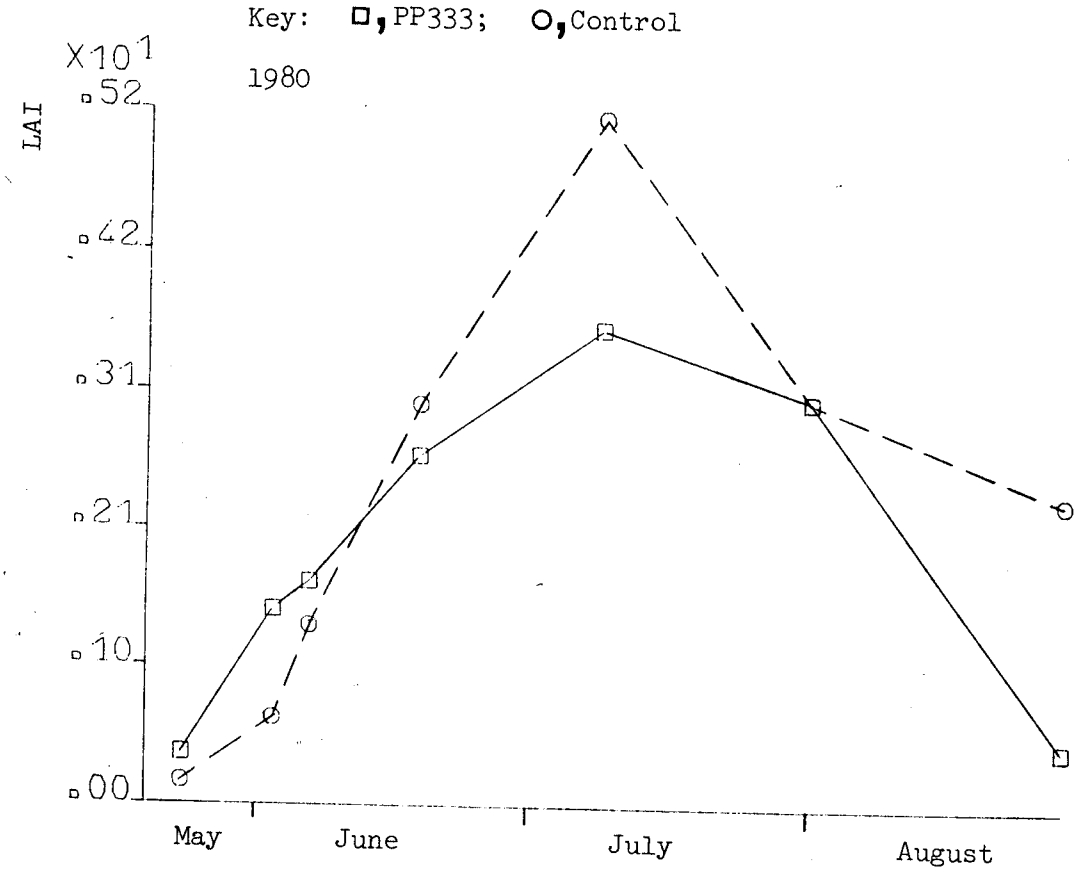
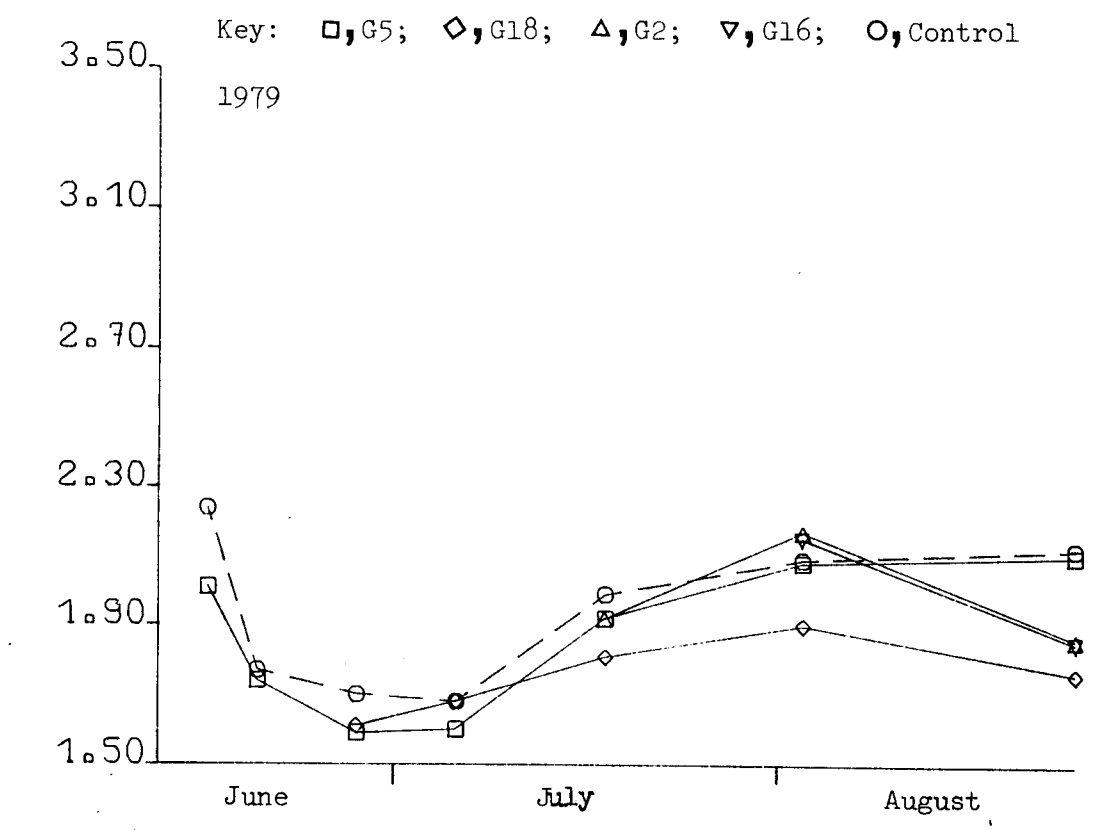


Figure 3.4.5 The effects of PP333 on leaf area index (LAI).



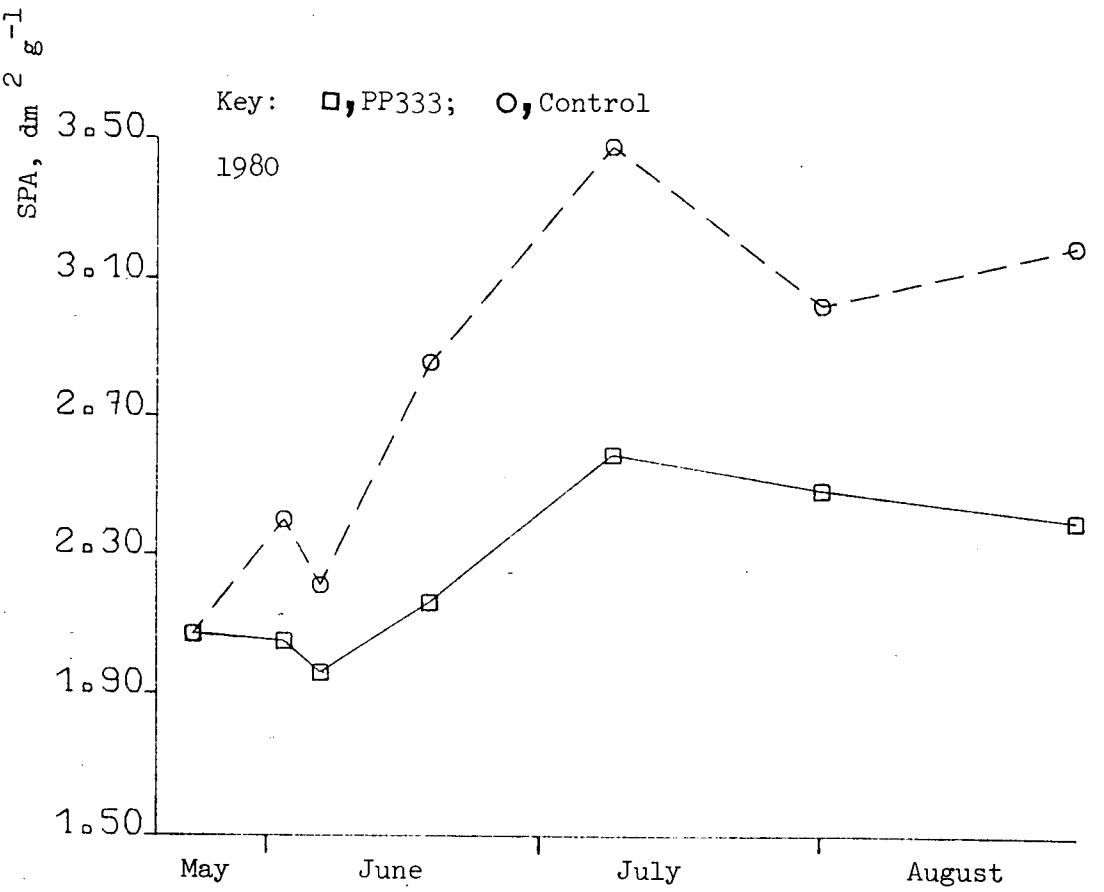
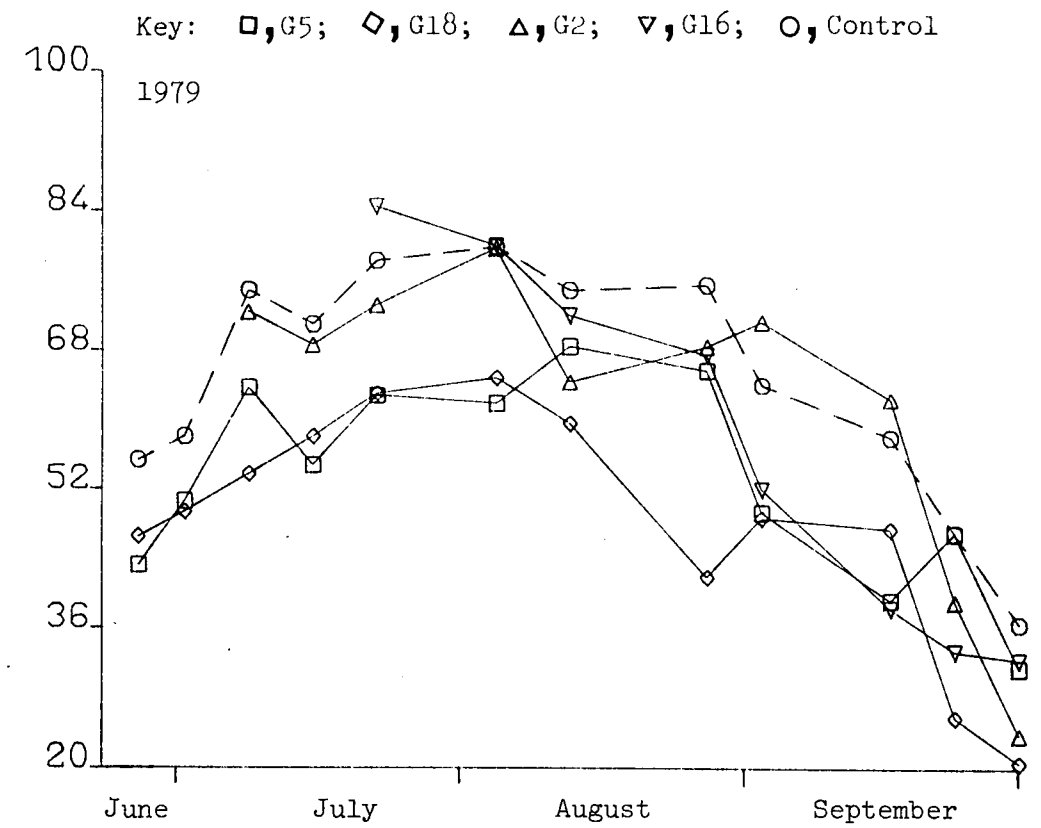


Figure 3.4.6 The effects of PP333 on specific leaf area (SPA).



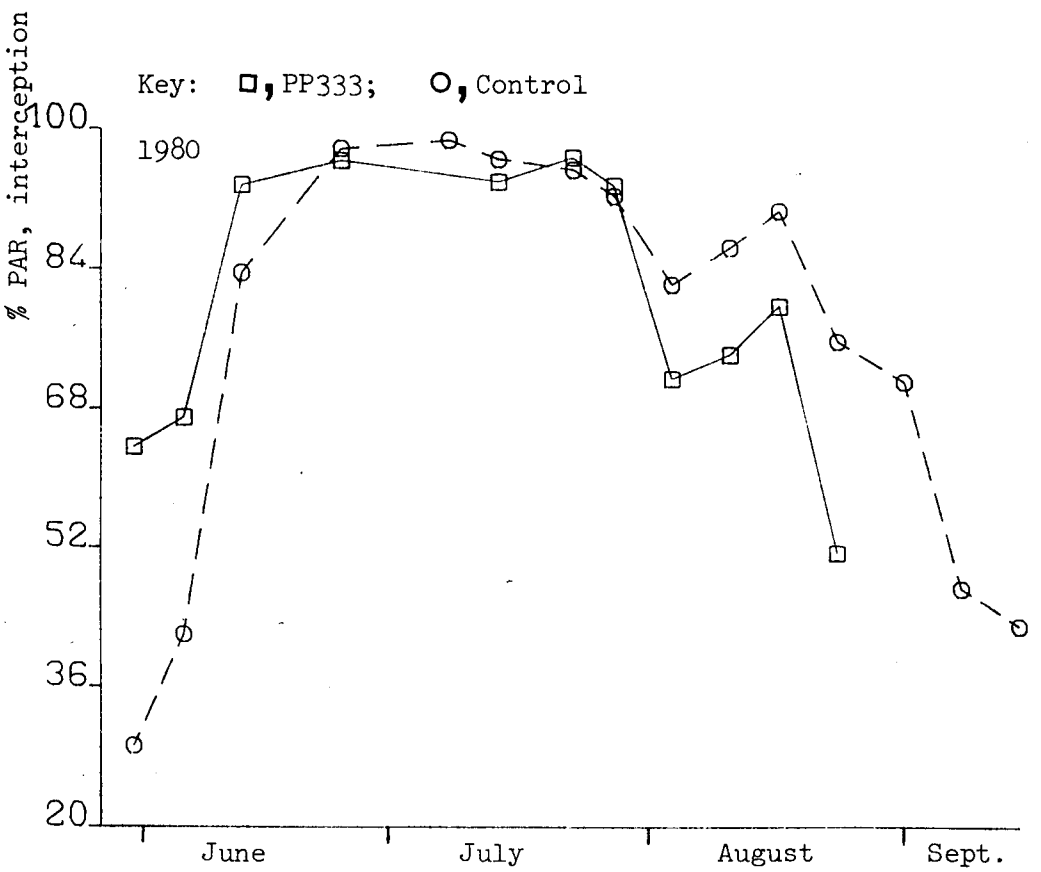
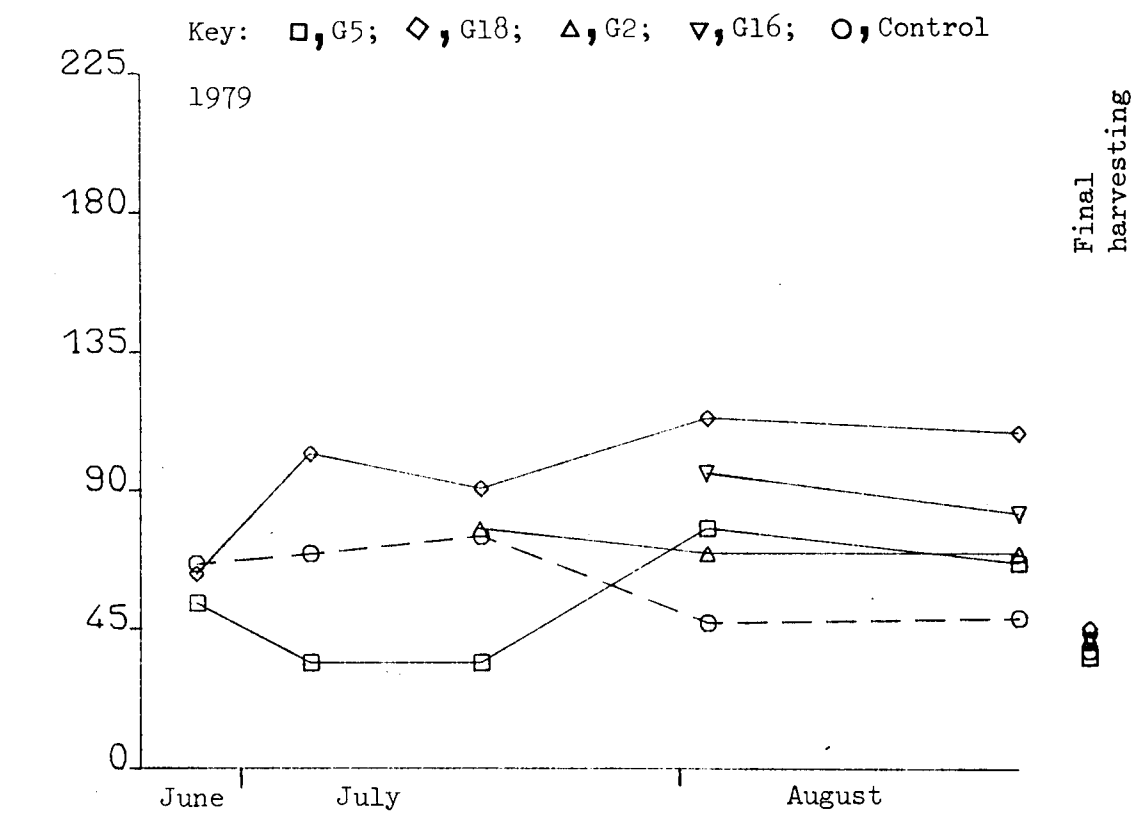


Figure 3.4.7 The effects of PP333 on photosynthetically active radiation (PAR) interception.



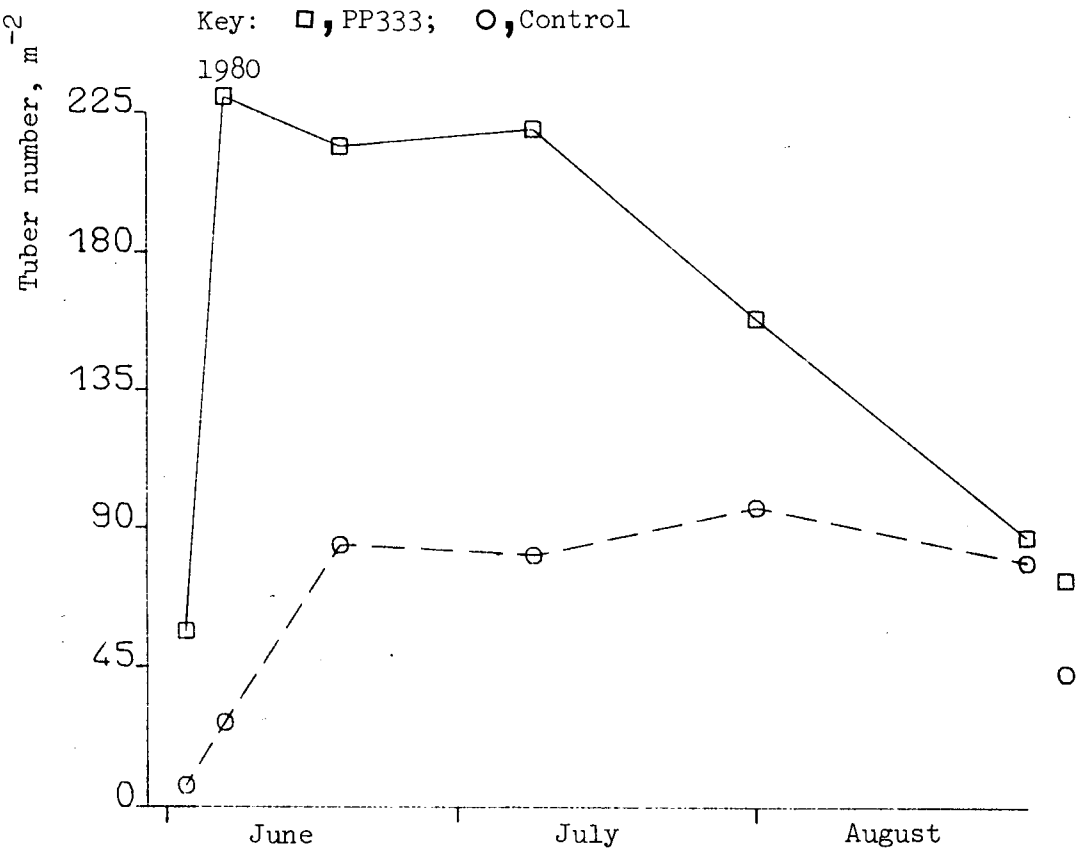


Figure 3.4.8 The effects of PP333 on total tuber number.

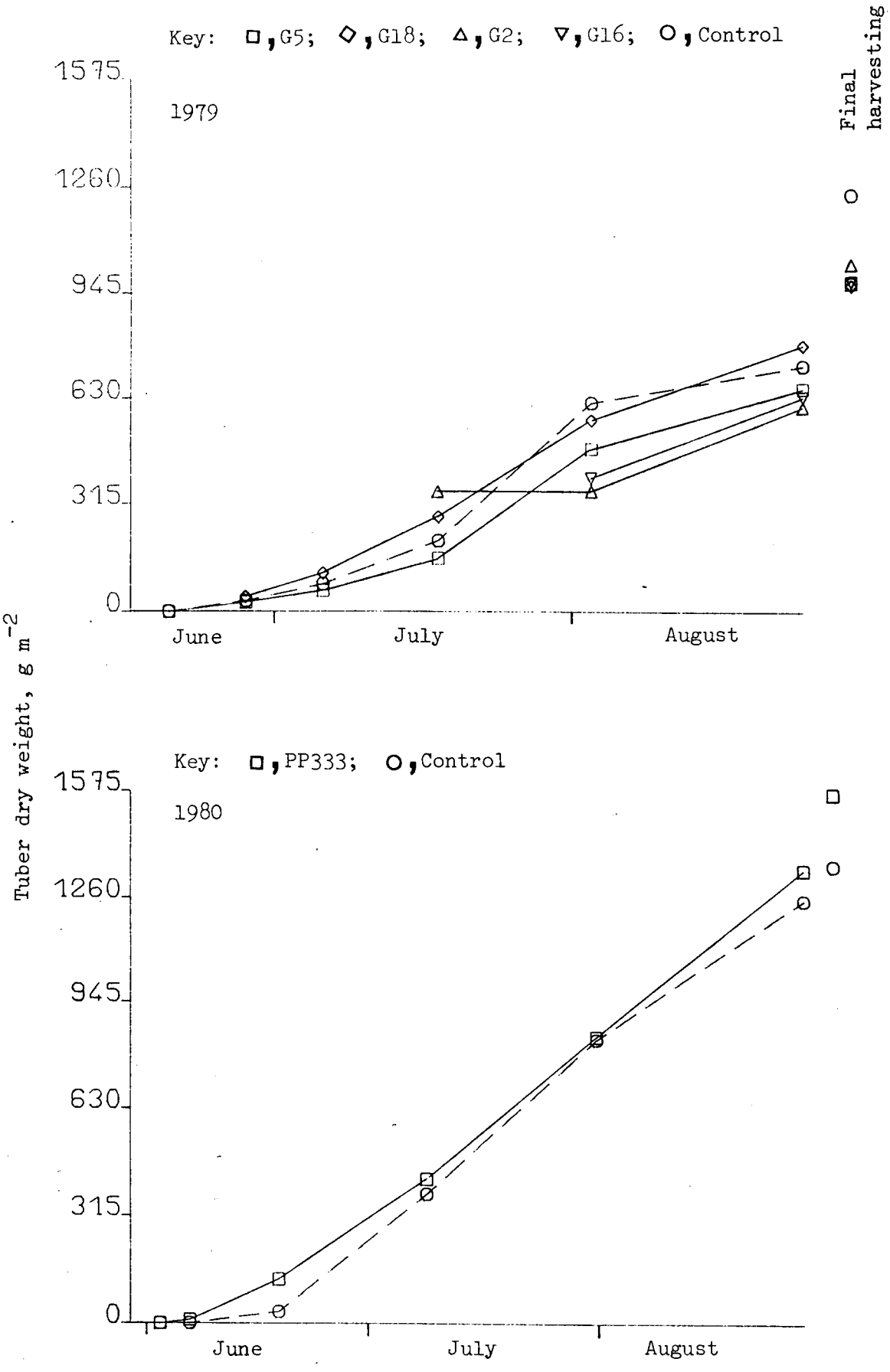


Figure 3.4.9 The effects of PP333 on tuber dry weight.

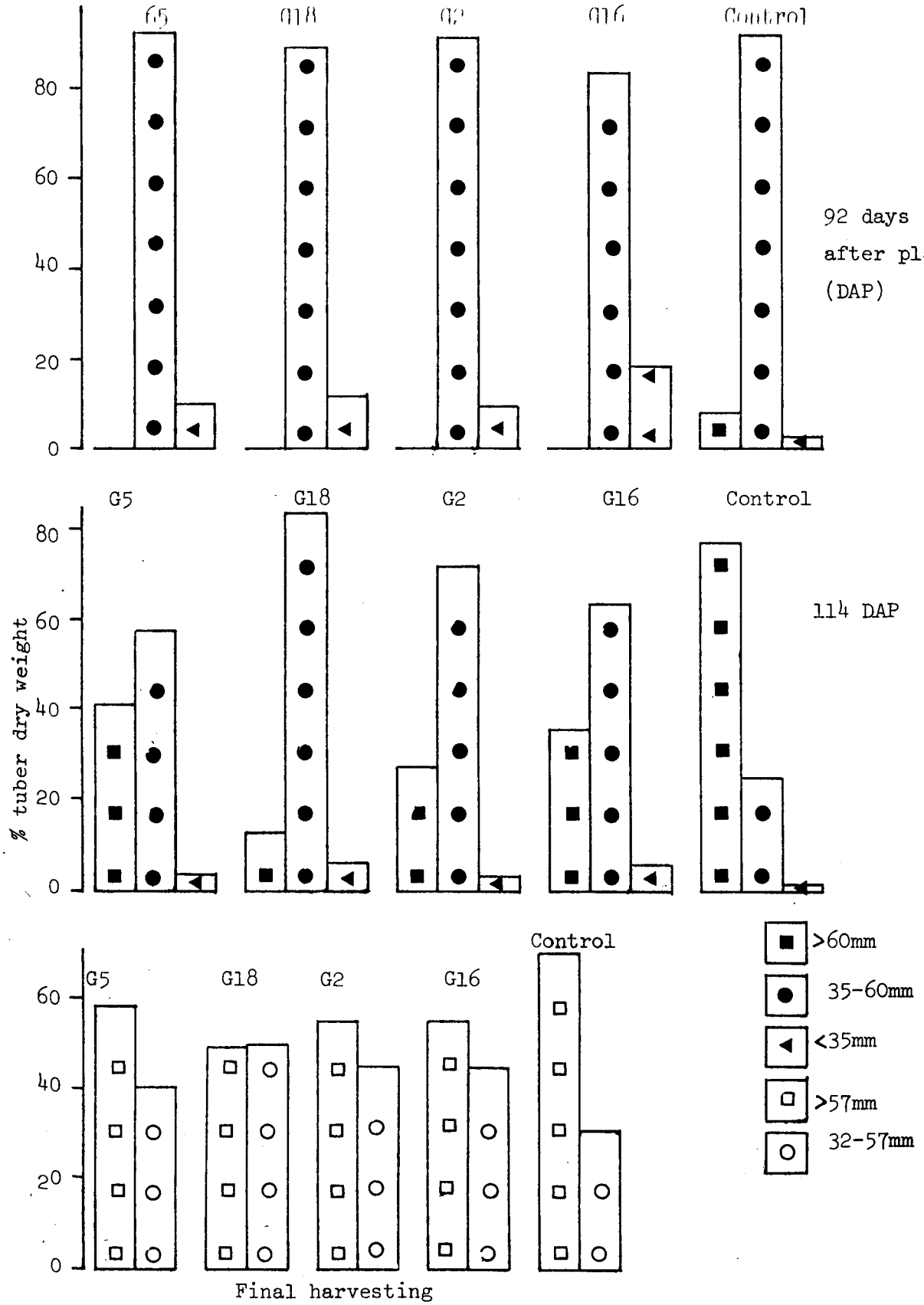


Figure 3.4.10a The effects of PP333 on proportion of tubers in size grades (dry weight basis((1979).

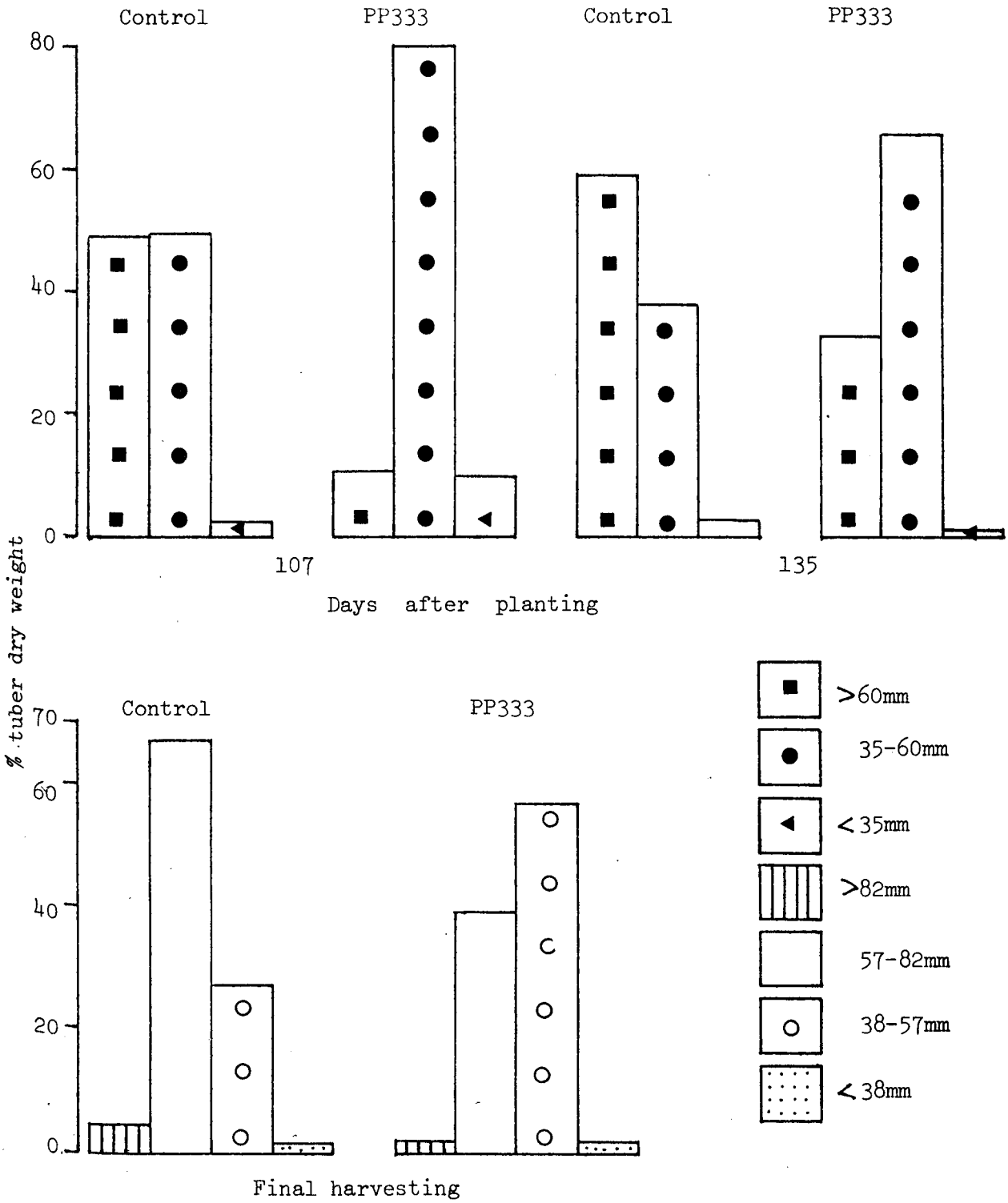
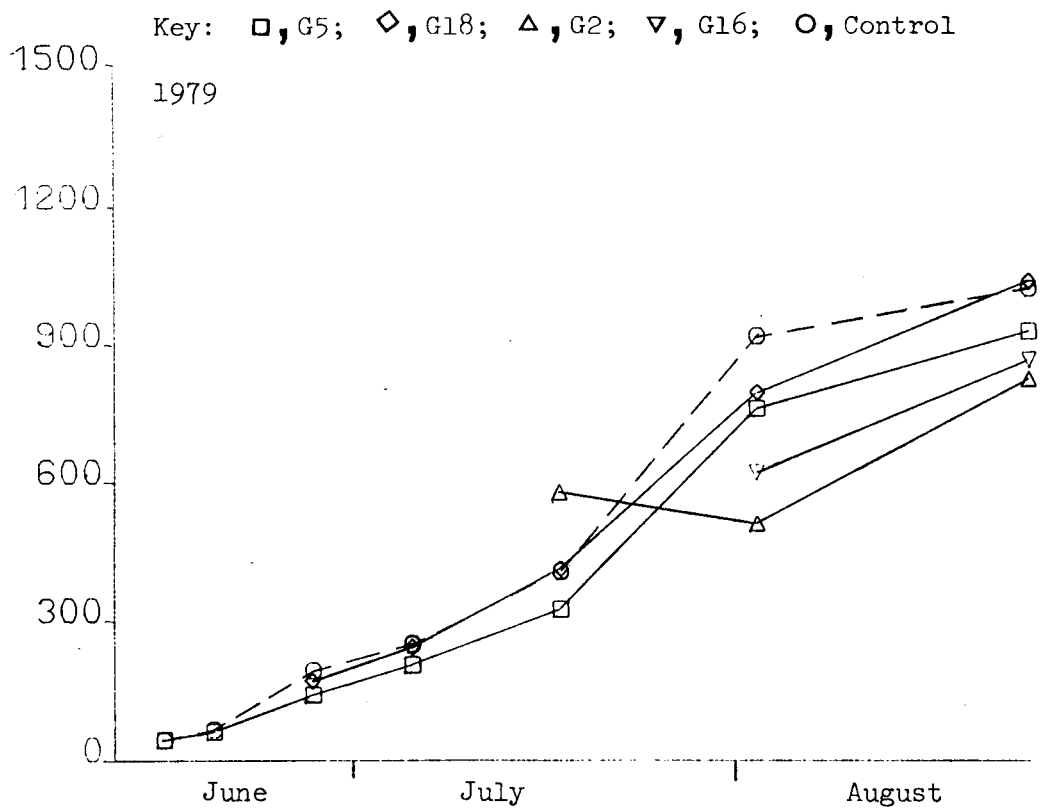


Figure 3.4.10b The effects of PP333 on proportion of tubers in size grades (dry weight basis) (1980).



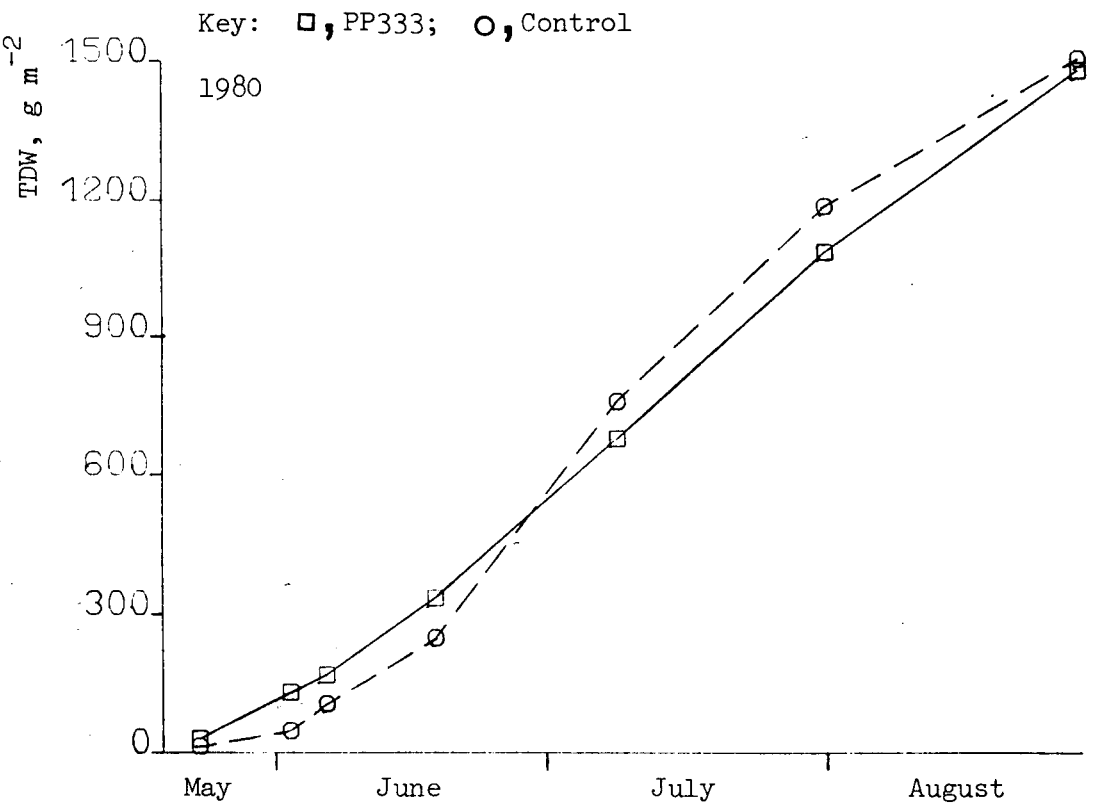


Figure 3.4.11 The effects of PP333 on total dry weight (TDW).

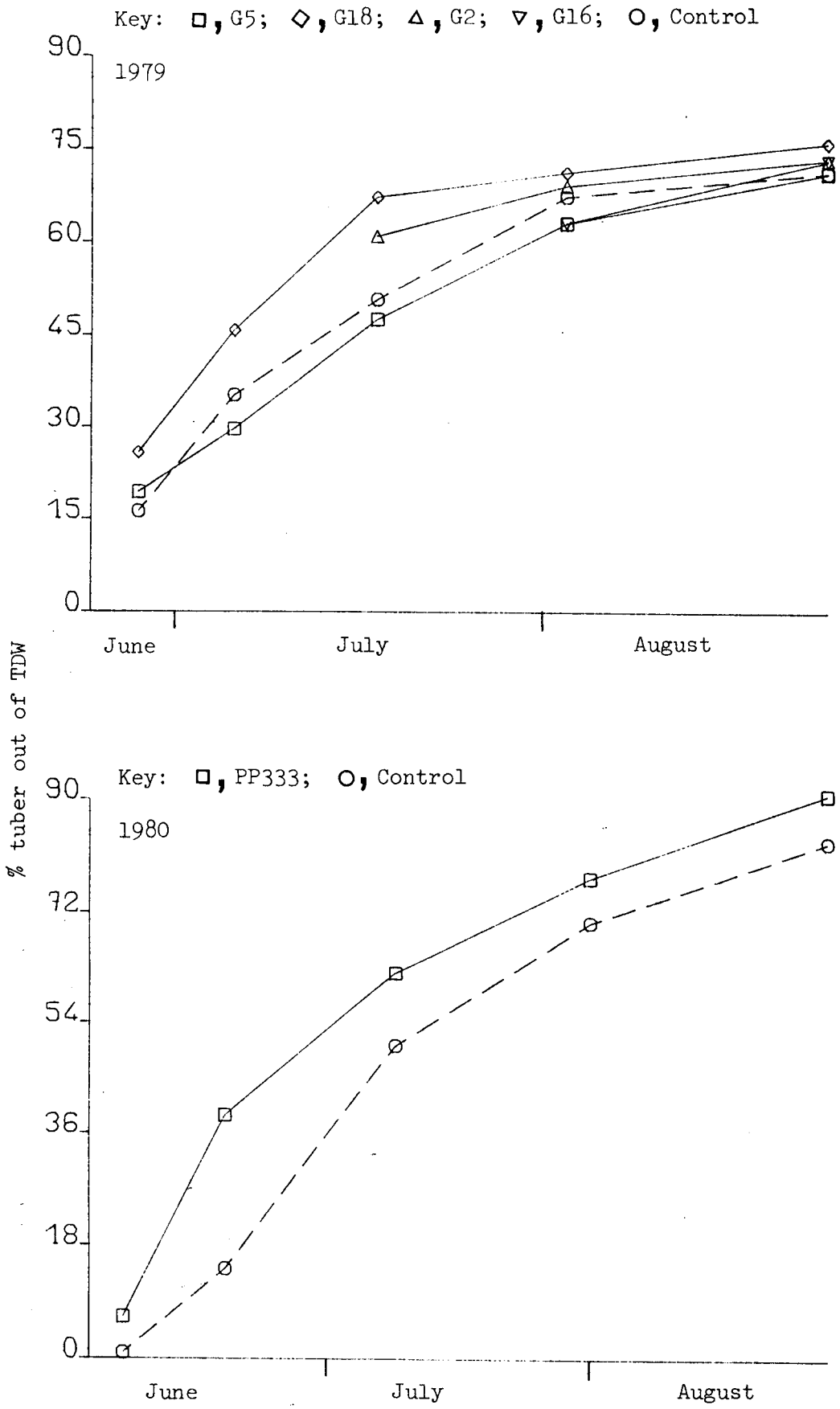


Figure 3.4.12 The effects of PP333 on percentages of tubers out of total dry weight (TDW).

3.5 DISCUSSION

Similar qualitative responses by the potato crop to the application of the growth regulator, pp333, were found in two years of experiments. However, the magnitude of the response was lower in 1979 probably because of drier conditions (Fig.3.3.1). The interaction with soil moisture probably relates to uptake and subsequent transport in the xylem rather than difference in growth regualtor activity per se.

Total dry matter production was slightly decreased in 1979 irrespective of the time of application of the growth regulator and it may be that had uptake of pp333 been greater then a larger effect would have been found. In 1979, there was a decrease in dry weight plant^{-1}, and since plant density was the same as for the control, then a decrease in productivity unit area^{-1} with pp333 resulted. However, since individual plant size was decreased the potential existed to increase plant density without suffering a detrimental degree of plant competition. The experiment in 1980 indicated that this hypothesis may be true since total dry weight unit area^{-1} was not decreased at closer plant spacing combined with pp333.

Total dry matter produced by the canopy depends on the light intercepted by the canopy. Since LAI was reduced by all the pp333 treatments in 1979, light intercepted per unit area was lowered and this resulted in lower total dry matter in the treated plots. In 1980, LAI was slightly reduced during the peak but LI was not as LAI in pp333 during that period was over 3.0, for light interception was independant of LAI at indices of more than 3.0. Treated plants intercepted more radiation early in the season when solar radiation was high, and so total dry weight was not affected in 1980.

An additional factor, other than solely the degree of pp333 uptake which may have influenced the 1979 results is the possible interaction between the physiological status of the plant and water stress. The control plants grew more slowly and yielded less in 1979 than in 1980. The crop was visibly affected by drought in 1979 and the calculated net assimilation rate (NAR) decreased during the dry period, whereas no decrease in NAR was found in 1980. pp333 had little effect on NAR in 1980, or in 1979 with the exception of the dry period. During the driest period (second week of July), the control NAR fell from 7.0 to 1.1g m^{-2} day^{-1} while the NAR of G5 and G18 treatments were maintained at 3.0 and 4.5gm^{-2} day^{-1} respectively. Therefore, the efficiency of dry matter accumulation was three to four times higher in the pp333 treatments during the drought period. Other growth regulators such as CCC have been reported to increase tolerance to water stress (Teubner, 1961) and the effect may be related to changes in physiological status in response to a general retardation of haulm extension growth.

Reduction in potato haulm growth and some degree of redistrubution of dry matter to the tubers has been reported following application of CCC (Dyson, 1965; Gunasena and Harris, 1969, 1971), and B9 (Humphries and Dyson, 1967). With the application of pp333, haulm growth was decreased and there was some redistribution of dry matter to the tubers. In 1979, the percentages of assimilates diverted to the tubers were lower in G5 as compared to G18. This was probably related to a greater uptake of the chemical by the G18 treatment as LAI was 0.7 at the time of its application while G5 was sprayed 4 - 5 days after emergence and soil uptake must have been very low as weather was dry in that year. Percentages of assimilates diverted to the tubers were higher in treated plots and since spacing was the same for treated as well as controls

which resulted in lower LAI in pp333 treated plots and so the final tuber yield was higher in the control. In 1980, the percentages of assimilates diverted to the tubers were much higher than in the control and differences were evident throughout the season, probably related to more uptake of the chemical in a wetter season. Since total light intercepted by the treated plots was the same as in the controls, final tuber yield was 16 per cent higher area^{-1} than control. The foliage was darker green, as occurred with CCC (Gifford and Moorby, 1967), and the leaves were either thicker or denser. Chlorophyll content per unit area was 25 - 35% higher in leaves from pp333 treated plants in an adjacent experiment in 1980 (McLaren, pers. commun.).

The higher proportion of dry weight found in the tubers of chemically manipulated plants is useful only when present in the appropriate tuber size. pp333 resulted in a higher proportion of tubers in the size range of 35 - 60mm. When nitrogen was applied early in the season, LAI was higher at tuber initiation compared to late application or no nitrogen. Since LAI was high, the assimilates available for tubers were more and this resulted in a higher number of tubers (Gunasena and Harris, 1968). Pratt, et al., (1952), have shown that irrigation during the period of tuber set increased the yield of the crop by increasing the number of tubers set, whereas when water was applied later in the season, irrigation had the effect of increasing the average tuber size rather than tuber numbers. Photosynthetic efficiency of the canopy is higher when soil mosture content is high (Moorby et al., 1975; Legg et al., 1979) thus irrigation at tuber set increased the availability of assimilates for the developing tubers, which resulted in higher number of tubers. The mechanism underlying the present experiment may be related to dry matter redistribution at an early stage of growth. For

example, the number of tubers present was similar but it may be that the amount of asimilates diverted to those tubers was initially higher in the pp333 treatment. If a maximum rate of growth for individual tubers is assumed then the additional assimilate may have stimulated growth of tubers which otherwise would not have grown at that time. Since more tubers would then have attracted more assimilate produced subsequently, individual tubers would have had fewer assimilates due to inter-tuber competition. The result of such a mechanism, related to assimilate availability at particular growth stages, would be to produce more tubers within the medium size range, as was found with the pp333 treatment. Increase in number of tubers has also been reported when CCC (Gunasena and Harris, 1969; Gifford and Moorby, 1967), or ethrel (Garcia - Torres and Gomez -Campe, 1972; Murti et al., 1978; Banerjee et al., 1979; Perumal et al., 1979) were sprayed at tuber initiation phase.

Ifenkwe and Allen (1978), showed that at lower plant density (24960 tubers ha^{-1}) all tubers developed from those initiated but at higher plant density (74880 tubers ha^{-1}) about 1000000 tubers ha^{-1} were initiated (June) but only 78000, developed (August). In 1980, all the tubers initiated in pp333 treated plots did not develop. It may be explained that at higher plant density LAI at tuber initiation was very high, thus more tubers were initiated, but the rate of increase of LAI was low due to interplant competition. Thus all the tubers which had initiated could not develop because the assimilates available following tuber initiation were not enough for all those tubers to develop.

In addition to any benefits from manipulation of the physiological processes within the crop, the altered canopy structure may have agronomic benefits under particular circumstances. For example, the canopy

micro-environment may influence the build-up and spread of pathogens, and the decreased canopy height may decrease the degree of lodging and rotting of stem tissue which often occurs under wet conditions. In 1980 lodging occurred in control plots and rotting of stems was observed, but rotting of stems was more in Experiment F4 where stem numbers area^{-1} were increased by using large seed. No lodging occurred in the sprayed (pp333) plot.

4. PHYSIOLOGICAL AGE, SPROUTING TECHNIQUE AND SPACING

4.1 LITERATURE REVIEW

4.1.1 Physiological age

It is well known that for a period immediately after harvest, no appreciable sprout growth will take place on seed tubers, even when they are stored in conditions ideal for growth. The length of this period of inactivity is referred to as the 'dormant' period (Burton, 1963) and it ranges in normal storage conditions (10°C) from 5 to 14 weeks after harvest. The dormant period is largely determined by variety (Krijthe, 1962; Burton, 1963; Bornman and Hammes, 1977; Reust, 1978) though not related to maturity classes i.e. early varieties do not necessarily start growing before main crops (Emilson, 1949). Many features of seed crop husbandry also affect the length of the dormant period e.g. time of planting (Jones; O'Brien (both quoted by Ali, 1979); Allen et al., 1979); site of production (O'Brien and Allen, 1975; Wurr, 1978b); time of haulm destruction of the seed crop (Hutchinson, 1978a; Wurr, 1978b); time of harvesting (O'Brien and Allen, 1975; Toosey, 1964); and state of maturity of the tuber at the time of harvesting (Krijthe, 1962; Hutchinson, 1978b; Wurr, 1978b). Temperature during storage also affects the length of the dormant period (Schippers, 1956; Sadler, 1961; Headford, 1962; Burton, 1963; Short and Shotton, 1970; Wurr and Allen, 1976; Bornman and Hammes, 1977; Hutchinson, 1978b; Allen et al., 1979; Jones et al., 1981). Wurr (1978b) stated that differences due to date of defoliation of seed crops on sprout length were due to its effect on dormancy break and O'Brien and Allen (1981) regarded all seed stocks which do not sprout i.e. until dormancy break as the same. Thus the period of post dormancy break is important for this may affect the field

growth.

Once buds have begun to grow however, the environment in the store, especially the temperature, becomes extremely important in determining subsequent sprout growth. The growth of sprouts is positively related to temperature over the range from a minimum of 4°C to 25°C (Sadler, 1961; Headford, 1962; Morris, 1966). Growth rate of sprouts at 30°C was low due to death of the sprout apices, later death of sprout apices occurred at 25°C also (Headford, 1962). Moreover sprouts produced at such high temperatures are bulbous in shape and restricted at the base whereas those produced at lower temperatures are more firmly attached (Davidson, 1958; Short and Shotton, 1970). Due to this reason temperatures higher than 15°C are not usually used in the store. A linear relationship between total sprout growth per tuber and temperature accumulated over base temperature from dormancy break has been reported by several workers, when tubers were stored in conditions ideal for sprout growth immediately after dormancy break (Wurr, 1978b; Ali, 1979; Rawi, 1981). Toosey (1963) and Madec and Perennec (1962) described physiological age as the physiological state of the tuber at any given time. Recently the research groups at University College of Wales and NVRS, Wellesbourne have suggested the measure of physiological age as day degrees above a base temperature from dormancy break. (O'Brien and Allen, 1981; Ali, 1979; Wurr, 1978c).

Varieties differ in their rates of sprout growth at a given temperature (Headford, 1962; Headford and Ingersent, 1962; Short and Shotton, 1970; Allen et al., 1979; Bodlaender and Marinus, 1981) and thus may emerge at different times in the field. Greater differences in sprout length at the time of planting have been found to affect the emergence and tuber initiation (TI), physiologically old seed emerging and

initiating tubers before the physiologically young seed (Headford, 1962; Toosey, 1963; Fischnech and Krug, 1963; Younger, 1975; Raquf, 1979; Ali, 1979; Rawi, 1981). LAI and total dry weight at the time of TI were higher in physiologically young seed (Raquf, 1979; Rawi, 1981; Younger, 1975) though difference varied between years and varieties. In the variety Home Guard a close relationship between tuber yield and physiological age has been found, tuber yield being increased with increase in physiological age but the effect changed as the harvesting was delayed and in some cases it became negative (O'Brien and Allen, 1978; Allen et al., 1979; Raquf, 1979). Decrease in tuber yield with increase in physiological age at later harvests was associated with a decrease in LAI and total dry weight with increase in physiological age (Raquf, 1979; Rawi, 1981), which may be overcome by decrease in spacing. Ali, (1979) working, with the variety Desiree and Jones et al., (1981) with the varieties Arran Comet and Desiree also reported increase in yield with increase in physiological age but in these cases also the effect disappeared as the harvesting was delayed. Major concern in maincrop varieties is not the early yield but the final yield which may also be affected by the total duration of the bulking period of the crop. Younger (1975) found that physiologically old seed emerged earlier and senesced earlier than the physiologically young seed. But still if early in the season LAI in the case of physiologically old seed is increased by decreasing plant spacing and thus making greater use of solar radiation of that time of the year (Allen and Scott, 1980) then even if it senesces earlier, the potential exists for higher tuber yields.

Stem number is now considered as the unit of population in potato (Allen and Bean, 1978). There are two types of stems which may emerge above ground i.e. main and branch stems (defined in Appendix E).

Differences in sprouting regimes cause differences in proportions of different types of stems produced by the seed tuber (Allen, 1978; Younger, 1975; Bagley, 1971). So stem numbers as such may not give the right idea of population but sizes of different types of stems have not been studied.

4.1.2 Inter-cropping

Different crops or varieties are mixed depending upon their habit of growth to ensure better light interception and extensive exploration of the soil for removal of water and nutrients. Inter-cropping of maize and beans is quite common in several parts of tropical America (Pinchinat et al., 1976). Finlay (1974) reported that 98% of the cowpea is inter-cropped in Africa. Inter-cropping of cotton and summer onion is practised in Egypt (Nasr, 1976). Over yielding of grains for mixtures due to the early flowering and maturation of one component than the other has been reported by the International Rice Research Institute (1974). In potatoes inter-cropping may be useful when one component emerges first and grows at the expense of another while the latter may have advantages later in the season. Schepers and Sibma (1976) obtained higher yields in various experiments by mixing early and late crop varieties of potato. Smith (1978) obtained significantly ($P = 0.05$) higher yield by mixing Arran Comet and Pentland Crown in alternate rows, compared to Pentland Crown grown alone. Chowdhury (1980) also obtained higher yields, when Desiree and Majestic were mixed within or between rows than the higher yielding monoculture. This increase in yield was associated with increase in leaf area duration. Mixing of different varieties especially within the row may be only useful when the product

is required for starch industry or for other uses for which a mixed product is acceptable. When sprouted and unsprouted seed of the same variety were mixed alternately within or between rows higher tuber yields were obtained than the higher yielding monoculture but the increase was higher in Majestic than Desiree and the effect also varied between years (Chowdhury, 1980).

4.1.3 Light interception

Potato crop growth has often been considered in terms of the LAI, leaf area duration and net assimilation rate (Watson, 1952). A linear relationship has been reported between tuber yield and leaf area duration when leaf area indices above three were assumed to be three (Bremner and Radley, 1966; Bremner and Taha, 1966; Gunasena and Harris, 1968; Chowdhury, 1980), which implies that light interception, or photosynthetic efficiency, does not limit yield at leaf area indices greater than three. Published reports on light interception in potatoes are few (Scott and Wilcockson, 1978; Allen and Scott, 1980; Bean and Allen, 1981), while crop growth rate has been related to radiation intercepted in barley, wheat and sugarbeet (Biscoe and Gallagher, 1977) and maize (Williams et al., 1965).

Total global radiation has been found to be positively correlated with the yields of several crops (Sibma, 1970) and potato tuber yields have been related to total radiation during the growing season (Scholte Ubbing, 1959). However, leaf photosynthesis is essentially a wavelength dependent with photosynthetically active radiation (PAR) being defined as radiation between 400 - 700nm (McCree, 1972). Although the ratio of PAR to total radiation appears to be relatively insensitive to

atmospheric factors, and when considering both direct and diffuse radiation is often taken as being 0.5 (Monteith, 1969), it may be important to measure PAR interception within crop canopies. One factor which may influence within canopy measurements of total radiation, relative to PAR, is the transmission of wavelengths above 700nm (Holmes and Smith, 1977; Scott et al., 1968), with the relative differences being related to leaf canopy size and characteristics. Puckridge and Ratkowsky (1971) in wheat and Jeffers and Shibles (1969) in soybeans reported increases in photosynthetic efficiency of the crop canopy with increase in LAI.

Thus a study involving regular measurements of sprout growth during storage and various crop characteristics in the field along with regular measurements of light interception may help in a better understanding of the growth and development of the potato crop in relation to yield.

4.2 OBJECTIVES

Greater physiological age results in an increase in the percentage of total dry matter found in tubers but reduces LAI which ultimately results in lower final yields. If LAI is increased by manipulating the density then potential existed for higher tuber yield at final harvesting. With this in mind the experiment in 1979 was carried out. Depending upon the results obtained in 1979, where physiological age did not affect the emergence or senescence or tuber yield, but bigger seed emerged first and senesced first, in 1980 it was decided to repeat the treatments of 1979 (Exps. F2, F3) and since different seed sizes emerged and senesced at different times, in theory if they are mixed, then potential exist for increase in total duration of the crop. So Experiment F4 was undertaken to investigate this and seed with greater differences in physiological age were mixed.

Emergence in 1979 may have been affected by the growth rate of sprouts rather than physiological age or length of the sprout. Therefore sprouting techniques were changed before planting by keeping them in the dark, to see its effect on emergence and further growth and development.

In 1980 cold treatment of seed took more time to initiate tubers than apical or multi sprouted when counted from the date of 50% emergence. This may have been affected by longer days, as cold treated seed emerged later and day length increases in spring and short days do stimulate tuberization (Chapter 2). Thus in 1981 it was decided to see the effect of time of planting on early tuber yield and other treatments were included to have results for two years. Since emergence was not affected by differences in physiological age of the seed (except cold) in 1979

and 1980. It was decided to investigate minimum number of day degrees above which emergence would not be enhanced (Experiment F6).

4.3 MATERIALS AND METHODS

The experiments were carried out at the University of Nottingham farm, at Sutton Bonington, over the three years: 1979; 1980; 1981. In 1979 (Exp. F1), soil was sandy clay loam (Field 32) and in 1980 (Exps. F2, F3 and F4) and 1981 (Exps. F5 and F6), it was sandy loam (Field 10 and 6 respectively). On receipt, the seed (details for seed source in Appendices: B; C; D) in general was handled in the same way as described earlier (3.3), except that in 1981 seed was affected with Rhizoctonia and thus was treated with Polyram (dithiocarbamate) (100g Polyram dissolved in 50 litres of water and seed dipped for 2 minutes).

4.3.1. Experiment F1

4.3.1.1 Experimental design and practical details

There were 2 varieties, Pentland Crown and Record. Each variety was given two sprouting treatments (physiological age), apical (stored at 12°C for 110 days, starting from 20 December, followed by 22 days at 8°C) and multi (stored at 4°C for 97 days, starting from 20 December, followed by 13 days at 12°C and 22 days at 8°C), and then planted at 2 spacings between plants, 30 and 40cm. Thus there were 8 treatments, all combinations of 2 physiological ages, 2 spacings and 2 varieties. 27th December was taken as the date when dormancy of the seed was broken as total sprout length per tuber on the tubers stored at 12°C was about 3mm (Wurr, 1978b). Thus apical and multi had 912 and 192 day degrees above 4°C from break of dormancy respectively.

The seed sizes used in the experiment are given in Table 4.3.1.1.

Table 4.3.1.1. The weight of seed sizes used (g).

Replicates	I	II	III
Variety			
Pentland Crown	34.1 ± 0.39*	61.6 ± 0.52	105.3 ± 1.31
Record	39.6 ± 0.59	51.5 ± 0.72	63.0 ± 0.48

* SE, calculated by weighing 40 tubers individually in every case.

The experiment was planted on 1st. May 1979 in randomized block design, consisting of 3 blocks. Spacing between rows was 76cm. There were 6 or 8 rows (depending on spacing treatment) of 4.8 metres each to accommodate 96 tubers per plot. Fertilizer at the rate of 1318Kg ha^{-1} (15: 15: 15; N: P_2O_5: K_2O) was given before planting. Other details such as: stem emergence; light interception; plant protection measures; weed control; rainfall and temperature etc. were the same as those described in Chapter 3.3.1.

4.3.1.2. Growth analysis

Nine growth analyses were carried out for the variety Record and eleven for the variety Pentland Crown. In addition a few plants were harvested from specific replication (as size of the tubers used affected slightly emergence) to have a better idea of tuber initiation. Methods of harvesting and laboratory procedure, were the same as those described in Chapter 3.3.3 (2 plants were harvested at each growth analysis),

except that foliage was not cut off the ground in the field rather it was harvested along with underground parts and separated into main and branch stems in the laboratory, to study the contribution made by different types of stems, particularly the LAI. In general statistical analyses were done as factorial randomized block design, thus residual degrees of freedom (RDF) was 14. But for studying different type of stems analysis was done as a split plot design. RDF for split plot analyses is given on the Figures itself.

4.3.1.3. Sprout growth during storage

Length of the sprouts on 40 tubers (10 per tray) each of the 3 sizes (Table 4.3.1.1) and of the two treatments (apical and multi) in the both varieties was measured on: 23rd Jan.; 7th Feb.; 13th March; 11th and 28th April, in the case of apical and 11th and 28th April in the case of multi.

4.3.1.4 Measurement of soil water content

Volumetric soil water content was determined at weekly intervals between May and October for all the 24 plots using a modified version of the Wallingord neutron probe (Bell, 1969). Essentially this consists of the emission of fast neutron from a sealed radioactive source (some Am/Be mixture) and a count of the density of the cloud of slow neutrons resulting from collisions with the hydrogen nuclei in the soil water. Aluminium access tubes were installed in the furrow about one metre inside from guard plant. Soil profile was monitored to a depth of 100cm at 10cm depth interals. The date of initial extraction of

water by roots for individual soil horizons was determined as described by McGowan (1973).

4.3.1.5 Final harvesting

This was as described earlier (Chapter 3.3.3)

4.3.2 Experiment F2

4.3.2.1 Experimental design and practical details

There were 9 treatments, details are shown in Table 4.3.2.1. The variety used was Pentland Crown.

Table 4.3.2.1. Details of experimental treatments.

Treatments	Details
Apical	Stored at 12°C from 28.11.79 to 12.4.80 (both days inclusive)
Multi	Stored at 4°C from 28.11.79 to 26.3.80 and at 12°C from 27.3.80 to 12.4.80.
Cold	Stored at 4°C from 28.11.79 to 12.4.80
A+M 25, A+M 36, A+C 25, A+C 36, M+C 25, M+C 36,	+ = two sprouting treatments mixed by planting alternately along the row. 25 and 36 is the spacing in cm within row for that particular treatment.

N.B. Apical, multi and cold were planted at 36cm spacing within row.

All seed was moved to 8°C 24 hours before planting on 14.4.1980.

14th December was taken as the date when dormancy of the seed was broken (Chapter 4.3.1.1). Thus apical, multi and cold had, 972, 140 and 4 day degrees above $4^{o}C$ from break of dormancy, respectively. Seed sizes used were 116 $\pm$ 2g in replication 1 and 62 $\pm$ 0.9g in replications 2 and 3.

The experiment was planted on 14th April 1980 in randomized block design, consisting of 3 blocks. Spacing between rows was 76cm. There were 10 or 7 rows (depending on spacing within row) of 5.40 metres each to accommodate 150 tubers in the case of 36cm and 147 in the case of 25cm spacing within the row. Fertilizer at the rate of 1318Kg ha^{-1} (15: 15: 15; N: P_2O_5: K_2O) was given before planting. Other details such as: stem emergence; light interception; plant protection measures; weed control; rainfall and temperature etc. were the same as those described in Chapter 3.3.1.

4.3.2.2 Growth analysis

8 growth analyses were carried out and 4 plants were harvested per plot at each growth analysis. In addition a few plants were harvested from specific replicates (as size of the tubers used affected slightly emergence) to aid the assessment of tuber initiation. Methods of harvesting and laboratory procedure were the same as those described for Experiment F1 (Chapter 4.3.1.2). In general statistical analyses were done as randomized block design, thus residual degrees of freedom (RDF) was 16. But for studying different type of stems analysis was done as a split plot design taking stem type within the plot as a sub plot. Similarly for studying growth of 2 types of plants within plot

was also done as split plot design, taking the 2 types of plants in a plot as sub plots. RDF for split plot analyses is given on the Figures itself.

4.3.2.3 Sprout growth during storage

To study the growth of individual sprouts, eyes were numbered, the first eye (eye No.1) on the apical end and then working down towards heel end systematically with last eye number given to the eye closest to the heel end. 40 tubers (10 per tray) each of the 2 seed sizes (62g and 116g) in case of apical and 30 tubers of seed size 62g and 20 of the 116g in case of multi were used for sprout measurements. Apical sprouts were measured on 14 and 21 December; 8 and 21 January; 4 and 18 February; 3,17 and 31 March; 11 April and in multi on 1 and 11 April.

4.3.2.4 Measurement of soil water content

Soil water content was measured for 18 plots (Replications 1 and 2) as described earlier (4.3.1.4).

4.3.2.5 Final harvesting

This was as described earlier (Chapter 3.3.3).

4.3.3. Experiment F3

4.3.3.1. Experimental design and practical details

There were 4 treatments, combinations of two physiological ages (apical and multi) and 2 sprouting treatments (fast and slow). Details are given in Table 4.3.3.1. Again the variety used was Pentland Crown.

Table 4.3.3.1. Details of experimental treatments

Treatments	Details
Apical slow	Stored at 12°C from 6.12.79 to 12.4.80
Multi slow	Stored at 4°C from 6.12.79 to 4.3.80 and at 12°C from 5.3.80 to 12.4.80.
Apical fast	Same as apical slow, but covered with black polythene sheet from 6.4.80 until planting.
Multi fast	Same as multi slow but covered with black polythene sheet from 6.4.80 until planting.

N.B. All seed was moved to 8°C 24 hours before planting on 14.4.80.

15th December was taken as the date when dormancy of the seed was broken (Chapter 4.3.1.1), thus apical and multi had 964 and 316 day degrees above 4°C from break of dormancy respectively. Seed size used was 77.5 ± 1.26g.

The experiment was planted in randomized block design, consisting of 3 blocks. Spacing between rows was 76cm and between plants 36cm. There were 6 rows of 5.40 metres each accommodating 90 tubers per plot.

All other details were the same as those described for Experiment F2.

4.3.3.2 Growth analysis

Six growth analyses were carried out and 4 plants were harvested per plot at each growth analyses except for one (6th June), when 2 plants per plot were harvested. Method of harvesting and laboratory procedures were the same as those described for Experiment F1 (Chapter 4.3.1.2). In general statistical analyses were done as a factorial randomized block design, so residual degrees of freedom (RDF) was 6. But for studying different type of stems (main and branch), it was done as split plot design taking stem type within plot as sub plots and RDF was 8.

4.3.3.3 Sprout growth during storage

91 tubers out of 12 trays in case of apical (46 slow + 45 fast) and 34 tubers (out of 4 trays) in case of multi (14 slow + 20 fast) all with numbered eyes were used for sprout measurements. In the case of apical slow sprouts were measured on: 15th and24th Dec.; 9th and 22nd Jan.; 4th and 18th Feb.; 3rd, 18th and 31st March; 10th April and for apical fast, the first 9 dates were the same and after that these were measured on 9th,11th and 13th April. In case of multi slow sprouts were measured on: 12th and 18th March; 1st and 9th April and for multi fast in addition to these 4 dates sprouts were also measured on 11th and 13th April.

In addition some tubers (6 per treatment before the start of fast and 3 after that) were used to study the sprout weight, 3 times before

planting and 2 times after planting but before emergence.

4.3.3.4 Final harvesting

This was as described earlier (Chapter 3.3.3).

4.3.4 Experiment F4

4.3.4.1 Experimental design and practical details

There were 4 treatments: B36; S25; B+S25; B+S36, where:

B = Seed stored at 4°C from 6.12.79 to 4.3.80 and at 12°C from 5.3.80 to 12.4.80 and seed size was 204 ± 5.7g (316 day degrees above 4°C).

C = Seed stored at 4°C from 6.12.79 to 12.4.80 and seed size was 62 ± 0.9 (4 day degrees above 4°C).

\+ = Two seed sizes (B,S) mixed by planting alternately along the row.

25 or 36 = The spacing in cm used for that particular treatment within row.

All seed was moved to 8°C 24 hours before planting on 14.4.80. The variety used was Pentland Crown. The experiment was planted in a randomized block design, consisting of 3 blocks. Spacing between rows was 76cm. There were 6 or 4 rows (depending on spacing within row) of 5.40 metres each to accommodate 90 tubers in case of 36cm and 84 tubers in case of 25cm spacing within row. All other details were the same as those described for Experiment F2.

4.3.4.2 Growth analysis

Six growth analyses were carried out and 4 plants were harvested per plot but on 1st July only one replication was harvested and on 15th July 2 replications were harvested, while on remaining dates all the three replications were harvested. In addition a few plants were harvested from specific replication to help with the determination of tuber initiation. Methods of harvesting and laboratory procedures were the same as those described for Experiment F1 (Chapter 4.3.1.2) except that different type of stems and axillary branches were not studied. Statistical analyses were done as randomized block design, thus residual degrees of freedom (RDF) was 6 where all the three replications were harvested and 2 where, only 2 replications were harvested.

4.3.4.3 Sprout growth during storage

Eyes were numbered as described earlier. 20 tubers from 2 trays were used in the case of B36 for sprout measurements on: 12th and 18th March; 4th and 11th April.

4.3.4.4 Final harvesting

This was the same as described earlier (Chapter 3.3.3).

4.3.5 Experiment F5

4.3.5.1 Experimental design and practical details

There were 6 treatments: cold 6; apical 13; A+C 13; cold 16; apical 22; A+C 22, where:

cold = Seed stored at $4^{o}C$ from 14th Dec. 1980 until 24 hours before planting.

apical = Seed stored at $12^{o}C$ from 14th Dec. 1980 until 24 hours before planting.

A+C = Apical and cold mixed by planting alternately along the row (Fig.4.3.1).

6, 13, 16 and 22 are the dates of planting in the month of April for particular treatments. All seed was moved to $8^{o}C$ 24 hours before planting.

The variety used was Pentland Crown and seed size was 52.8 ± 1.1g. 22nd December was taken as the date when dormancy of the seed was broken (Chapter 4.3.1.1). So apical 13 and apical 22 had 892 and 964 day degrees above $4^{o}C$ from dormancy break respectively and cold had 4 day degrees only.

The experiment was planted in a randomized block design consisting of 3 blocks. Spacing between rows was 76cm and between plants 36cm. There were 5 rows of 7.92 metres each accommodating 110 tubers per plot. Fertiliser at the rate of 1125Kg ha^{-1} (17:17:17; N: P_2O_5: K_2O) was given before planting. All other details were the same as those described for Experiment F1.

4.3.5.2 Growth analysis

Seven growth analyses were carried out and for each, 4 plants were harvested per plot. Methods of harvesting and laboratory procedures were the same as those used for Experiment F4. Statistical analyses was done as factorial (2 dates x 3 treatments i.e. apical, multi and A+C) randomized block design. Thus residual degrees of freedom was 10.

4.3.5.3 Sprout growth during storage

Eyes were numbered as described earlier (Chapter 4.3.2.4) 29 tubers out of 3 trays were used for sprout measurements on: 22nd Dec.; 5th and 20th Jan.; 4th and 17th Feb.; 3rd and 17th March; 14th April 1981.

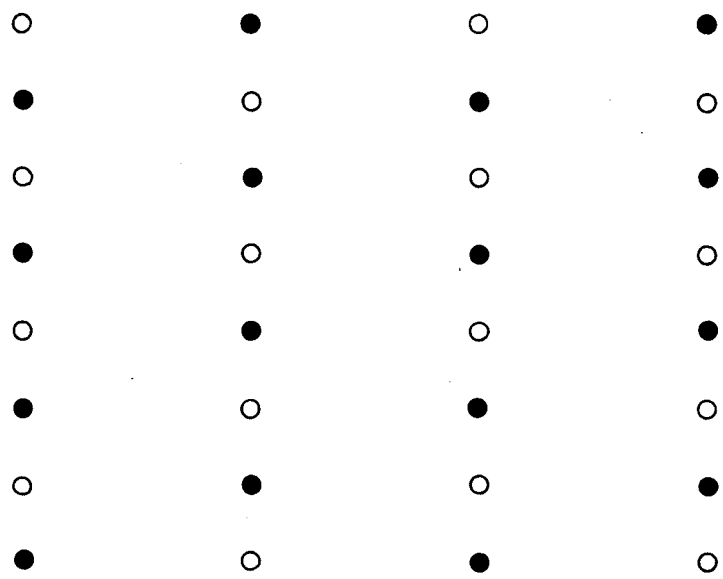
4.3.6 Experiment F6

4.3.6.1 Experimental design and practical details

There were 10 treatments: 4D; 24D; 48D; 80D; 128D; 184D; 232D; 280D; 352D; 920D, where numbers before D stand for the number of day degrees given above $4^{\circ}C$ from break of dormancy. Seed used was the same as that used in Experiment F5. Treatment 920D was the same as apical in Experiment F5. For the remaining treatments seed was stored at $4^{\circ}C$ until moved to $12^{\circ}C$ on: 3rd, 12th, 18th, 24th, 31st March and 6th, 10th and 13th April, to obtain the required number of day degrees mentioned above. All seed was moved to $8^{\circ}C$, 24 hours before planting on 16th April 1981.

The experiment was planted in a randomized block design consisting

1980 (Experiments: F2; F4)



1981 (Experiment F5)

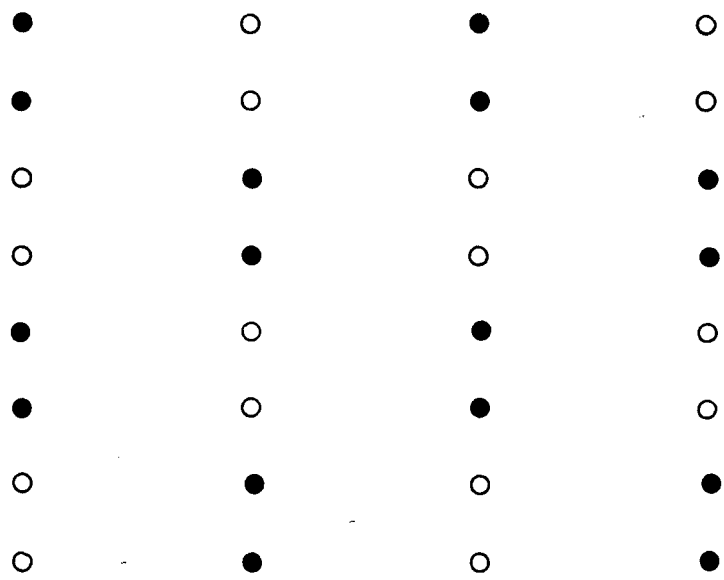


Figure 4.3.1 Planting patterns in mixed plots.
Key: ●, sprouted (i.e. multi or apical); ○, unsprouted (Cold).

of 4 blocks. Spacing between rows was 76cm and between plants 36cm. There were 3 tubers per replication. All other details were the same as those described for Experiment F5.

4.3.6.2 Growth analysis

All plants were harvested 64 days after planting and growth parameters studied are presented in Table 4.4.8.2.

4.3.6.3 Sprout growth during storage

Ten tubers per treatment were used for sprout measurement on 23rd March, 8th and 14th April.

4.4 RESULTS

4.4.1 Sprout growth during storage

The following dates were taken as the days when dormancy of the seed was broken: 27th December (Exp. F1); 14th December (Exp.F2); 15th December (Exp. F3); 22nd December (Exps. F5 and F6) when sprout length per tuber reached about 3mm (Wurr, 1978b), and the number of day degrees shown were counted from these dates. In the case of multi treatment, it took about 50 - 60 day degrees to reach a sprout length of 3mm tuber^{-1} (Figs.4.4.1.2 and 4.4.1.3) but day degrees shown here are from the date they were moved to warm conditions (above 4°C) as it was thought that tubers had broken dormancy by then. Residual degrees of freedom and the way the data were analysed is shown in Table 4.4.1.1.

Total sprout length per tuber increased with increase in tuber size (Figs.4.4.1.1; 4.4.1.2; 4.4.1.5). Tubers of the same size of two varieties: Pentland Crown and Record (Fig.4.4.1.1) had the same sprout length. Linear regression between tuber size and total sprout length per tuber for both varieties (Exp. F1) of apical treatment measured on 28th April (900 day degrees above 4°C from dormancy break) accounted for 98% of the variance (Fig.4.4.1.5). Similar relationships are evident for other dates of measurements (Fig.4.4.1.1). Sprout numbers also increased with increase in tuber size (Tables 4.4.1.2 and 4.4.1.3). Total sprout length per tuber increased with increase in day degrees above 4°C (Figs. 4.4.1.1; 4.4.1.2; 4.4.1.3; 4.4.1.6; 4.4.1.7). Growth rate (extension) of the sprouts was increased by storing the tubers in cold (3 $\pm$ 1°C) before moving to warm conditions for sprouting

(Figs. 4.4.1.1; 4.4.1.2; 4.4.1.3; 4.4.1.7). For example in 1979 growth rate of Pentland Crown from 11th April to 28th April was 33.6mm per 100 day degrees above $4^{o}C$ for multi while this figure for apical was 7.66 (average of 3 seed sizes). Storing the tubers in cold ($3 \pm 1^{o}C$) before moving them to warm conditions for sprouting also increased the number of sprouts (Tables 4.4.1.2 and 4.4.1.3).

In 1979 it was observed that some sprouts stopped growing during storage in the case of apical treatment. To investigate this in detail, in the following two years, eyes were numbered (Chapter 4.3). If there were more than one sprout on any eye then they were also numbered, in this way the growth of individual sprouts was monitored. In case of apical, on the basis of the length of the sprouts attained by the end of the storage period, sprouts were divided into four categories: those that had reached between 2 to 3mm; 3 to 6mm; 6 to 9mm or over 9mm (Fig.4.4.1.4a). Sprout growth rate of all sprouts less than 9mm was low but the important result was that they stopped growing, while others (>9mm) continued to grow (Fig.4.4.1.4). Similar results were obtained for Experiments F3 and F6, where for simplification growth of only two types of sprouts is shown i.e. <9 and >9mm (Figs.4.4.1.4 and 4.4.1.7). Further it was found that sprouts which continued to grow were usually present on the eye number 1 (Table 4.4.1.3). But if this eye was damaged then it was not necessarily so that eye number 2 would continue to grow, as in many cases sprouts on the heel end were seen growing while others stopped. The length of the sprouts on different eyes is shown in Figure 4.4.1.8. In Experiments F2 and F6 only a few tubers had damaged eyes and so the sprout length is greater on eye No.1, while in Experiment F3 eyes were damaged in many tubers, and so there was no difference between different eye positions as far as sprout length is

concerned. Data in Figure 4.4.1.8 for growth of sprouts on different eyes is presented only for 3 dates but similar results were obtained for the remaining dates of measurements also. Another factor which should be taken into consideration is the number of eyes present on the tuber and data for this is shown in Table 4.4.1.5. Storing seed in the cold ($3 \pm 1^{o}C$) before moving them to warm conditions for sprouting removed the inhibiting effect of the dominating eye (Table 4.4.1.3 and 4.4.1.4). For simplification, data from different experiments is presented for the last measurement only but similar results were obtained for other measurements also. Lower values for sprout length and their number from eye no.7 onwards were not due to the fact that their growth was inhibited by other growing sprouts but because these eyes were not present on all the tubers (Table 4.4.1.5).

Total sprout length in case of multi was equal to apical by the end of storage in all the four experiments (Figs.4.4.1.1; 4.4.1.2; 4.4.1.3; 4.4.1.7), but length of the longest sprout (LS) in the case of multi was much lower than that in the apical in all the experiments (Table 4.4.1.6). To investigate this further, growth of the longest sprout of 2 types of treatments is presented in Figure 4.4.1.9. Although total sprout growth rate was much higher in multi (Figs.4.4.1.1; 4.4.1.2; 4.4.1.3; 4.4.1.7), due to intersprout competition, growth of the longest sprout was not higher than the apical.

Table 4.4.1.1. Residual degrees of freedom (RDF) for various Figures and Tables presented in this Chapter.

Fig./Table No.	RDF	Remarks
Fig. 4.4.1.1	118	Analysed as completely randomized design (CRD) taking tubers as replicates.
Fig. 4.4.1.2		
apical	78	same as above
multi	48	same as above
Fig. 4.4.1.3		Different number of tubers were involved for computing their mean;
apical (slow)		91 for first 8 dates and 46 for last date
apical (fast)		45
multi (slow)		34 for first 3 dates and 14 for last date
multi (fast)		20
Fig. 4.4.1.4		
(a)	18	Analysed as split plot design taking seed sizes as main plots and categories as sub-plots. Trays (8) were taken as replicates.
(b)	10	Analysed as CRD, trays (6) were taken as replicates. (Fast not included).
Fig. 4.4.1.5	4	
Fig. 4.4.1.6		Mean for 19 tubers.
Fig. 4.4.1.7		For total sprout length mean for 29 tubers in case of apical and 10 in case of multi
For different categories	4	Analysed as CRD, taking trays (3) as replicates.

continued..

Fig./Table No.	RDF	Remarks
Fig. 4.4.1.8		
(a)	66	Analysed as split plot design, taking seed size as main plot and eyes as sub plot. Trays (8) were taken as replicates.
(b)	22	CRD, trays (3) taken as replicates.
(c)	110	For first 2 dates — All dates analysed as CRD taking trays as replicates (fast not included).
	50	For last date
Fig. 4.4.1.9		
(a)apical		Mean for 19 tubers
multi		Mean for 10 tubers
(b)apical		Mean for 46 tubers
multi		Mean for 14 tubers
Table 4.4.1.2	234	Analysed as factorial (seed size X physiological age) CRD, taking tubers as replicates.
Table 4.4.1.3		Mean for different number of tubers specified earlier for different experiments. In Exp.F3 tubers from fast treatment were not included.
Table 4.4.1.4	11	For Exp. F3 and F4 analysed as CRD taking trays (2) as replicates. In case of Exp. F6 they are mean for 10 tubers.
Table 4.4.1.5		Calculated from different number of tubers: Exp.F2, 70 for 62g tubers and 60 for 116g one; Exp.F3, 125; Exp.F4, 19; Exp.F5, 40.
Table 4.4.1.6		
(a)	234	Analysed as factorial (seed size X physiological age) CRD, taking tubers as replicates.
(b)		Diff. for different Exps.: Exp.F2, 126; Exp.F3, 121 (both analyses as factorial CRD). Exp.F4, mean for 19 tubers; Exp.F6, mean for 29 tubers in the case of apical and 10 tubers in the case of multi.

Table 4.4.1.2. The effects of variety, tuber size (TS) and physiological age (PA) on sprout number on 28.4.1979 (Exp. F1).

Number of sprouts over 2mm tuber^{-1}

Pentland Crown				Record			
PA TS,g	Apical	Multi	Mean	PA TS,g	Apical	Multi	Mean
34	2.70	5.27	3.99	40	3.58	4.83	4.20
62	3.90	6.17	5.03	52	3.85	5.55	4.70
105	4.63	8.82	6.72	63	3.90	6.30	5.10
mean	3.74	6.75		mean	3.78	5.56	

	P Crown	Record
SED for age (mean)	0.267	0.187
SED for tuber size (mean)	0.328	0.229
SED for body of the table	0.463	0.324

Table 4.4.1.3. The effects of tuber size (TS) and eye number on sprout number of different size category (SC), (2-3 days before planting).

Number of sprouts, tuber^{-1} on different eyes.

	Exp. F2				Exp. F3				Exp. F4		Exp. F5 and F6			
TS, g	62		116		78				204		53			
Treatment	apical		apical		apical (slow)		multi (slow)		B36 (multi)		apical		352 D (multi)	
SC, mm	2-9	>9	2-9	>9	2-9	>9	2-3	>3	2-3	>3	2-9	>9	2-3	>3
Eye no.														
1	0.13	0.58	0.08	0.7	0.39	0.30	0	1.21	0.16	1.63	0.14	0.52	0.2	1.0
2	0.23	0.08	0.35	0.03	0.39	0.17	0.07	0.71	0	1.75	0.38	0.14	0.2	0.8
3	0.18	0.10	0.3	0.10	0.28	0.35	0.09	0.79	0	1.37	0.34	0.10	0.3	0.8
4	0.15	0.08	0.48	0.08	0.35	0.35	0.29	1.07	0.05	1.32	0.45	0.14	0.2	0.7
5	0.25	0.08	0.33	0.13	0.46	0.26	0.29	1.64	0.05	1.32	0.45	0.14	0.1	1.0
6	0.10	0	0.25	0.13	0.26	0.24	0.14	1.36	0.21	0.95	0.38	0.03	0.4	0.7
7	0.13	0.10	0.13	0.05	0.41	0.20	0.36	0.71	0.42	1.32	0.10	0	0.3	0.9
8	0.15	0.10	0.10	0	0.26	0.04	0.21	0.57	0.26	0.84	0.17	0	0.4	0.3
9	0.10	0.25	0.10	0.13	0.13	0.24	0.07	0.21	0.16	0.63	0.14	0.06	0	0.1
10	0.15	0.13	0.2	0.08	0.02	0	0	0.14	0.05	0.26	0.14	0.03	0.1	-
11	0.05	0.08	0.05	0.10	-	-	0.07	0.14	0.05	0.16	0.07	0.03	-	-
12	-	-	0.03	0.03	-	-	0	-	0	0.05			-	-
Total	1.6	1.45	2.4	1.53	2.96	2.02	1.5	8.57	1.42	11.57	2.75	1.34	2.2	6.3

Table 4.4.1.4. The effects of tuber size and eye number on total sprout length (2-3 days before planting).

Sprout length, mm tuber^{-1} on different eyes

Experiment	F3	F4	F6	F6	F6
Treatment	Multi (slow)	B36 (multi.)	352D	280D	232D
Tuber size, g	78	204	53	53	53
Eye No.					
1	11.42	19.12	9.45	9.25	9.15
2	6.91	19.14	6.40	6.70	8.25
3	6.54	16.72	6.15	6.75	5.45
4	11.61	14.49	5.15	3.85	9.35
5	13.98	14.53	7.77	5.75	6.05
6	11.96	9.75	7.30	6.80	3.15
7	6.82	12.42	6.30	6.10	2.95
8	4.86	7.34	2.40	3.90	3.55
9	2.14	5.68	0.55	2.35	0.50
10	1.18	2.72	1.00	0.20	0.60
11	1.20	2.01	-	-	-
SED	1.65	3.01	-	-	-

Table 4.4.1.5. The effect of tuber size on number of eyes.

Experiment	F2		F3	F4	F5
Tuber size, g	62	116	78	204	53
Eye No.	Percentage of tubers had these eyes				
6	97	98	94	97	100
7	94	98	82	93	100
8	86	95	50	90	97
9	61	88	29	80	90
10	19	65	14	60	62
11	6	23	8	37	24
12	0	12	0	17	3.4

N.B. At least five eyes were present on every tuber.

Table 4.4.1.6(a). The effects of physiological age (PA), variety and tuber size (TS) on length of the longest sprout, mm tuber^{-1} on 28.4.1979 (Exp. F1).

Pentland Crown				Record			
PA	Apical	Multi	Mean	PA	Apical	Multi	Mean
TS,g				TS,g			
34	19.05	8.68	13.86	40	16.35	10.50	13.43
62	18.70	9.07	13.89	52	17.75	11.22	14.49
103	20.43	9.85	15.14	63	19.32	10.68	15.00
mean	19.39	9.20		mean	17.81	10.81	

	P Crown	Record
SED for age (mean)	0.440	0.415
SED for tuber size (mean)	0.538	0.509
SED for body of the table	0.761	0.720

Table 4.4.1.6(b). The effects of physiological age (PA), sprouting treatment (ST) and tuber size (TS) on length of the longest sprout, mm tuber^{-1} (measured 2-3 days before planting).

Exp.	F2		F3		F4		F6	
	TR	SPL (mm)	TR	SPL (mm)	TR	SPL (mm)	TR	SPL (mm)
	TS, g		ST					
	62	14.7	fast	29.8	B36	16.0 ± 0.48	920D	19.6 ± 0.56
							352D	10.9 ± 0.87
	116	18.5	slow	24.4			280D	10.5 ± 0.55
	SED	0.53	SED	1.07			232D	10.4 ± 0.50
	PA		PA				184D	9.1 ± 0.63
	apical	22.3	apical	31.6			128D	8.3 ± 0.62
	multi	7.0	multi	15.3			80D	4.9 ± 0.53
	SED	0.54	SED	1.20			48D	1.77 ± 0.31

Where; TR = treatment; SPL = sprout length.

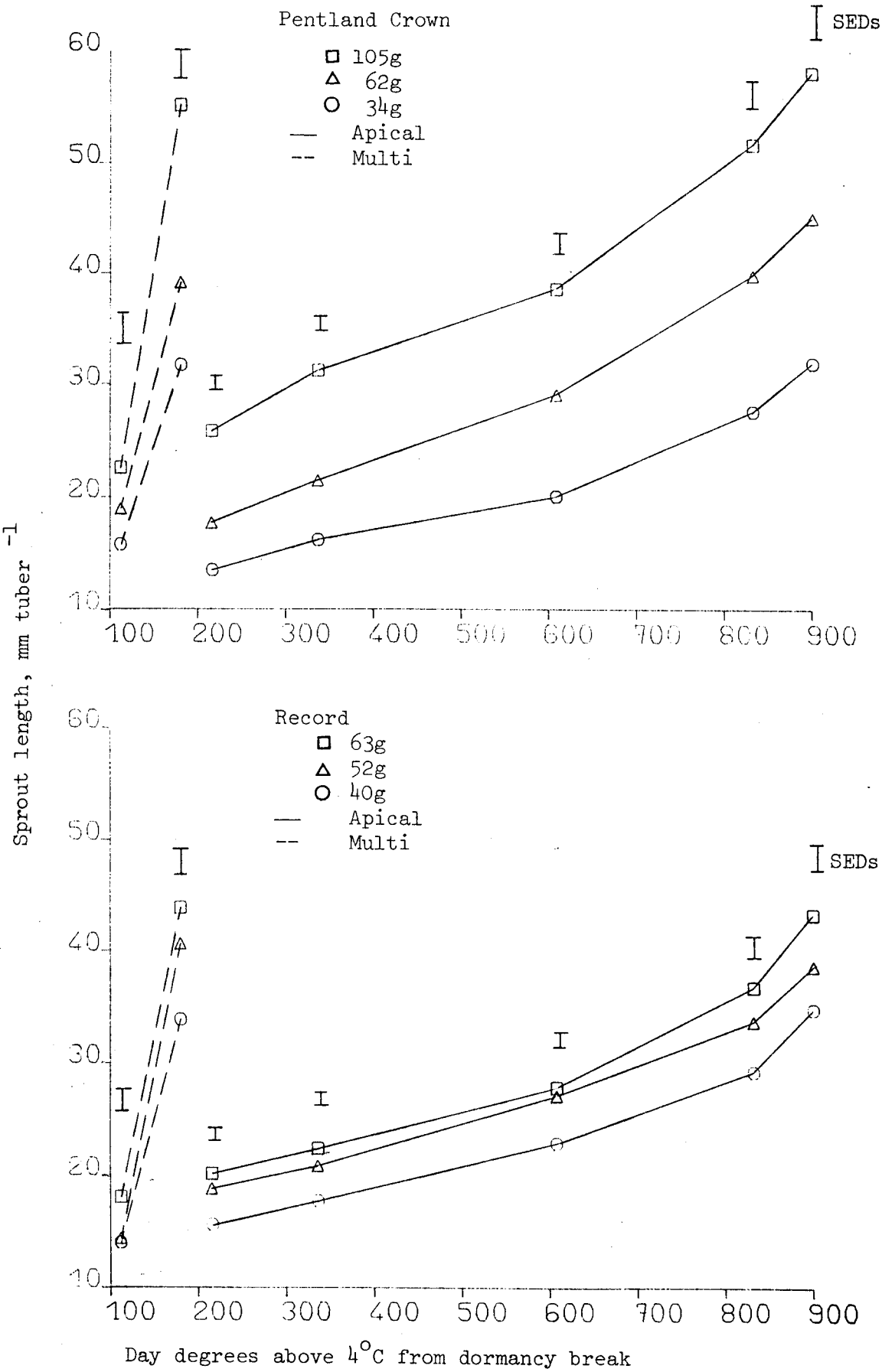


Figure 4.4.1.1 The effects of tuber size, variety and sprouting technique on total sprout length during storage (Experiment F1).

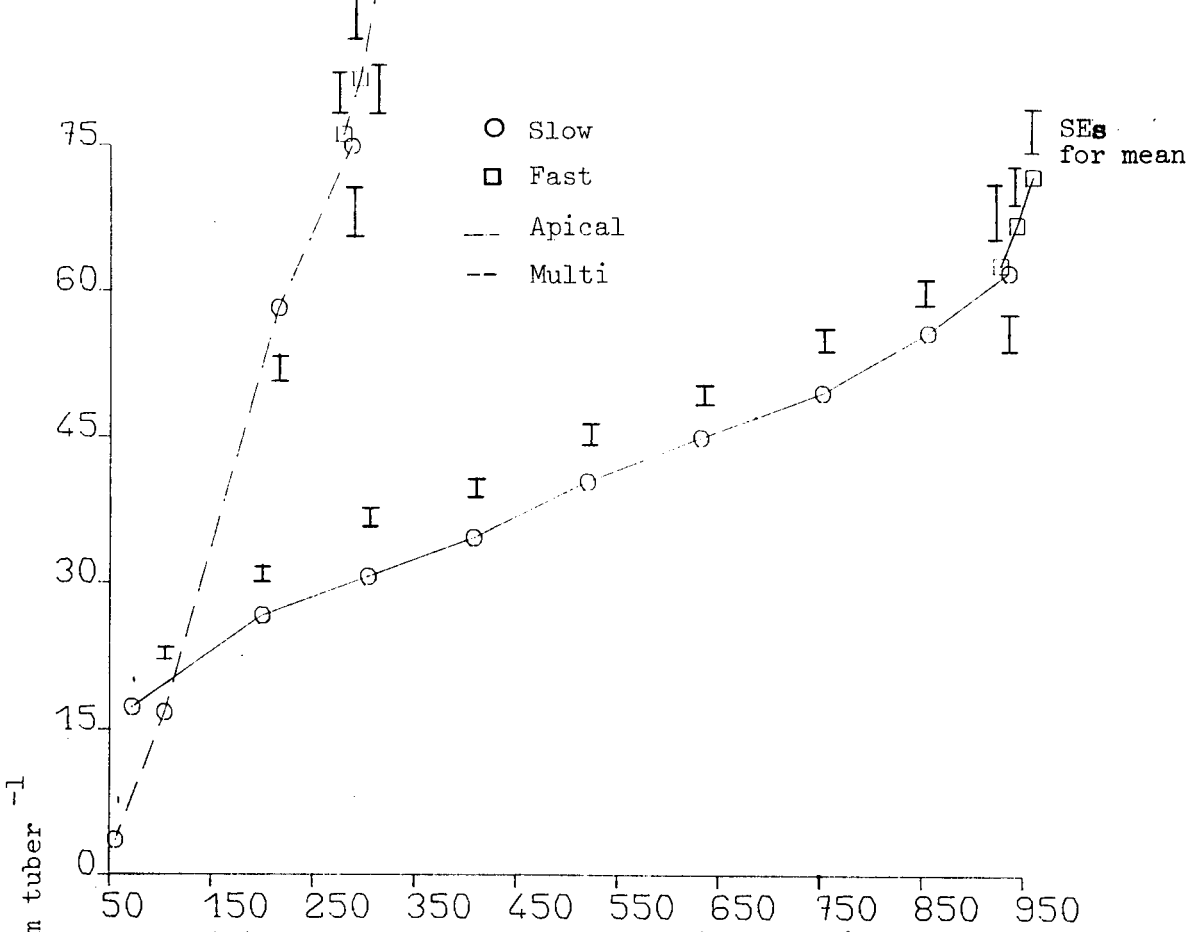


Figure 4.4.1.3 The effects of sprouting technique on total sprout length during storage (Experiment F3).

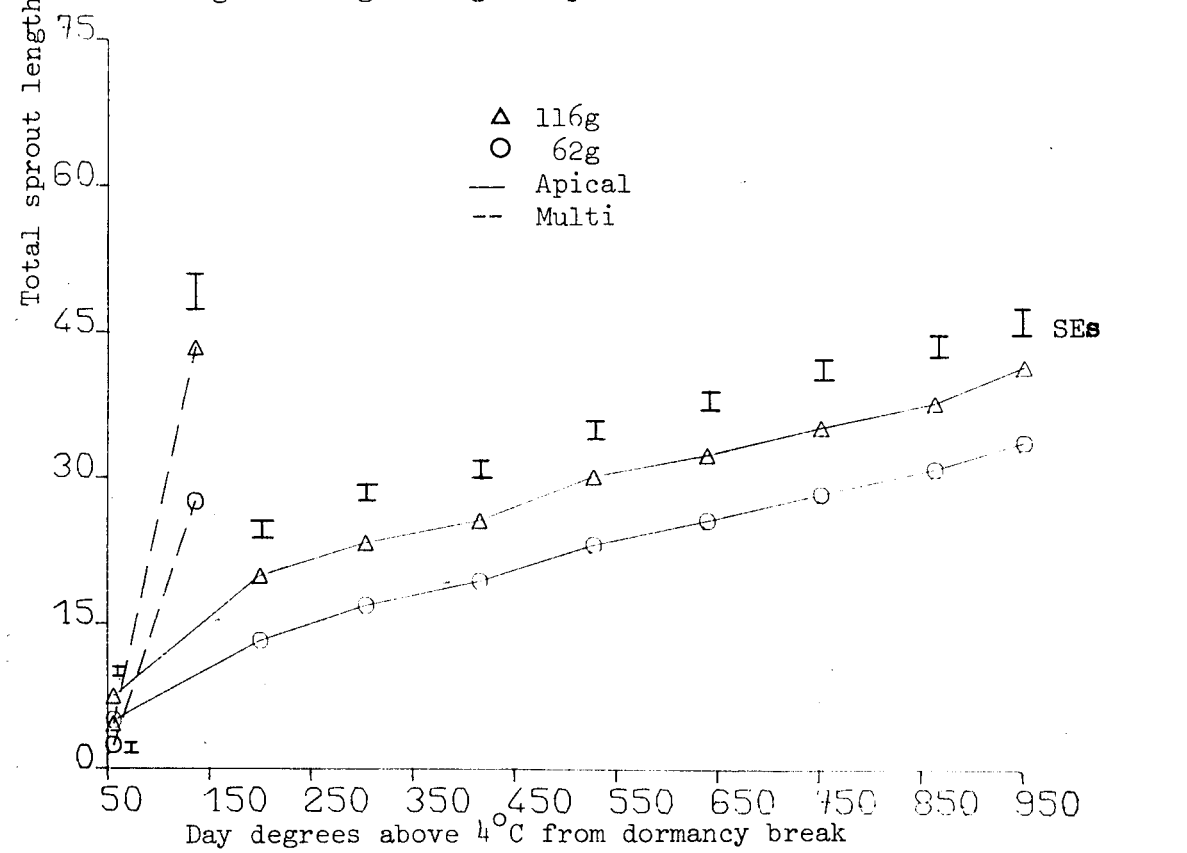


Figure 4.4.1.2 The effects of tuber size and sprouting technique on total sprout length during storage (Experiment F2).

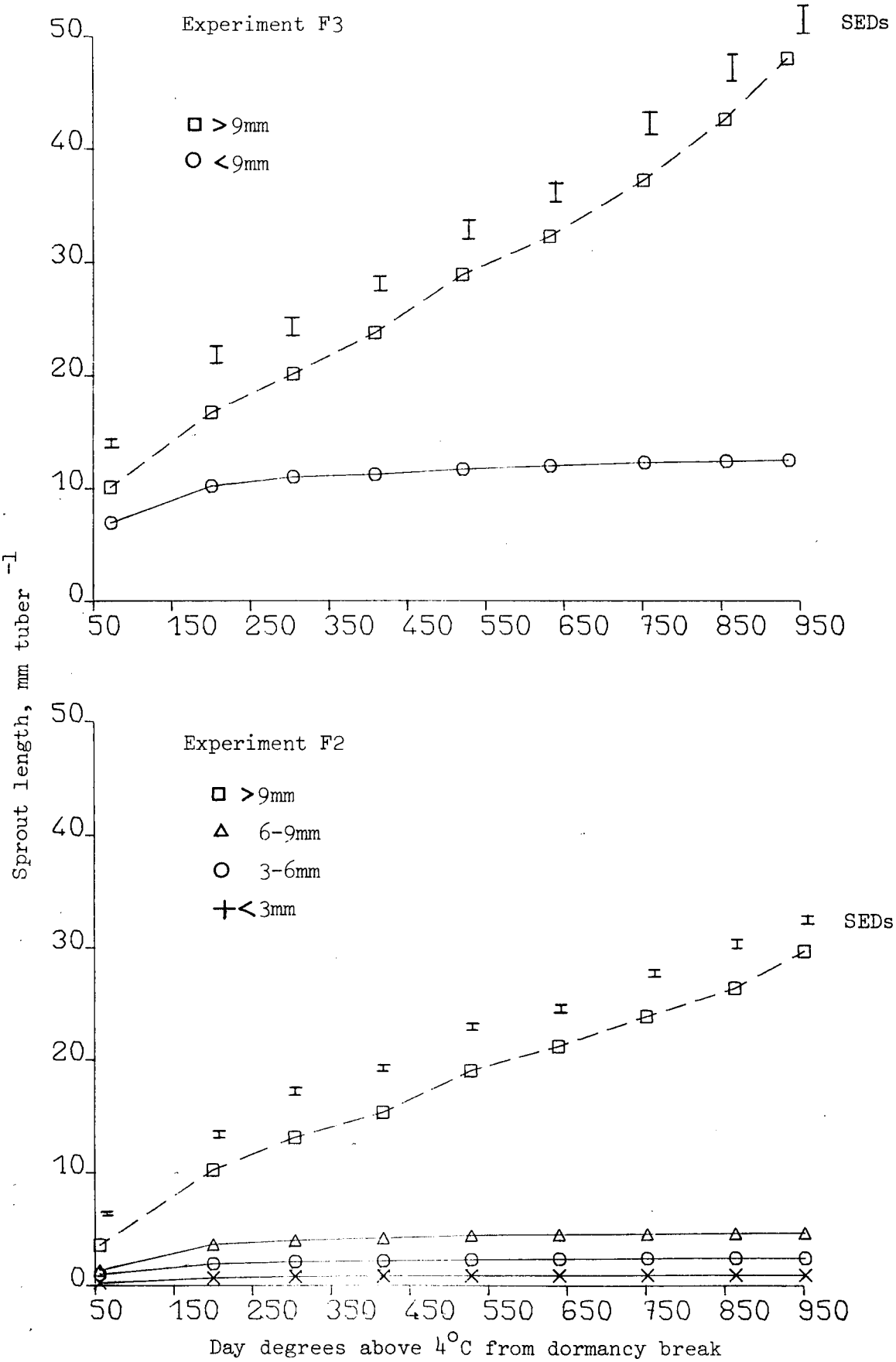


Figure 4.4.1.4 Growth of sprouts of different categories (see text for details) during storage.

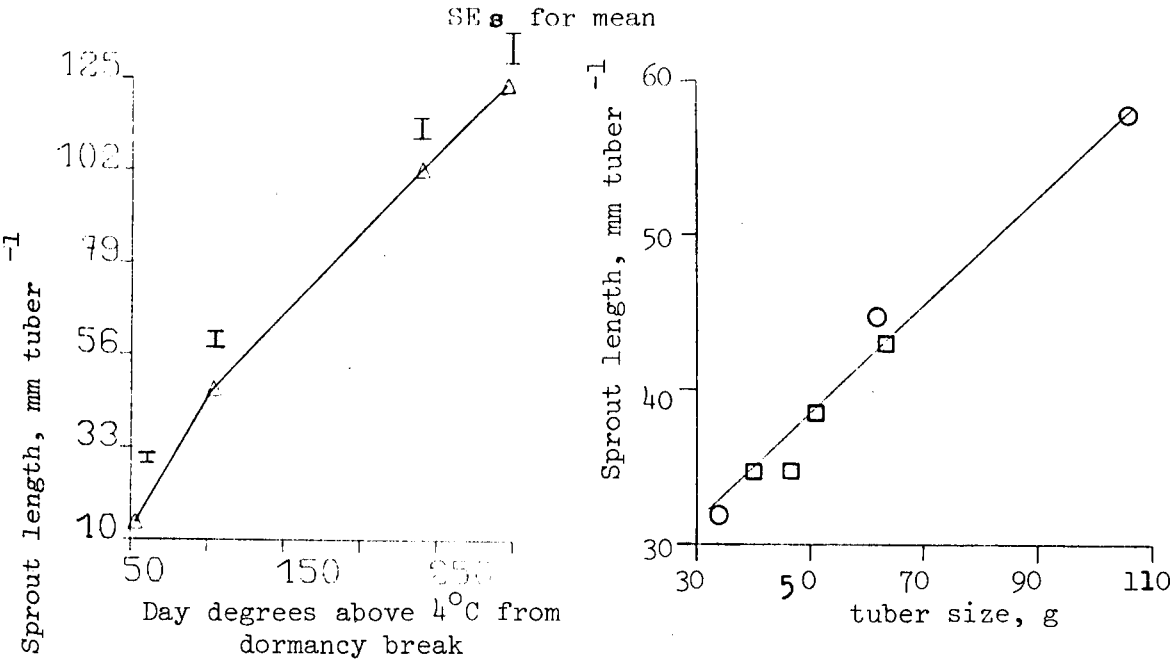


Figure 4.4.1.6 Total sprout length per tuber during storage (Experiment F4).

Figure 4.4.1.5 The relationship between tuber size and total sprout length measured on 28 April (Experiment F1)
$y=20.48(\pm1.38) + 0.36(\pm0.02)x$
% variance accounted for 98.2, residual standard deviation 1.23.

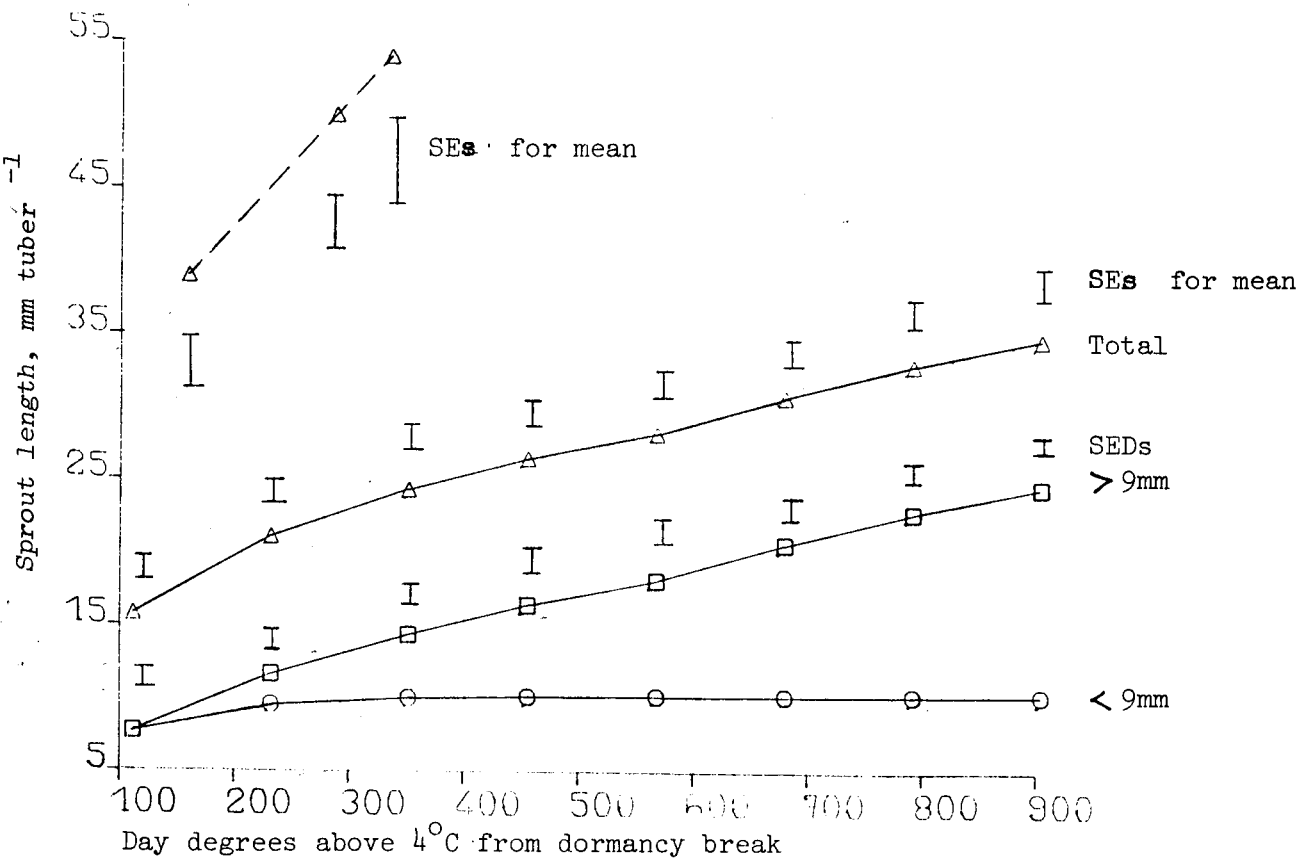


Figure 4.4.1.7 Total sprout length and sprout length of different categories during storage. Experiments: F5 and F6.
Key: ___, Apical; --, Multi.

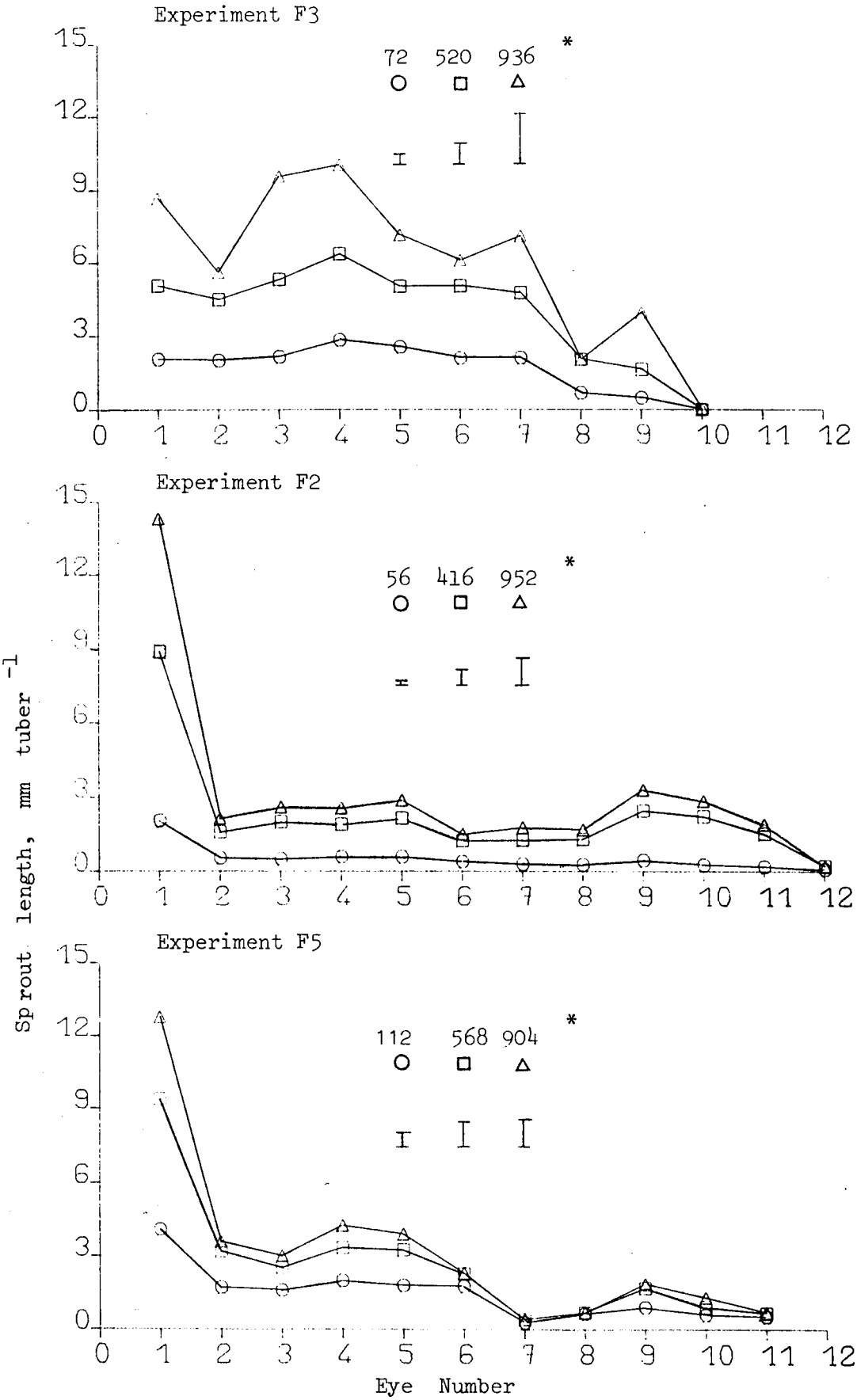


Figure 4.4.1.8 Total sprout length contributed by different eyes during storage, for apical treatment only.

* Day degrees above 4°C from dormancy break and SEDs to compare between eyes.

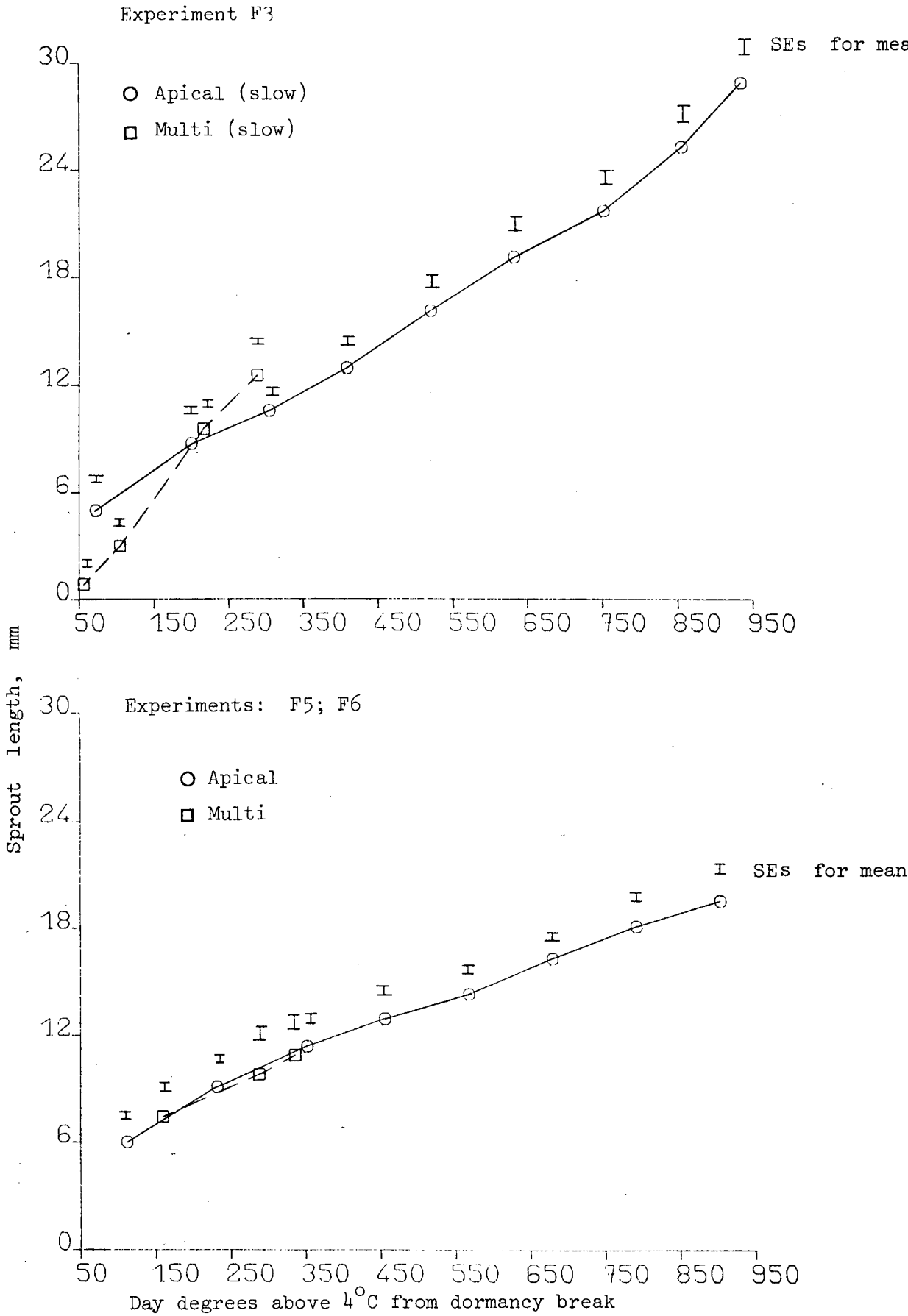


Figure 4.4.1.9 Length of the longest sprout during storage.

4.4.2 Experiment F1.

Soil temperature, at 10cm. depth, screen, max and minimum air temperature and rainfall data are presented in Figures 3.3.3a, 3.3.2a, 3.3.1.

4.4.2.1 Emergence and stem number

The variety Record started emerging about 10 days after Pentland Crown, but emergence was more homogenous in this variety thus the difference in time to 50% emergence was reduced to 8 days (Fig.4.4.2.1.). Once emergence had started the rate of emergence was higher in Record while physiological age and spacing did not affect it. Inspite of differences in the length of the longest sprout at the time of planting, physiological age did not affect the emergence, may be due to the fact that total sprout growth rate was higher in case of multi (Fig.4.4.1.1.). Stem number stopped increasing after the end of June and thus were averaged for the various dates of growth analyses carried out after that as there was no significant difference between different dates. The total number of stems per unit area were higher at 30cm. (22.11,M^{-2}) spacing as compared to 40cm. (17.09,M^{-2}) but this increase was in proportion to the increase in number of plants per unit area. Apical treatment increased the number of branch stems in both varieties (Fig.4.4.2.1.). Record had a higher number of branch stems but a lower number of main stems and total stem number was also higher in this variety (Fig.4.4.2.1.). There was no increase in the number of axillary branches (AB) after the end of June and so they were averaged for all dates of growth analyses. AB were higher in Pentland Crown (Fig.4.4.2.2.).

Apical treatment increased the number of AB in Pentland Crown but decreased in Record (Fig.4.4.2.2.). It may be explained by increase in total stem number by this treatment (Apical) in Record, which increased shading of the lateral buds. Similarly planting at closer spacing also decreased the number of AB. In Pentland Crown about 98% of the AB present were contributed by the main stems, this may be because branch stems were fewer in number (Fig.4.4.2.1.) and further they were smaller in size (Fig.4.4.2.15), thus lateral buds may have been shaded and stayed dormant. Development of AB depends on the release of dominance from the apical bud, which may be related to the lower auxin production by the lateral buds. Thus development of AB may be related to the speed of ground cover by the crop canopy. To investigate this the leaf area duration for a period of 30 days from the date of 50% emergence (LAD'E30) was calculated and plotted against number of AB present (Fig.4.4.2.2.). Number of AB present decreased with increase in LAD'E30 i.e. with the increase in speed, with which ground was covered by the canopy. Speed of ground cover was faster in Record.

4.4.2.2 Stolon growth and development

The variety Pentland Crown increased stolon weight (Fig.4.4.2.3) for a longer time and this may be related to delay in tuber initiation (TI). The variety Record initiated tubers 5 days before Pentland Crown (Table 4.4.2.1), when counted from the date of 50% emergence. Thus while Record started feeding its tubers, assimilates in Pentland Crown may still have been used for stolon growth. Stolon growth slowed down after TI in both the varieties (Fig.4.4.2.3). Early in the growing

season before TI, apical treatment increased stolon weight per unit area (Fig.4.4.2.3). Percentage of stolon dry weight out of total dry weight was also higher in this treatment. Spacing, did not affect stolon growth or its number (Fig.4.4.2.3). Stolon number were also unaffected by physiological age. Like stolon weight, stolon number also stopped increasing after TI. Stolon number were higher in Pentland Crown. In general before TI stolon growth was found to be linearly related to the LAI of the canopy (Fig.4.4.2.4).

4.4.2.3 Growth and development of stem and leaf

In general main stems were slightly longer than the branch stems but on an overall basis they were longer in Pentland Crown than in Record (Fig.4.4.2.5). Physiological age and spacing did not affect the plant height. Total number of stems were higher in Record (Fig.4.4.2.1) and they had higher weight of under ground stem (UGS) (Fig.4.4.2.7). Increase in weight of above ground stem (AGS) was not proportional to the UGS, in fact Record had decreased AGS weight. This may be explained by the decrease in height of the plant (Fig.4.4.2.5). Physiological age did not affect the stem weight, while planting at closer spacing increased stem weight (UGS as well as AGS) per unit area (Figs.4.4.2.6 and 4.4.2.7). This may be due to higher number of plants per unit area.

Record emerged 8 days later (Fig.4.4.2.1) and thus had lower LAI early in the season (Fig.4.4.2.8), when considered from the date of planting but it was much higher in Record when considered from the date of 50% emergence, and the rate of increase in LAI was also higher thus later on it had higher LAI than Pentland Crown, but later it declined rapidly due to earlier senescence (Table 4.4.2.1). Apical treatment

decreased LAI (may be due to decrease in stem no.) Although the effect was not significant at any date of Growth analysis but was consistent during most of the growing season (Fig.4.4.2.8). Planting at closer spacing (30cm.) increased the LAI and the effect was consistent throughout the growing season (Fig.4.4.2.8). This may be due to the higher number of plants per unit area. Overall about 80% of the LAI was contributed by the main stems in Pentland Crown while in Record this figure was 52%. Apical treatment increased the number of branch stems thus decreased the proportion of LAI contributed by the main stems, from 82 to 57% and this degree of decrease (25%) was the same for both varieties. Although there was no increase in the number of AB after end of June but existing branches continued to grow. Size of AB may be studied by working out their leaf area separately and is presented in Figure 4.4.2.9. LAI contributed by the AB (LAI'AB) was higher in Pentland Crown. Number of AB were also higher in this variety. Closer spacing and multi treatment decreased the LAI'AB. This may firstly be due to a lower no. of AB present in these treatments and secondly due to higher competition, as they had higher number of stems (main + branch) (Fig.4.4.2.1). Higher LAI'AB in Pentland Crown and the treatment apical was mainly due to the higher number of leaves present on the AB of these treatments. There was also a slight increase in the average leaf size of the leaves present on the AB, due to these treatments.

Apart from the leaves present on the AB, the total leaf numbers were neither affected by the varieties nor by the physiological ages. While planting at closer spacing did significantly increase the total leaf number (Fig.4.4.2.11) but average leaf size was slightly decreased. Although total leaf numbers were not affected by the varieties and physiological ages but the important result was that leaves coming from

different type of stems were affected. In the case of Record more leaves were contributed by the branch stems and the reverse was the case for Pentland Crown (Fig.4.4.2.12). Apical treatment which increased the number of branch stems, also increased the proportion of leaves contributed by the branch stems (Fig.4.4.2.12). Leaves present on the AB were much smaller in size, thus average leaf size for main and branch stem presented (Fig.4.4.2.13) was calculated without including these leaves. Leaves coming from the branch stems were much smaller and difference was greater in the variety Pentland Crown (Fig.4.4.2.13). Branch stems of multi treatment had much smaller leaves than those of the apical treatment.

Decrease in leaf size resulted in differential values for leaf to stem ratios (Fig.4.4.2.14). Branch stems had a lower leaf to stem ratio and the difference was greater in Pentland Crown. Leaf to stem ratio of branch stems was increased by the apical treatment (Fig.4.4.2.14). Spacing did not affect the leaf to stem ratio of any particular type of stem. In general leaf to stem ratio was slightly decreased by planting at closer spacing.

Total above ground stems are usually accepted as criteria for plant population in potato, thus it may be important to study the size of the different type of stems. Size of the stem is presented in term of LA per stem (Fig.4.4.2.15). Branch stems were much smaller than the corresponding main stems and this difference was greater in Pentland Crown. Apical treatment increased the size of main stem in Pentland Crown but decreased it in Record. However size of branch stem was increased by the apical treatment in both varieties but degree of increase was more in Pentland Crown (Fig.4.4.2.15).

The effects of varieties and spacings on specific leaf area is

presented in Figure 4.4.2.10. Specific leaf area was higher in Record and at closer spacing, this may be related to the mutual shading by the leaves as both these treatments increased the LAI also. Decrease in specific leaf area due to decrease in irradiance was also found in the experiment GR2 (Chapter 2). Physiological age did not affect the specific leaf area.

4.4.2.4 Light Interception

Figure 4.4.2.16 shows the proportion of PAR intercepted by the crop canopy. Quantity of PAR intercepted by the canopy was increased by planting at closer spacing and this increase was in proportion to increase in the LAI (Fig.4.4.2.8). Effects of variety and physiological age on PAR interception were also similar to their effects on the LAI (Figs.4.4.2.8 and 4.4.2.16). Relationship between LAI and light interception is shown in Chapter 4.4.6.

4.4.2.5 Tuber growth and development

Tuber initiation (TI) was considered as the date when tuber dry weight of 0.25g plant^{-1} was reached and was calculated by interpolation from the growth analyses and additional sampling data, taken frequently during the early growth of the crop. TI in Record occurred 3 days later than in Pentland Crown (Table 4.4.2.1) but when considered from the date of 50% emergence it was in fact 5 days earlier in Record (Table 4.4.2.1). Apical treatment enhance, TI (one day) by enhancing the emergence (Fig.4.4.2.1) thus there was no difference in the number of days taken for tuber to initiate when counted from the date of 50% emergence.

Table 4.4.2.1. The effects of variety, physiological age and spacing on number of days taken: from planting to tuber initiation (TI) (TIP); from 50% emergence to TI (TIE); from planting to senescence (SENP).

	TIP	TIE	SENP
		Variety	
Pentland Crown	49.92	20.83	159.8
Record	52.67	15.58	137.9
		Physiological age	
Multi	51.92	18.25	150.3
Apical	50.67	18.17	147.5
		Spacing	
30cm	51.50	18.17	149.3
40cm	51.08	18.25	148.4
SED	0.453	0.497	2.90

Record gave consistently higher tuber weights as well as tuber numbers throughout the growing season (Figs.4.4.2.17 and 4.4.2.18) but final tuber yield was higher in Pentland Crown because it stayed green in the field for a further period of 22 days after Record had senesced (Table 4.4.2.1). Just after TI apical treatment did give higher tuber weight and number (Figs.4.4.2.17 and 4.4.2.18) but this difference soon disappeared and final tuber yield was not affected and tuber numbers were increased by the multi treatment. Planting at closer spacing increased tuber number as well as tuber weight (Figs.4.4.2.17 and 4.4.2.18).

The effect of spacing on tuber number was more, early in the season (Fig.4.4.2.18), which may be attributed to the increase in LAI by planting at closer spacing but subsequently percentage of increase in LAI decreased along with the season due to higher interstem competition, thus differences at final harvesting were reduced. Tuber numbers are usually related to the total stem numbers as the latter increase the LAI at the time of TI and this was found to be the case in the present experiment (Fig.4.4.2.19). Tuber numbers which result seems to depend on assimilates available for their growth for some period after TI. Thus it was of interest to look at this in further detail. Leaf area duration for a period of 30 days (LAD'TI30) was calculated from the date of TI and is plotted against tuber number (Fig.4.4.2.20). About 98.7% of the variance in tuber number was accounted by linear regression between tuber number and LAD'TI30 in Record and 72% in Pentland Crown. Record and Pentland Crown had two separate significantly different regression lines. Record developed 1.10 tubers per unit of LAD'TI30, while this figure for Pentland Crown was 0.78. This difference may be explained by the fact that a higher percentage of assimilates were allocated to the tubers in the case of Record (Fig.4.4.2.25).

Total tuber yield was found to be linearly related to the total leaf area duration (LAD) accumulated over the whole season by the crop canopy (Fig.4.4.2.21). Tuber yield per unit of LAD was 5.31 in case of Pentland Crown and 6.34 in case of Record. Higher efficiency of Record may be related to the higher percentage of assimilates allocated to the tubers (Fig.4.4.2.25). Since higher tuber numbers were found in Record, assimilates available for the growth of individual tuber were lower, which resulted in higher proportion of medium sized tubers (Fig.4.4.2.22). At final harvesting Record gave 72% of the medium

sized tubers (32-57mm), while this figure for Pentland Crown was only 37% most others being larger. Closer spacing (30cm) and multi treatment also increased the proportion of medium sized tubers but difference was not significant. Tuber size may be related to the presence of AB. Because AB present, may increase the amount of assimilates available for a particular tuber to grow and thus increase the tuber size. To examine this leaf area duration contributed by the AB (LAD'AB) was calculated and is plotted against tuber weight over 57mm (Fig.4.4.2.23). Linear regression between tuber weight over 57mm and LAD'AB accounted for 63% of the variance in the tuber weight over 57mm.

4.4.2.6 Total dry matter accumulation

Roots were not collected and those present on stems and stolons were removed and discarded, thus the total dry weight (TDW) presented is excluding roots. Later in the season (end of July) leaves started to fall off and were not collected from the ground. Pentland Crown completed 50% emergence about 8 days earlier than the variety Record (Fig.4.4.2.1) and thus had higher total dry weight early in the season but crop growth rate was higher in the variety Record and thus TDW produced by the canopy of this variety was higher during the middle part of the growing season (Fig.4.4.2.24). Later it senesced before Pentland Crown (Table 4.4.2.1). Planting at closer spacing also increased the TDW per unit area (Fig.4.4.2.24) which may be due to the higher number of photons intercepted by the canopy (Fig.4.4.2.16). Physiological age did not affect the TDW (Fig.4.4.2.24). Various components making up the TDW may be of importance as tubers are the economic part of the crop. Record allocated a higher percentage of

assimilates to the tubers (Fig.4.4.2.25) and less to the AGS. Apical treatment also resulted in an allocation of a higher percentage of assimilates to the tubers and this effect was consistent throughout the growing season (Fig.4.4.2.25). Planting at closer spacing increased the percentage of assimilates allocated to the stems and decreased to the tubers.

4.4.3. Experiments: F2; F3; F4.

4.4.3.1 Emergence and stem number

As in experiment F1 (1979), apical and multi treatments of experiments F2 and F3 started emerging at the same time (28 days after planting (DAP) (Figs.4.4.3.1 and 4.4.3.2) but the time to reach 50% emergence in case of apical was 34.3 days in experiment F2 and 31.7 in experiment F3, which may be due to the fact that apical in experiment F2 made more total stem number and proportion of branch stems was higher (Fig.4.4.3.2 and Table 4.4.3.1) and branch stems may have emerged later. Cold started emerging 34 DAP but emergence in cold was more homogenous and difference in time to reach 50% emergence was reduced to 5 days compared to multi and 3.7 days compared to apical (Fig.4.4.3.1), while in experiment F4 the difference in time to 50% emergence was 8 days, between S25 (cold) and B36 (multi). This may be explained by the difference in seed size in two experiments.

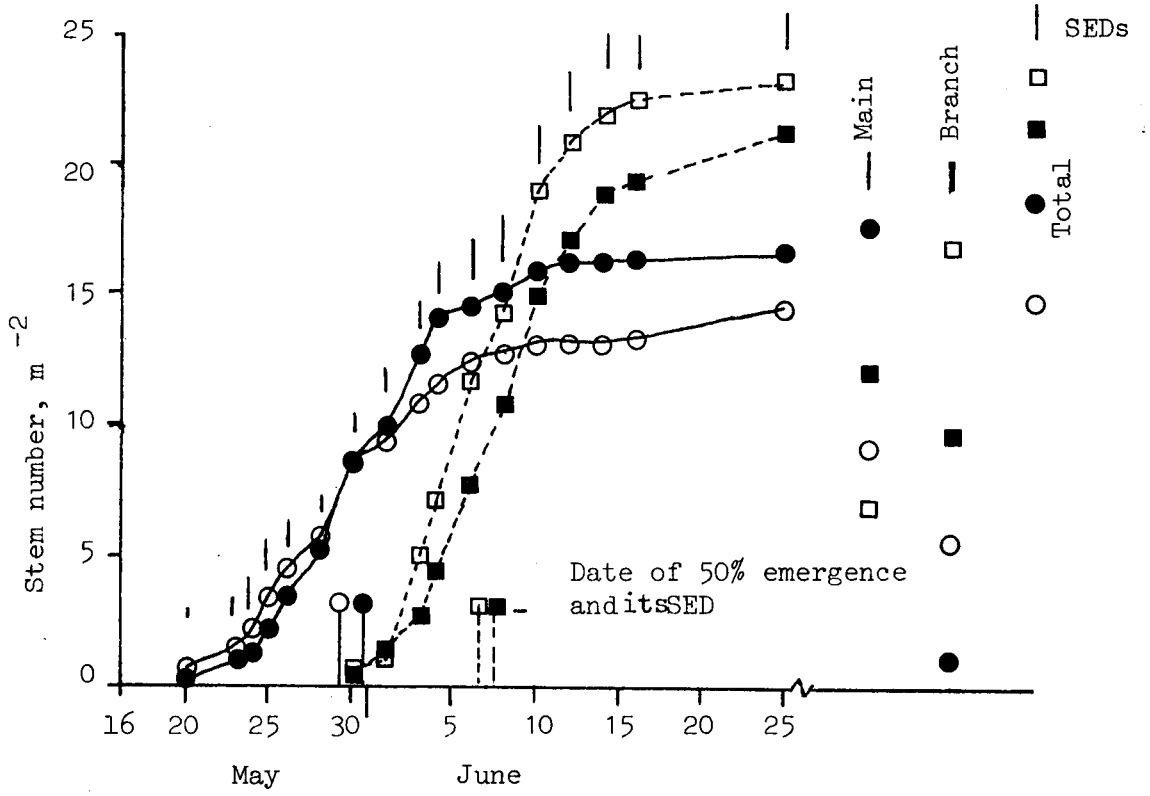


Figure 4.4.2.1 The effects of variety and physiological age on emergence.

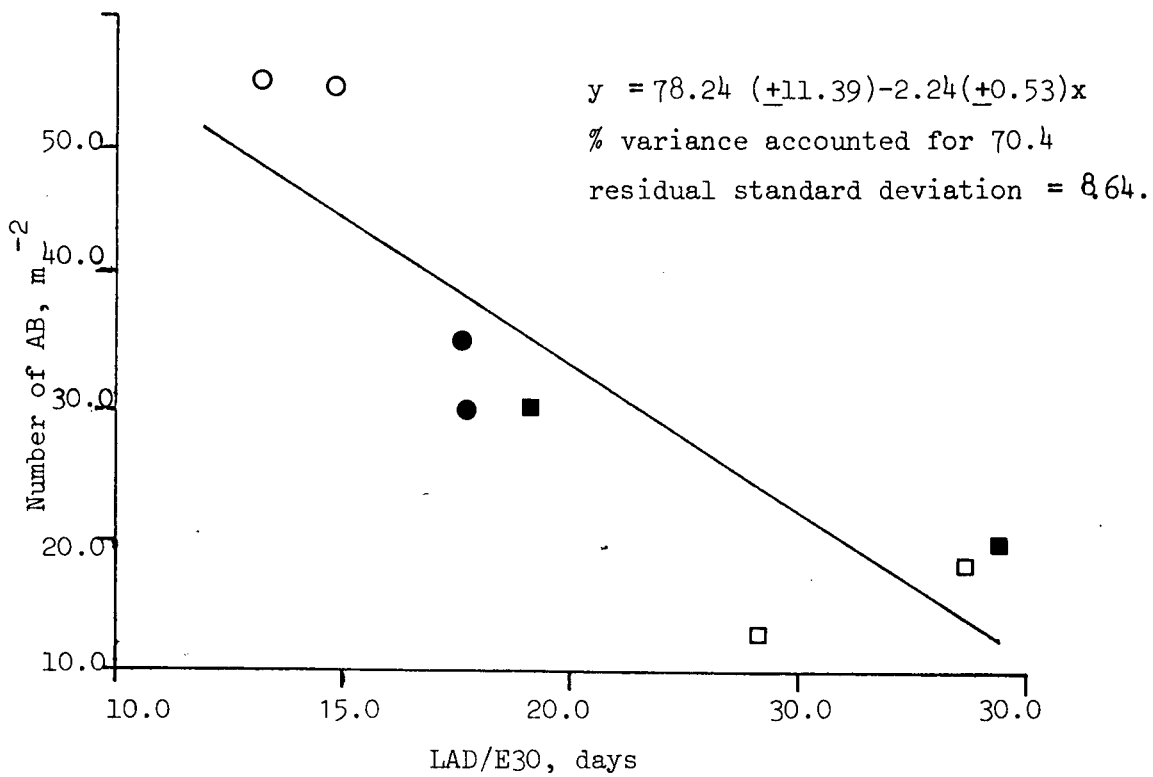


Figure 4.4.2.2 The relationship between leaf area duration, accumulated over a period of 30 days from the date of 50% emergence (LAD/E30) and the number of axillary branches (AB). Key: ○, Pentland Crown; □, Record; open symbols, apical; closed symbols, multi.

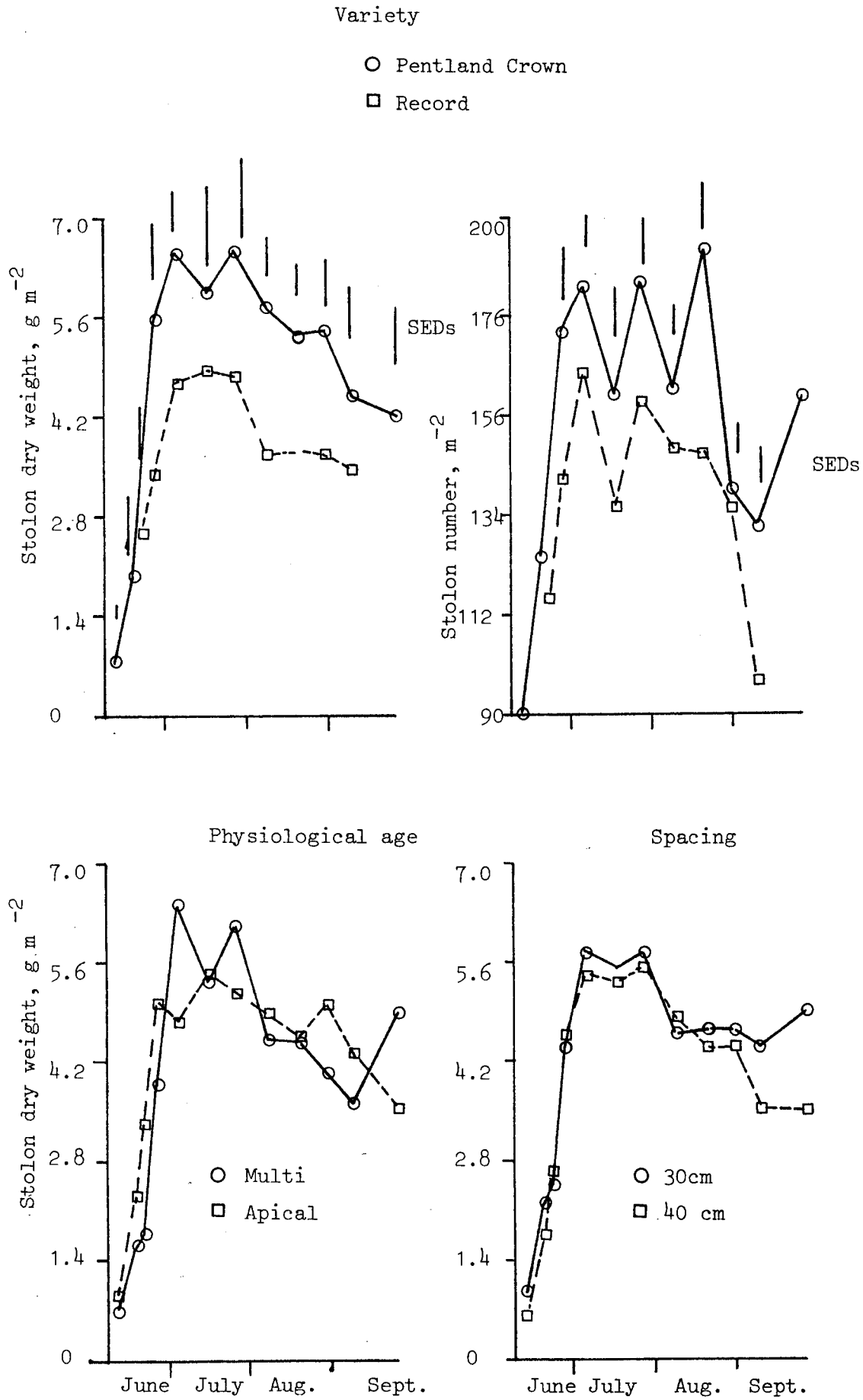


Figure 4.4.2.3 The effects of variety, physiological age and spacing on stolon dry weight and the effects of variety on stolon number.

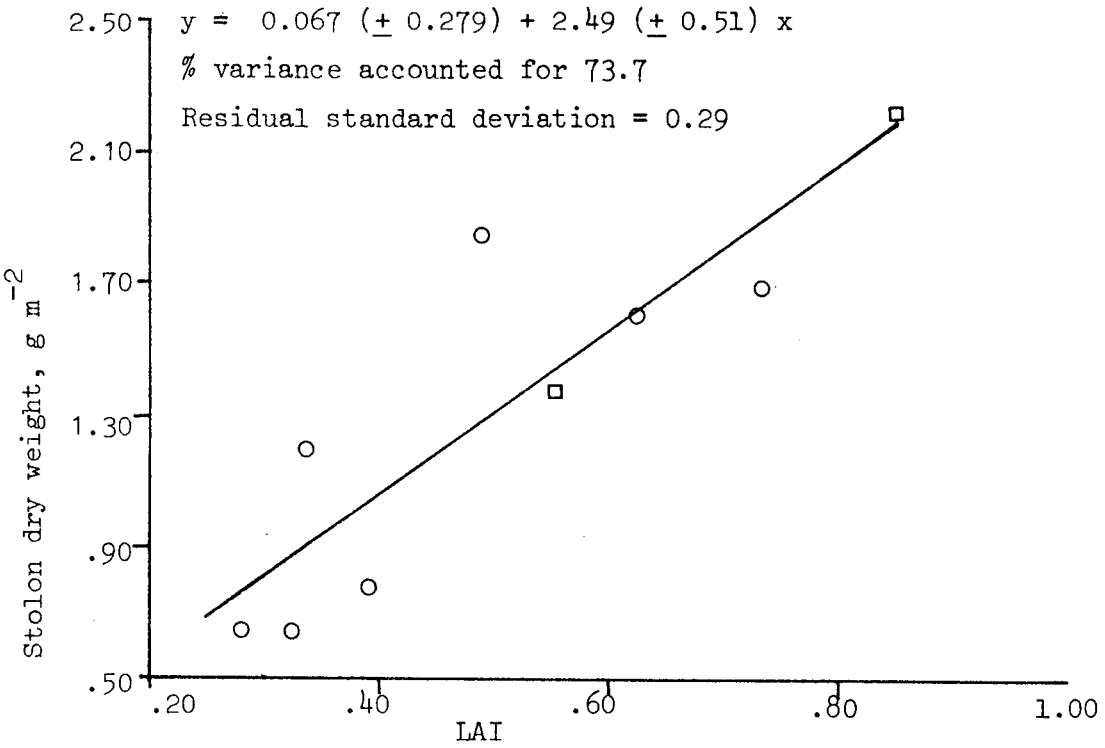


Figure 4.4.2.4 The relationship between stolon dry weight and LAI. Key: ○, Pentland Crown; □, Record.

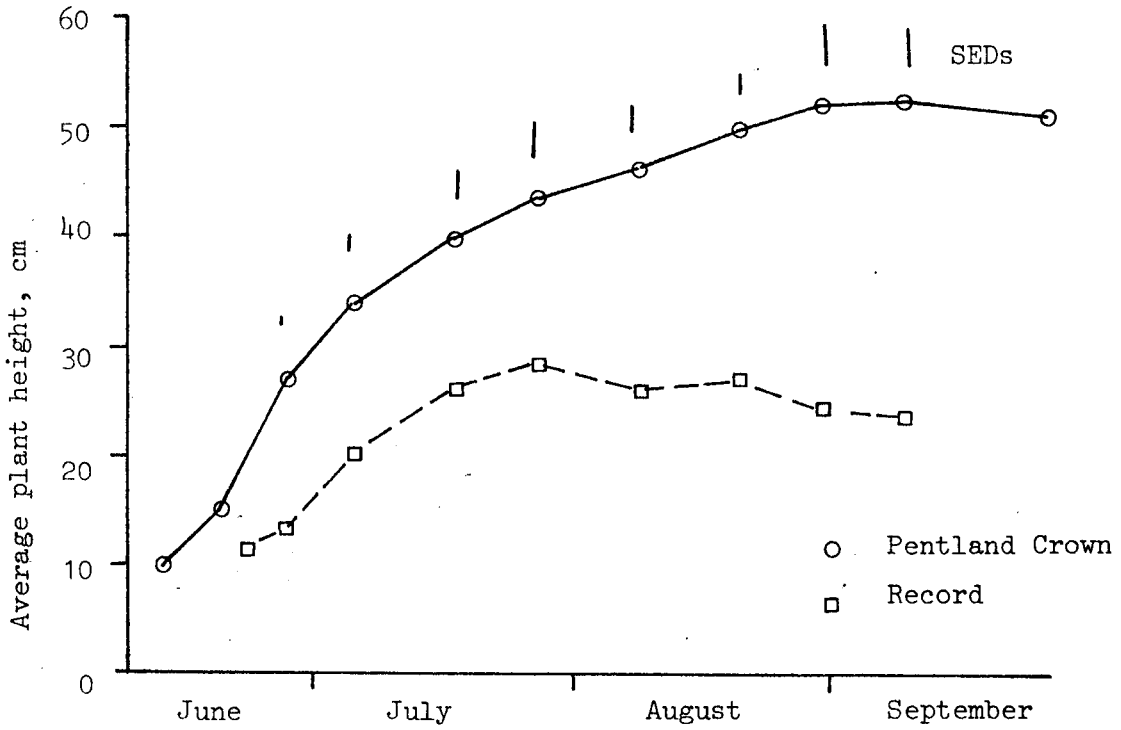


Figure 4.4.2.5 The effects of variety on average plant height.

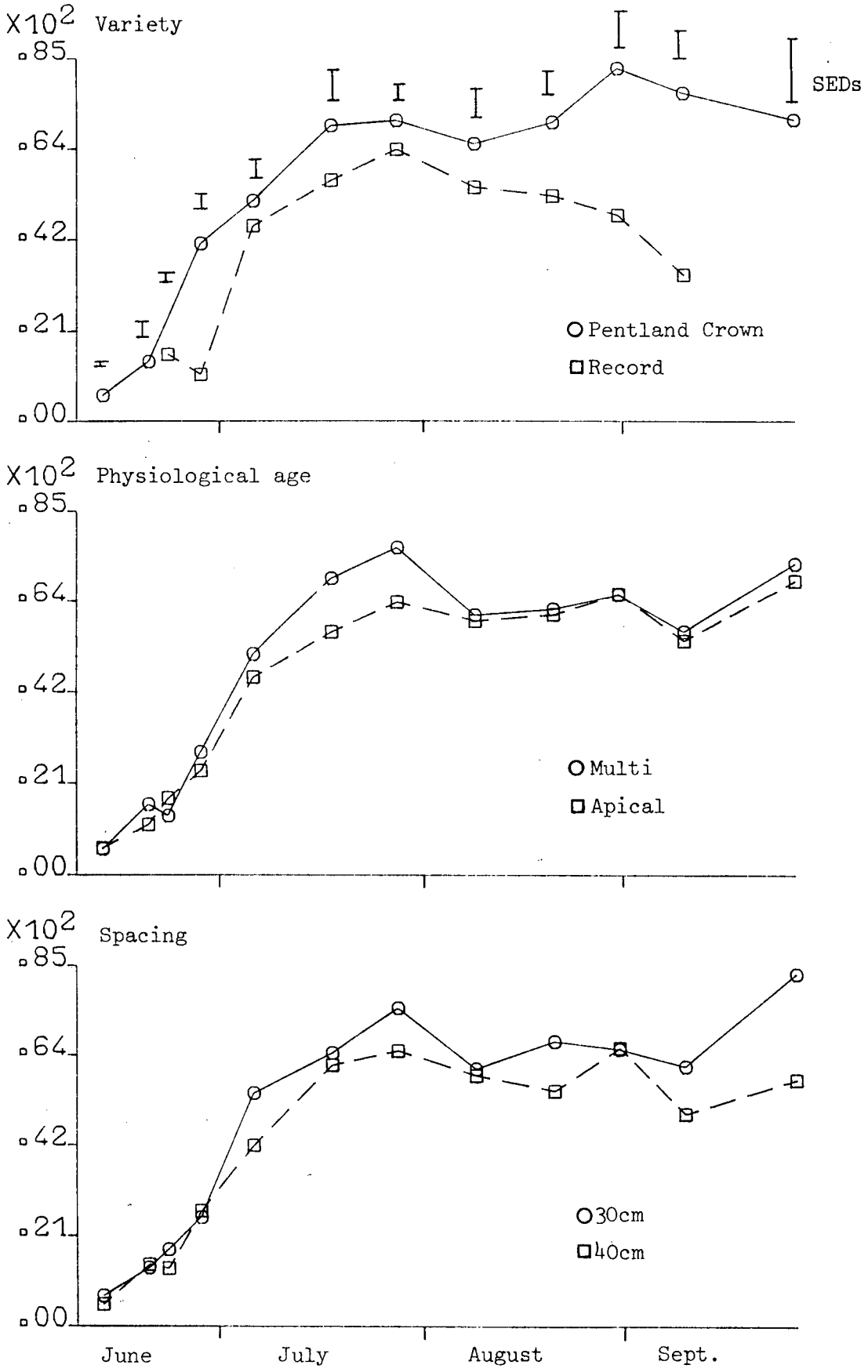


Figure 4.4.2.6 The effects of variety, physiological age and spacing on dry weight of above ground stems (AGS).

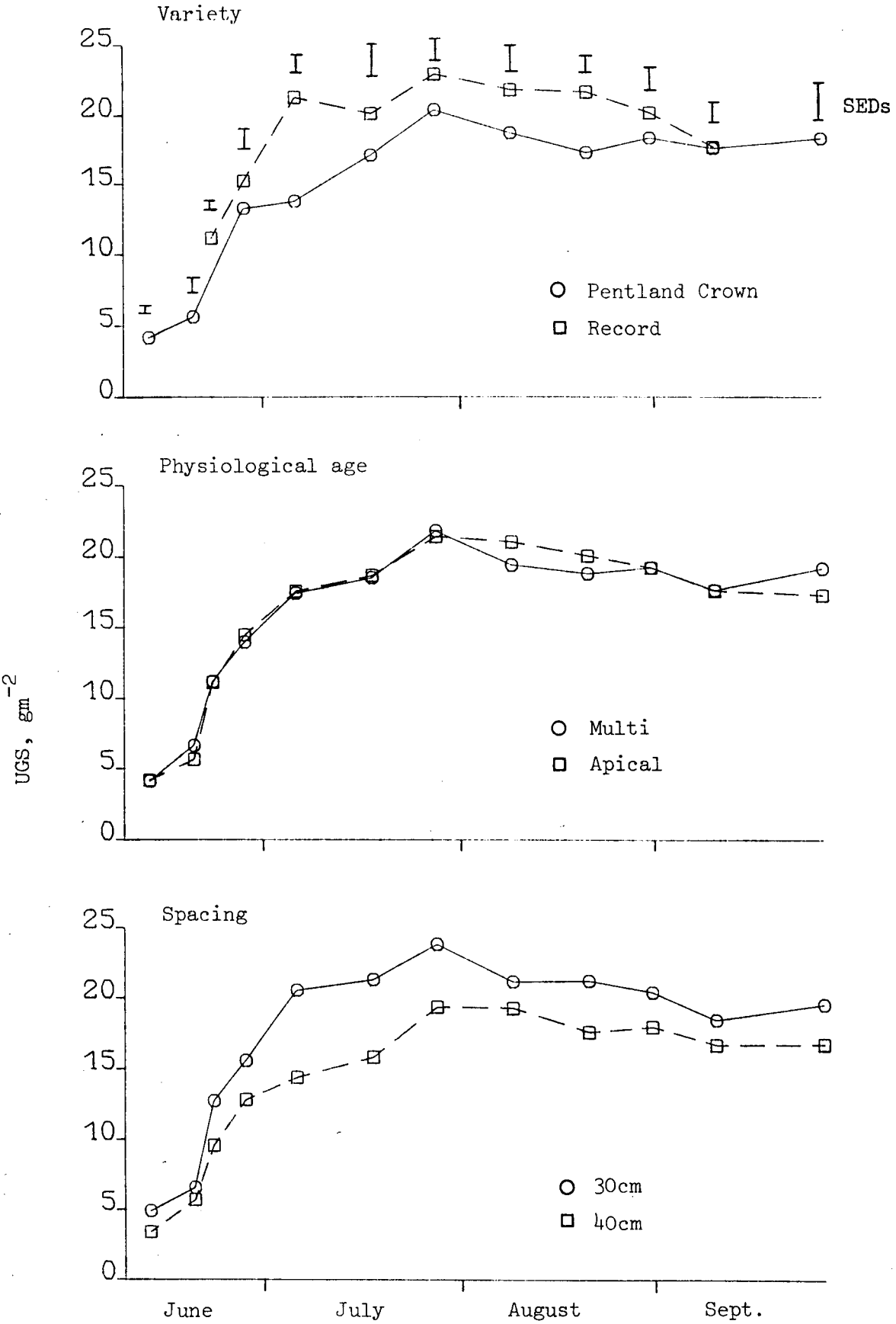


Figure 4.4.2.7 The effects of variety, physiological age and spacing on dry weight of under ground stems (UGS).

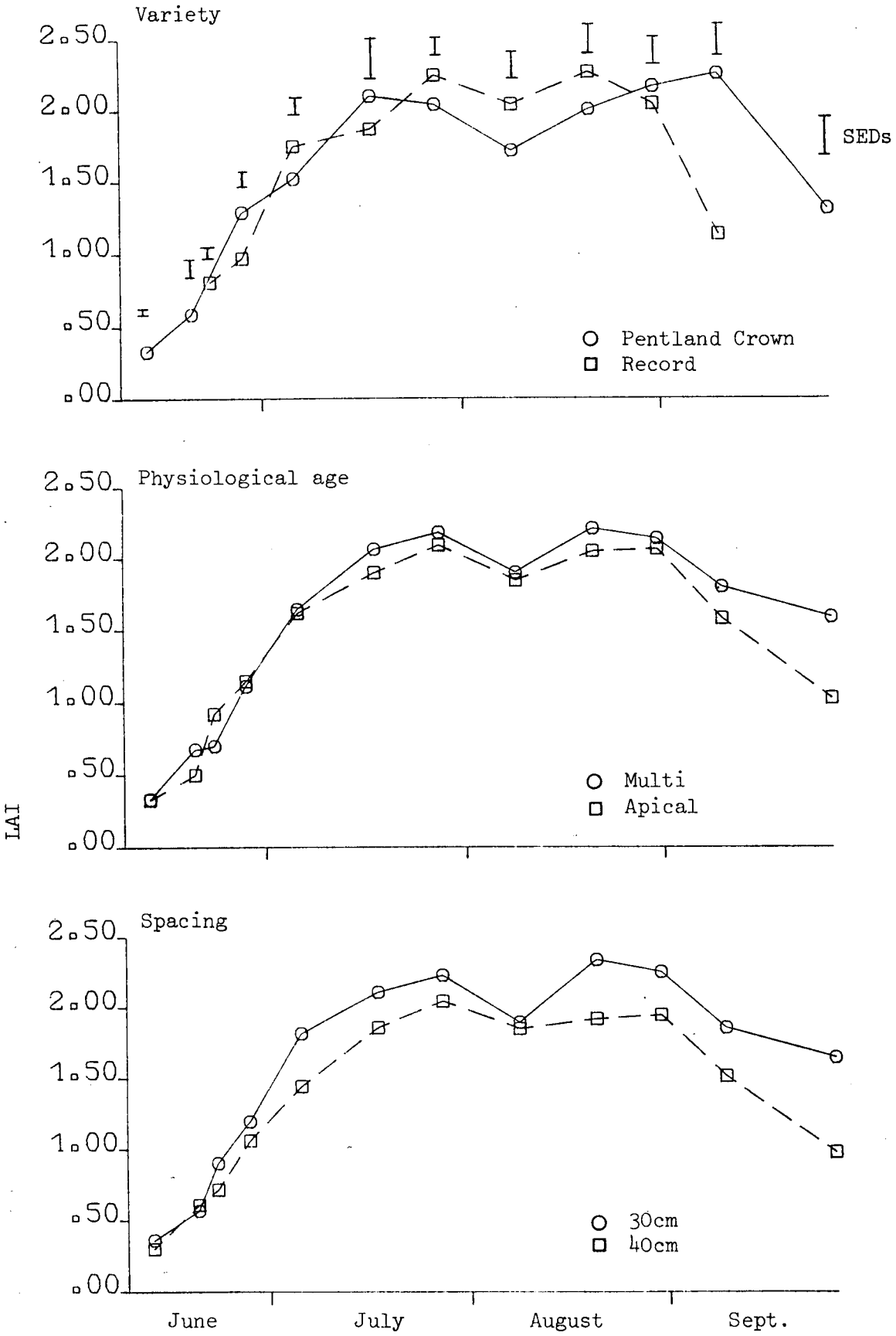


Figure 4.4.2.8 The effects of variety, physiological age and spacing on leaf area index (LAI).

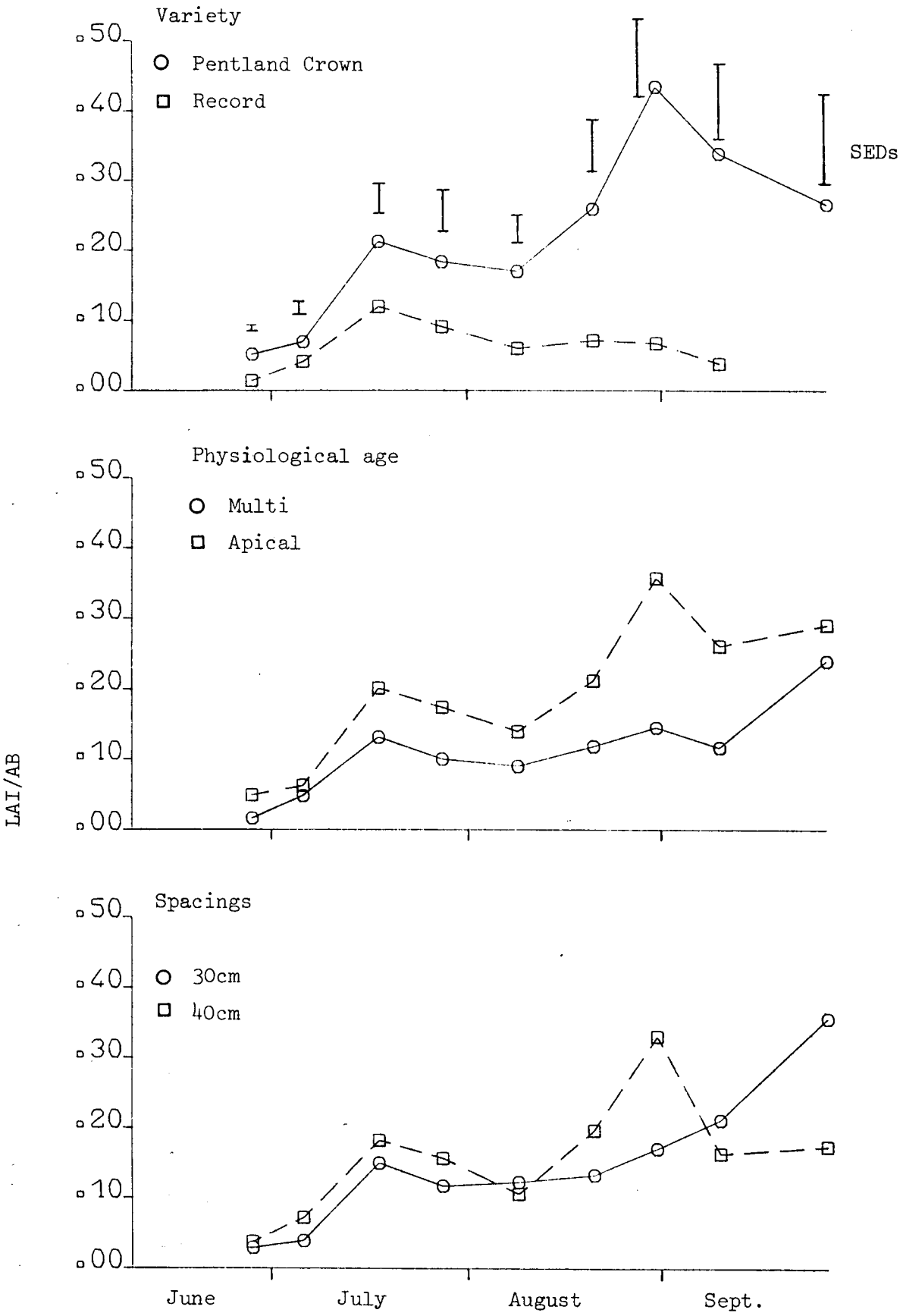


Figure 4.4.2.9 The effects of variety, physiological age and spacing on leaf area index contributed by the axillary branches (LAI/AB).

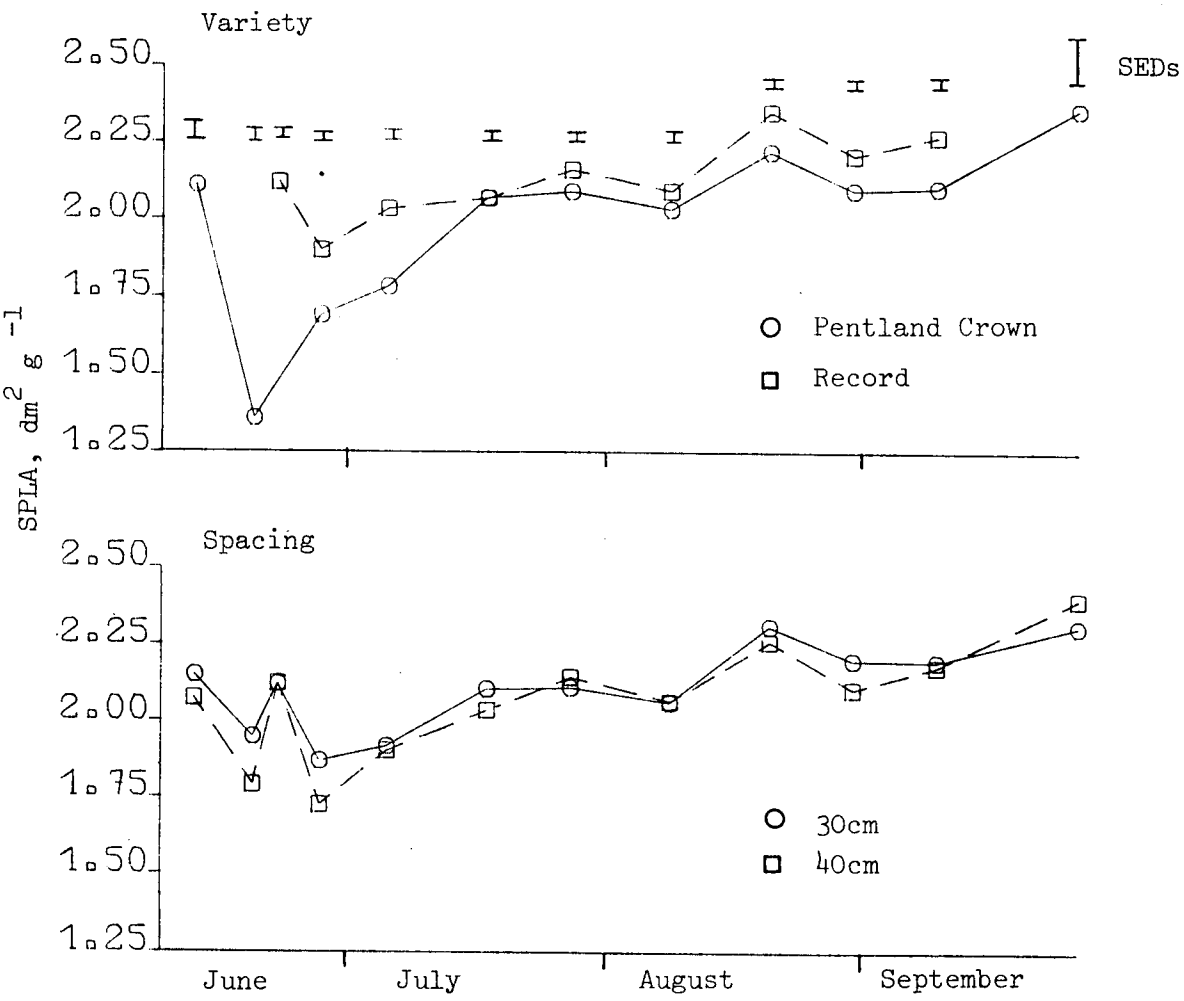


Figure 4.4.2.10 The effects of variety and spacing on specific leaf area (SPLA).

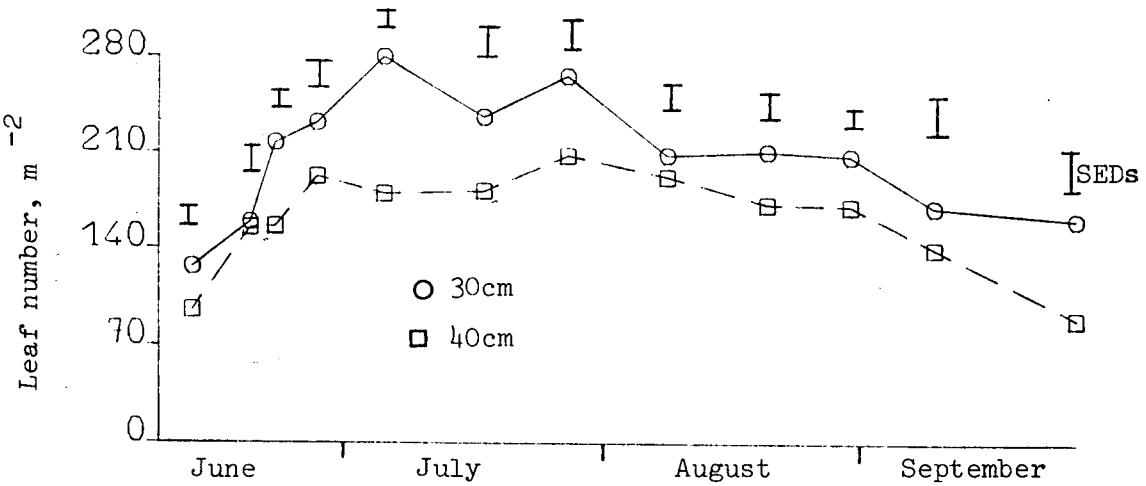


Figure 4.4.2.11 The effects of spacing on leaf number, excluding the leaves coming from the axillary branches.

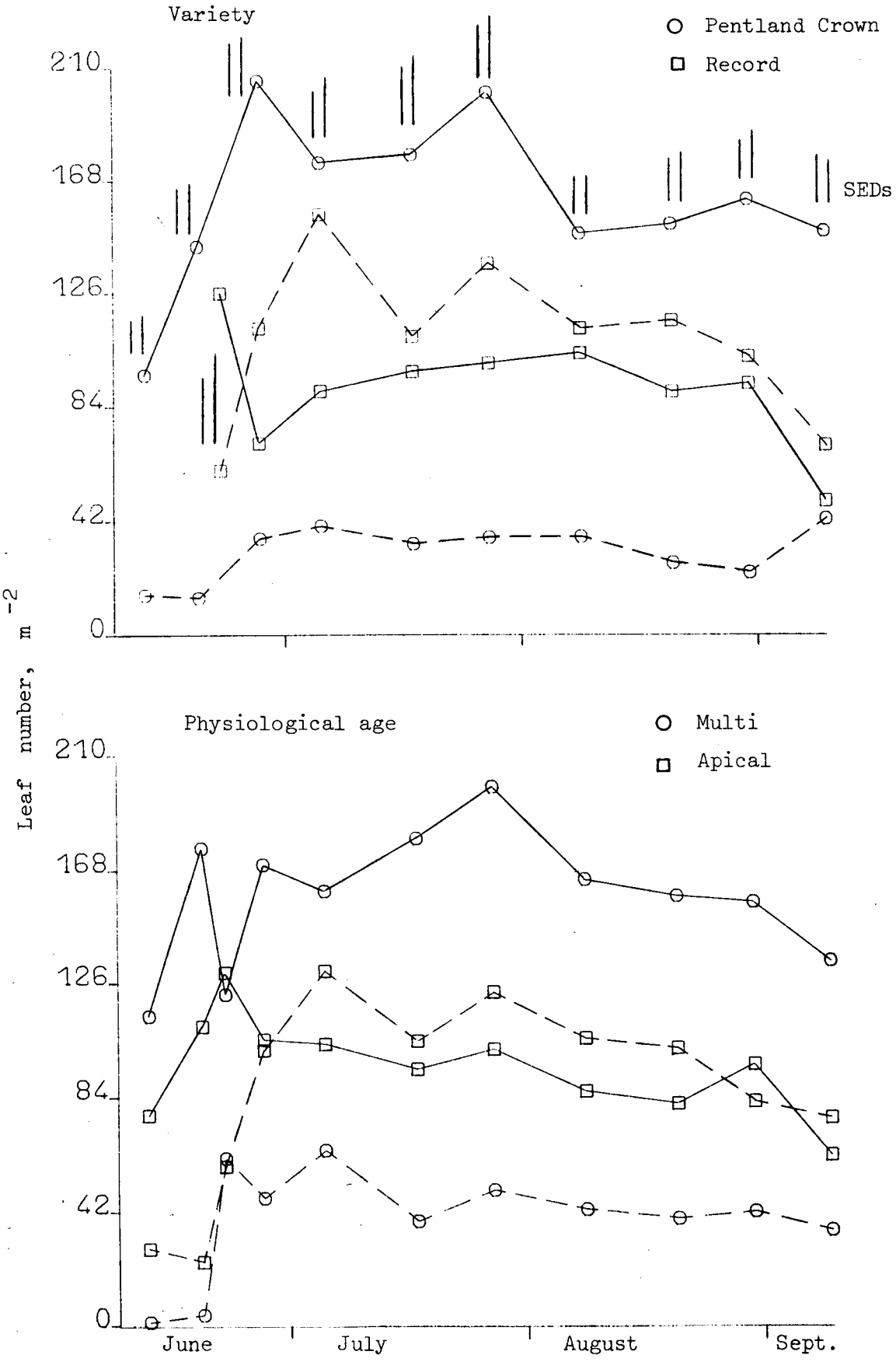


Figure 4.4.2.12 The effects of variety (V) and physiological age (PA) on leaf number contributed by the differant types of stems, excluding the leaves coming from the axillary branches. SED on the right side is to be used for comparing means within same levels of V or PA. Residual degrees of freedom is41.

Key: ——, main stem; ----, branch stem.

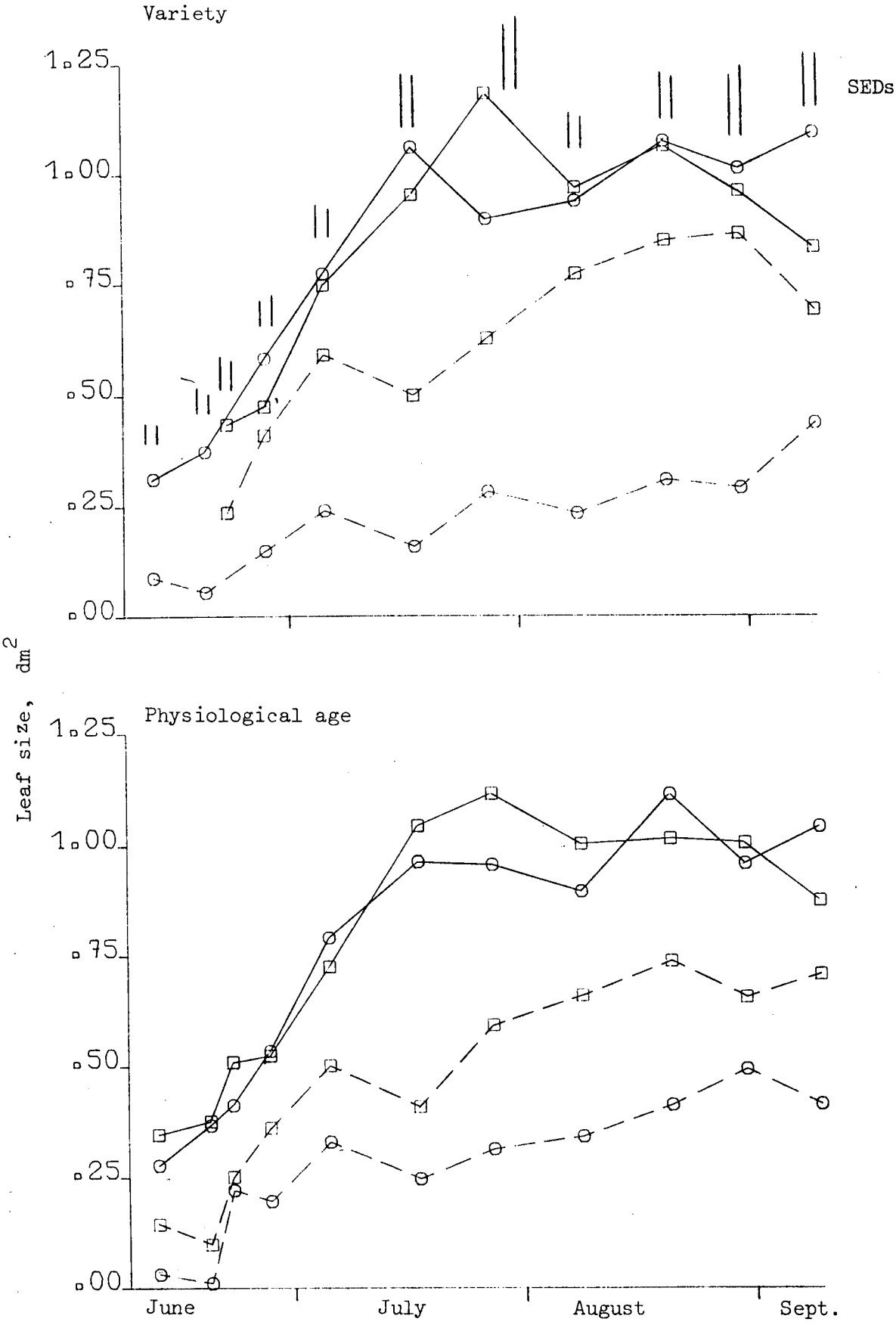


Figure 4.4.2.13 The effects of variety (V) and physiological age (PA) on leaf size (leaves coming from the axillary branches were not included). For meaning of SEDs, symbols and residual degrees of freedom see figure 4.4.2.12.

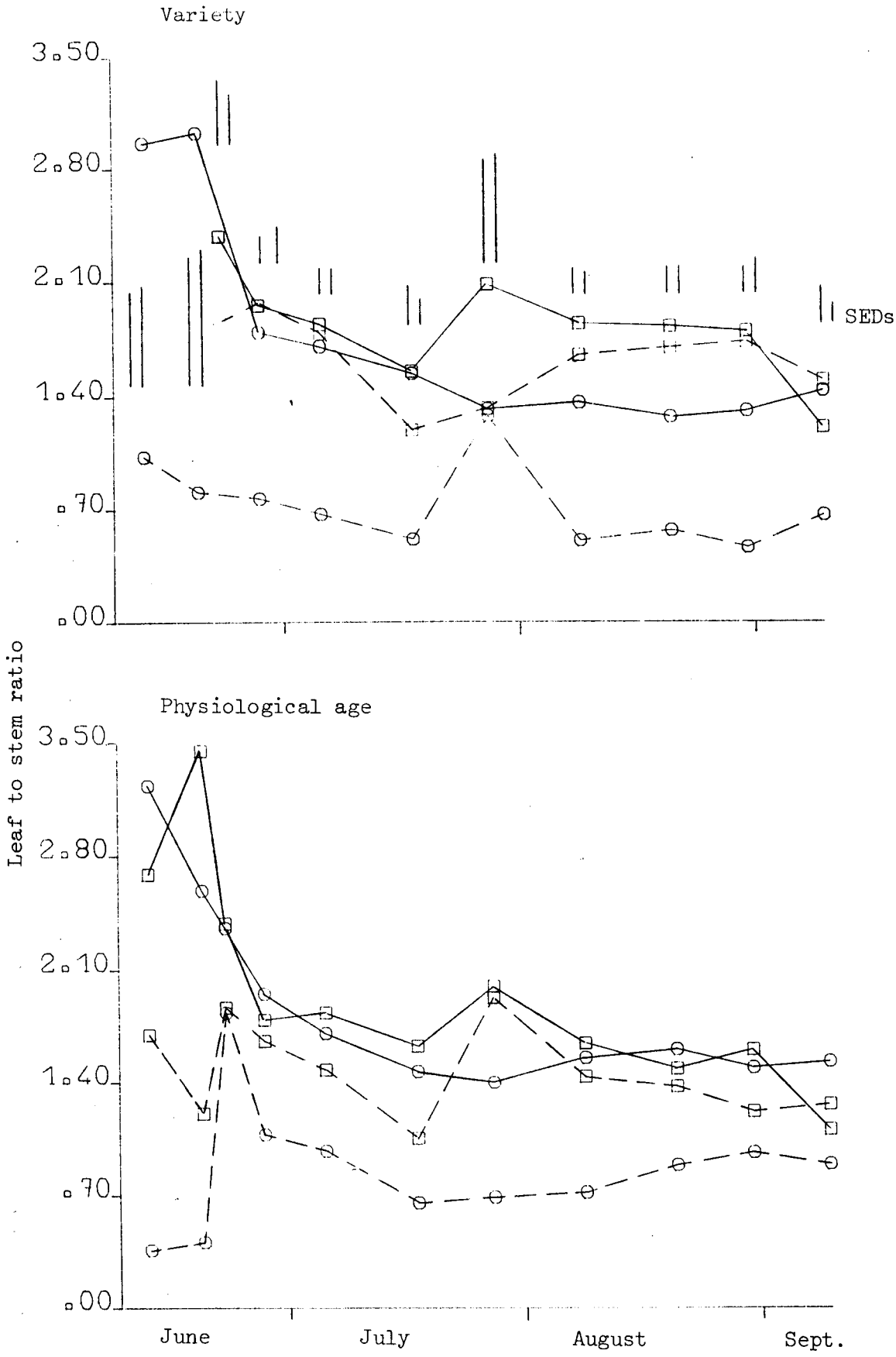


Figure 4.4.2.14 The effects of variety (V) and physiological age (PA) on leaf to stem ratio (dry weight basis). For meaning of SEDs, symbols and residual degrees of freedom see figure 4.4.2.12.

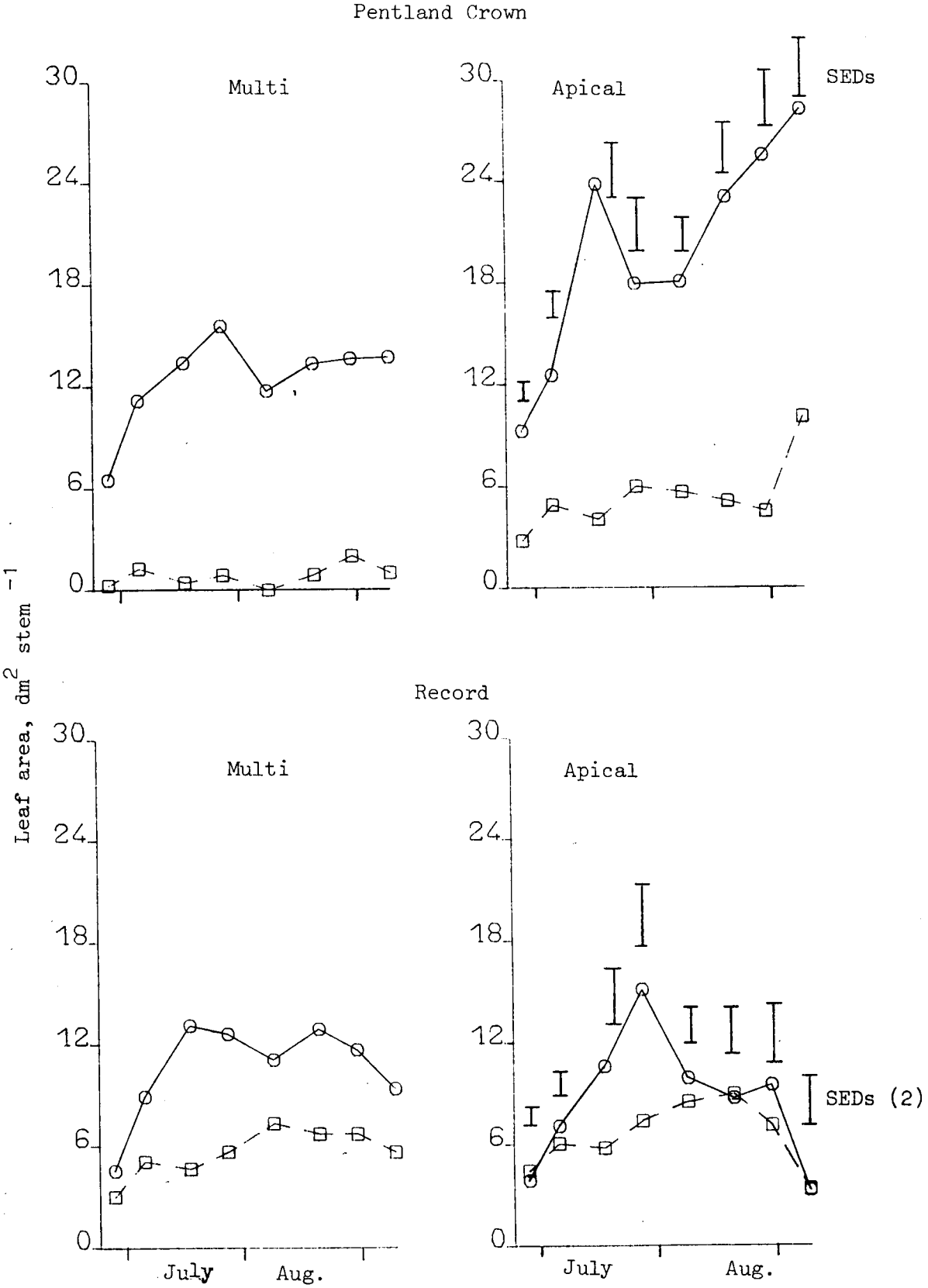


Figure 4.4.2.15 The effects of variety (V) and physiological age (PA) on stem size.

Key:____, main stem; ---, branch stem. SEDs (2) is to be used for comparing means within same levels of V or PA.

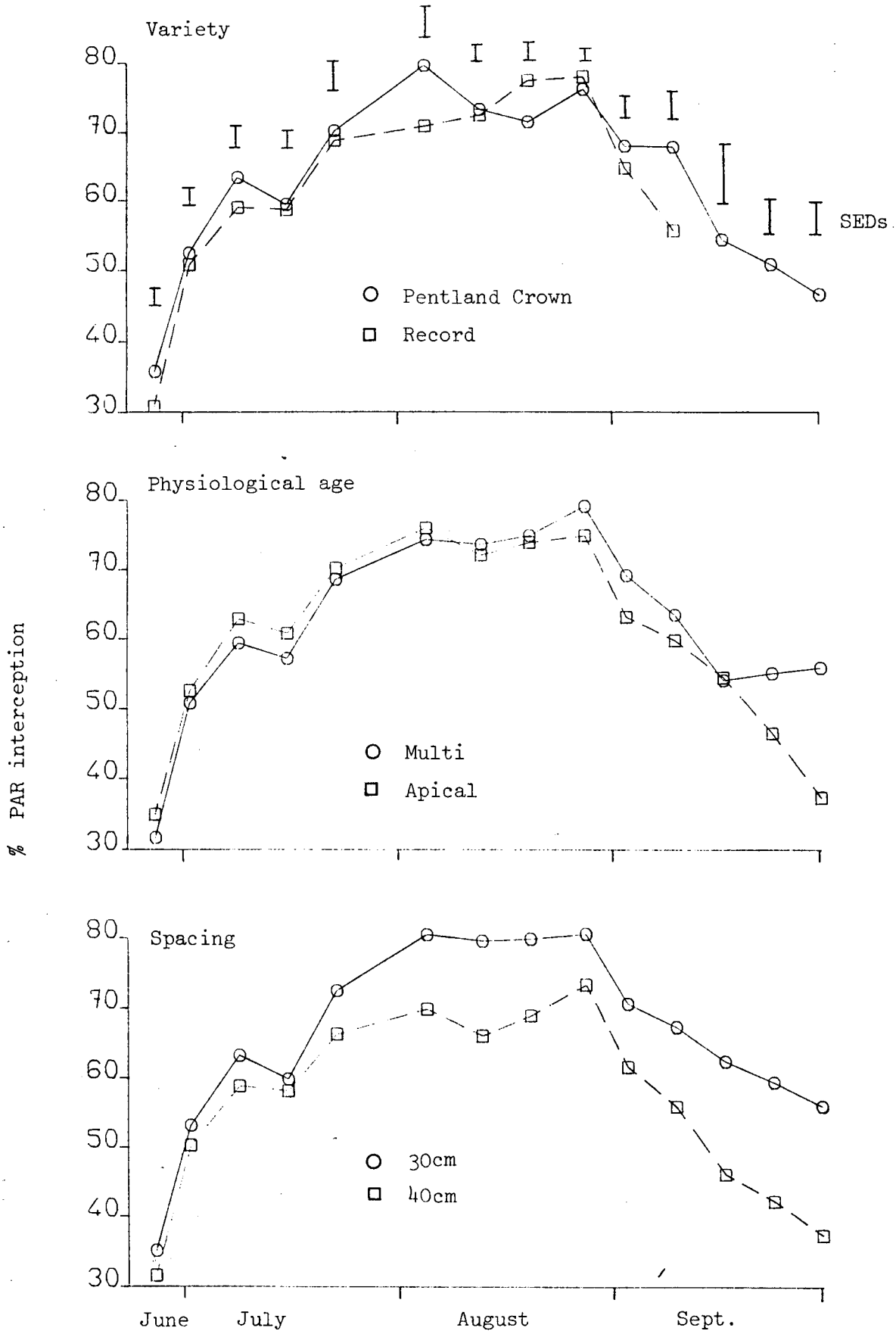


Figure 4.4.2.16 The effects of variety, physiological age and spacing on photosynthetically active radiation (PAR) interception.

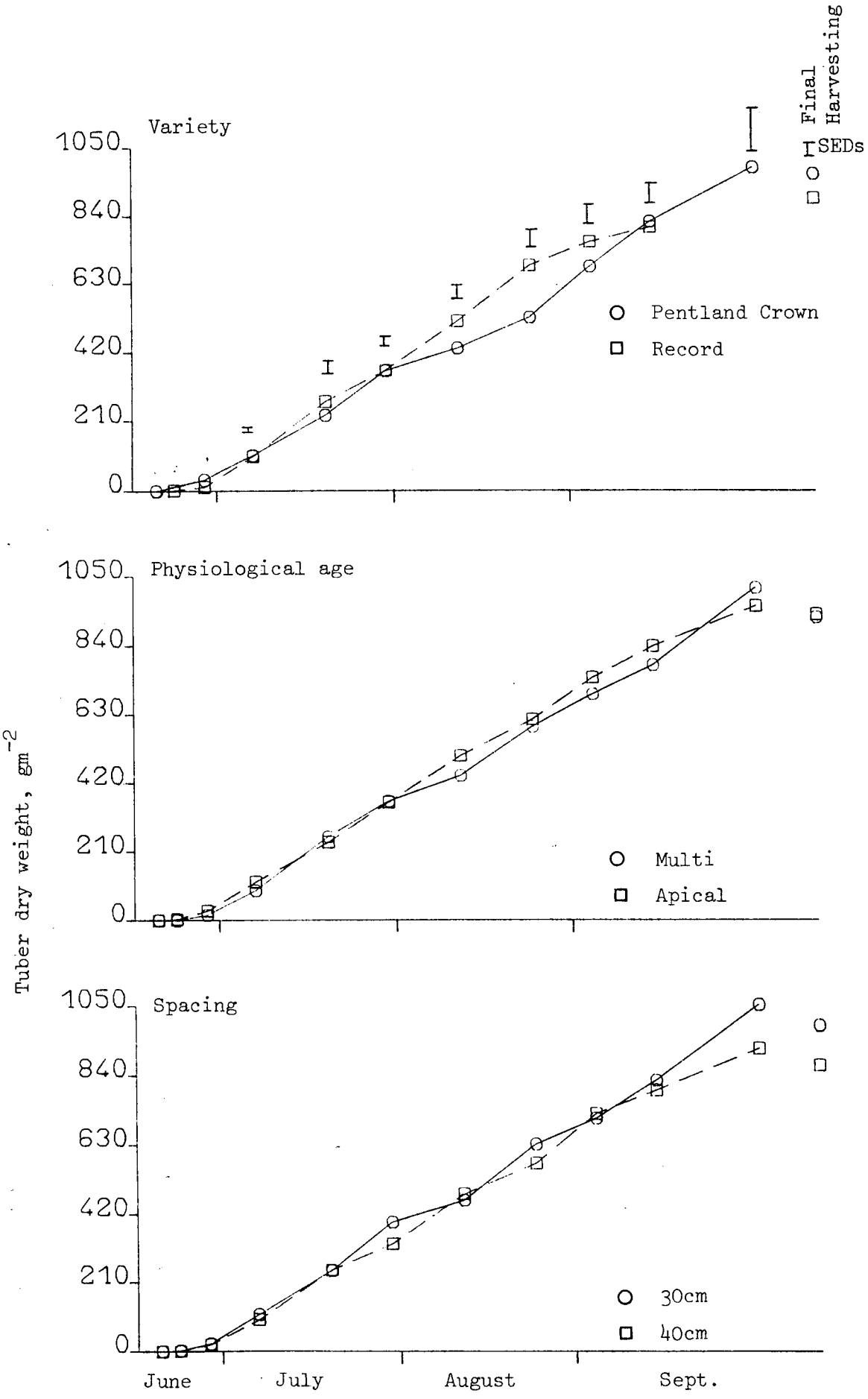


Figure 4.4.2.17 The effects of variety, physiological age and spacing on tuber dry weight.

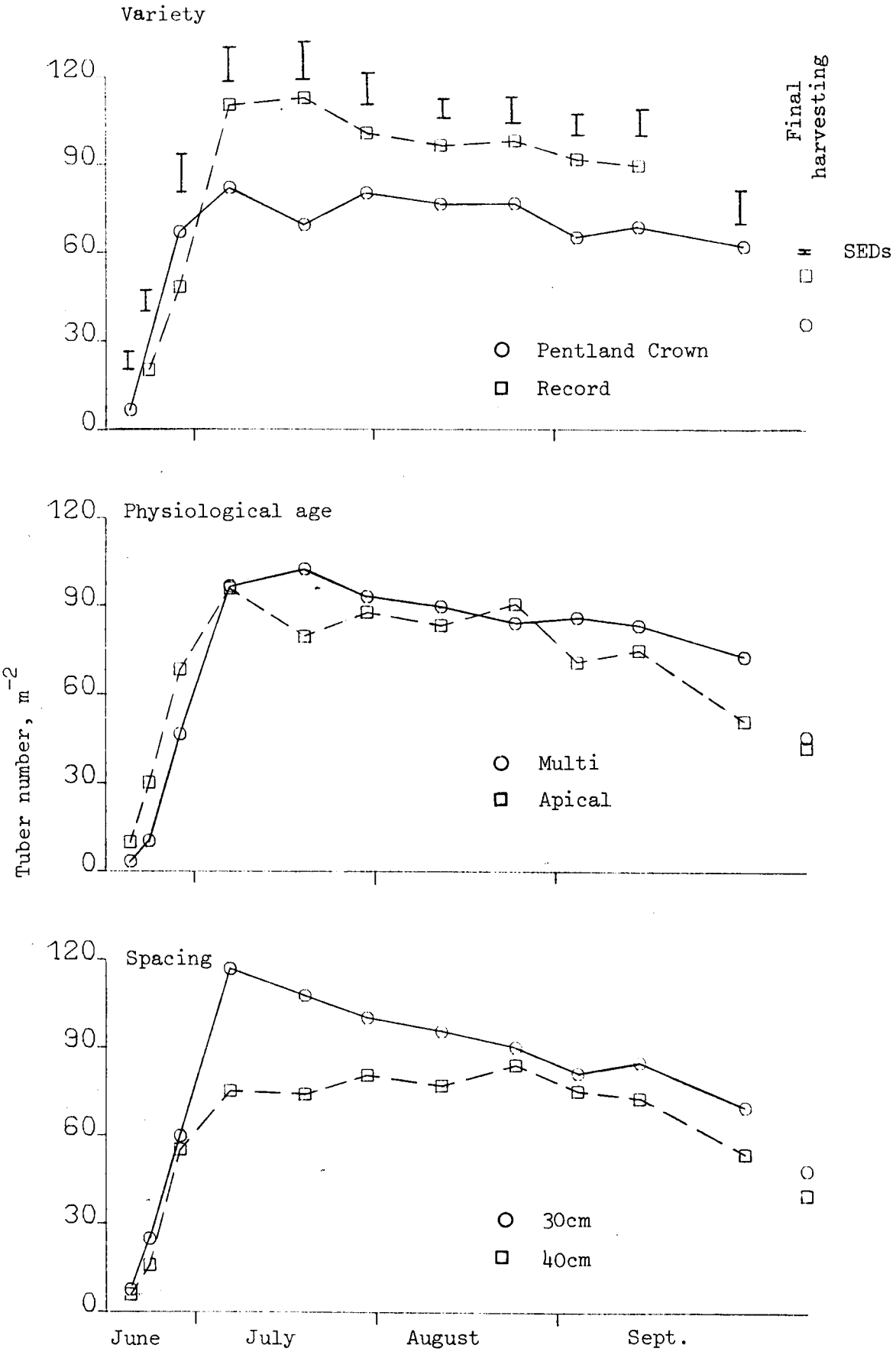


Figure 4.4.2.18 The effect of variety, physiological age and spacing on tuber number.

Key: ○,Pentland Crown; □ , Record; open symbols, apical; closed symbols, multi.

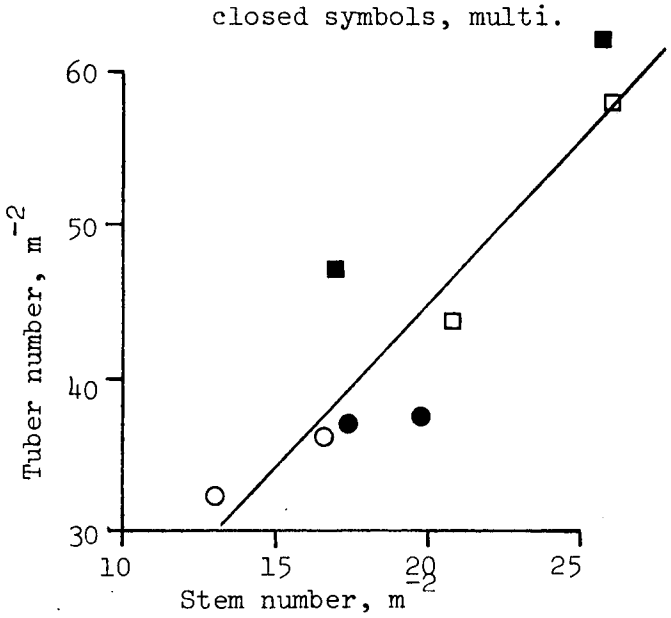


Figure 4.4.2.19 The relationship between total stem number (SN) (main & branch) and total tuber number (TN).
TN = 2.86(±8.45)+2.10(±0.42)SN
%variance accounted for 77.4
residual standard deviation = 5.12.

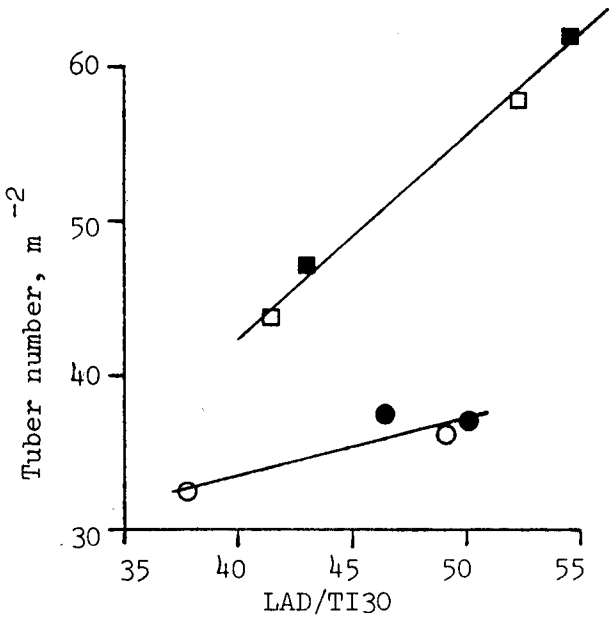


Figure 4.4.2.20 The relationship between leaf area duration accumulated for a period of 30 days from the date of tuber initiation (LAD/TI30) and total tuber number (TN).
TN=10.44(±4.84)+1.32(±0.10)LAD/TI30
for Record and
TN=18.15(±7.23)+0.38(±0.15)LAD/TI30
for Pentland Crown.
% variance accounted for 98.8
residual standard deviation = 1.14.

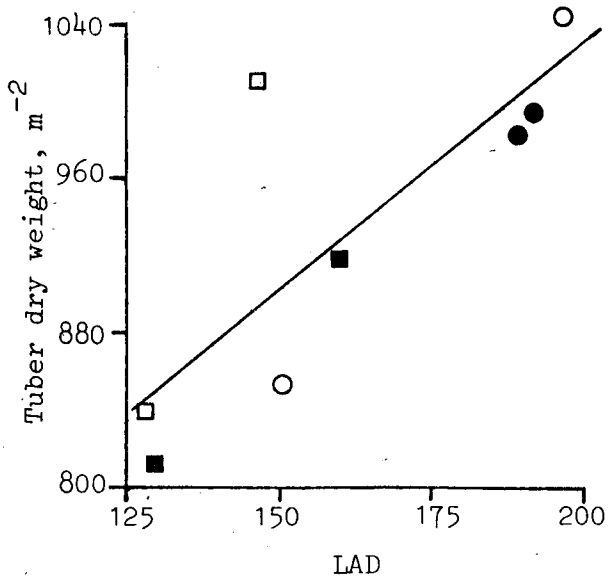


Figure 4.4.2.21 The relationship between leaf area duration (LAD) and total tuber dry weight (TW).
TW= 517.57(±123.58)+2.56(±0.75)LAD
% variance accounted for 60.0
residual standard deviation = 55.74.

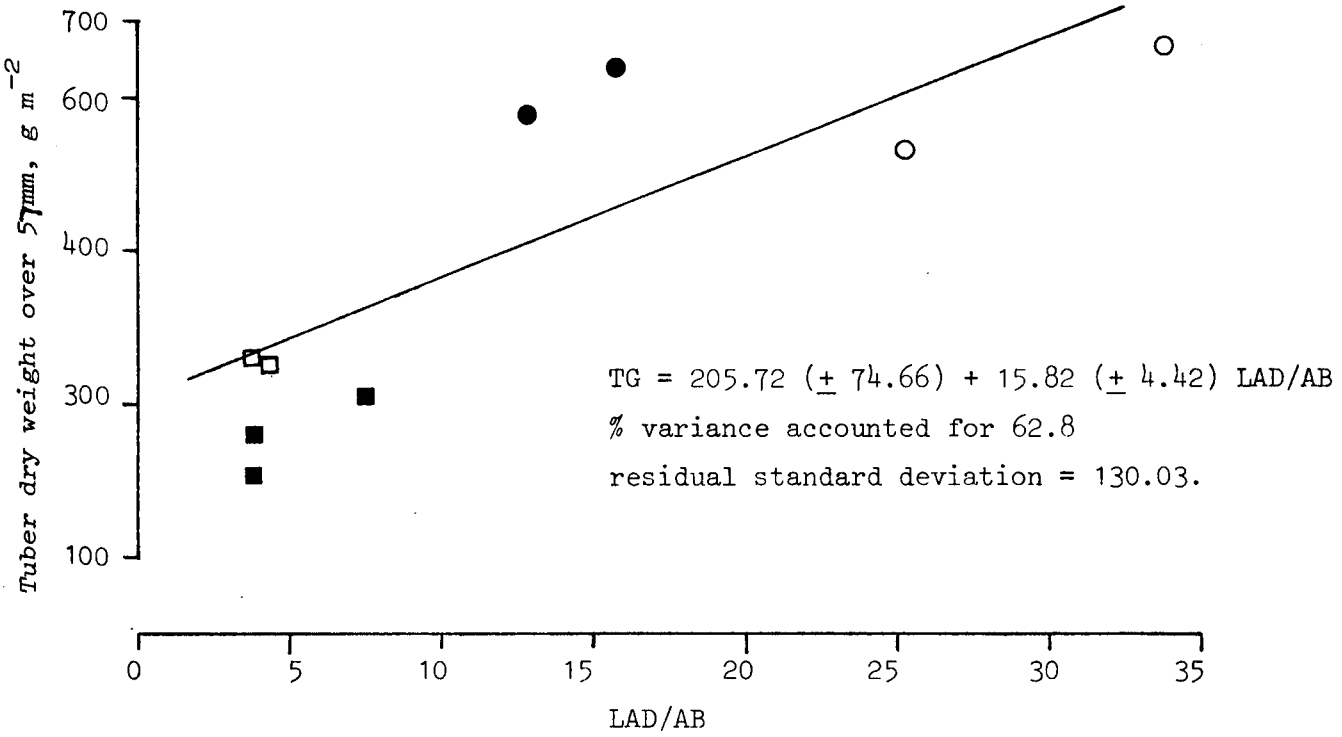


Figure 4.4.2.23 The relationship between tuber dry weight over 57mm (TG) and leaf area duration contributed by the axillary branches (LAD/AB). For meaning of symbols see figure 4.4.2.19.

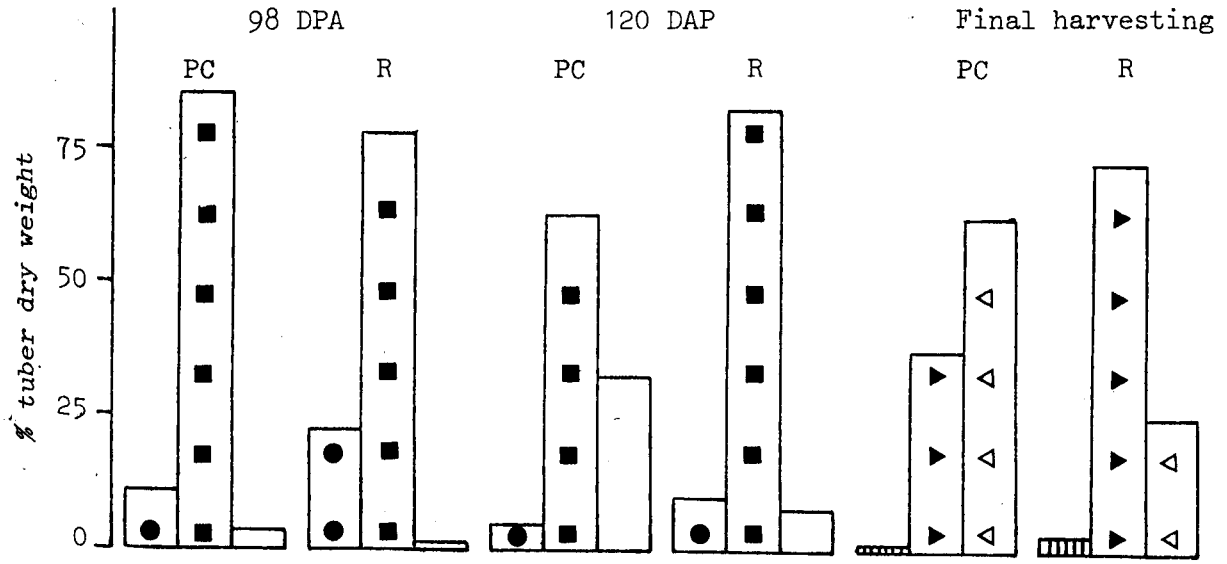
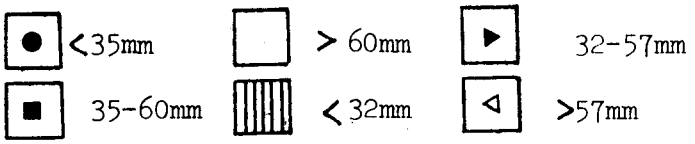


Figure 4.4.2.22 The effects of variety on proportion of tubers in size grades (dry weight basis). Key: PC, Pentland Crown; R, Record; DAP, days after planting.



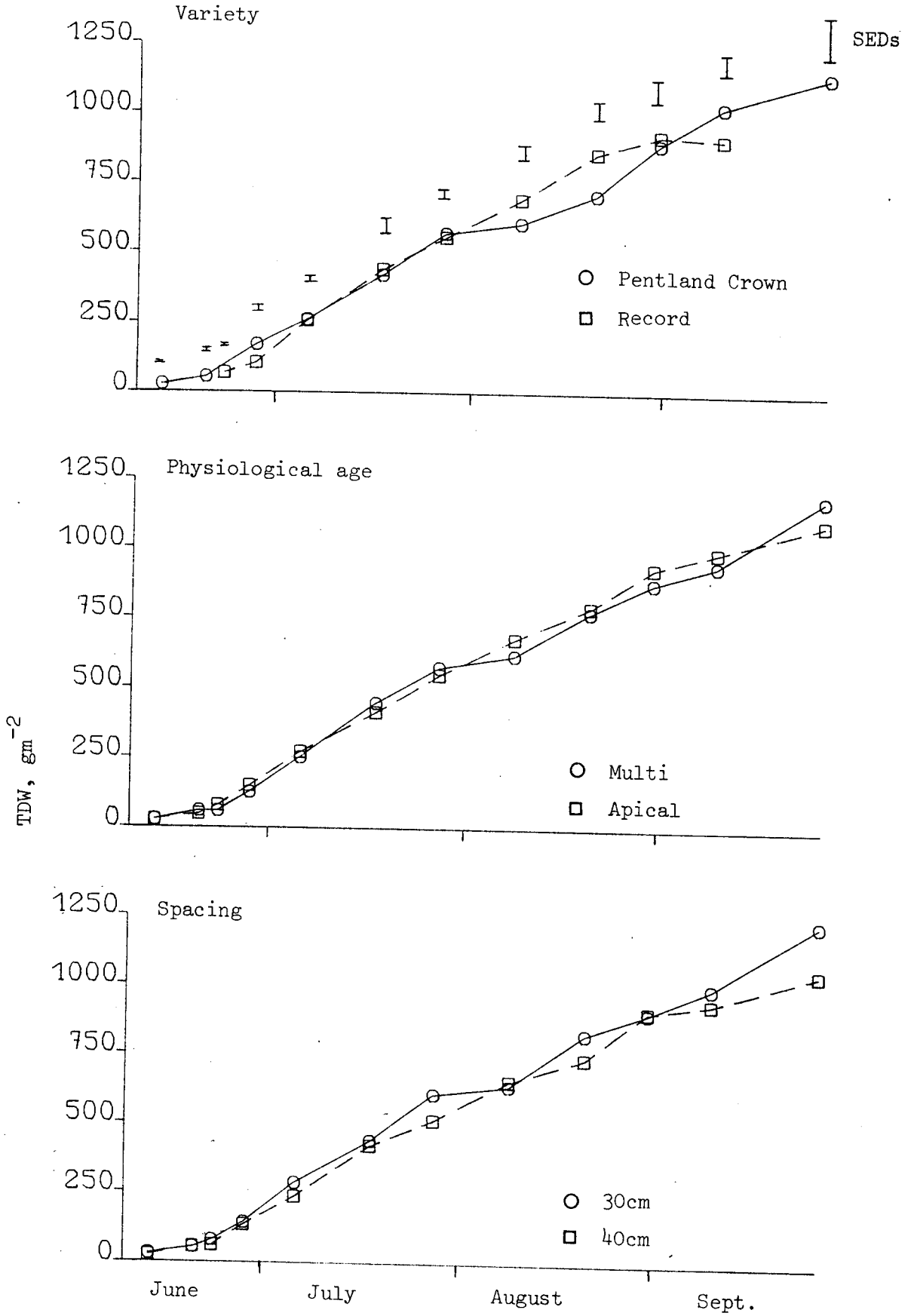


Figure 4.4.2.24 The effects of variety, physiological age and spacing on total dry weight (TDW).

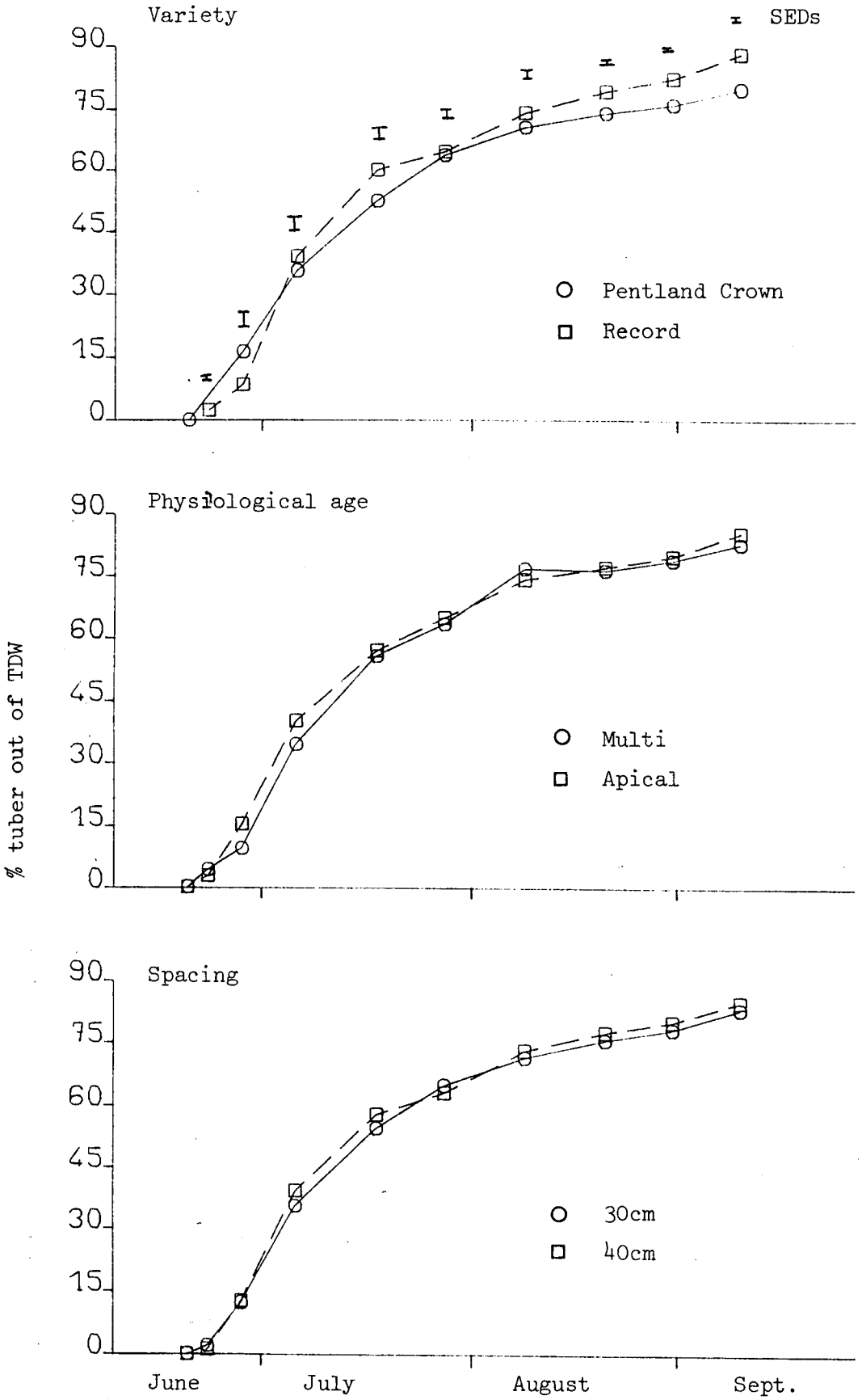


Figure 4.4.2.25 The effects of variety, physiological age and spacing on percentages of tubers out of total dry weight (TDW) (on dry weight basis).

Table 4.4.3.1. The effects of mixing seed tubers of different physiological age on: No. of days from planting to tuber initiation (TI) (TIFP); No. of days from emergence to TI (TIFE); No. of days from planting to senescence; (SENP) main stem number (MSTN); Branch stem number (BSTN); number of axillary branches (AB).

Treatment	TIFP	TIFE	SENP	MSTN m^{-2}	BSTN m^{-2}	AB m^{-2}
Apical	53.67	19.34	161.00	10.15	16.05	26.03
Multi	54.00	21.00	162.67	17.59	6.58	30.33
Cold	64.00	26.00	161.67	17.28	5.11	17.63
A+M 25	53.67	20.67	158.00	17.65	14.38	17.65
A+M 36	53.00	19.67	156.67	14.02	10.83	22.04
A+C 25	59.33	23.33	160.67	20.41	11.37	18.23
A+C 36	58.17	21.83	161.67	12.42	9.60	25.32
M+C 25	58.83	23.56	157.00	22.39	4.39	29.71
M+C 36	58.00	21.67	159.67	18.33	3.44	23.27
SED	0.778	1.092	3.031	1.09	1.92	5.06

In experiment F3, 3 tubers of each treatment were dug up before emergence to study the growth rate of sprouts after planting. With

Table 4.4.3.2. The effects of physiological age and sprouting treatments on total sprout length after planting but before emergence (Exp.F3).

	Total sprout length, mm tuber^{-1}				
Date	21/4	30/4		21/4	30/4
Treatment			Treatment		
Apical	79.5	121	Fast	79.4	204
Multi	87.5	251	Slow	87.4	167
SED	13.68	58.1		13.68	58.1

availability of moisture and nutrients after planting, extension rate of sprouts was increased in all treatments (Table 4.4.3.2 and Fig.4.4.1.2), and so the initial difference in length of the largest sprout between apical and multi of various experiments (Table 4.4.1.6 a,b) did not affect the emergence. Numbers of main sprouts were greater in multi and so this treatment had higher total extension rate of sprouts than apical after planting (Table 4.4.3.2), while the higher extension rate of fast (Fig.4.4.1.3) was not maintained in the field (Table 4.4.3.2). As a result there was no difference in emergence due to sprouting treatments (Fig.4.4.3.2). In case of multi the growth rate of sprout weight was also higher (Fig.4.4.3.3) mainly due to a larger number of sprouts. Due to increase in extension rate of sprouts, specific sprout weight was decreased after planting in all treatments (Fig.4.4.3.3). Apical had higher specific sprout weight because sprouts were thicker than

those of multi. Mixing of different physiologically aged tubers or different seed sizes (Exp. F2, F4) did not affect the emergence. There was no significant difference in stem numbers between different dates of growth analyses in all the experiments, and so they were averaged for various dates of growth analyses until the middle of August for after that they started to die. Like experiment F1, apical increased branch stems, compared to multi in both experiments F2 and F3 (Table 4.4.3.1 and Fig.4.4.3.2), but the proportion of increase was more in experiment F2 compared to F3 and total stem numbers were increased in F2 and decreased in F3. Planting at closer spacings and using bigger seed size increased total stem number per unit area (Table 4.4.3.1 and Fig.4.4.3.1). Mixing of different type of seeds and sprouting treatments did not affect the stem number or their type (Table 4.4.3.1 and Fig.4.4.3.1). Numbers of axillary branches (AB) were averaged for various dates of growth analyses after they stopped increasing in number. Cold had lower number of AB compared to multi (Table 4.4.3.1), this may be because emergence was more homogenous in cold (Fig.4.4.3.1). Apical, in experiment F2 decreased the number of AB (Table 4.4.3.1) while in F3 it increased (34.9,m^{-2}) compared to multi (25.4,m^{-2}), this may be explained by the fact that apical increased the total stem number in F2 and decreased in F3, thus lateral buds in F2 may have been shaded more. On an overall basis over 90 per cent of the AB present were contributed by the main stems which may be due to two reasons: firstly, branch stems were lower in number (Table 4.4.3.1 and Fig.4.4.3.2) and secondly they were smaller in size (Fig.4.4.3.26) and thus may have emerged later, so their lateral buds were shaded and stayed dormant. In fact most of the effect appears to be due to the second reason because numbers of AB contributed by the branch stems

were not in proportion to their total numbers. For example in apical (Exp. F2) the numbers of branch stems were more than the main still main stems contributed about 85% of the total AB present. This is also supported by the fact that in case of mixing different physiologically aged seed where cold was one of the components, cold only contributed 23% of the AB present, because it emerged later, so its lateral buds were shaded by the plants those emerged before it. As in 1979 (Exp. F1) a linear relationship was found between leaf area duration accumulated for a period of 30 days from the date of 50 per cent emergence and the number of AB present (Fig.4.4.3.9). Data shown in this Figure is from experiments F2 and F3 and every point is average for 3 replicates.

4.4.3.2 Stolon growth and development

Cold and S25 increased stolon weight (Fig.4.4.3.4 and 4.4.3.7) for a longer time and this may be due to delay in TI (Chapter 4.4.3.5). Stolon numbers were also higher in these treatments (Figs.4.4.3.5 and 4.4.3.7). Stolon growth slowed down after TI in all the three experiments. Mixing of different type of seeds and sprouting treatments did not affect the stolon weight or their number (Figs.4.4.3.4; 4.4.3.5; 4.4.3.6; 4.4.3.7). As in 1979 (F1), a positive linear relationship was found between LAI and stolon dry weight for all the three experiments (Fig.4.4.3.8), until tuber dry weight of 1g plant^{-1} was reached. Data in Fig.4.4.3.8 is from all the three experiments and every point is average for 3 replicates.

4.4.3.3 Growth and development of stem and leaf.

As in the previous year main stems were slightly longer than the branch stems, but overall plant height was not affected by any treatment (Figs.4.4.3.10; 4,4,3,11; 4.4.3.12), except that early in the season plants were smaller in cold and S25 treatments because they emerged later.

Due to this their stem weight was also lower early in the season (Figs.4.4.3.12 and 4.4.3.13). Increase in stem numbers per unit area, either by planting at closer spacing or by using bigger seed size, increased the stem weight per unit area, while other treatments did not affect it (Figs.4.4.3.12; 4.4.3.13; 4.4.3.14; 4.4.3.15). Increase in stem number also increased the LAI early in the season. (Figs.4.4.3.16 and 4.4.3.19). Cold (Experiment F2) emerged later (Fig.4.4.3.1) so had lower LAI early in the season compared to Apical and Multi when considered from the date of planting, but there was no difference when considered from the date of 50% emergence, for example after 15 days of emergence multi had LAI of 0.7 compared to 0.99 for cold and after 30 days of emergence multi and cold had LAI of 3.32 and 3.33 respectively. S25 (Experiment F4) also had lower LAI early in the season (Fig.4.4.3.19), compared to other treatments in that experiment, which was affected in two ways: firstly it emerged late and secondly it had lower total stem numbers (Fig.4.4.3.1).

In mixed treatments where, cold or S25 was one of the two components, LAI early in the season was lower (Figs.4.4.3.16 and 4.4.3.19). Competition between different components within plot is presented later (Chapter 4.4.4.). Physiological age and sprouting treatments did not differ in experiment F3 (Fig.4.4.3.18).

After about 70 days from planting in all the 3 experiments LAI was over 4.0 and effects due to different treatments disappeared (Figs.4.4.3.16; 4.4.3.18; 4.4.3.19). In experiments, F2 and F3 senescence of the canopy was not significantly affected by any treatment, thus there was no great difference between different treatments in the decline of LAI. In experiment F4, S25 stayed green for 16 days after other treatments had senesced and thus had higher LAI later in the season. For example after 149 days of planting it had LAI of 1.73 and B36 had only 0.25 (Fig.4.4.3.19). Although physiological age (apical, multi) did not affect the LAI but the proportion contributed by different types of stems was affected. For example in experiment F2, main stems of apical, multi and cold contributed 62, 91 and 97% of the total LAI respectively. In experiment F3 these figures were 83 and 96 percent for apical and multi respectively. Difference between the results of experiments may be explained by the different sources of seed which affected the type of stems (Table 4.4.3.1 and Fig.4.4.3.2). Other treatments such as mixing of different types of seed (Exp. F2) and sprouting (Exp. F3) did not affect the proportion of LAI contributed by different types of stems. As in 1979, the size of AB was studied by working out their LAI (LAI'AB) separately. LAI'AB was decreased by cold and planting at closer spacing (Fig.4.4.3.17), these treatments decreased the number of AB also. In Experiment F3, apical had higher number of AB and thus had higher LAI'AB compared to multi (Fig.4.4.3.21) while sprouting treatment showed no effect.

In general over 90 percent of the LAI'AB in both experiments F2 and F3 was contributed by the AB present on the main stems. Number of leaves present on the AB were proportional to LAI'AB. Apart from leaves coming from the AB, treatments those increased total stem number also

increased leaf numbers, for example, planting at closer spacing in Experiments F2 and F4 and use of big seed size in Experiment F4 (Figs.4.4.3.22 and 4.4.3.19). Physiological age (apical, multi, cold) did not affect the total leaf number except that cold emerged later and thus had lower leaf numbers early in the season; but the important result was that the leaves contributed by different types of stems were affected. In apical branch stems contributed a higher proportion of leaves, while in multi and cold most of the leaves were contributed by their main stems (Fig.4.4.3.23).

Size of the leaves coming from the AB was not affected by any treatment but their size was much smaller than those coming straight from the main stems. Thus average leaf size for main and branch stems presented in Figure 4.4.3.24 was calculated without including the leaves coming from the AB. In all the treatments leaves present on the main stems were much bigger than those present on the branch stems. Leaves present on the branch stems of cold were smallest in size. Differences in leaf size resulted in differential values for leaf to stem ratios for different types of stems (Fig.4.4.3.25) leaf to stem ratio decreased as the season advanced due to increase in stem length. This ratio was higher for main stems than for branch stems apparently because the latter were smaller in size and so were more affected by interstem competition. Increase in stem numbers decreased the leaf to stem ratio (Fig.4.4.3.27).

Specific leaf area in Experiment F2 was only slightly affected by interstem competition, increased by planting at closer spacings and was not affected in Experiment F3. Thus leaf dry weight was proportional to their LAI (Figs.4.4.3.18 and 4.4.3.20). In Experiment F4 due to greater difference in stem number specific leaf area was increased

with increase in stem numbers (Fig.4.4.3.19). As in Experiment F1, the size of different type of stems was studied in Experiment F2 and F3 and the results are presented as leaf area per stem (Fig.4.4.3.26). Main stems in general were much bigger than the branch stems, owing to increased leaf size and the presence of higher numbers of AB. Apical increased the size of branch stems compared to cold and multi (Fig.4.4.3.26) and this difference was consistent throughout the season. Mixing of different physiologically aged tubers or sprouting treatments did not affect the size of specific types of stems.

4.4.3.4 Light interception (LI)

Early in the season the effects of treatments on photosynthetically active radiation (PAR) interception were similar to their effects on LAI.

The relationship between LAI and LI is presented later (Chapter 4.4.6). Cold and S25 intercepted less PAR early in the season because they emerged later and had lower LAI. Increase in stem number due to closer planting or the use of big seed increased PAR interception until about 65 days after planting. About 90 percent and most of the times over 90 percent of the PAR was intercepted by the canopy of all treatments during the middle part of the growing season (65 to 120 days) and differences due to treatments disappeared (Figs.4.4.3.27; 4.4.3.28; 4.4.3.29).

4.4.3.5 Tuber growth and development

Tuber initiation (TI) was calculated by interpolation from growth analyses and additional sampling data, taken during early growth of the

crop. Cold and S25 delayed TI for 4 to 5 days when considered from the date of 50% emergence. Thus sprouting tubers before planting may have increased the tuberization stimulus. TI for mixed treatments, in which cold or S25 was one of the two components, was calculated separately for the different type of plants and then averaged to obtain a figure for that treatment. Apical or multi sprouting treatments and mixing of different type of seeds did not affect the date of TI.

In Experiment F2, cold increased tuber number over apical and multi and the effect was more immediately after TI compared to final harvesting (Fig.4.4.3.30). This may be explained by the fact that LAI at the time of TI in cold (2.69) was higher compared to apical or multi (1.74), thus higher number of tubers initiated but this difference did not last very long due to better growing conditions (higher rainfall, Fig.3.3.1). As growth rate was very high, it did not take very long to reach LAI of 4.0 when most of the incoming radiation was being intercepted. In apical LAI of 4.0 was reached after 14 days of TI while in multi and cold it reached after 12 and 8 days of TI respectively. Therefore assimilates available for the development of the tubers after 14 days of TI may be similar in all the three treatments, but cold had initiated more tubers and so the percentage survival of tubers was more in apical and multi compared to cold. Similarly as in Experiment F2 S25 had higher LAI (2.8) at the time of TI compared to B36 (2.40) thus S25 initiated higher number of tubers but percentage survival was more in B36. Apical and multi did not differ significantly, but multi had higher numbers of tubers and this difference was consistent throughout the season (Figs.4.4.3.30 and 4.4.3.31). Planting at closer spacings also increased tuber numbers which may be attributed to the greater LAI at the time of TI (Figs.4.4.3.30 & 4.4.3.32).

Grading of tubers showed that tubers which did not survive never attained a size of 25mm diameter and most of them did not attain the size of 10mm (Figs.4.4.3.30; 4.4.3.31; 4.4.3.32). Some wrinkled tubers and few in the process of shrivelling were found especially at the last two harvests. As in 1979, a linear relationship between total stem numbers (main + branch) and tuber numbers was found. Linear regression between them accounted 31% of the variance. S25 and cold appeared different from other points, may be due to different physiological status of the seed excluding only S25 from the regression, improved the linear relationship (accounted 43.5% of the variance (Fig.4.4.3.36)). Data in Figure 4.4.3.36 is from all the three experiments (F1, F2, F3) and every point is an average for 3 replicates. Since stem number do not take any account of stem size, thus regression equation between tuber number and LAD, accumulated for a period of 30 days from the date of TI accounted more variance (53.6%) and removal of S25 from the regression improved the linear relationship (accounted 60% variance) (Fig.4.4.3.37). Data in Figure 4.4.3.37 is from all the 3 experiments (F1, F2, F3) and every point is an average for replicates. Cold treatment in Experiment F2 initiated tubers later than the apical and multi, thus had lower tuber weight early in the season but when considered from the date of TI there was no difference. For example after 12 days of TI, cold, multi and apical yielded 78.3, 88.7 and 87.8g m^{-2} respectively. Similarly after 26 days of TI their yield was 352, 329.8 and 326.6g m^{-2} respectively. S25 in Experiment F4 also gave lower yields early in the season. This effect was not only due to delay in TI but this treatment also had a much lower LAI but then it senesced later than other treatments and so the final tuber yield was not less. Other treatments did not differ significantly but planting at closer

spacing in Experiment F2 and F4 and apical in Experiment F3 gave consistently higher tuber weights during the growing season (Figs.4.4.3.31; 4.4.3.32; 4.4.3.33). As in Experiment F1 (1979), tuber weight was related to LAD, which accounted 30% of the variance (Fig.4.4.3.43). Data in Figure 4.4.3.43 is from all the three experiments and every point is average for 3 replicates. Tuber yield per unit of LAD was 4.3, which is lower than in 1979. This may be due to higher rainfall during 1980 which stimulated more haulm growth. Tuber yield is usually related to LAD, calculated by assuming LAI over 3.0 as 3.0 (LAD'3) (Bremner and Radley, 1966; Bremner and Taha, 1966; Gunasena and Harris, 1968; Choudhury, 1980). This relationship was examined here. Linear relationship between LAD'3 and tuber weight accounted only 6 percent of the variance and was not significant (tuber weight = 1038.57($\pm$ 343.29) + 1.81($\pm$ 1.28) LAD'3, RSD = 90.6). This may be due to the reason that PAR interception was still increasing with increase in LAI over 3.0 (Chapter 4.4.6). Although there was not much increase in PAR interception with increase in LAI after 4.0, even than assuming the LAI over 4.0 did not give the significant linear relation between tuber weight (TW) and LAD'4(TW = 982.95($\pm$ 310.16) + 1.64($\pm$ 0.94) LAD'4, RSD = 87.89). This may be explained by the fact that although there was no increase in PAR interception with increase in LAI after 4.0 conversion efficiency of the canopy was improving (Chapter 4.4.6).

Tuber size grades are of practical importance. Percentages of various size grades for two dates of growth analyses in addition to final harvesting are presented for all the three experiments (Table 4.4.3.3, Figs.4.4.3.34 and 4.4.3.35). Similar results were obtained for other dates of growth analyses not presented here. For simplification in some cases tuber weight less than 35 or 38mm is not presented as their

proportion was low (most of the time less than 2%) and there was no difference between treatments. In Experiment F2 the cold treatment had higher tuber numbers compared to apical and multi thus assimilates available for the growth of individual tuber were lower, and this resulted in higher proportions of medium sized tubers. For example at final harvesting cold had only 3.6 percent of tubers over 76mm while this figure for apical and multi was 19.9 and 21.3 percent respectively. The percentages of 38-57mm tubers were 25.3, 7.0 and 9.8 percent for cold, apical and multi repectively. Percentages of 57-76mm tubers did not differ significantly among these treatments. S25 in Experiment F4 also gave increased proportions of medium sized tubers (Fig.4.4.3.35). Apical and multi of Experiment F2 did not differ but in Experiment F3 multi gave a higher proportion of medium sized tubers compared to apical maybe because multi increased total stem number in Experiment F3. Planting at closer spacing in Experiment F2 increased tuber numbers and this resulted in a higher proportion of medium sized tubers (Table 4.4.3.3). In Experiment F4, planting at closer spacing only slightly increased the tuber number and did not affect the tuber size grades. Tuber size over 76mm was related to leaf area duration contributed by the AB, and linear regression between them accounted for 45% of the variance (Fig.4.4.3.38). Data in Figure 4.4.3.38 is from experiments F2 and F3 and every point is average for 3 replicates.

4.4.3.6 Total dry matter accumulation

Roots were not collected and those present on the stems and stolons were removed and discarded; thus total dry weight (TDW) figures which are presented exclude roots. By the end of June leaves started to fall

off and these were not collected from the ground. TDW figures presented in this chapter also exclude those leaves. Cold and S25 treatments had lower TDW because they emerged later. Planting at closer spacing had consistently higher TDW throughout the season, while other treatments did not affect it (Figs.4.4.3.39; 4.4.3.41; 4.4.3.42). As in 1979, (Exp. F1) the percentages of various components were worked out for these experiments. Cold and S25 recorded a lower percentage of tubers out of TDW (Figs.4.4.3.40 and 4.4.3.42) when considered from the date of planting. But when considered from the date of TI there was no difference. For example after 12 days from TI cold had 18.7 percent of tubers, out of TDW while this figure for apical and multi was 20.8 and 20.9 respectively. Similarly after 26 days from TI cold had 45.8 percent of tubers while apical and multi had 47.2 and 43.9 percent respectively. Other treatments did not affect the percentage distribution of TDW but apical of Experiment F3 did record a consistently higher percentage of DW in tubers compared to multi, but the difference was not significant on any date (Fig.4.4.3.41).

4.4.4 Competition between two components within plot.

In experiment F2 there was no interaction between apical and multi, so results are presented as sprouted and cold (average for apical and multi). Similarly in Experiment F4 there was no interaction between 2 spacings used and so the results presented for that experiment are averaged for 2 spacings. In all the three experiments statistical analyses were carried out as split plot design taking two components (sprouted and cold) within plot as sub plot and residual degrees of freedom (RDF) is given on the figures itself. RDF for SED No. 5,6 of

Table 4.4.3.3. The effects of mixing seed tubers of different physiological age on percentage of tubers in different size grades out of total tuber weight.

Days after planting	90			121		Final harvesting		
Size (mm)	<35	35-45	<45	35-60	>60	38-57	57-76	>76
Treatment								
Apical (A)	2.5	15.0	82.5	14.4	84.4	7.0	72.9	19.9
Multi (M)	1.4	18.0	80.6	24.1	75.3	9.8	68.7	21.3
Cold (C)	19.7	65.2	15.1	73.6	24.7	25.3	70.4	3.6
A+M 25	4.0	14.6	81.4	42.9	56.1	17.6	72.4	9.5
A+M 36	2.6	20.1	77.3	24.0	75.2	7.6	75.6	16.5
A+C 25	11.3	16.7	72.0	53.7	44.5	23.6	68.7	7.0
A+C 36	10.3	18.1	71.6	33.6	65.2	18.0	68.6	13.0
M+C 25	18.8	20.6	60.6	60.5	37.9	29.1	63.8	6.3
M+C 36	10.1	21.1	68.8	35.6	63.4	23.3	66.1	10.2
SED	3.28	5.94	6.22	7.40	7.26	4.42	4.69	3.73

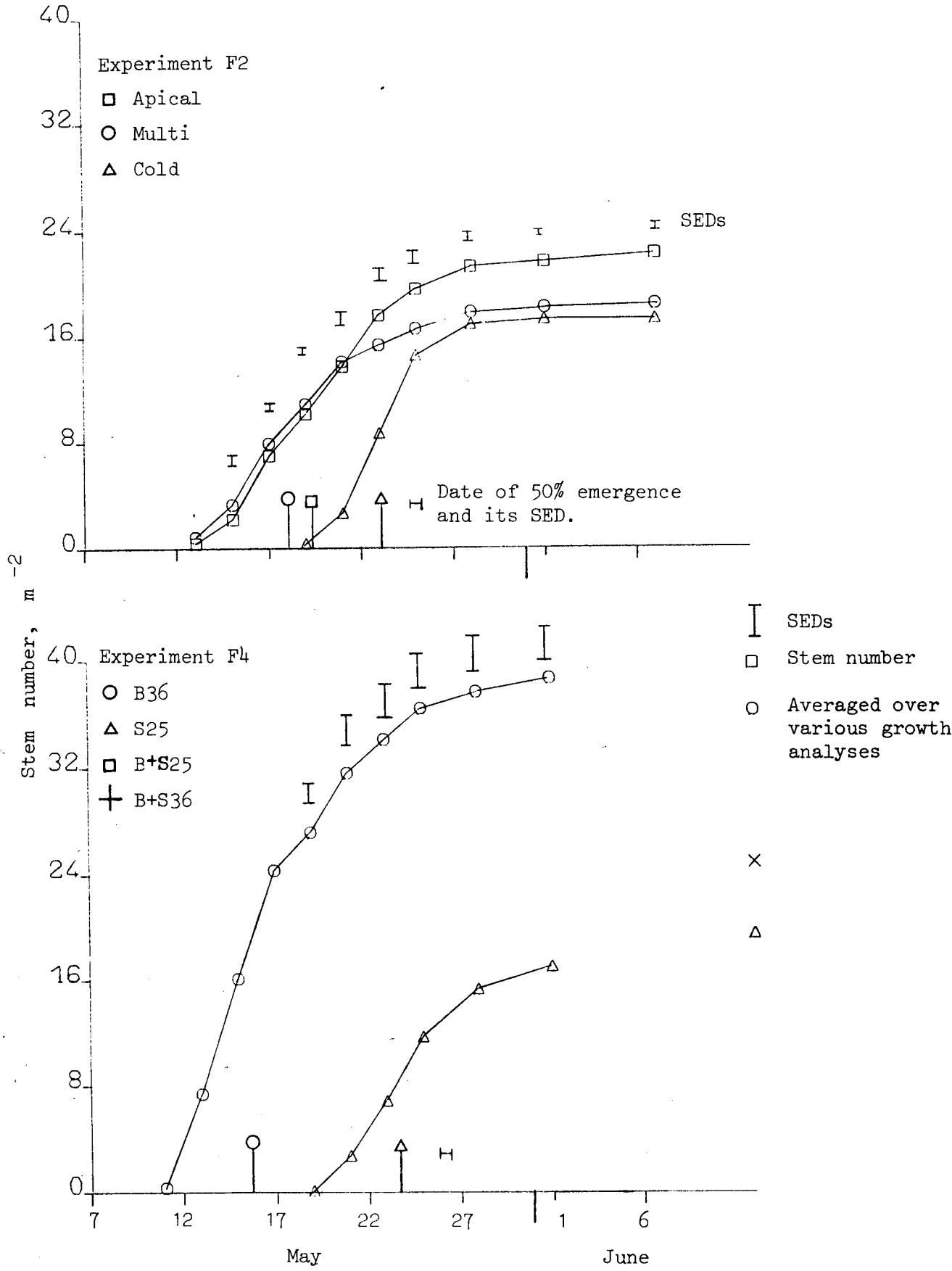


Figure 4.4.3.1 The effects of physiological age on emergence.

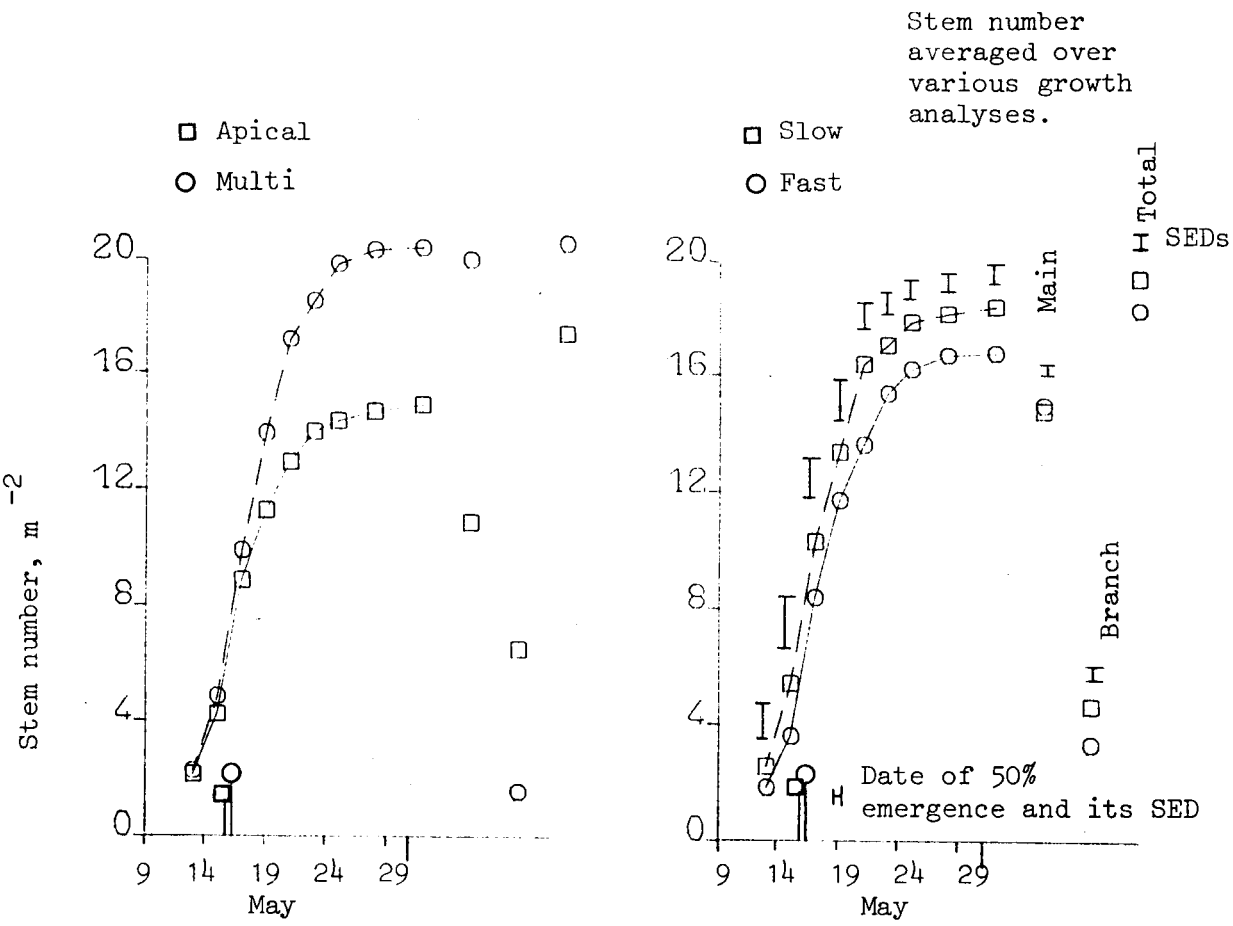


Figure 4.4.3.2 The effects of physiological age and sprouting treatments on emergence.

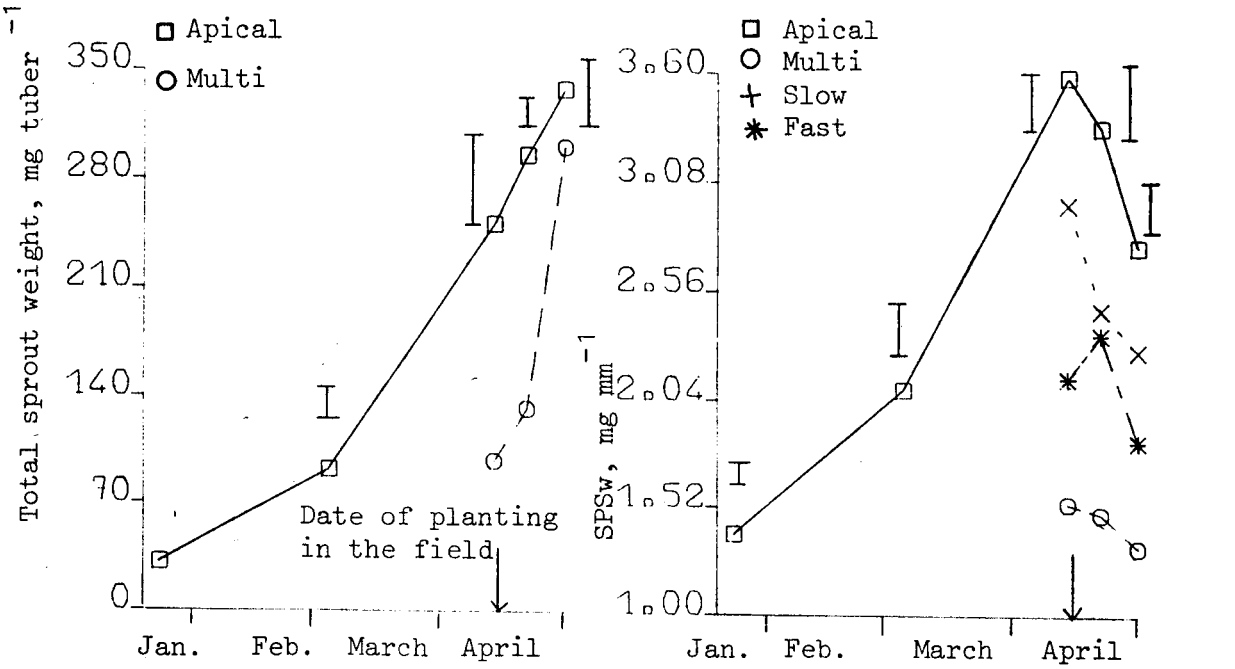


Figure 4.4.3.3 The effects of physiological age and sprouting treatments on specific sprout weight (SPSW) and the effects of physiological age on sprout weight. Vertical bars are SEDs for last 3 dates and SE_s of mean for first two dates of measurements.

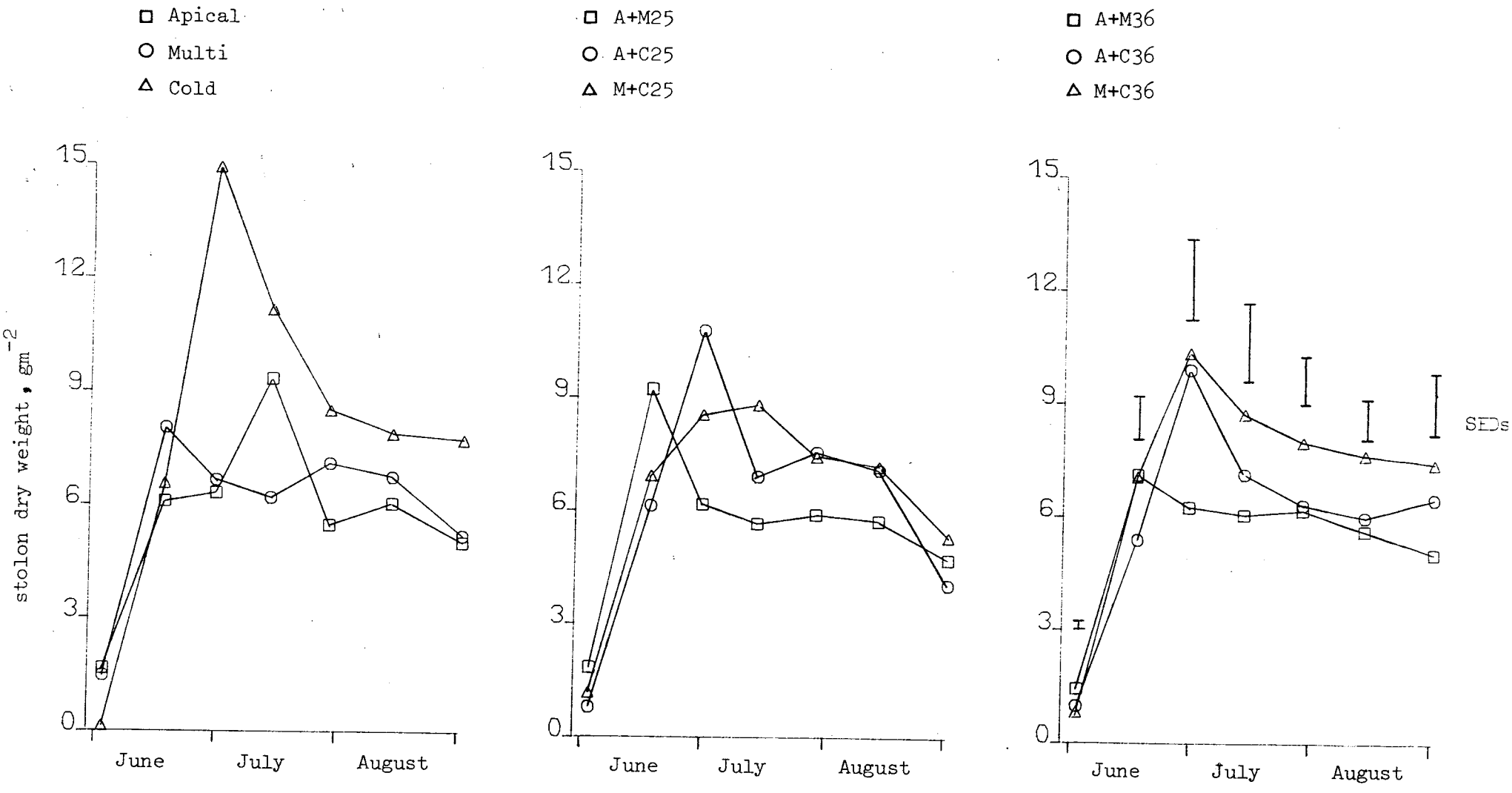


Figure 4.4.3.4 The effects of physiological age and mixing of different physiologically aged tubers on stolon dry weight (Experiment F2).

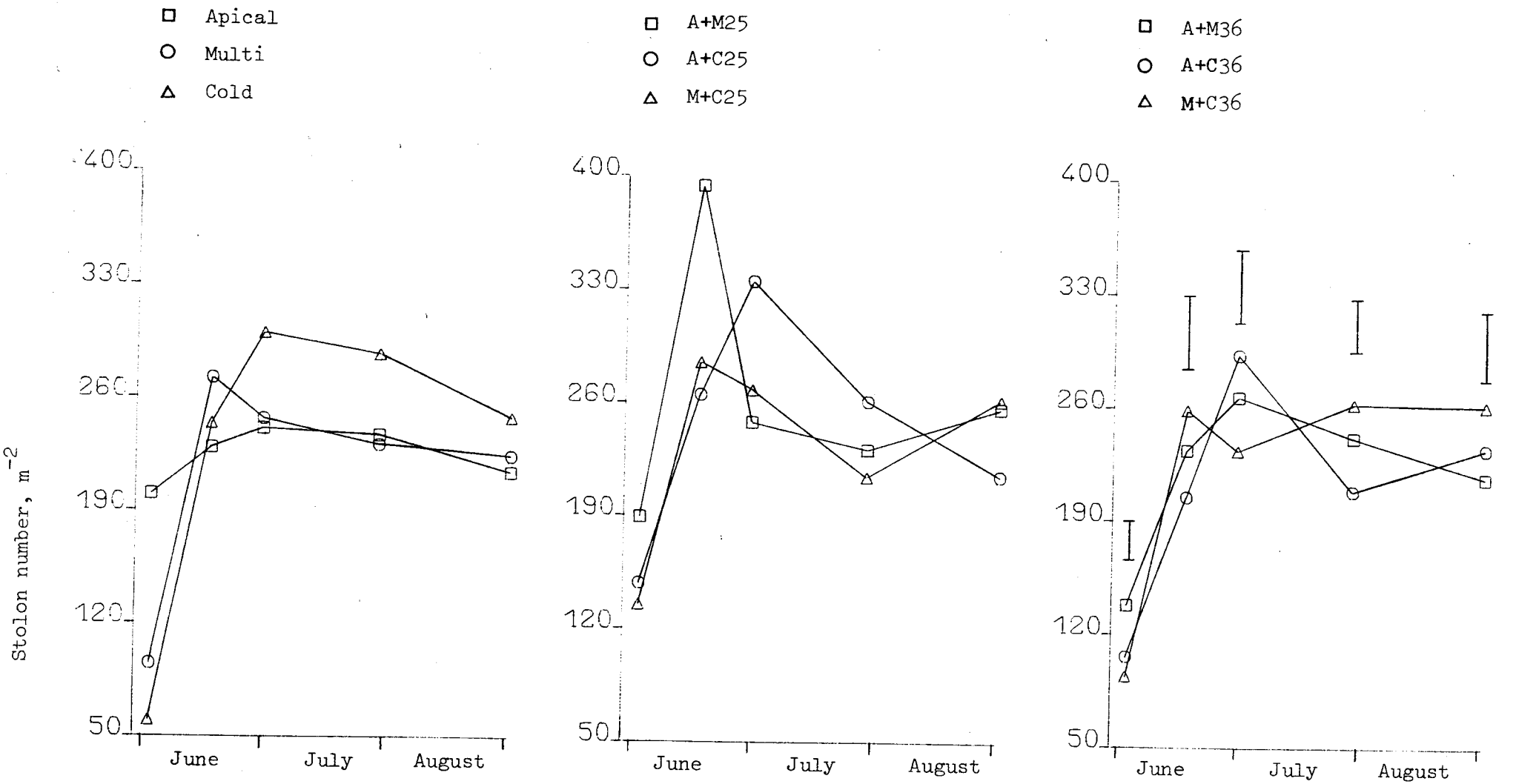


Figure 4.4.3.5 The effects of physiological age and mixing of different physiologically aged tubers on stolon number (Experiment F2).

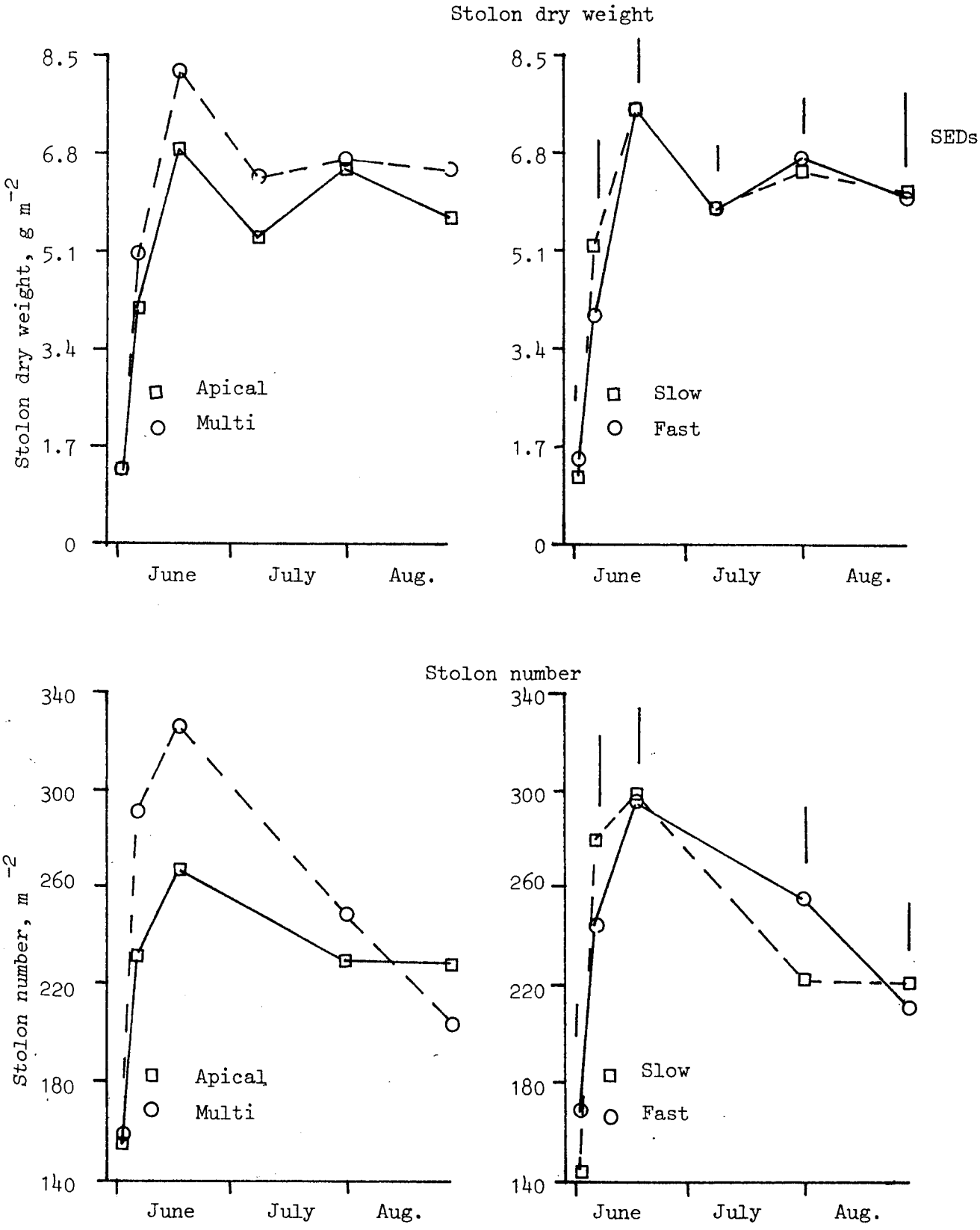


Figure 4.4.3.6 The effects of physiological age and sprouting treatments on stolon dry weight and stolon number (Experiment F3).

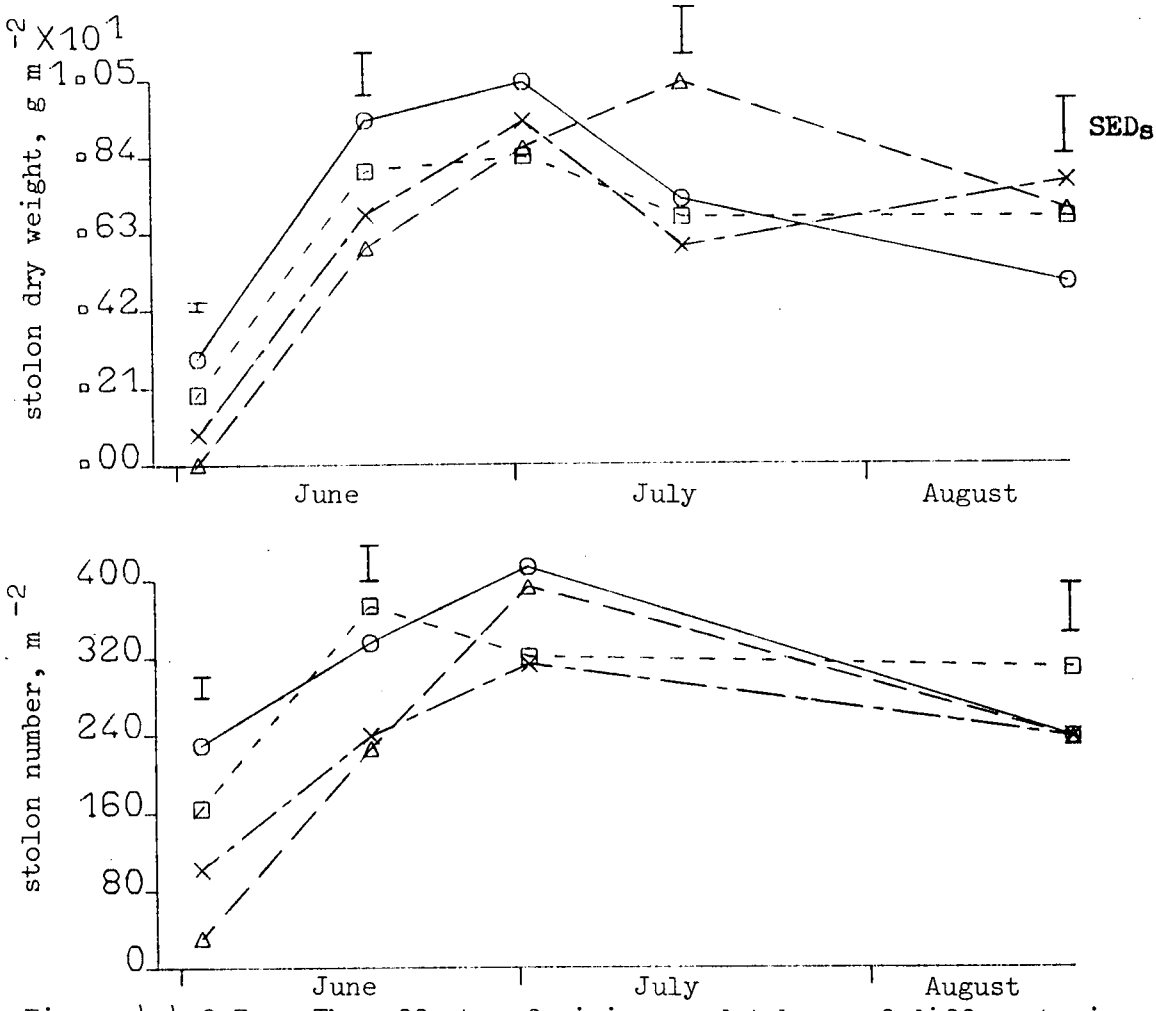


Figure 4.4.3.7 The effects of mixing seed tubers of different sizes on stolon dry weight and stolon number (Experiment F4)

Key: O,B36; Δ,S25; □,B+S25; +, B+S36.

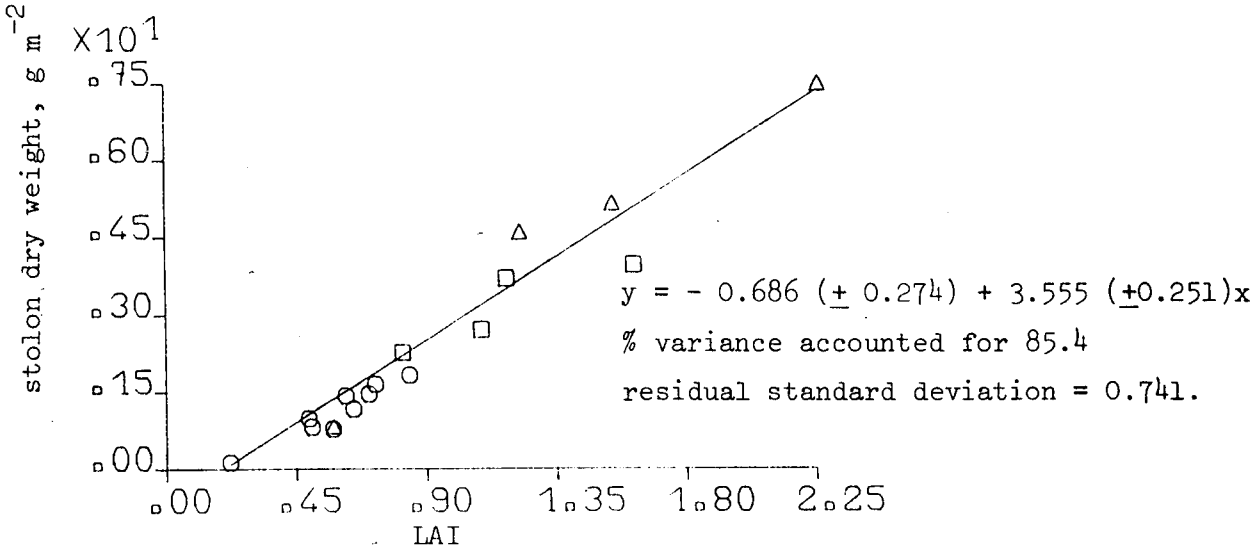


Figure 4.4.3.8 The relationship between LAI and stolon dry weight.

Data is average for replicates and is from experiments: F2,○ F3,Δ ; F4,□.

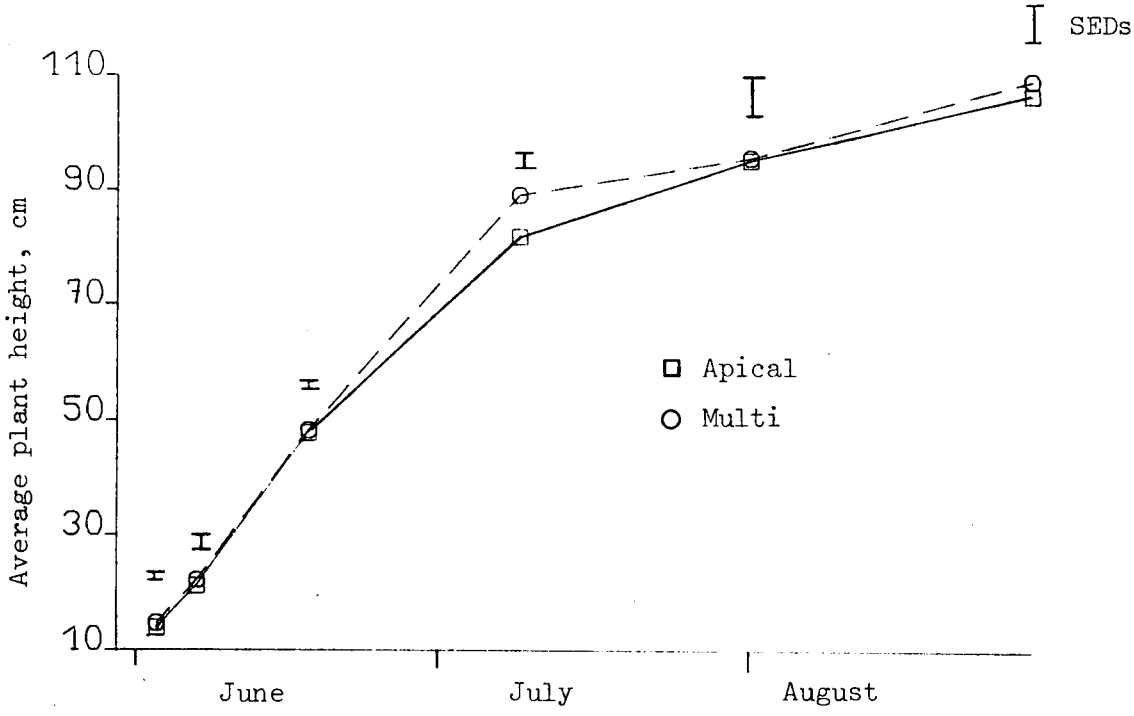


Figure 4.4.3.10 The effects of physiological age on average plant height (Experiment F3).

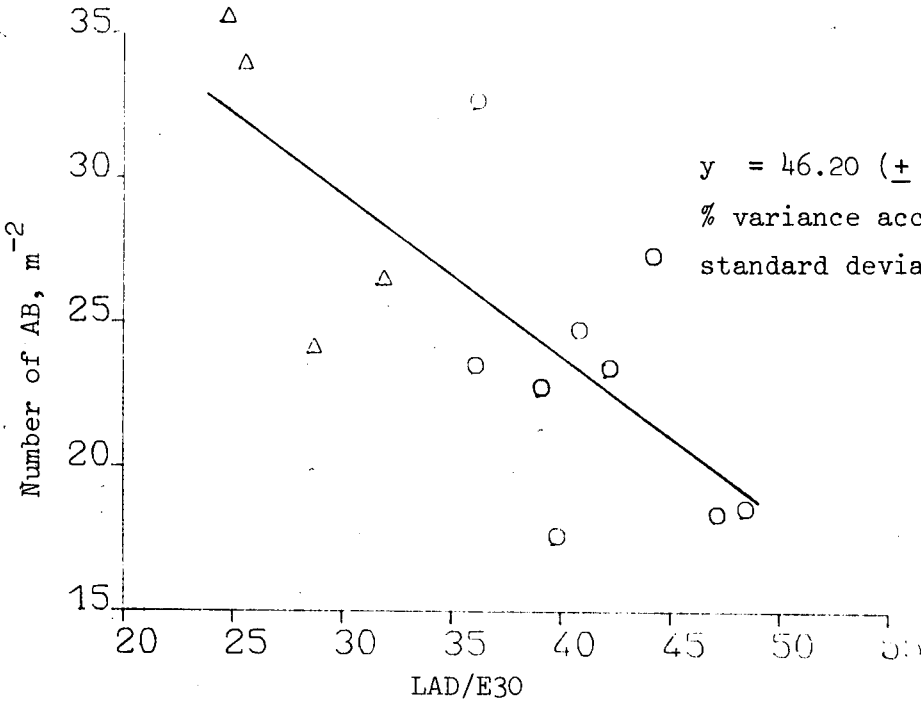


Figure 4.4.3.9 The relationship between number of axillary branches (AB) and leaf area duration accumulated over a period of 30 days from the date of 50% emergence (LAD/E30). Data is from experiments: F2, O ; F3, Δ

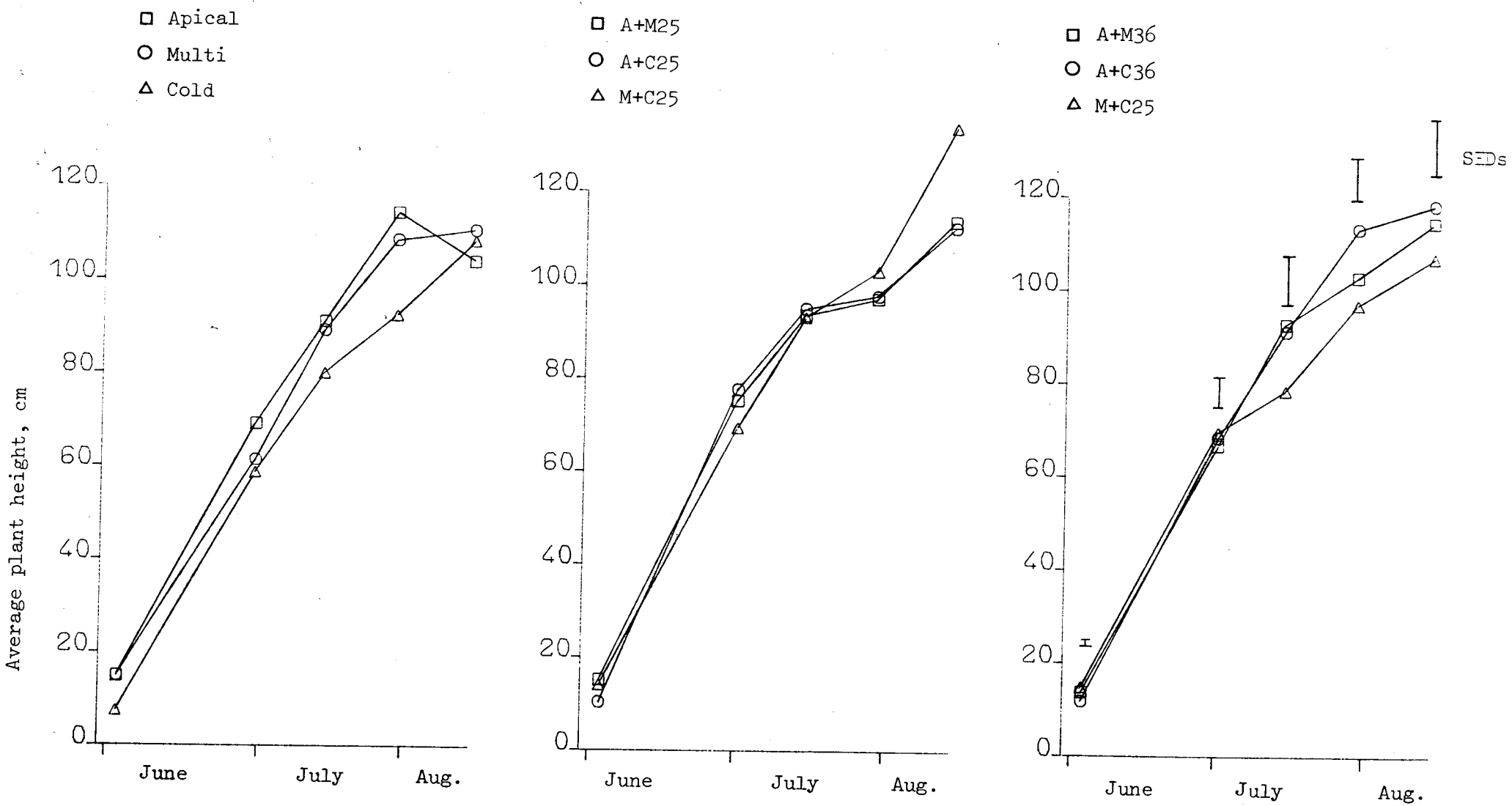


Figure 4.4.3.11 The effects of physiological age and mixing of different physiologically aged tubers on average plant height (Experiment F2).

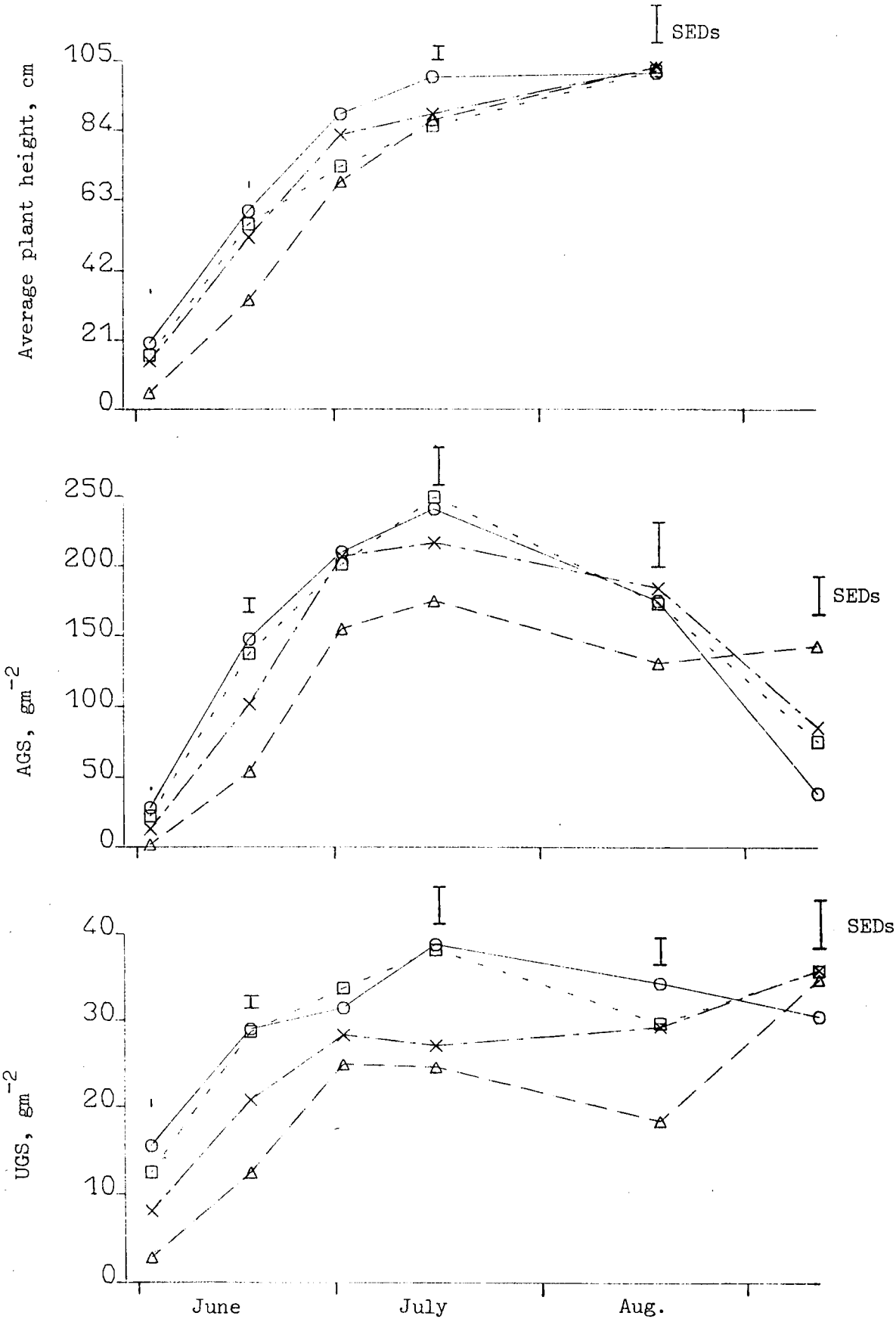


Figure 4.4.3.12 The effects of mixing seed tubers of different size on average plant height, above ground (AGS) and under ground (UGS) stem dry weight. Key: ○,B36; △,S25; □,B+S25; +,B+S36 (Experiment F4).

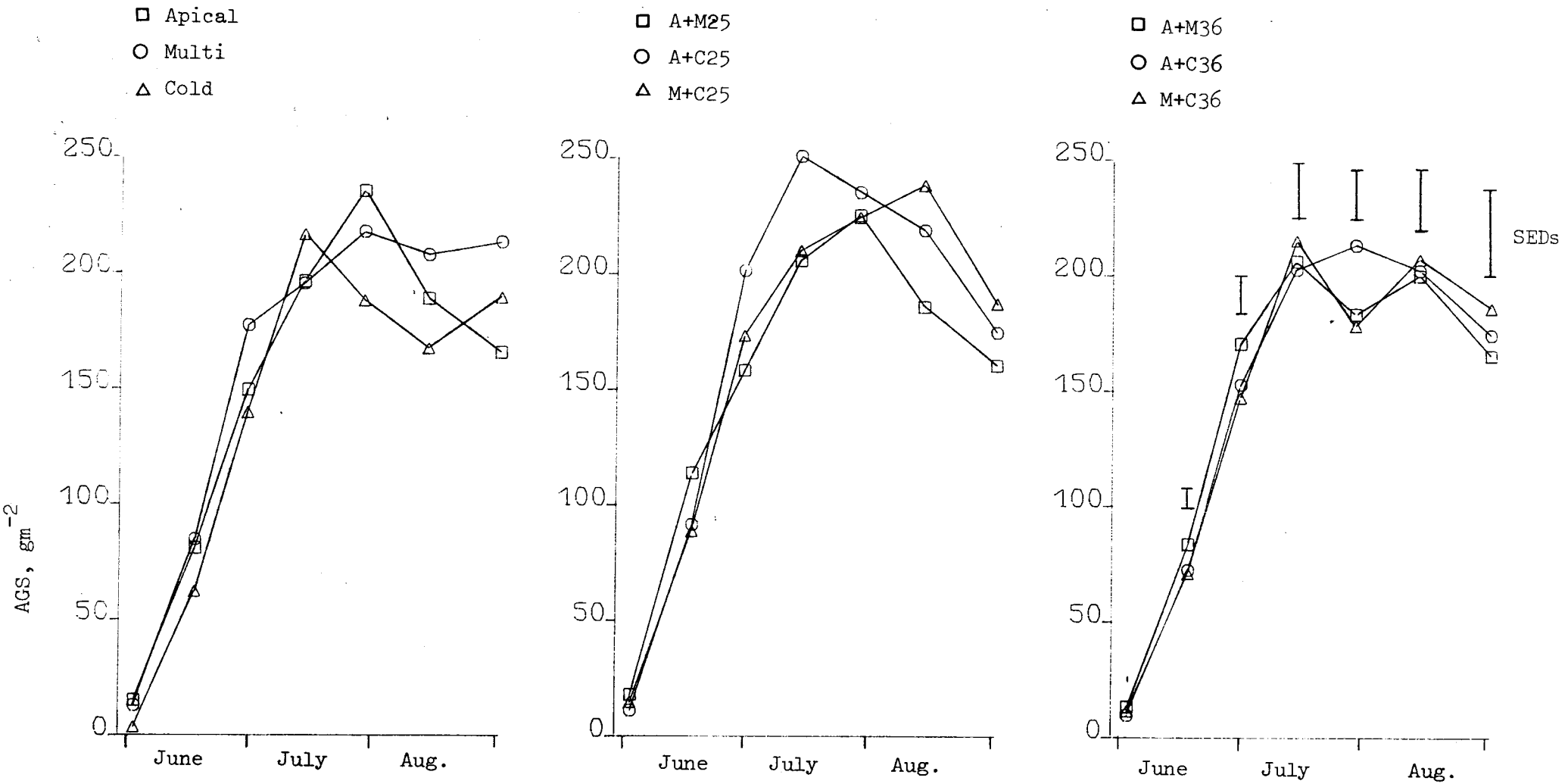


Figure 4.4.3.13 The effects of physiological age and mixing of different physiologically aged tubers on above ground stem (AGS) dry weight (Experiment F2).

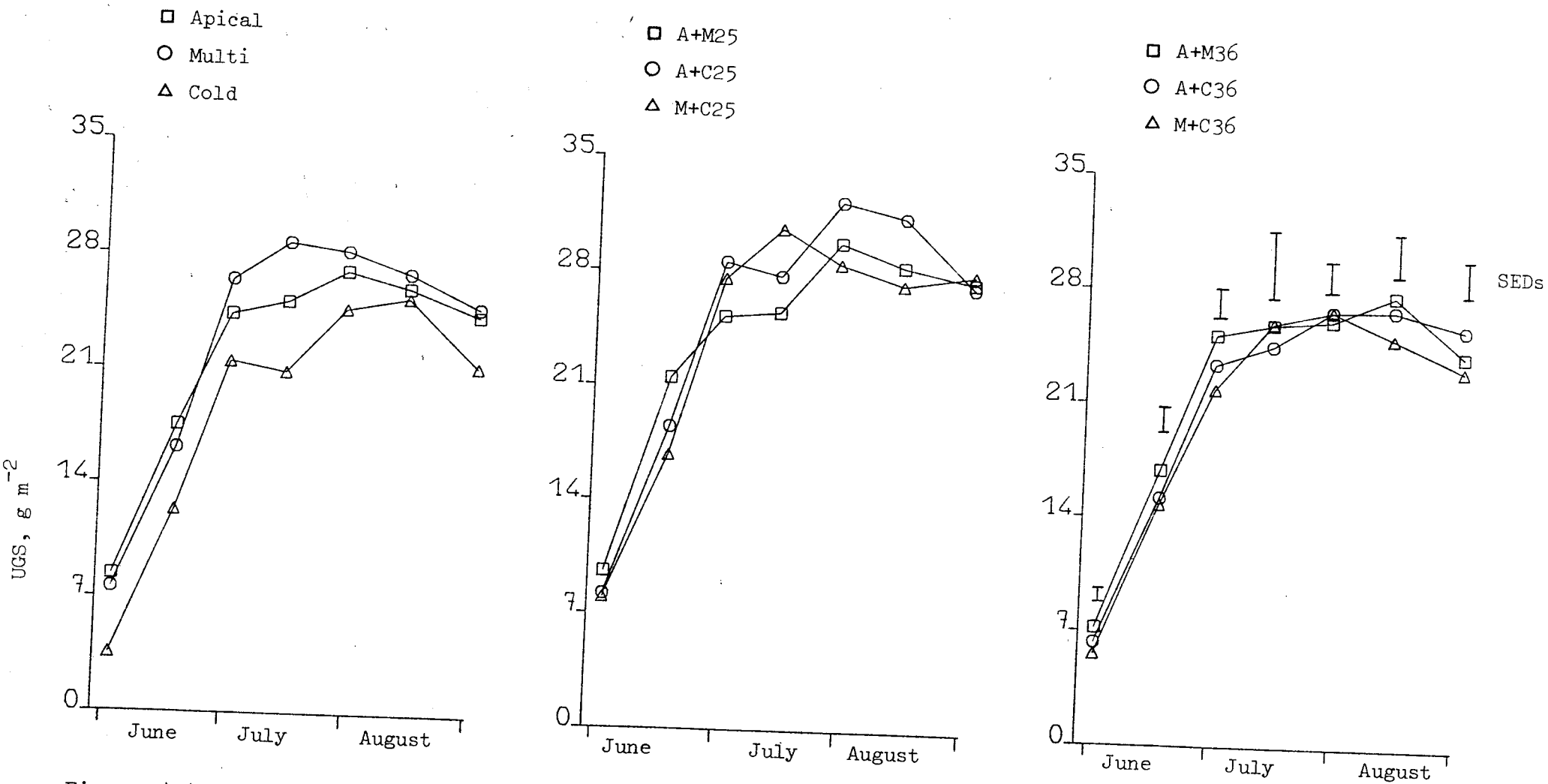


Figure 4.4.3.14 The effects of physiological age and mixing of different physiologically aged tubers on underground stem (UGS) dry weight (Experiment F2).

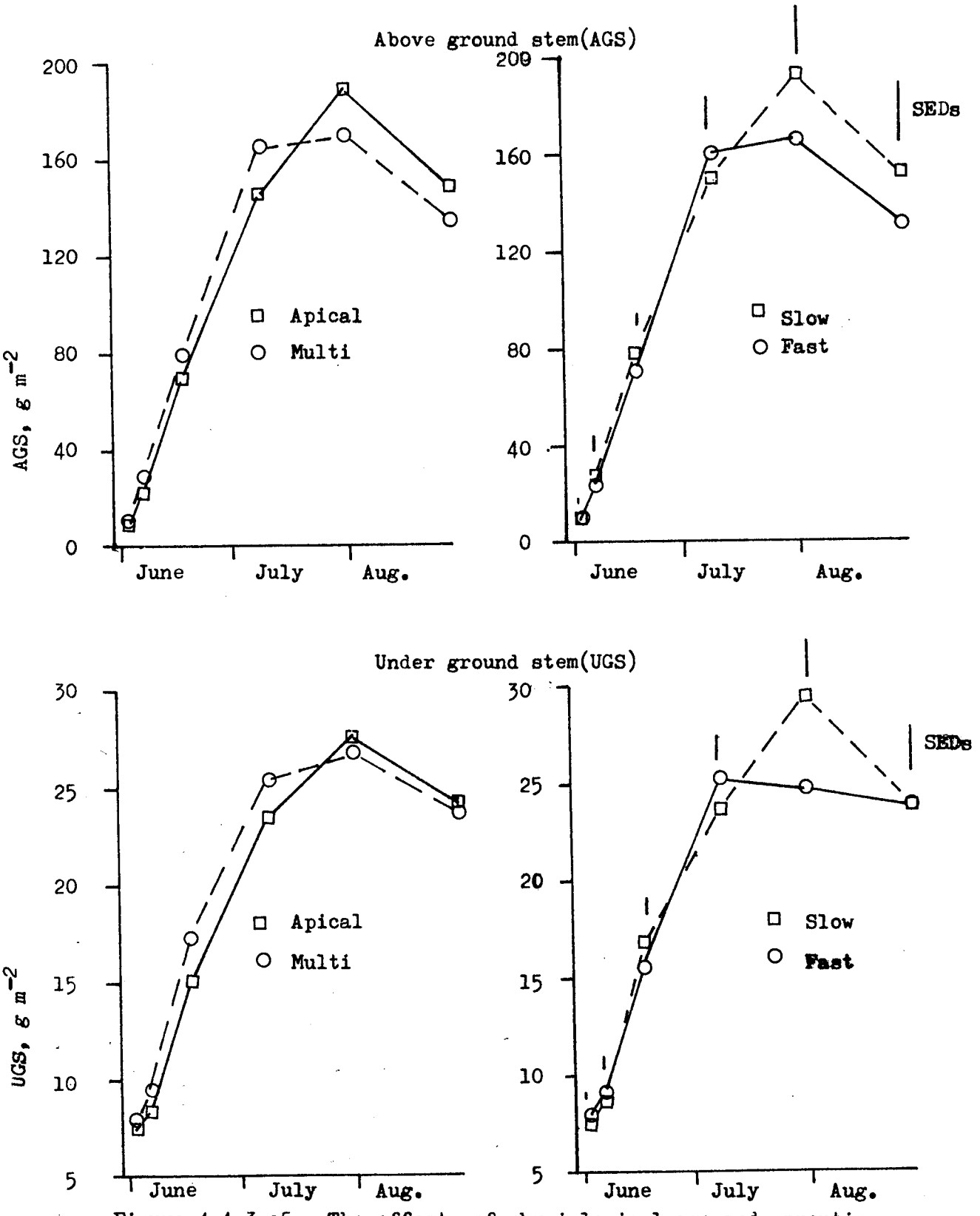


Figure 4.4.3.15 The effects of physiological age and sprouting treatments on stem dry weight (Experiment F3).

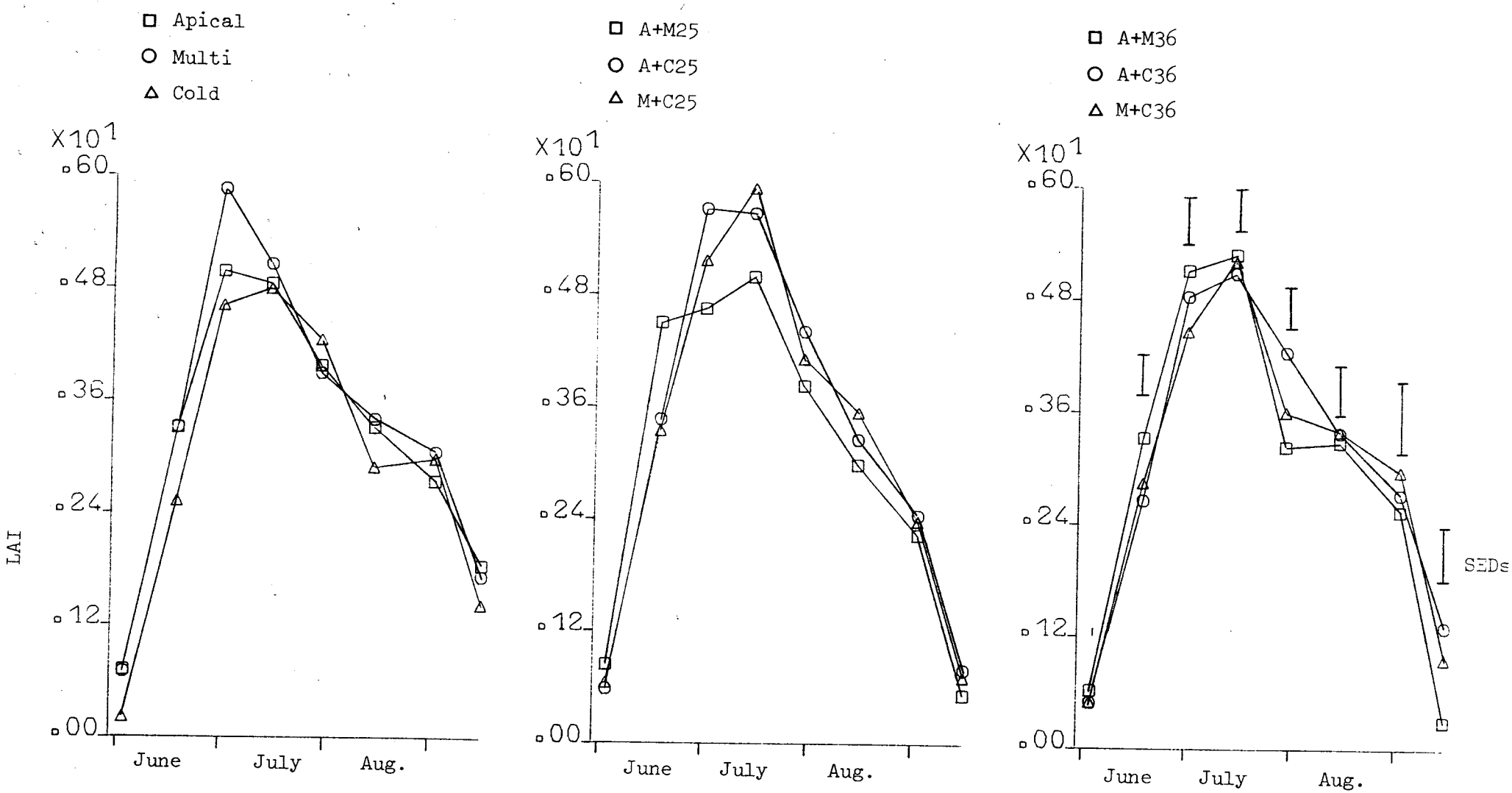


Figure 4.4.3.16 The effects of physiological age and mixing of different physiologically aged tubers on leaf area index (LAI) (Experiment F2).

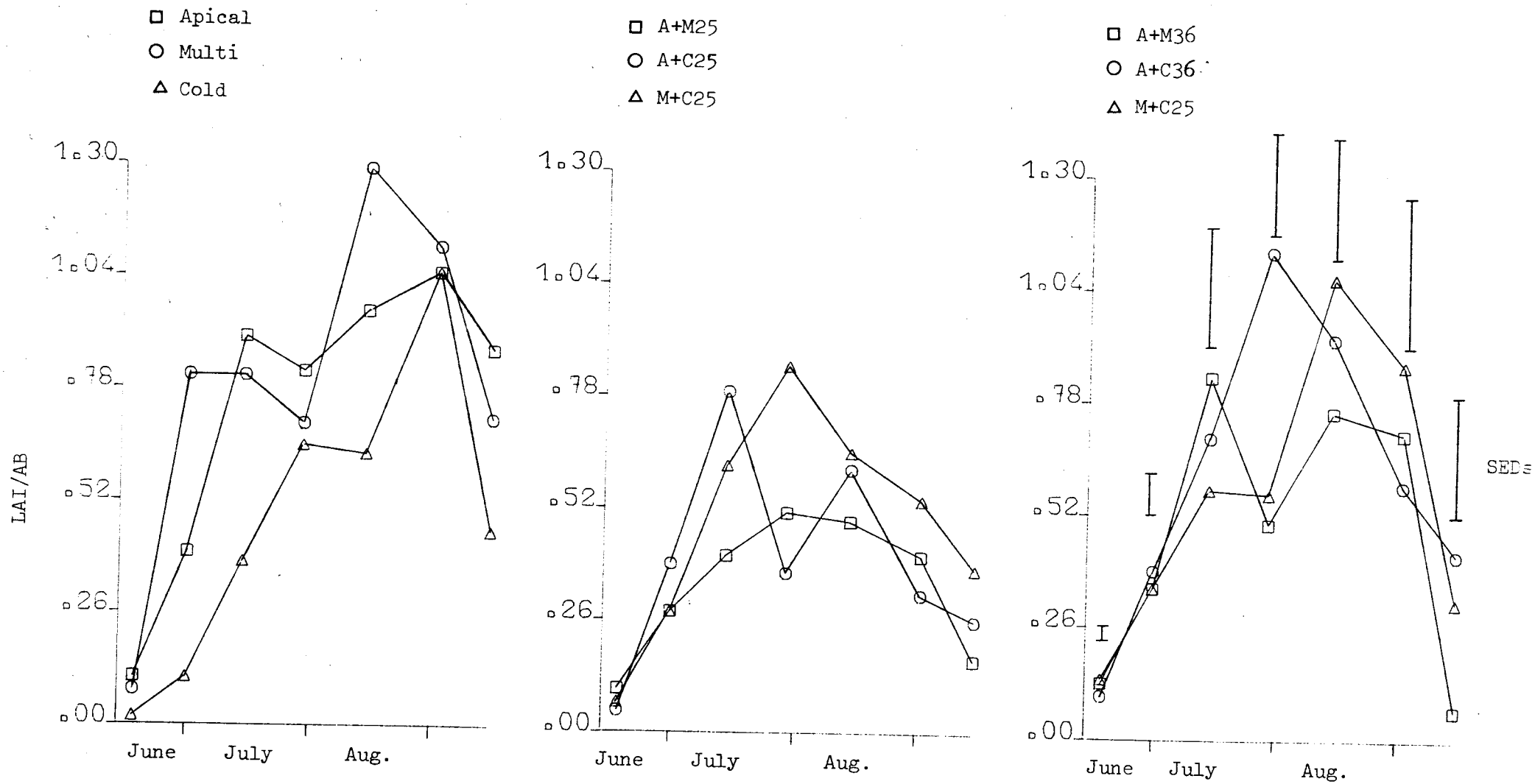


Figure 4.4.3.17 The effects of physiological age and mixing of different physiologically aged tubers on leaf area index contributed by the axillary branches (LAI/AB) (Experiment F2).

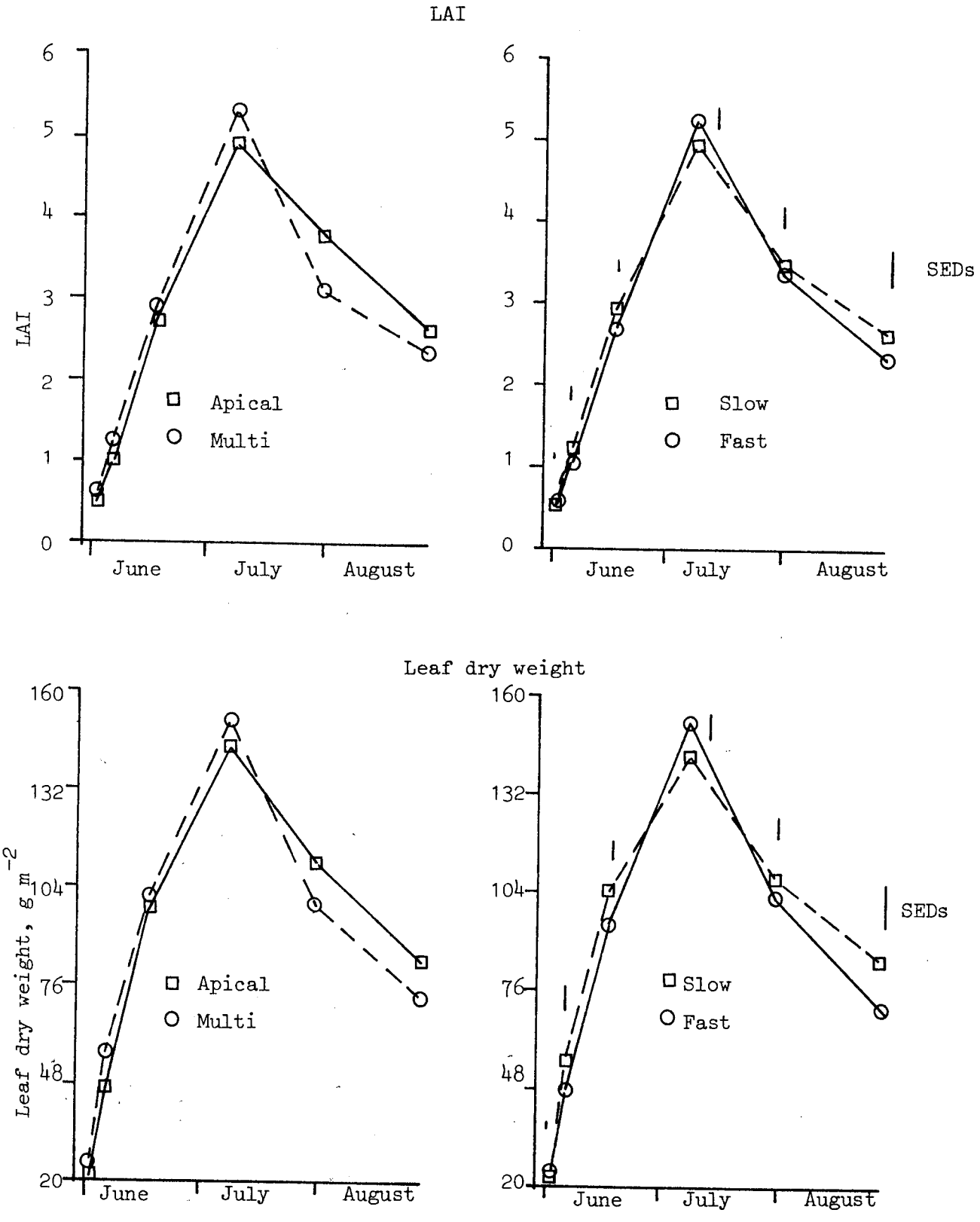


Figure 4.4.3.18 The effects of physiological age and sprouting treatments on LAI and leaf dry weight (Experiment F3).

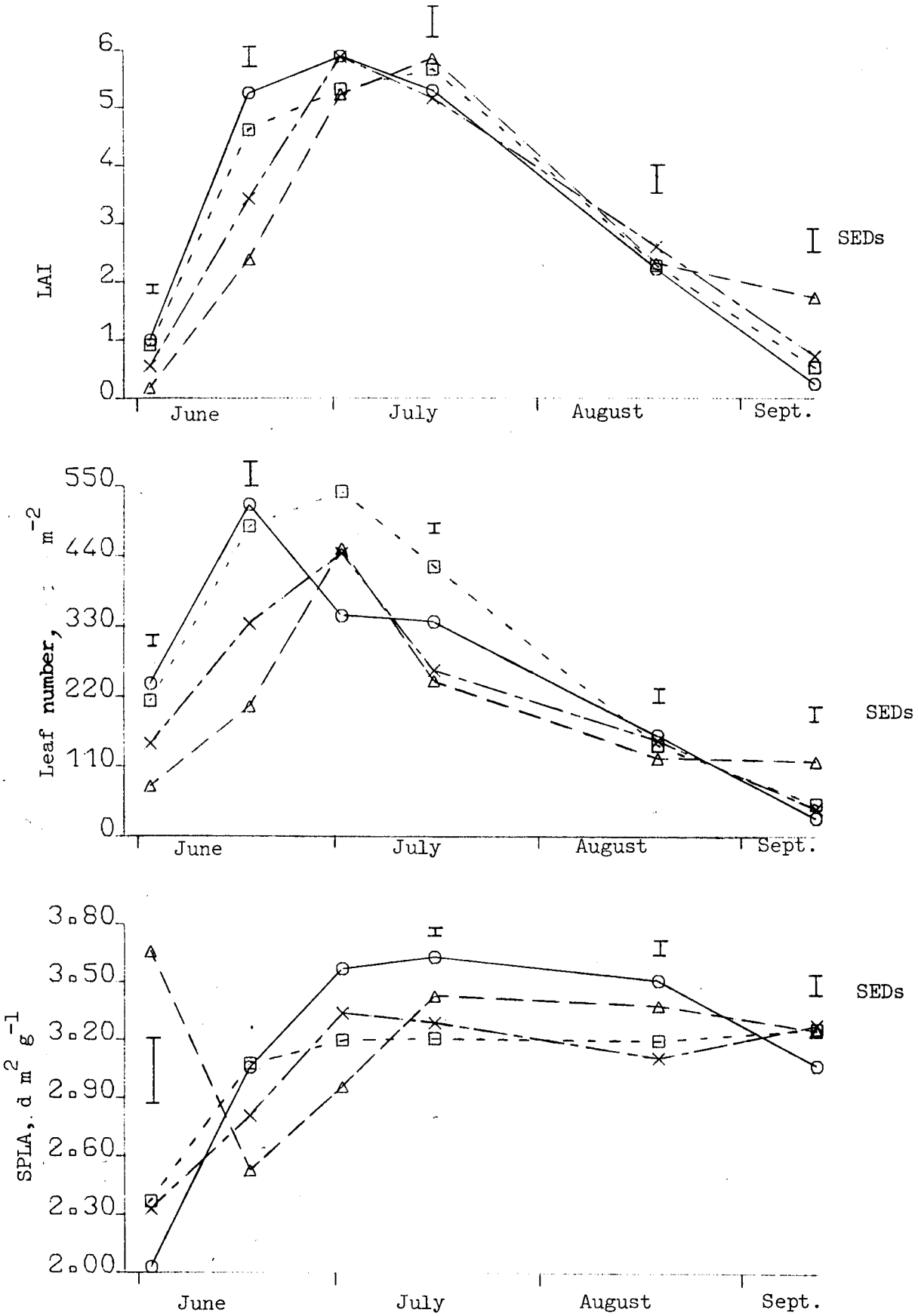


Figure 4.4.3.19 The effects of mixing seed tubers of different sizes on LAI, leaf number and specific leaf area (SPLA) (Experiment F4).

Key: ○ ,B36; △ ,S25; □ ,B+S25; + ,B+S36.

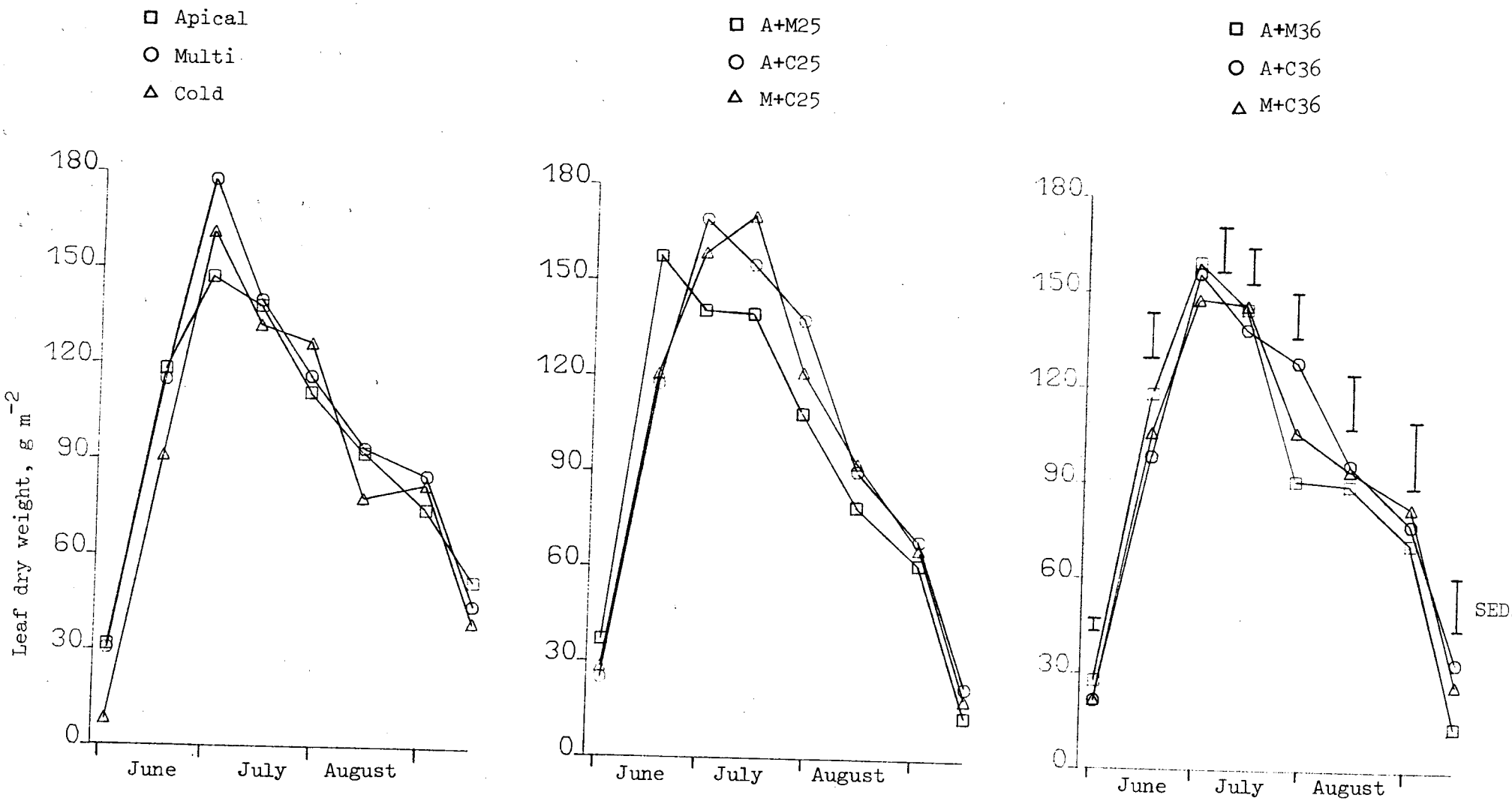


Figure 4.4.3.20 The effects of physiological age and mixing of different physiologically aged tubers on leaf dry weight (Experiment F2).

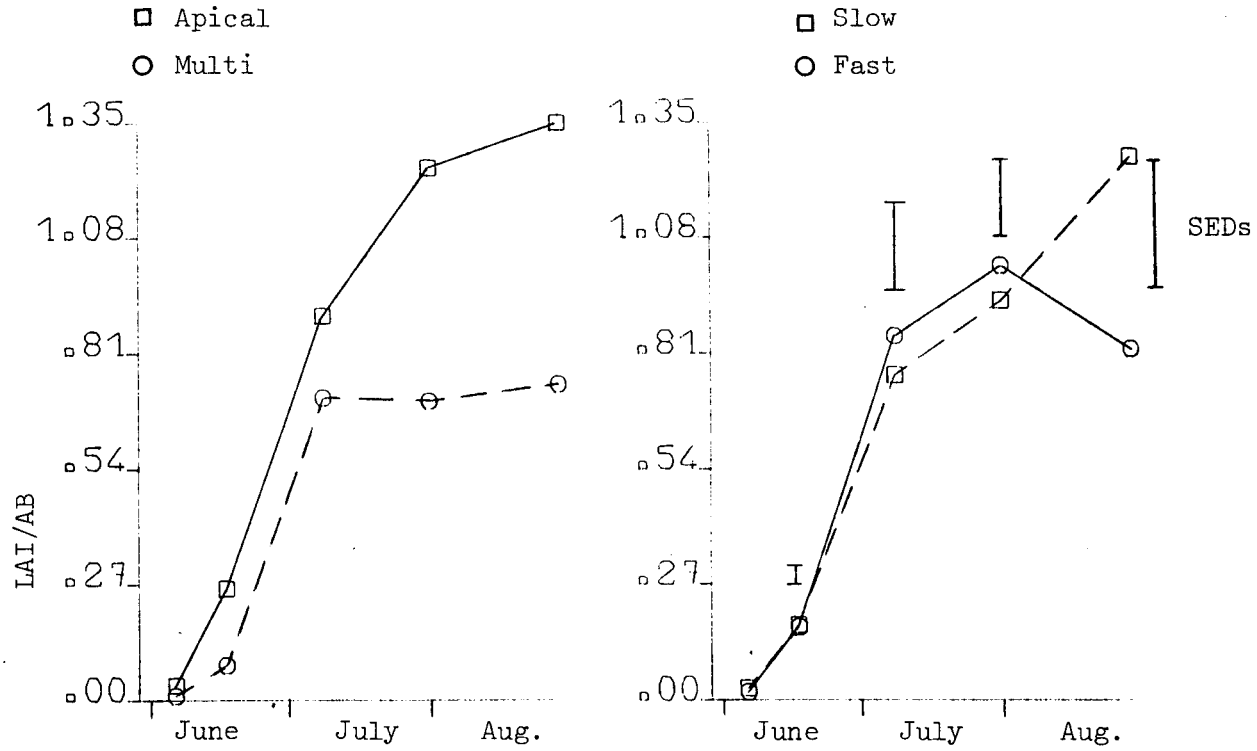


Figure 4.4.3.21 The effects of physiological age and sprouting treatments on leaf area index contributed by the axillary branches (LAI/AB) (Experiment F3).

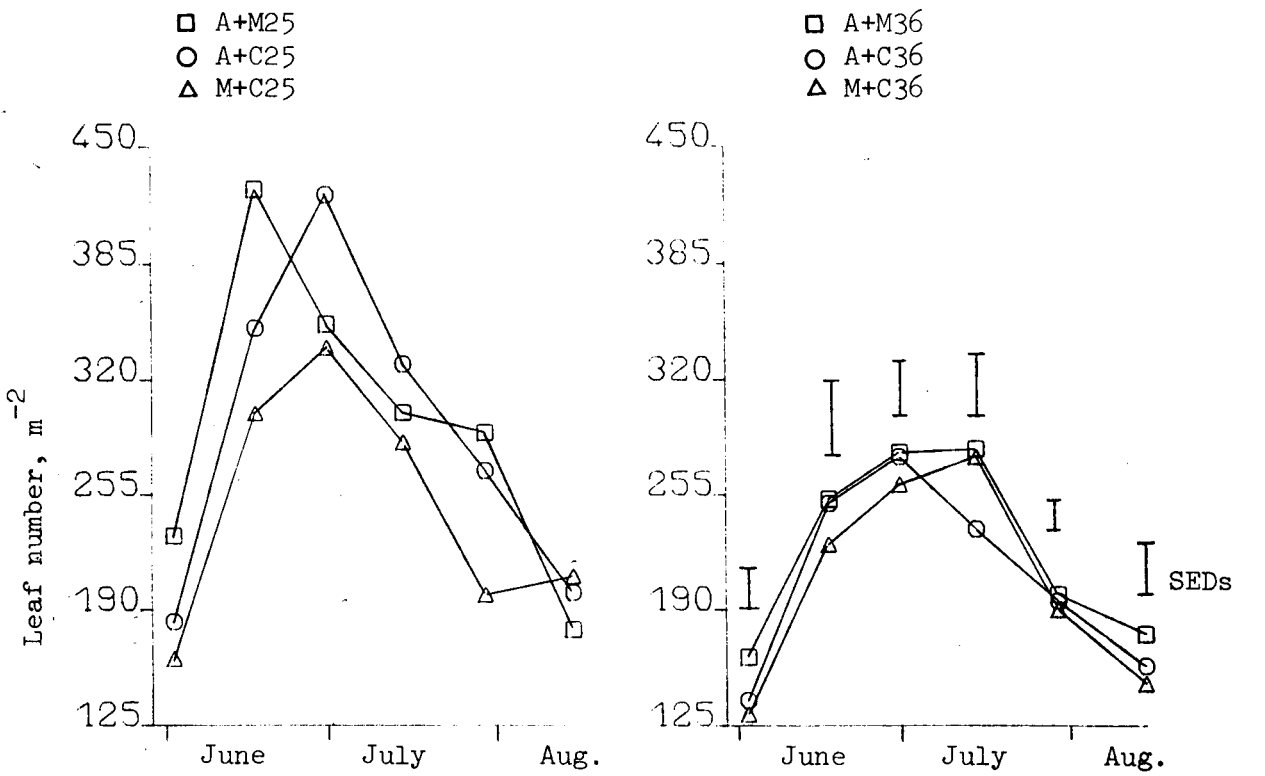


Figure 4.4.3.22 The effects of mixing seed tubers of different physiologically aged tubers on leaf number (Experiment F2).

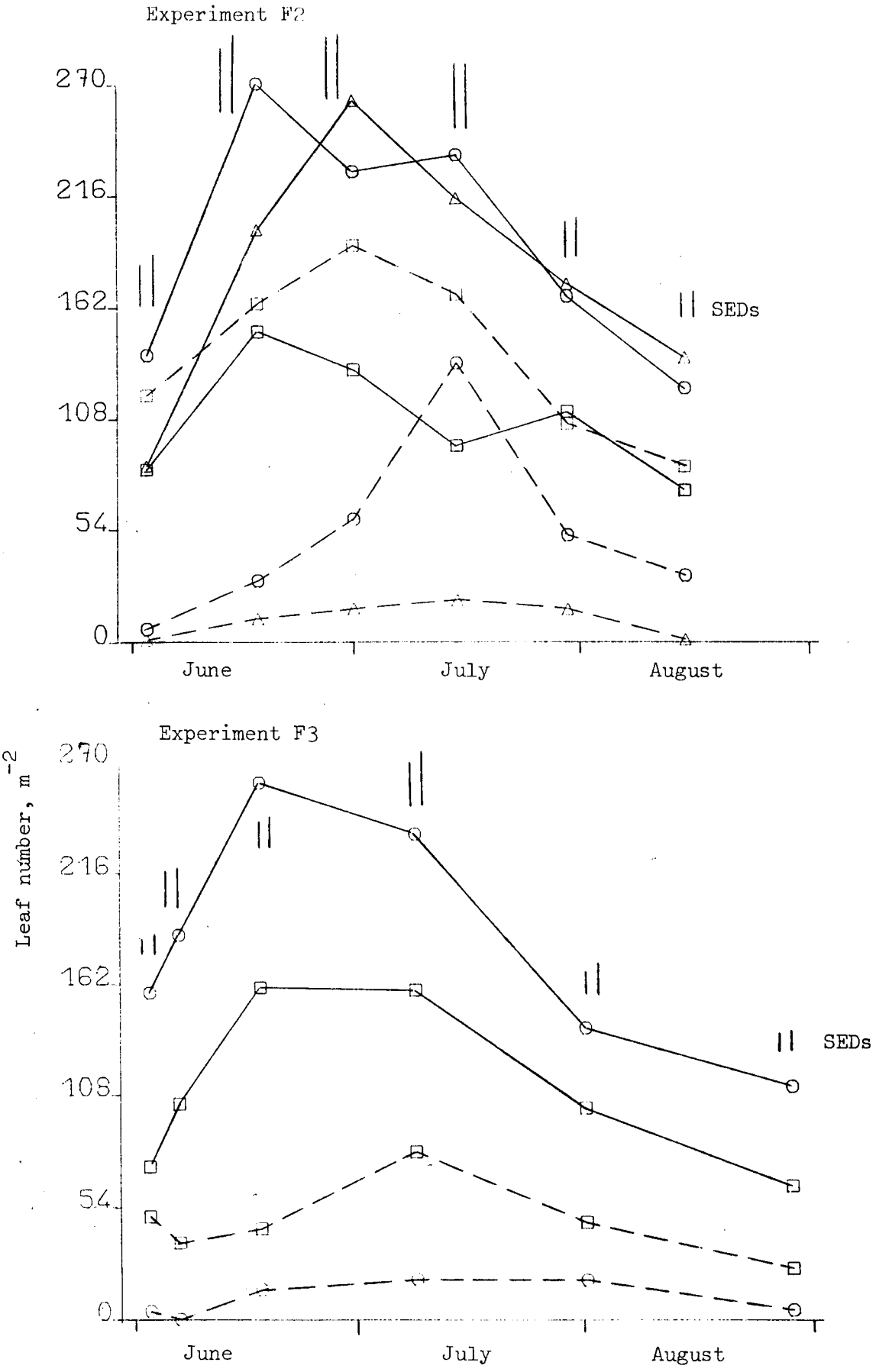


Figure 4.4.3.23 The effects of physiological age (PA) on leaf number contributed by the different types of stems, excluding the leaves coming from the axillary branches. SED on the right side is to be used for comparing means within same levels of PA. Residual degrees of freedom is 6 for experiment F2 and 8 for experiment F3.
Key: □ ,apical; O, multi; Δ ,cold;——, main stem;---, branch stem.

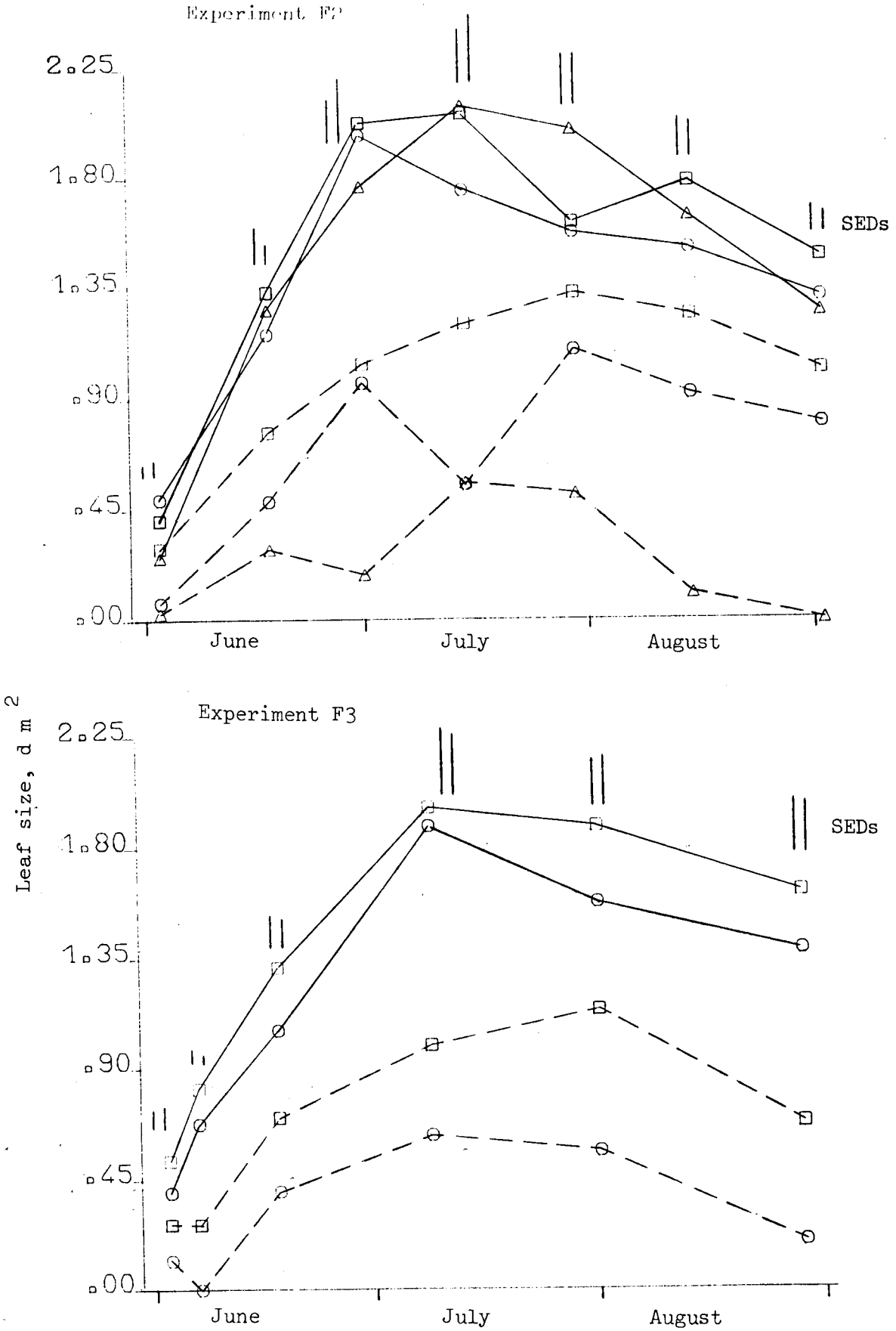


Figure 4.4.3.24 The effects of physiological age (PA) on leaf size of the different types of stems (leaves coming from the axillary branches were not included). For meaning of SEDs, symbols and residual degrees of freedom, see figure 4.4.3.23.

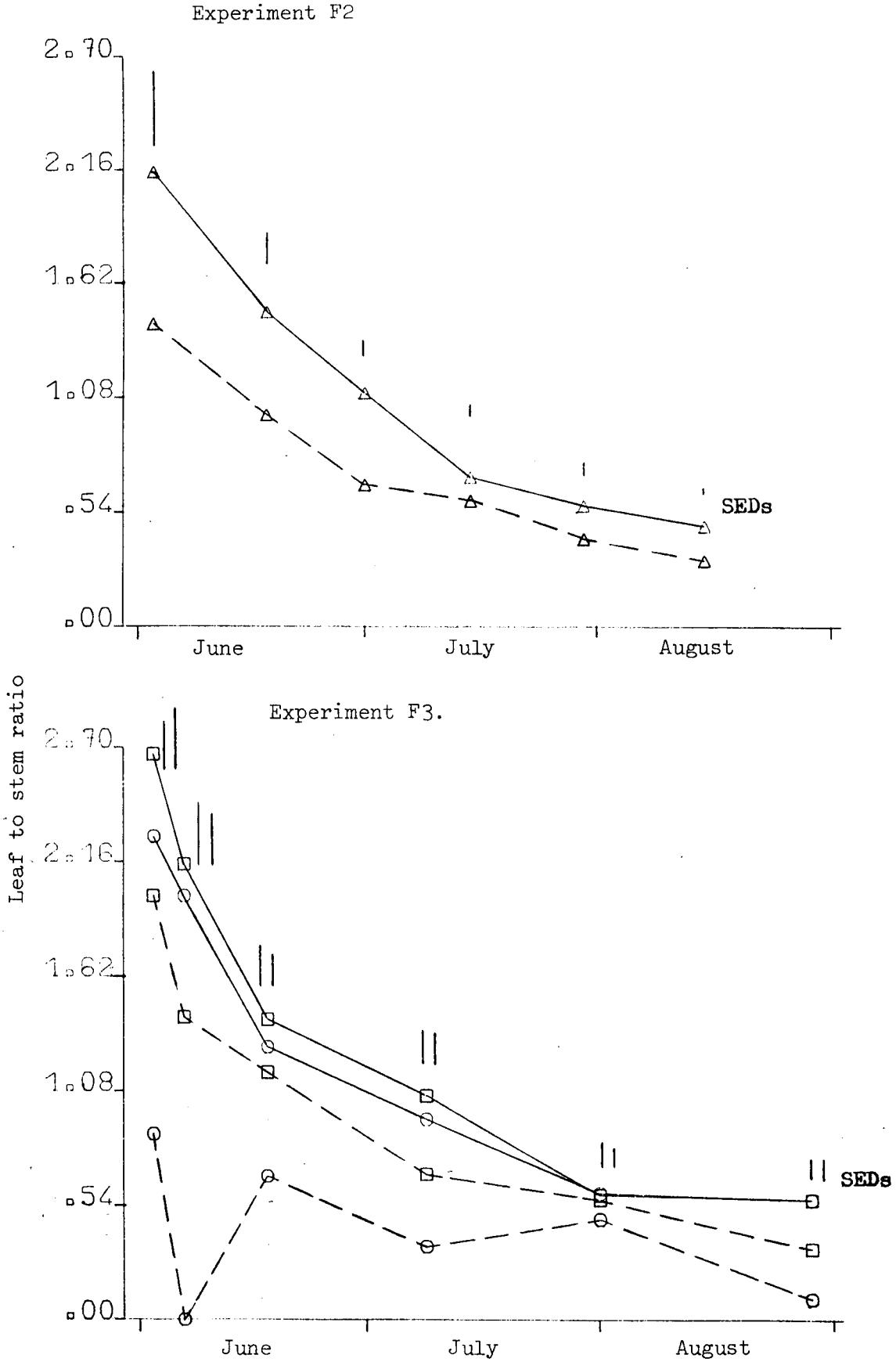


Figure 4.4.3.25 The effects of physiological age on leaf to stem ratio (dry weight basis) of different types of stems. For meaning of SEDs and residual degrees of freedom, see figure 4.4.3.23.

Key: □, apical; ○, multi; △, average for apical, multi and cold

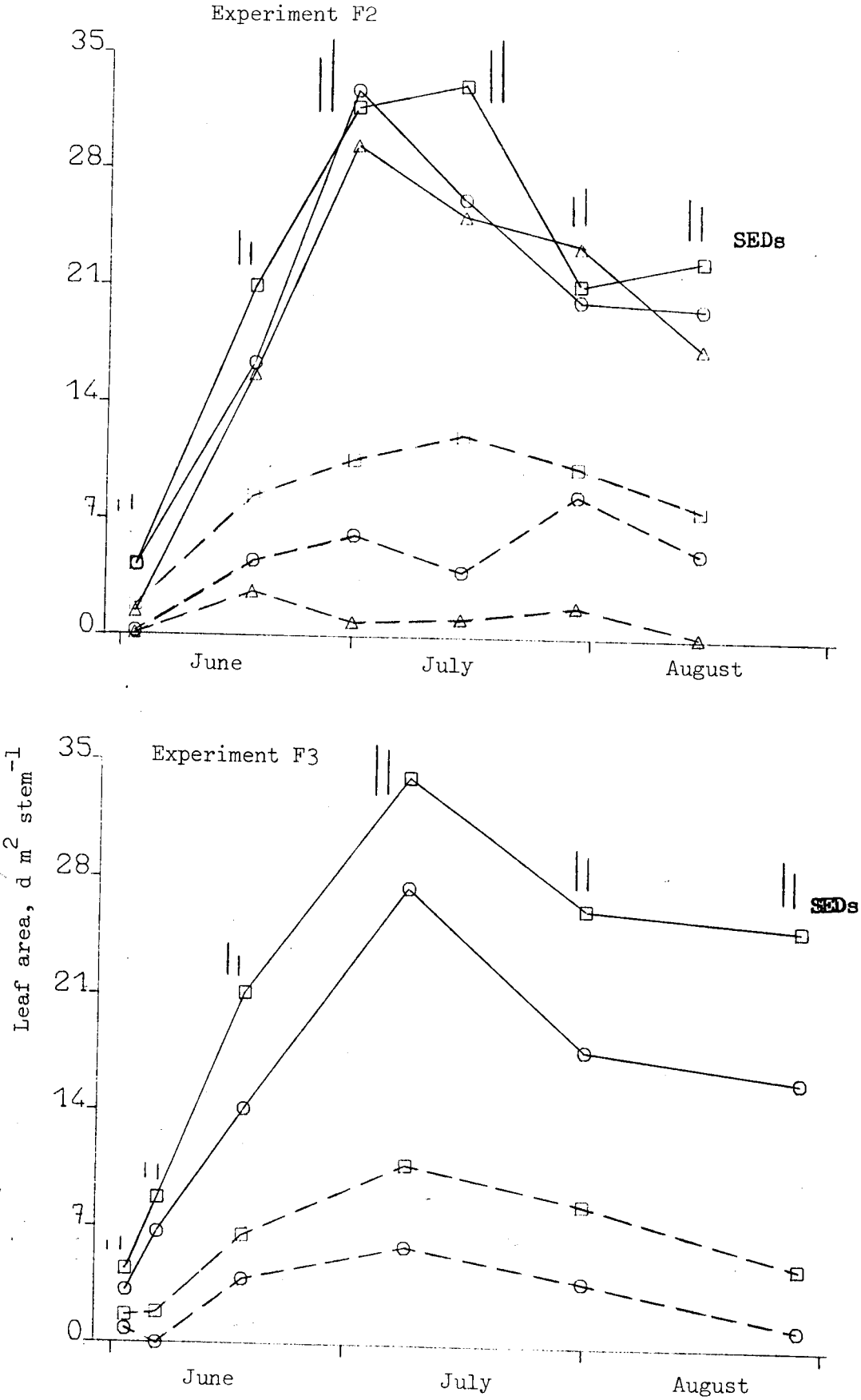


Figure 4.4.3.26 The effects of physiological age on stem size. For meaning of SEDs, symbols and residual degrees of freedom, see figure 4.4.3.23.

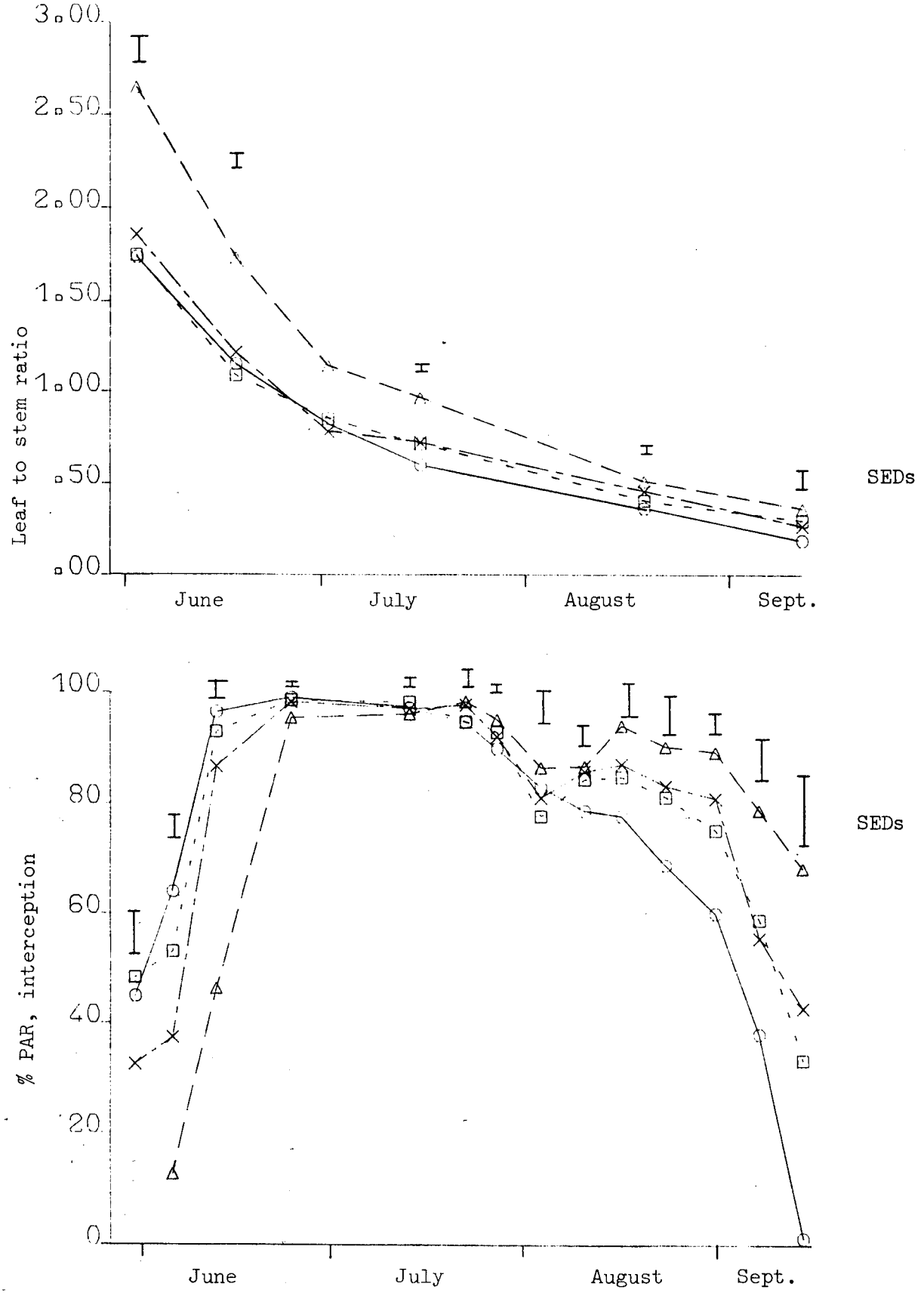


Figure 4.4.3.27 The effects of mixing seed tubers of different sizes on leaf to stem ratio (dry weight basis) and photosynthetically active radiation interception (PAR) (Experiment F4).

Key: O, B36; Δ, S25; □, B+S25; +, B+S36.

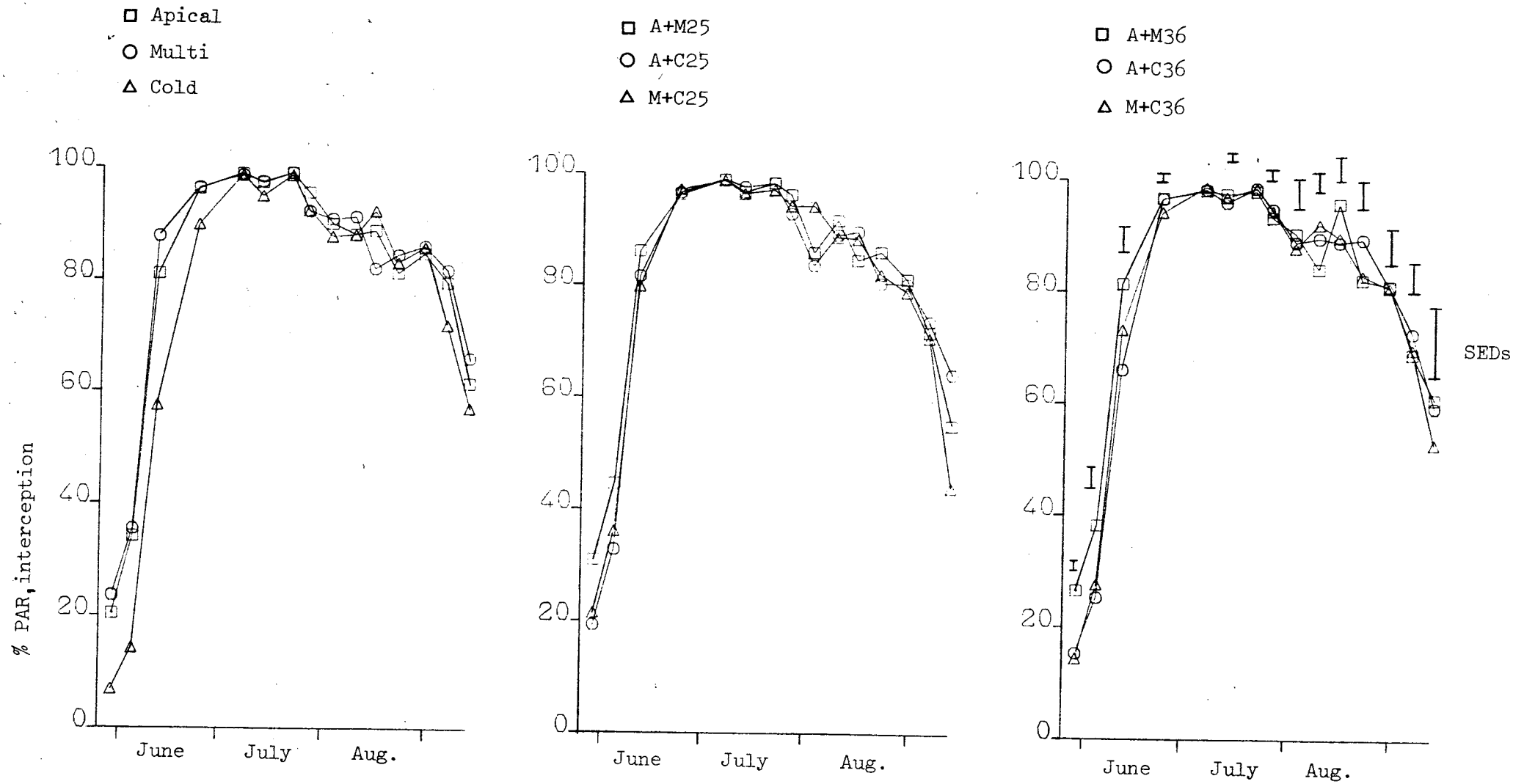


Figure 4.4.3.28 The effects of physiological age and mixing of different physiologically aged tubers on photosynthetically active radiation (PAR) interception (Experiment F2).

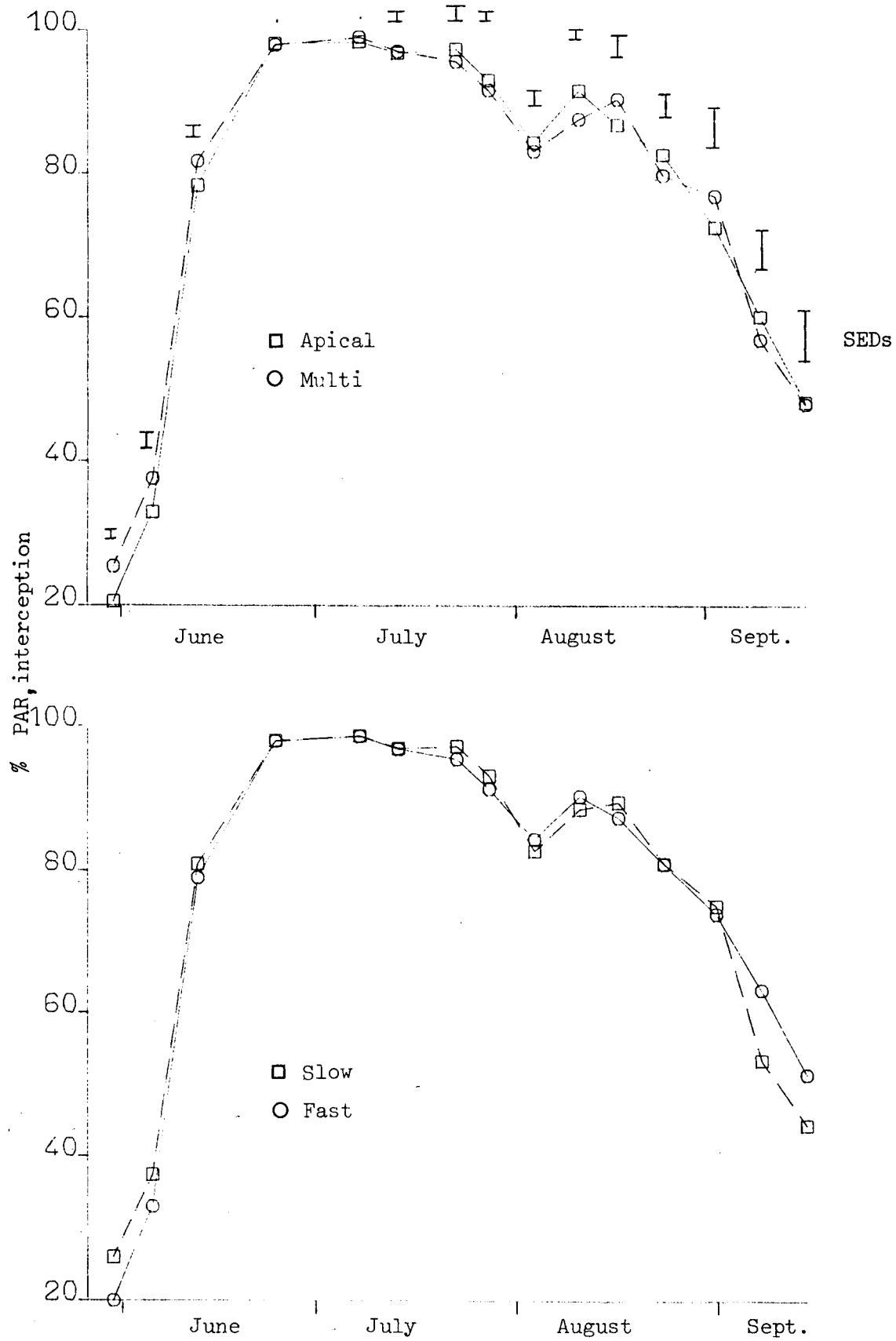


Figure 4.4.3.29 The effects of physiological age and sprouting treatments on photosynthetically active radiation (PAR) interception (Experiment F3).

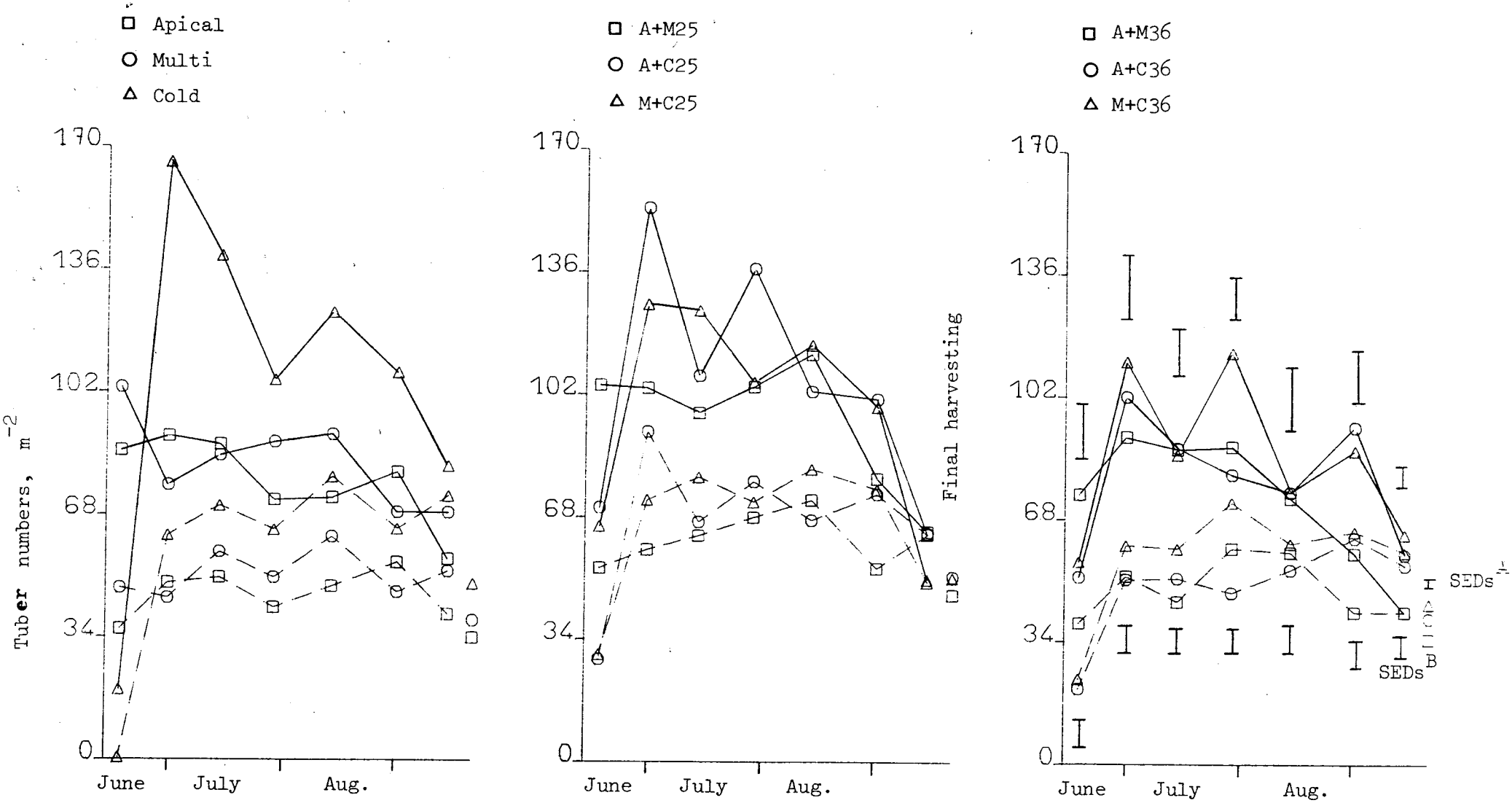


Figure 4.4.3.30 The effects of physiological age and mixing of different physiologically aged tubers on total tuber number (——) and tuber number over 10mm (– –). $SEDs^{A}$, are for total tuber number and $SEDs^{B}$ are for tuber number over 10mm (Experiment F2).

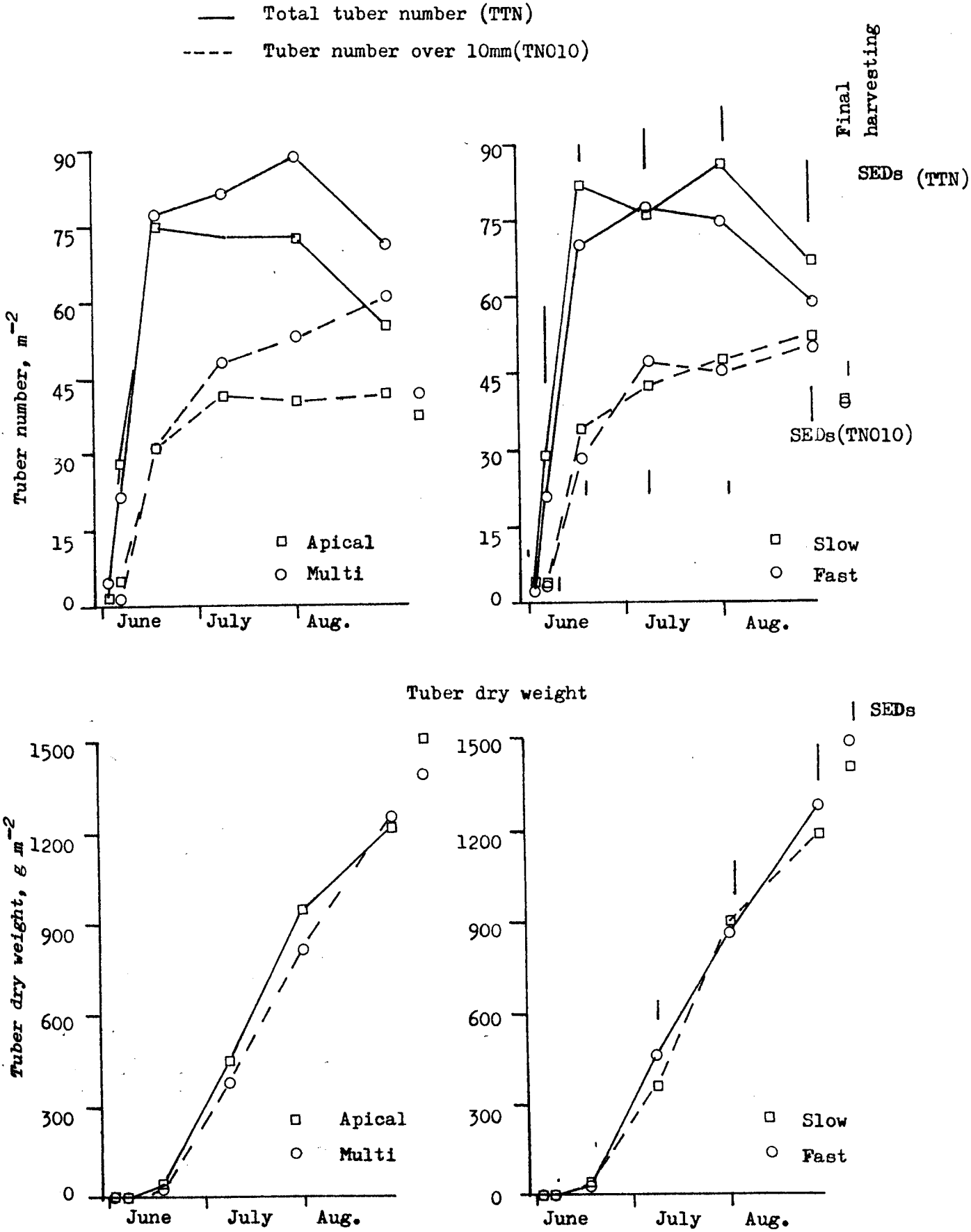


Figure 4.4.3.31 The effects of physiological age and sprouting treatments on total tuber number, tuber number over 10mm and tuber dry weight (Experiment F3).

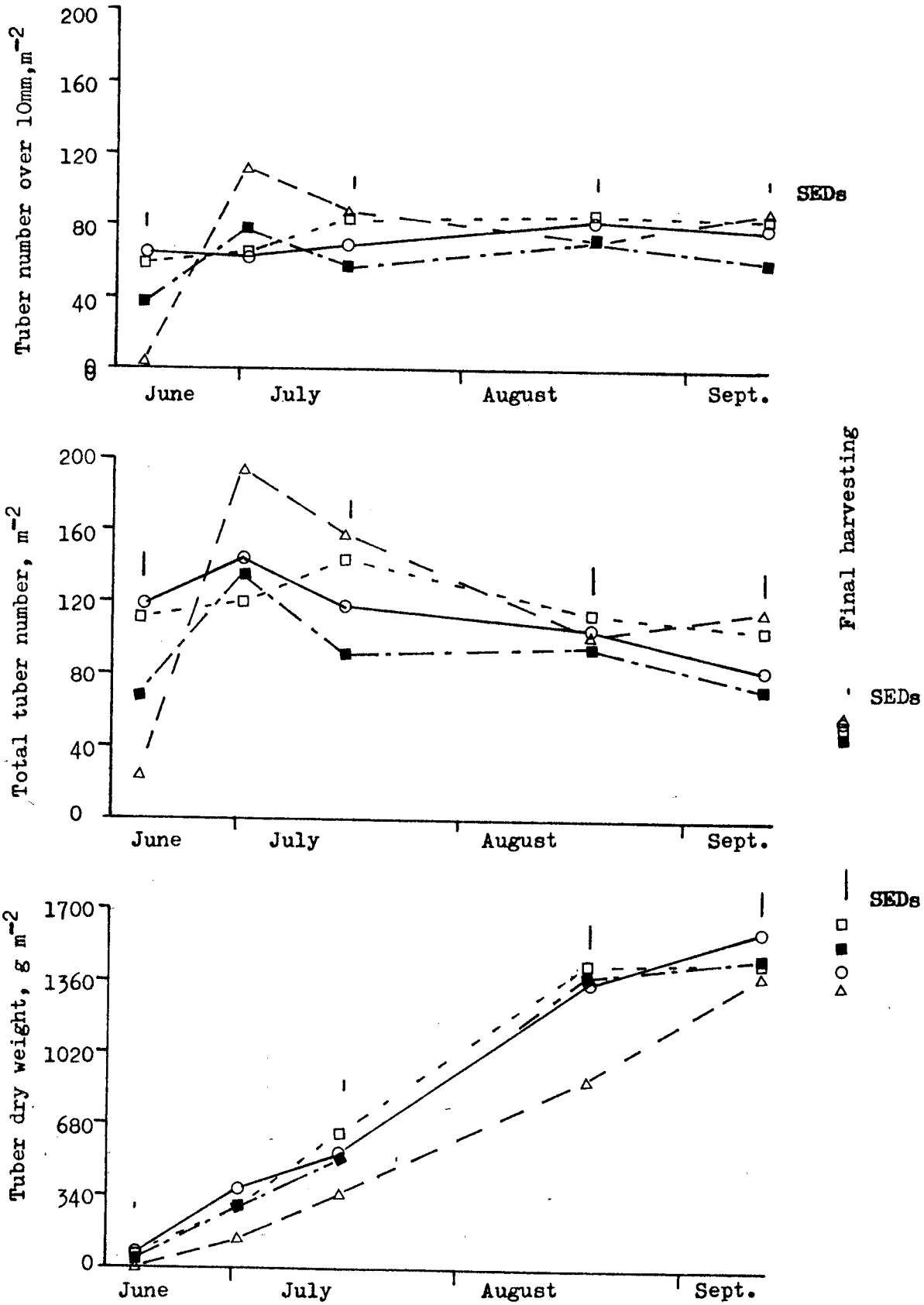


Figure 4.4.3.32 The effects of mixing seed tubers of different sizes on tuber number over 10mm, total tuber number and tuber dry weight (Experiment F4)
Key: ○ ,B36; △ ,S25; □ ,B+S25; ■ ,B+S,36.

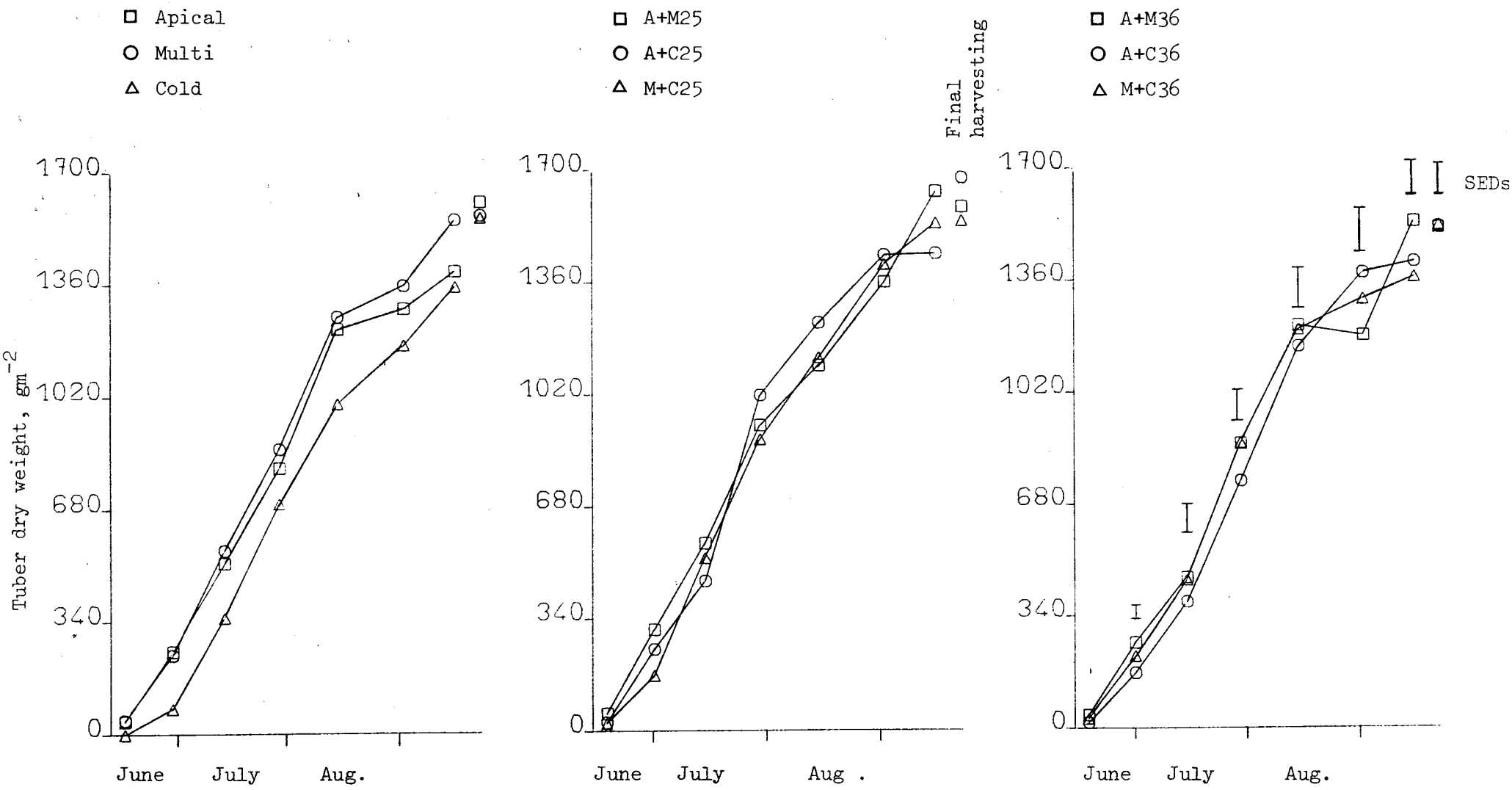


Figure 4.4.3.33 The effects of physiological age and mixing of different physiologically aged tubers on tuber dry weight (Experiment F2).

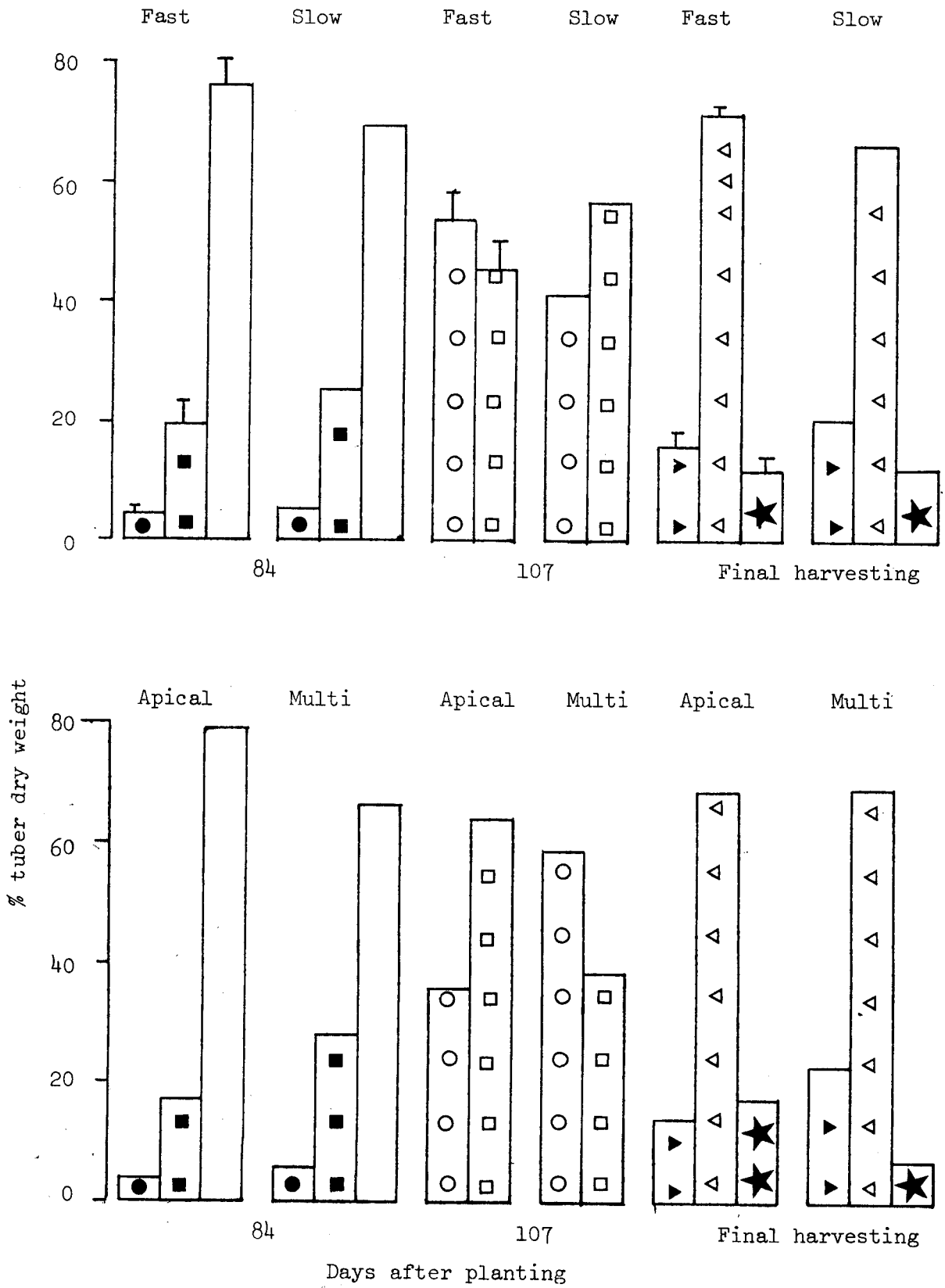


Figure 4.4.3.34 The effects of physiological age and sprouting treatment on proportion of tubers in size grades (dry weight basis). Vertical bars are the SEDs.

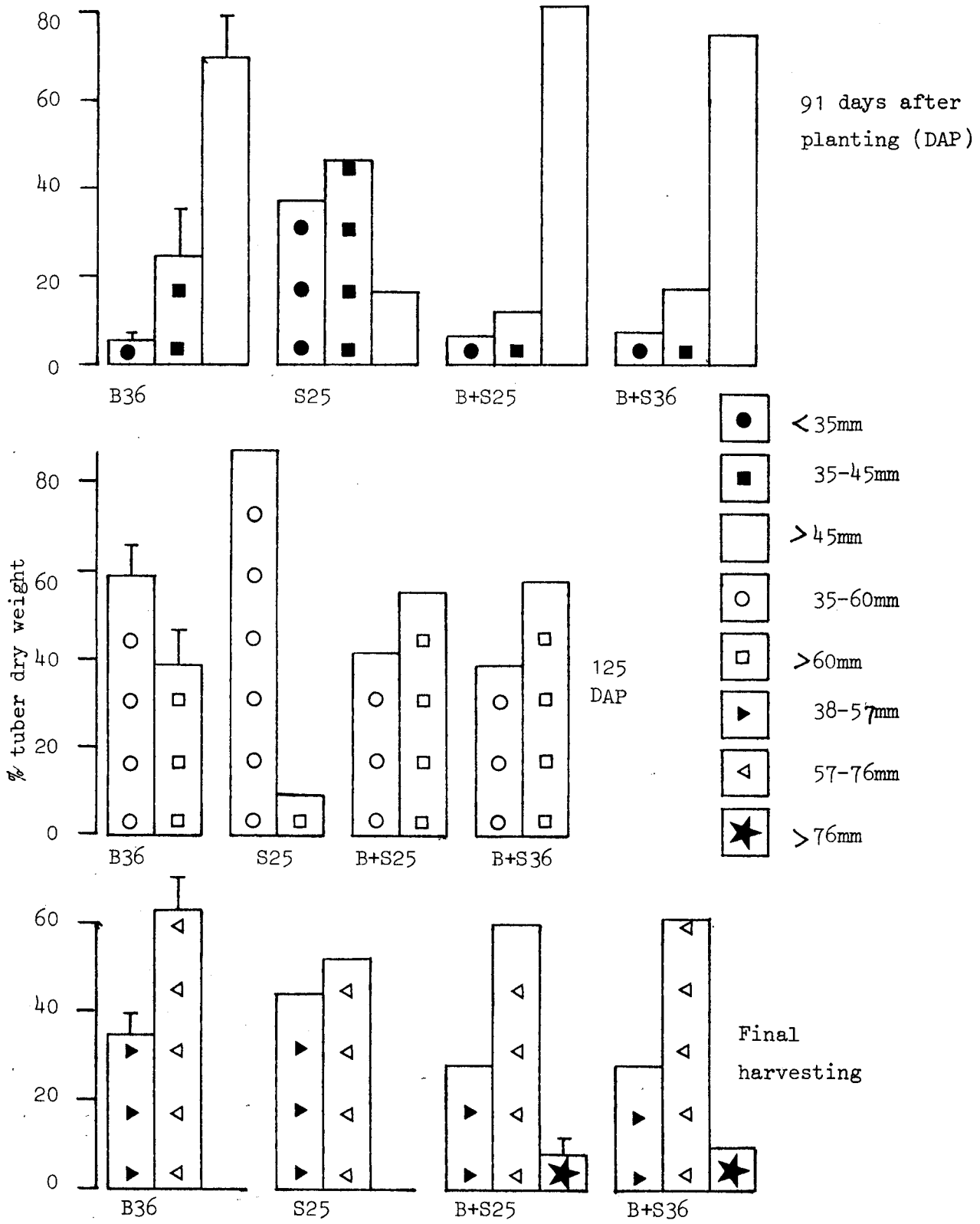


Figure 4.4.3.35 The effects of mixing seed tubers of different sizes on proportion of tubers in size grades (dry weight basis). Vertical bars are the SEDs.

y = 26.31 (± 5.14) + 0.70 (± 0.20) x
% variance accounted for 43.5
residual standard deviation = 5.08

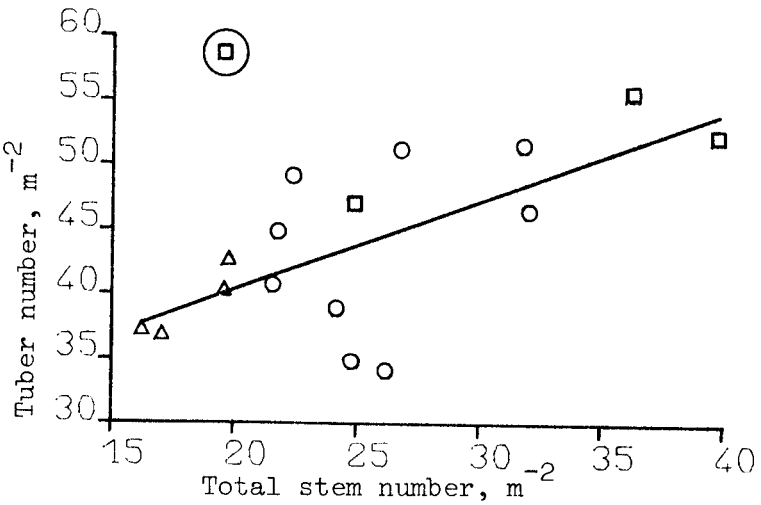


Figure 4.4.3.36 The relationship between tuber number and total stem number (main + branch). Data is average for replicates and is from experiments:
F2, O; F3, Δ ; F4, □ . One point encircled was not included in the regression (see text).

y = 1.92 (± 8.72) + 0.37 (± 0.08) x
% variance accounted for 60
residual standard deviation = 4.27

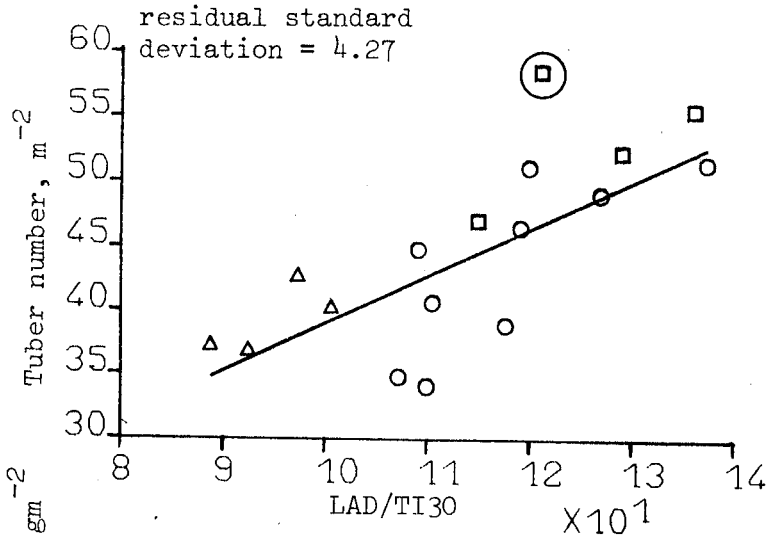


Figure 4.4.3.37 The relationship between tuber number and leaf area duration accumulated for a period of 30 days from the date of tuber initiation (LAD/TI30). Data is average for replicates and is from experiments:
F2, O; F3, Δ ; F4, □ . One point encircled was not included in the regression (see text).

y = -28.08 (± 67.48) + 3.44 (±1.05)x
% variance accounted for 44.9
residual standard deviations=68.36

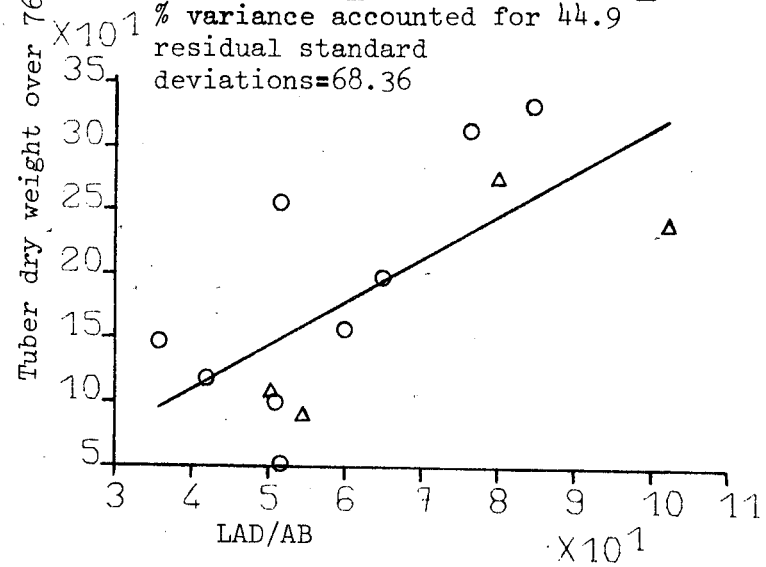


Figure 4.4.3.38 The relationship between tuber dry weight over 76mm and leaf area duration contributed by the axillary branches (LAD/AB) Data is average for replicates and from experiments:
F2, O; F3, Δ .

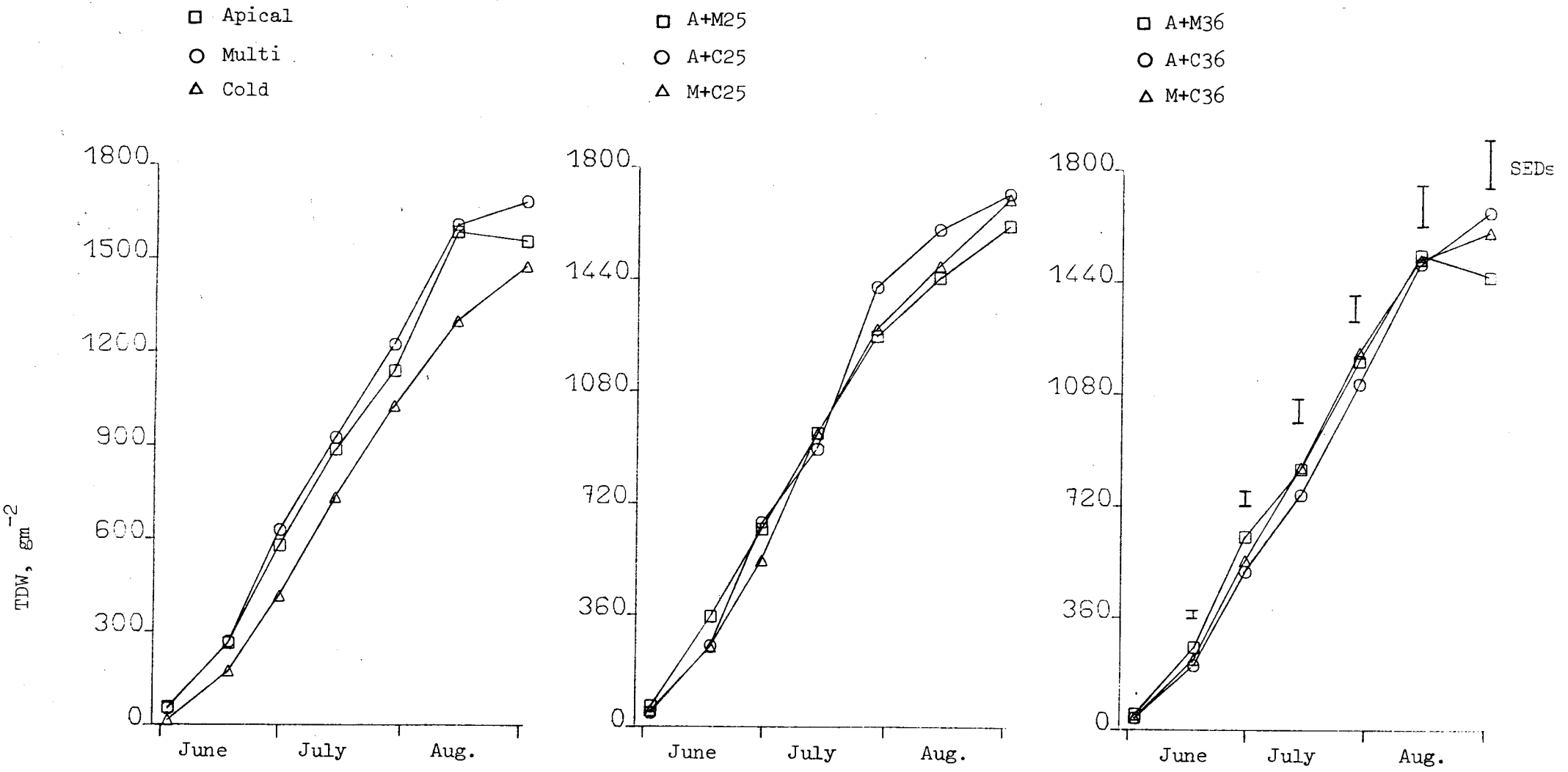


Figure 4.4.3.39 The effects of physiological age and mixing of different physiologically aged tubers on total dry weight (TDW) (Experiment F2).

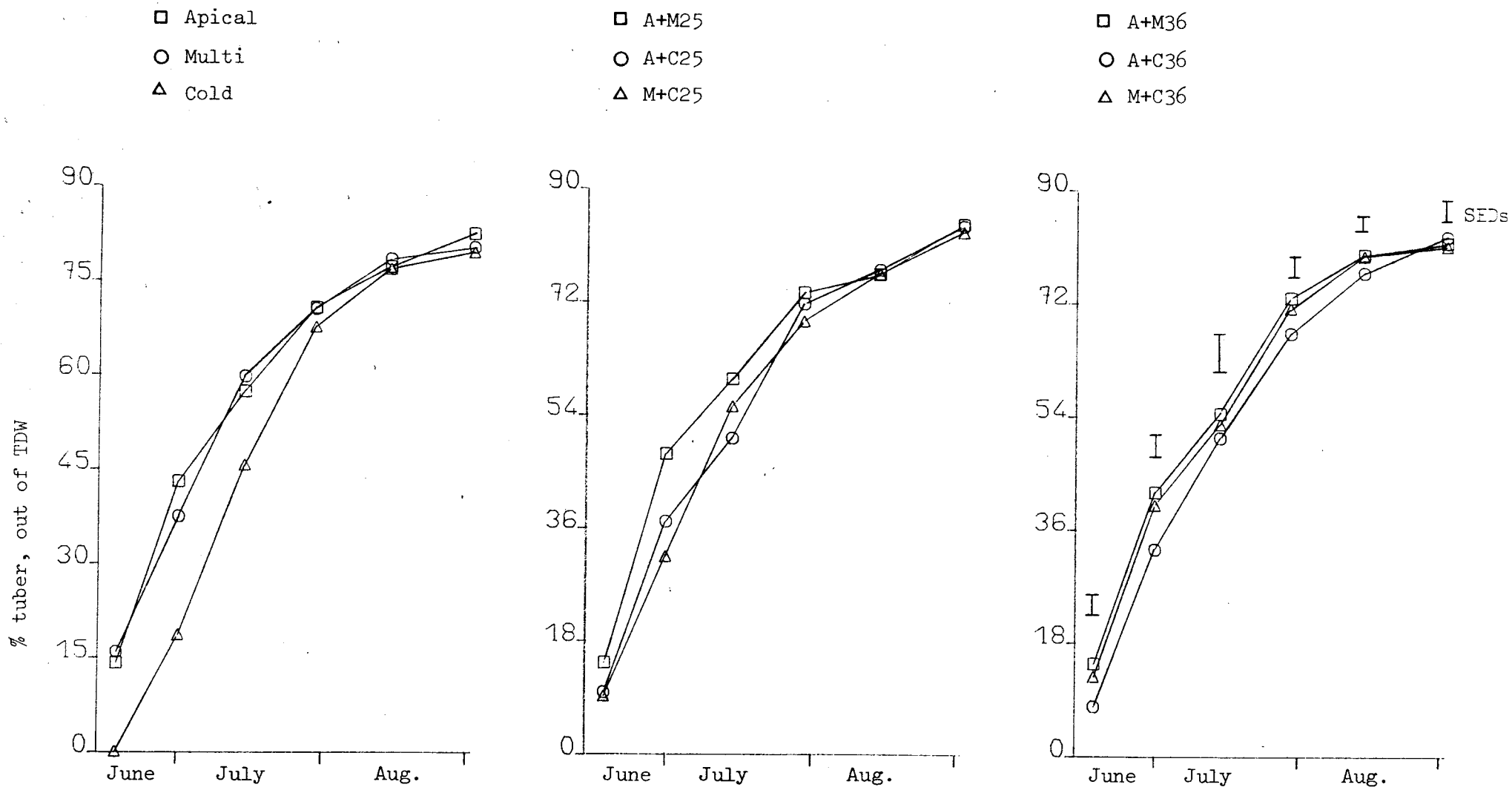


Figure 4.4.3.40 The effects of physiological age and mixing of different physiologically aged tubers on percentage of tubers out of total dry weight (TDW) (Experiment F2).

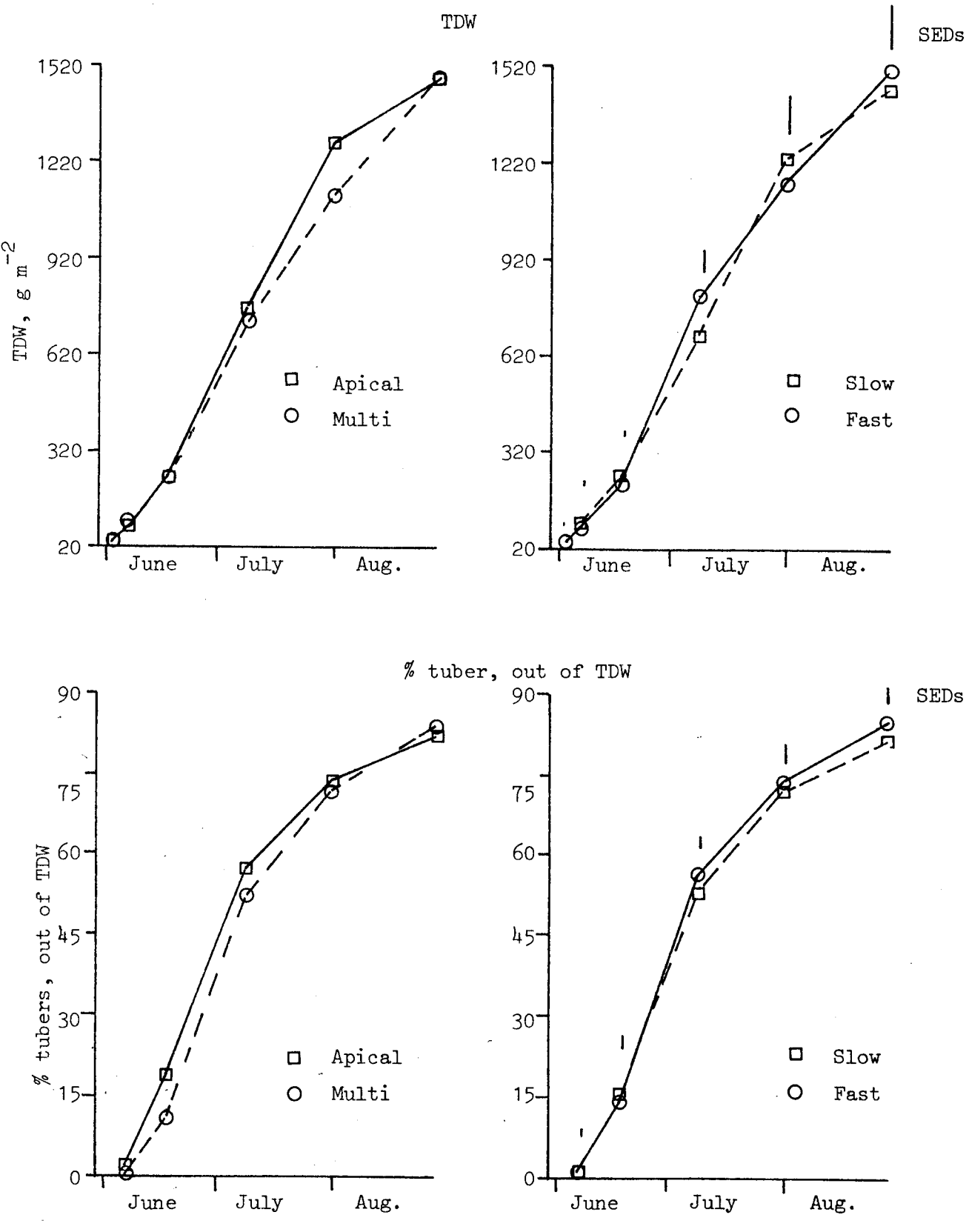


Figure 4.4.3.41 The effects of physiological age and sprouting treatments on total dry weight (TDW) and percentages of tubers out of TDW (Experiment F3).

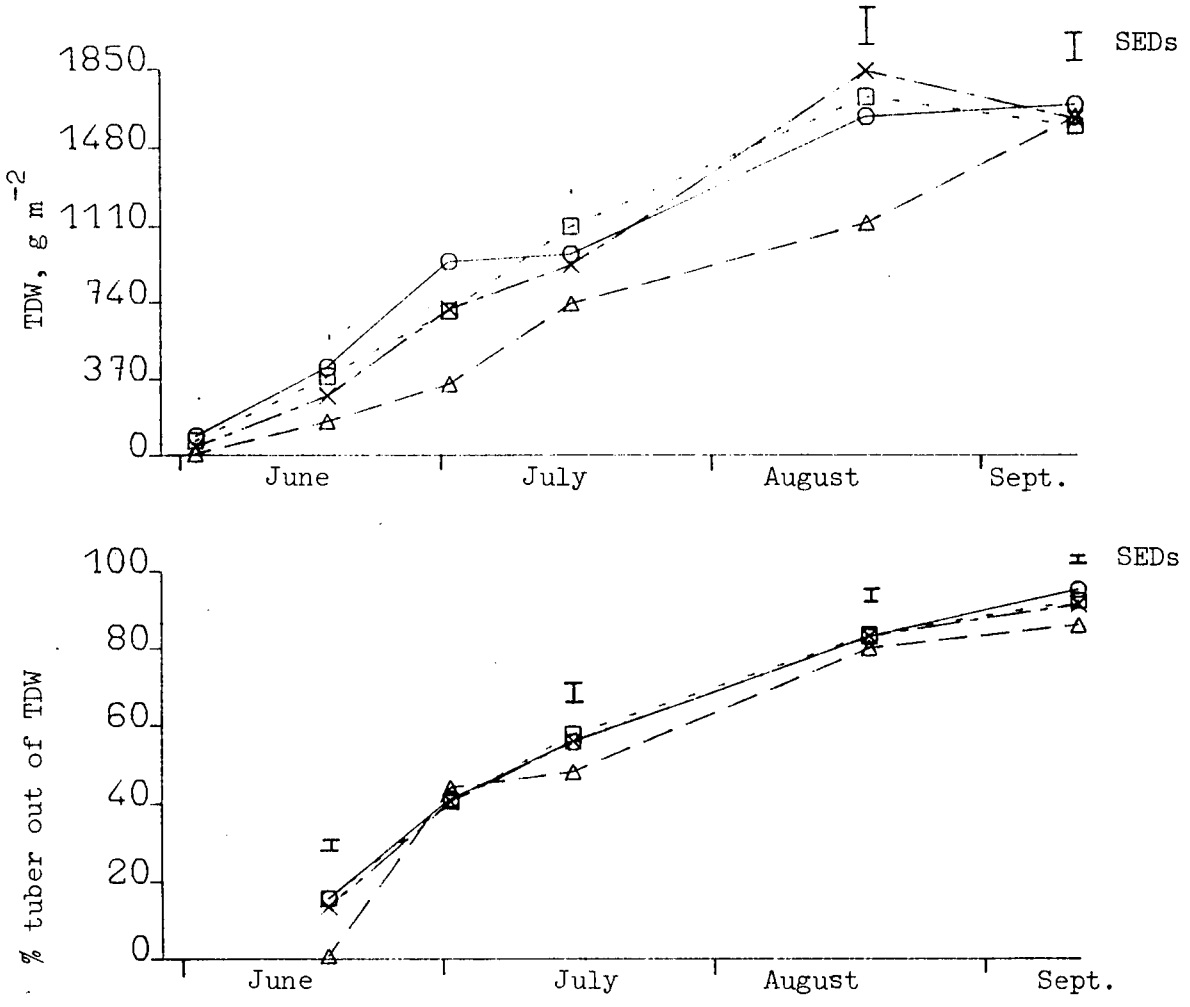
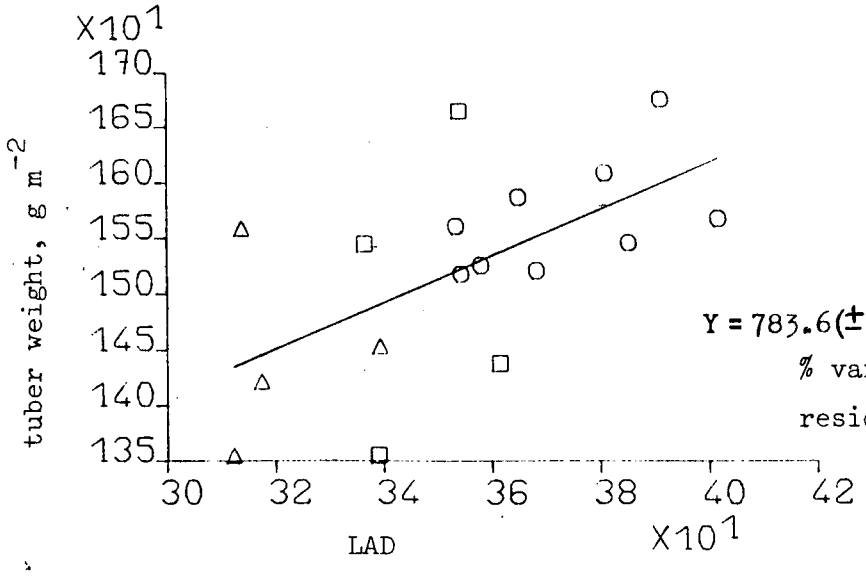


Figure 4.4.3.42 The effects of mixing seed tubers of different sizes on total dry weight (TDW) and percentages of tubers, out of TDW (Experiment F4).

Key: O, B36; Δ, S25; □, B+S25; +, B+S36



$Y = 783.6(\pm 262.5) + 2.09(\pm 0.74)X$

% variance accounted for 30.4

residual standard deviation =77.

Figure 4.4.3.43 The relationship between tuber dry weight and leaf area duration (LAD). Data is average for replicates and is from experiments: F2 (O); F 3 (Δ); F4 (□).

Figures 4.4.4.1 and 4.4.4.2 varied for different sampling dates, but there is not much difference in T value (Table) for the range of RDF found, so for simplification, average (for all dates) RDF along with range is given. In Experiment F2 the mixture never yielded significantly different from the expected yield, i.e. the average of sprouted and cold, when grown alone (Figs.4.4.4.1 and 4.4.4.2). Replacement diagrams for LAI and TDW (Figs.4.4.4.1 and 4.4.4.2) show that competition between 2 components within mixed plot, started after about 60 days from planting, as sprouted in mixture gave higher values for LAI and TDW compared to sprouted in mono and cold in mixture gave lower values for LAI and TDW compared to cold in mono (Figs.4.4.4.1 and 4.4.4.2). Similar results were obtained for tuber weight from 90 days of planting onward (Fig.4.4.4.2). In Experiment F2 at 25cm spacings differences between sprouted and cold were the same as found at 36cm spacings (Figs.4.4.4.1, 4.4.4.2 and 4.4.4.3). For example out of total LAI for mixture, after 63, 76, 90 and 105 days of planting sprouted contributed: 68; 64; 59; 60 percent at 36cm spacing and 67; 57; 69; 64 percent at 25cm spacing respectively. Similar results were for TDW and tuber weight. In Experiment F4 where difference between cold and sprouted was further increased by using different seed size, sprouted contributed about 90% of the total yield of mixture (Fig.4.4.4.4). During 1980, in both the experiments sprouted had an advantage over cold early in the season but both components senesced at the same time i.e. cold did not show any advantage over sprouted later in the season. But it was found that in case of Experiment F4, where cold was suppressed more, the proportion of oversize (>76mm) tubers were increased thus it may not be useful to have bigger differences. So in 1981 it was decided to use the same seed size with difference in sprouting only. Planting

pattern was slightly changed (Chapter 4.3). There was no interaction between 2 planting dates, and so the results presented are averaged for 2 dates. Results for Experiment F5 show that competition between sprouted and cold was not affected by change in planting pattern as results were quite similar to those obtained for Experiment F2 (Figs:4.4.4.5; 4.4.4.1; 4.4.4.2; 4.4.4.3). For example in Experiment F5 after 77, 98 and 119 days of planting (planting date taken as average of two planting dates), in mixture, sprouted contributed: 62; 63; 56 percent of LAI, these figures are quite similar to those obtained for Experiment F2, reported earlier.

4.4.5 Crop evaporation

In 1979, crop evaporation (ET) calculated from the neutron probe data was always lower than the potential evaporation (Penman, 1956) (Fig.4.4.5.1). This may be related to the lower LAI during that year (Fig.4.4.2.8) and evaporation from soil surface may have been very little as the soil was dry during most of the growing season (Fig.4.4.5.2). For convenience the ratio of actual to potential evaporation (Fig.4.4.5.2) is also presented which appears to be increasing in favour of actual, with a decrease in soil moisture deficit and an increase in LAI (Figs.4.4.5.2 and 4.4.2.8). It shows that potatoes are very sensitive to drought. Another factor which may have contributed to the lower values (calculated) of ET, is the capillary movement of ground water which was not measured in the present experiments. In 1980 the field had a slight slope, thus during heavy rains due to surface runoff and drainage loss, ET could have been over-estimated (Fig.4.4.1.3), and when the crop was senescing, measured values were lower than the

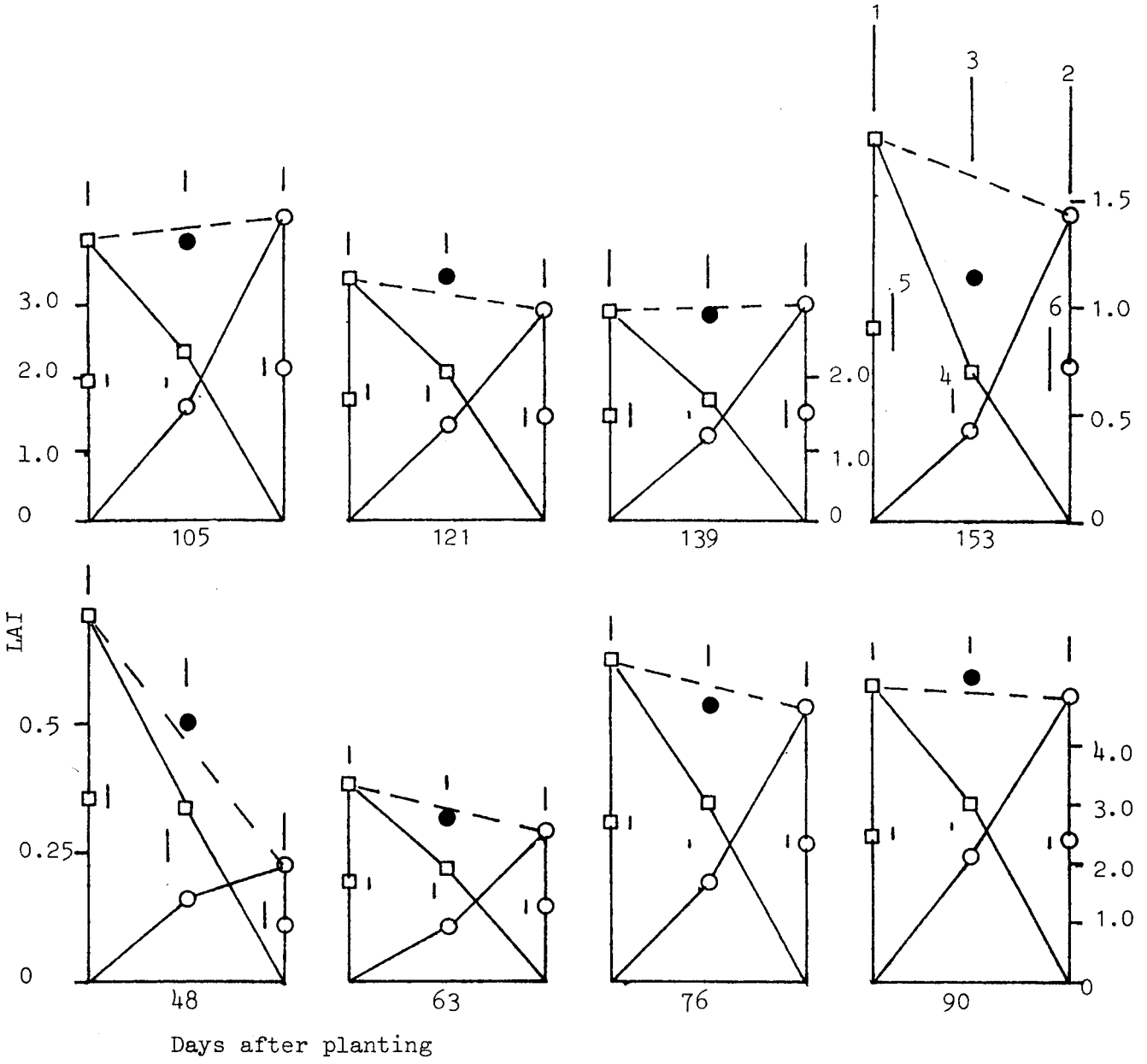


Figure 4.4.4.1 Replacement diagrams for LAI. The scale on left hand side is just for one diagram.

Key: O , Cold; □ , sprouted (average for apical and multi);

● , Mixture for whole plot; 1, SED to compare between sprouted and mixed (whole plot basis); 2, SED to compare between cold and mixed (whole plot basis); 3, SED to compare between mixed and mean of cold and sprouted (whole plot basis); 4, SED to compare between sprouted and cold within plot; 5, SED to compare between sprouted (half plot basis) and its counter part in mixed; 6, SED to compare cold (half plot basis) with its counter part in mixed. Residual degrees of freedom are: 16 for SEDs 1, 2, 3; 8 for SED 4; 21 (17-24) for SEDs 5, 6.

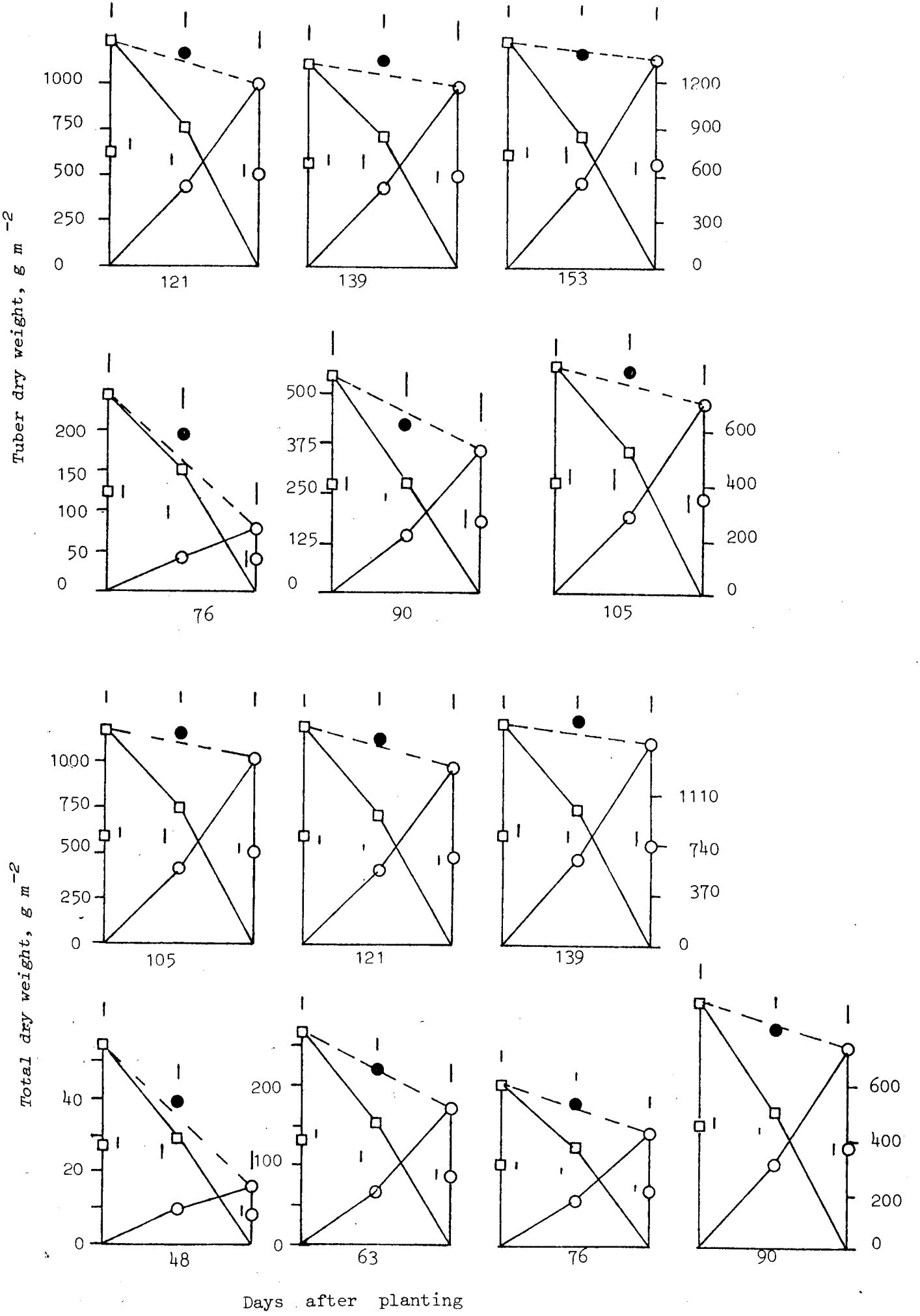


Figure 4.4.4.2 Replacement diagrams for total dry weight and tuber dry weight. For meaning of symbols, SEDs and residual degrees of freedom (RDF). see figure 4.4.4.1 except that RDF for SEDs 5 & 6 is 22(19-24) for tuber dry wt and 23(20-24) for total dry weight.

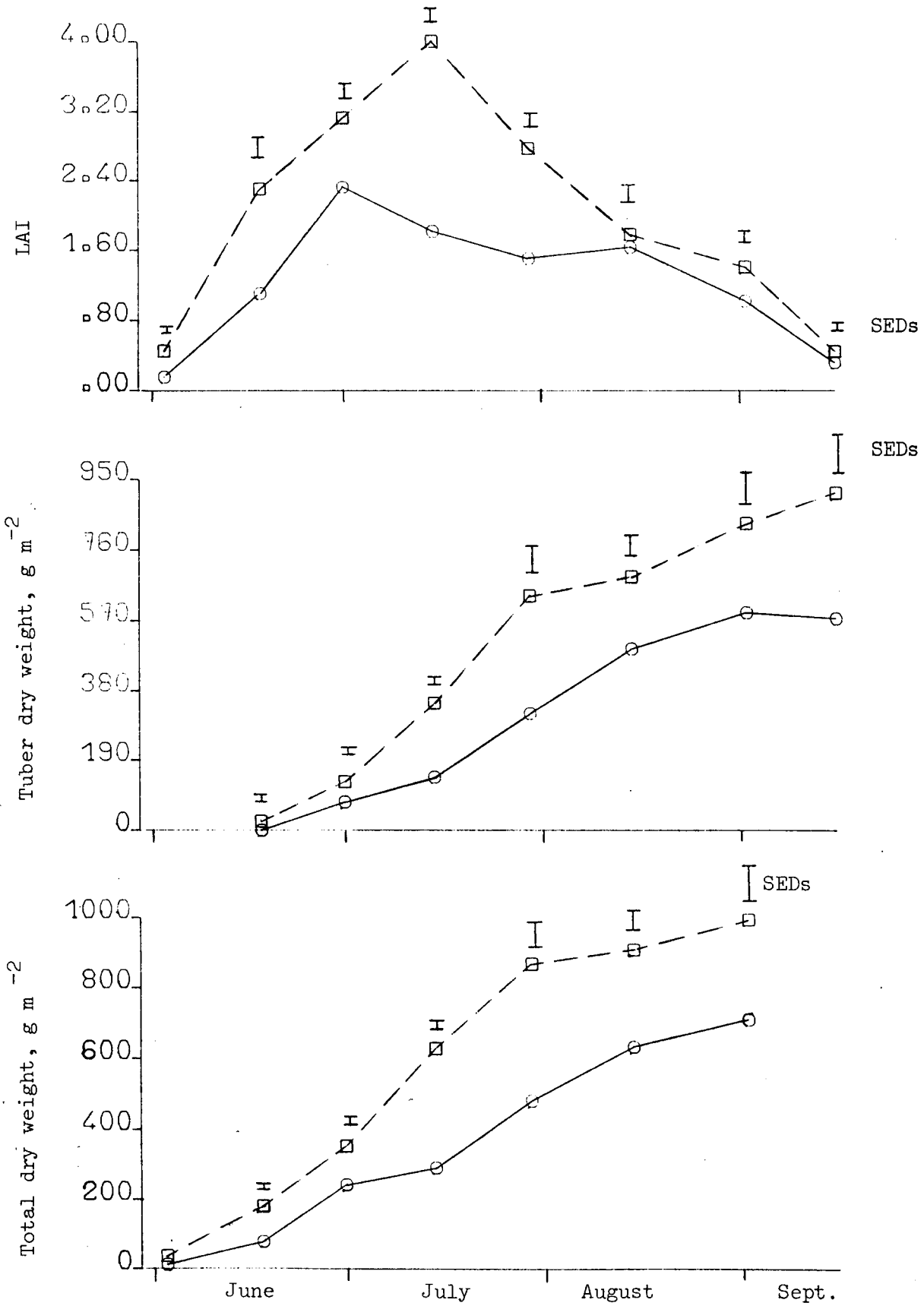
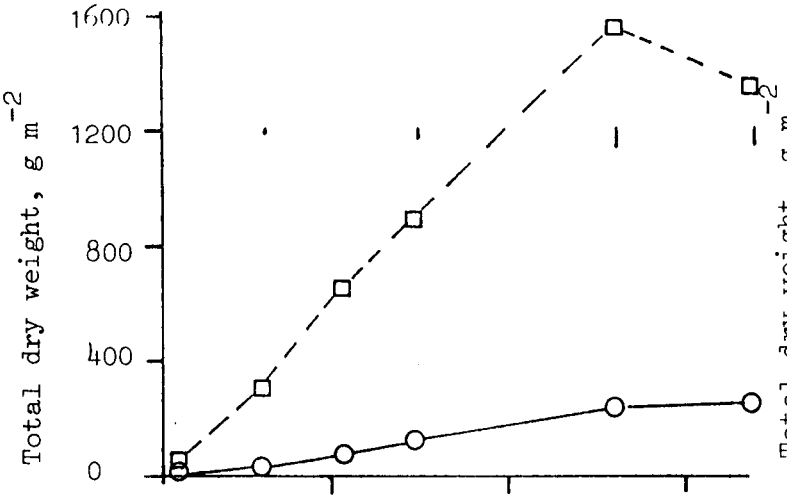
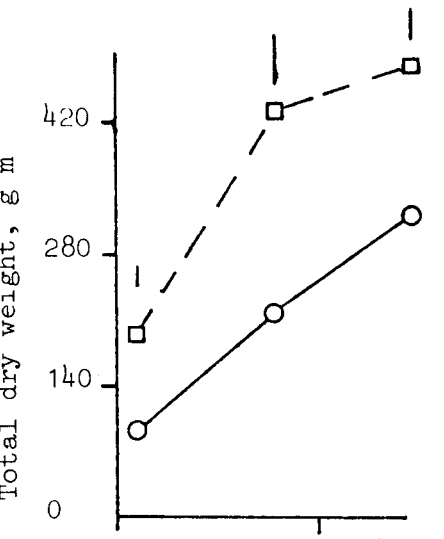
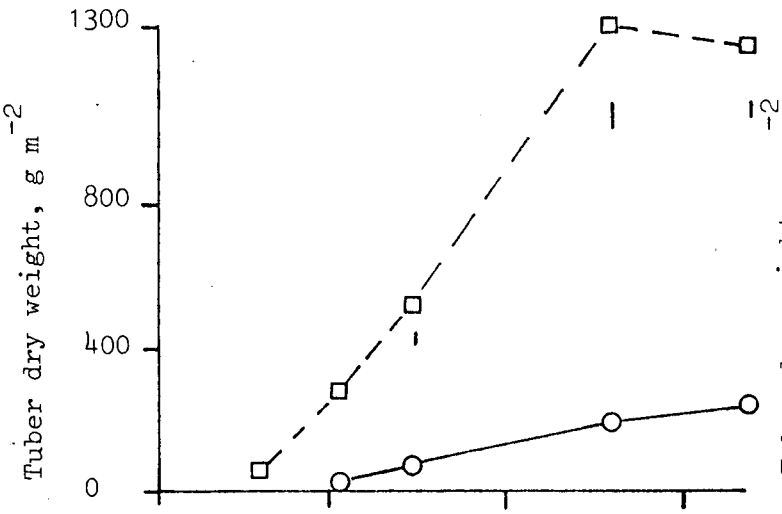


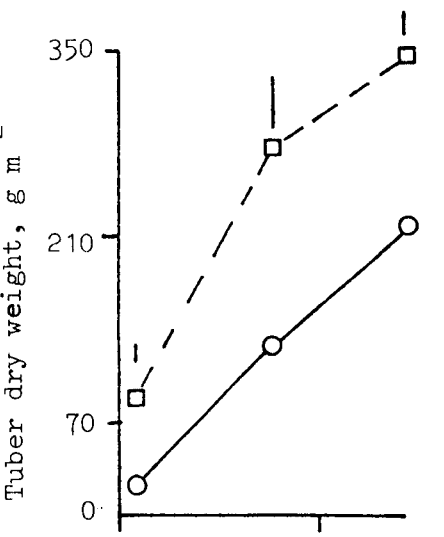
Figure 4.4.4.3 Growth of 2 components within mixed plot at 25cm spacing.

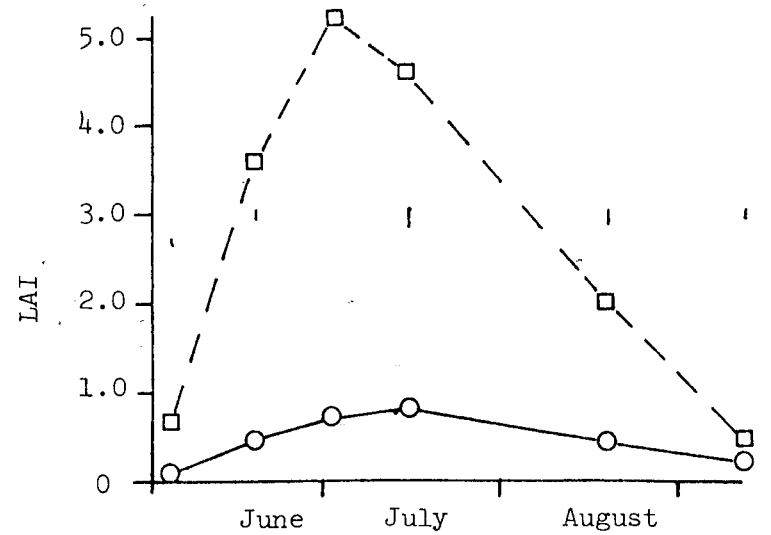
Key: □ ,sprouted (mean of apical and multi); ○ , unsprouted (cold)(Experiment F2).











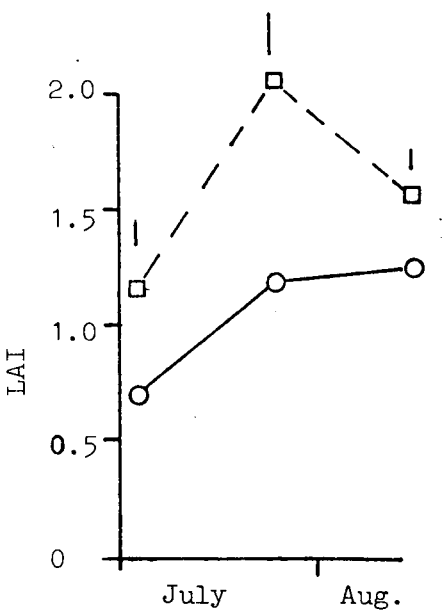


Figure 4.4.4.4 Growth of 2 components within mixed plot (Experiment F4). Residual degrees of freedom (RDF) is 4 except for 4th sampling for which it is 2.
Key: □, Big; ○, small. Vertical bars are the SEDs.

Figure 4.4.4.5 Growth of two components within mixed plot (Experiment F5). RDF is 4.
Key: □, apical; ○, cold. Vertical bars are the SEDs.

Potential, which is related to decline in LAI. For further calculations, Potential evaporation data for 1980 and measured for 1979, are used.

Evaporation for various treatments of Experiment F1 (1979) is presented in Fig.4.4.5.1. Evaporation was only slightly affected by varieties. Apical treatment had a slightly higher evaporation rate early in the season but later on multi had higher compared to apical. For example, total evaporation (MM) from 4th June to 30th July and 31st July to 7th October was 78.5 and 93.2 for apical and 71.0 and 101.2 for multi respectively. Spacing did not affect the evaporation (Fig.4.4.5.1) except that during the later part of the growing season evaporation was slightly higher in S40. During severe drought roots of the variety Record penetrated slightly deeper than those of Pentland Crown (Fig.4.4.5.3), other treatments had no effect on rooting depth (data not presented). In 1980 before the onset of heavy rains the soil was quite dry early in the season and roots by 11th June were extracting water from 70-80cm depth and there was no difference amongst the various treatments. After that root penetration could not be followed as most of the time the field was near field capacity. At the end of the season (beginning of Sept.) it was found that roots did not go deeper than 80cm.

The relationship between crop evaporation and crop growth rate is presented in Figure 4.4.5.4. Leaf senescence within the canopy was evident in 1980 at an earlier date than in 1979, which may have been due to differences in humidity and LAI between the years. Consequently, the total dry weights for 1980 were adjusted to account for the early leaf loss, with estimates of leaf weight loss being related to the dry weight of senesced leaves and number of missing leaves. Crop growth rate data presented in Figure 4.4.5.4 is adjusted (roots not included) and refer to harvests up to 15th August in 1980 and 20th August for Record and

10th September for Pentland Crown in 1979, since it was not possible to account for weight losses due to stem rotting after these dates. The five points encircled on the Figure 4.4.5.4 were not included in the regression, four were for the year 1980 when ground was not covered and thus Potential evaporation was over-estimated and one point for 1979, Pentland Crown, 27th July to 8th August, as a lot of the leaves had senesced during that period and no adjustment was made. Linear regression for the remaining points accounted for 79.5 percent of the variance in crop growth rate.

4.4.6 Light interception and potato growth

4.4.6.1 Leaf area index and photosythetically active radiation (PAR) interception.

The relationship between leaf area index (LAI) and the proportion of PAR intercepted by the crop canopy is shown in Figure 4.4.6.1. Up to LAI values around two the relationship appeared to be almost linear, while above four, PAR interception was relatively constant. The characteristics of light transmission in crop canopies have been related to Beerl's Law by the equation $I_L = I_0 e^{-kL}$, where I_L = the irradiance on a horizontal plane below a leaf area index of L, and k = a light extinction coefficient, assuming a homogenous canopy, which depends on the transmission characteristics of single leaves and their geometrical arrangement (Monteith, 1965). The relationship generated by this equation did not fit the measured data over the range of LAI found in these experiments (Fig.4.4.6.1). From the analysis it appeared that the light extinction coefficient value, k, was not constant as LAI increased.

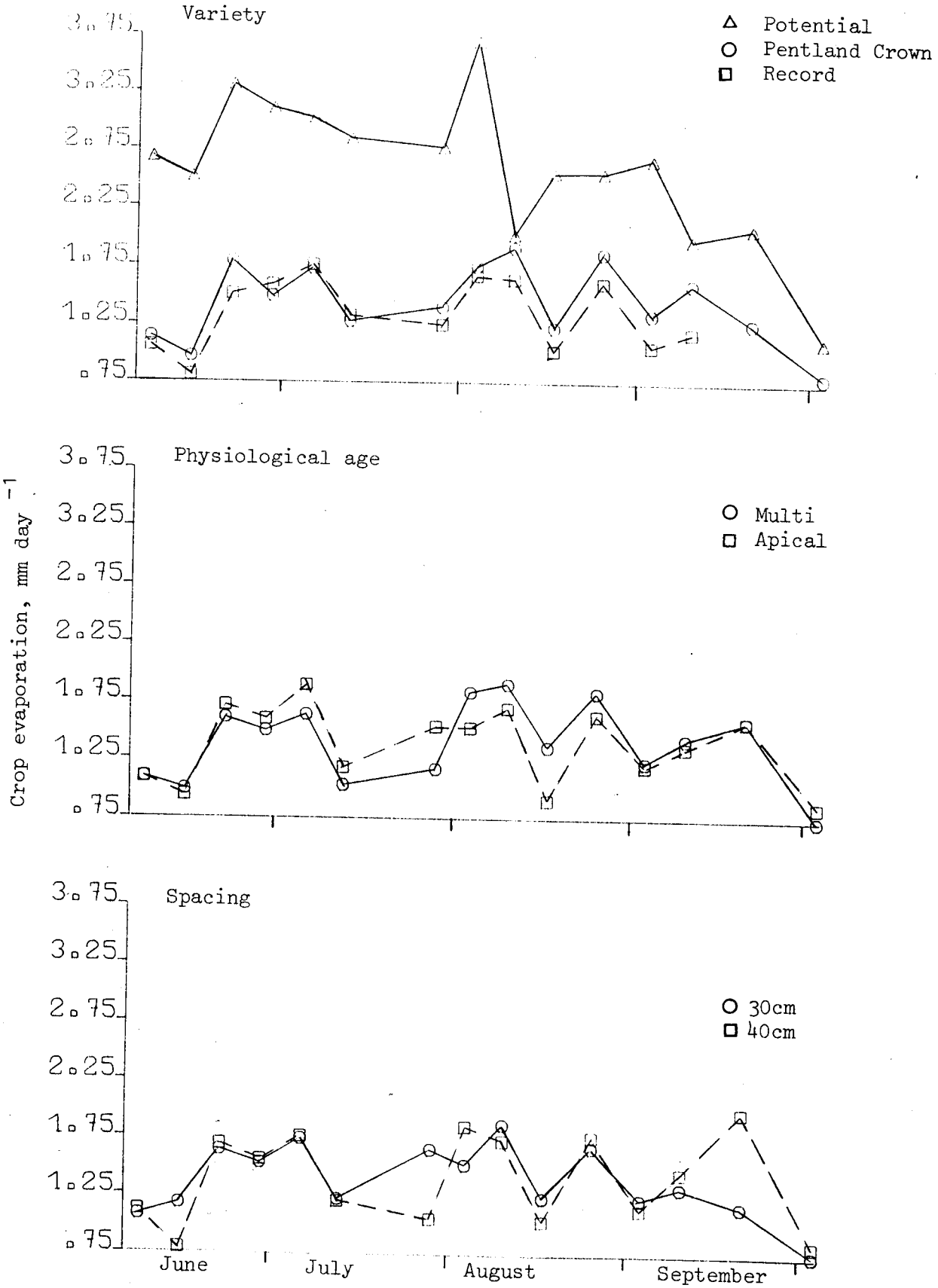


Figure 4.4.5.1 The effects of variety, physiological age and spacing on crop evaporation (Experiment F1).

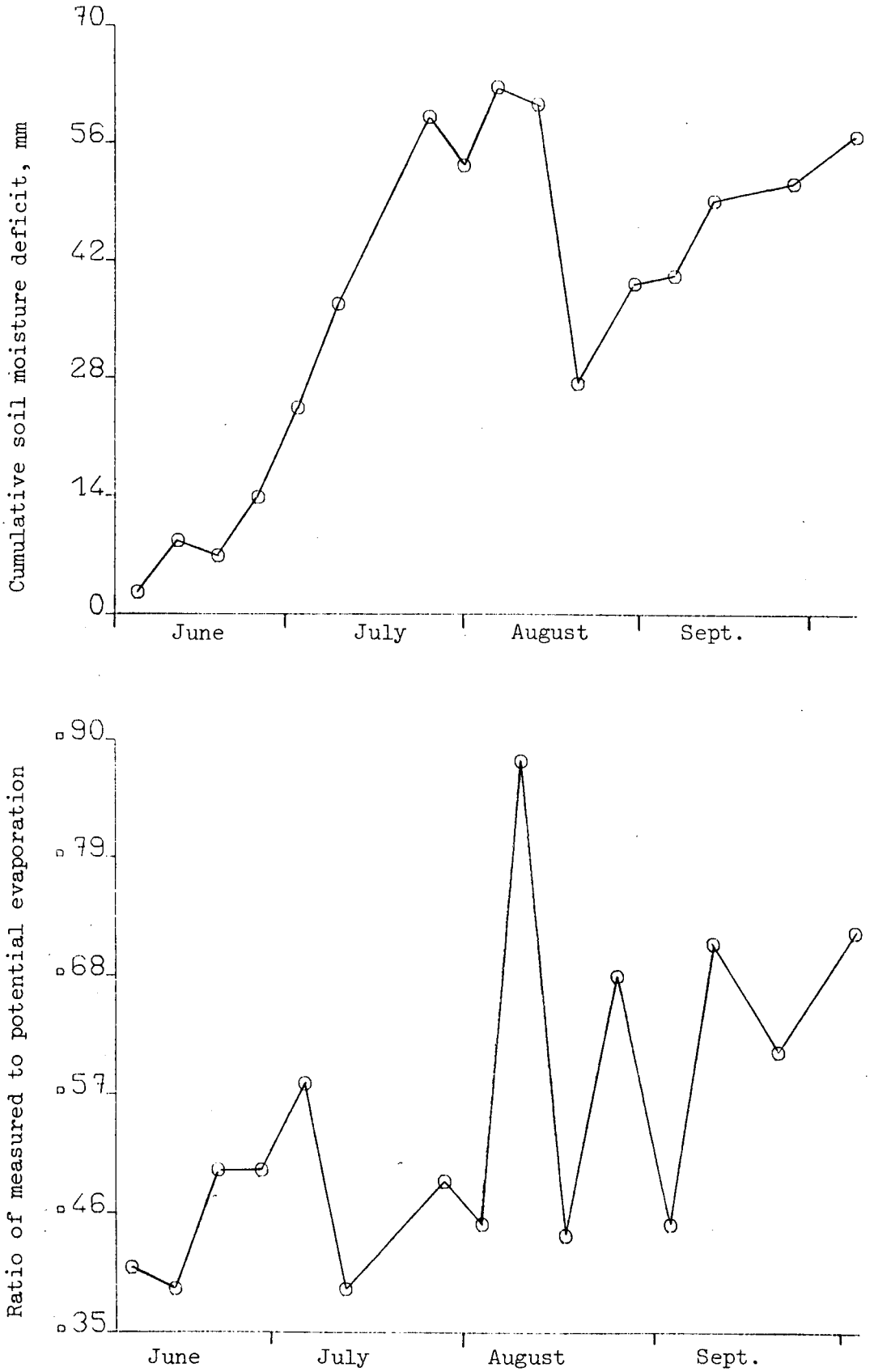


Figure 4.4.5.2 Cumulative soil moisutre deficit and ratio of measured (neutron probe) to potential evaporation (Experiment F1, average for 2 varieties).

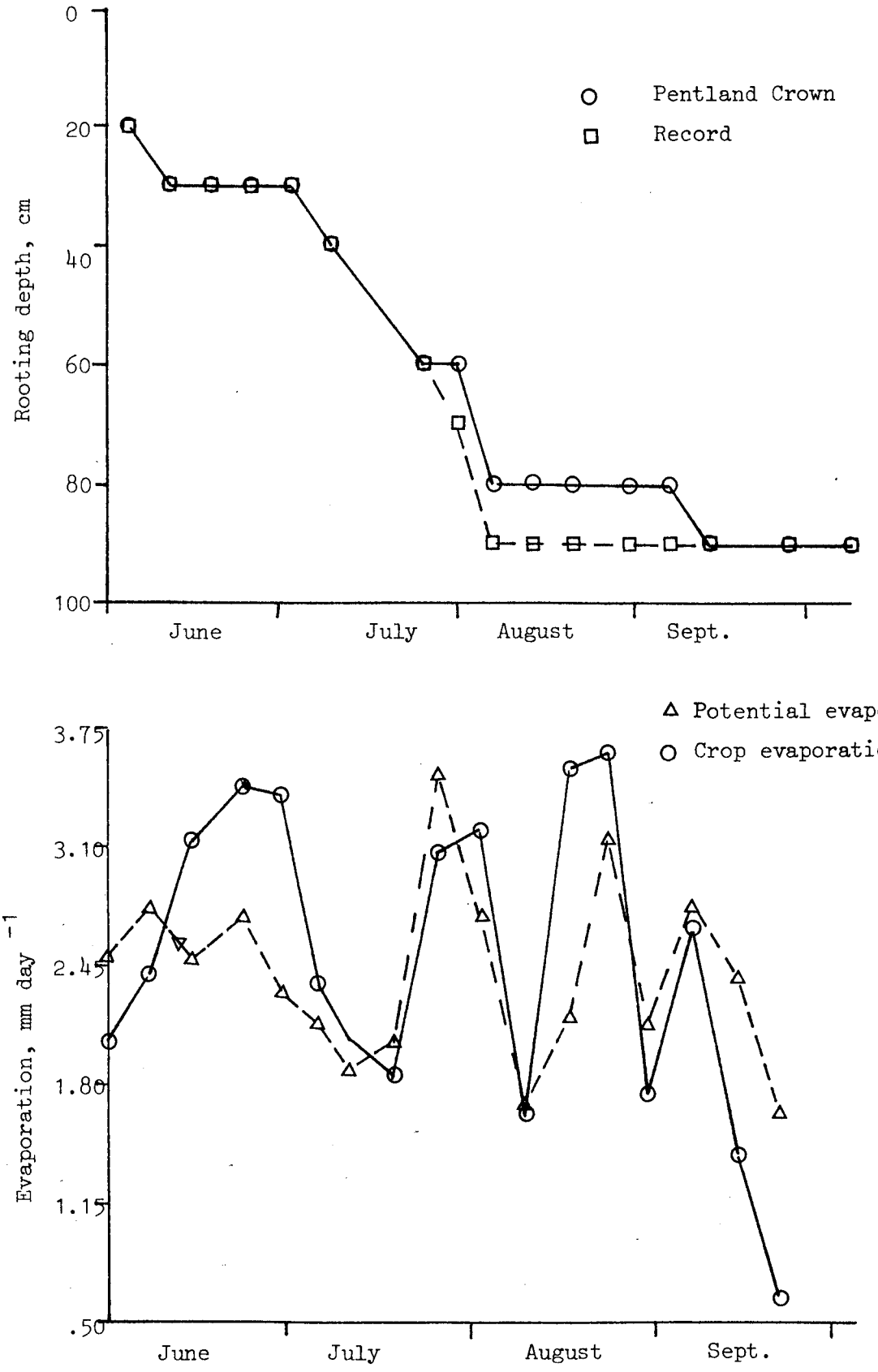


Figure 4.4.5.3 The effects of variety on rooting depth (Experiment F1) and crop and potential evaporation during, 1980 (Experiment F2).

$Y = 10.98 (\pm 1.27) x - 2.56 (\pm 2.48)$

% variance accounted for 79.5

residual standard deviation = 2.78

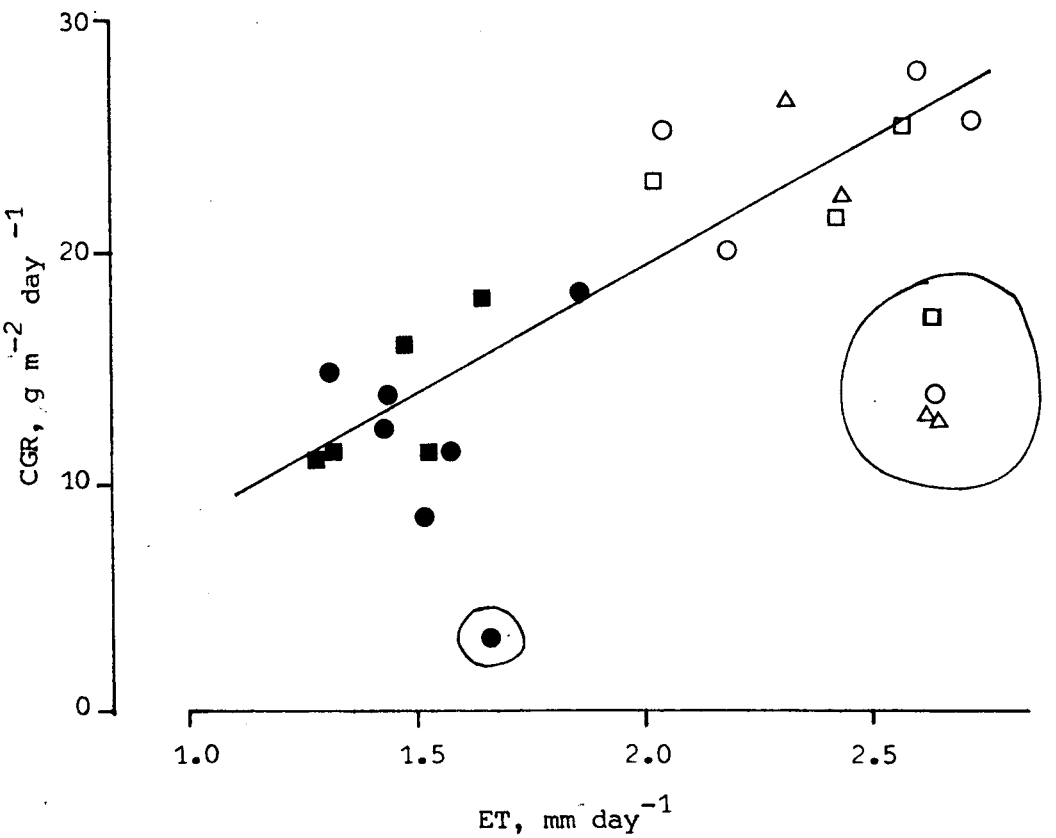


Figure 4.4.5.4. The relationship between crop growth rate and crop evaporation (ET). Key: ○ , exp. F2; △ , exp. F3; □ , exp. F4; ● and ■ , exp. F1 (Pentland Crown and Record respectively). The points encircled were not included in the regression (see text).

In these experiments, increased LAI was associated with crop growth as a function of time and therefore it may be expected that changes in leaf angle, size, distribution and transmission characteristics with leaf age would occur. A significant ($P = 0.001$) quadratic relationship was found between k and LAI and could be represented by the equation; $k = 0.335 + 0.151L - 0.013L^2$ (Fig.4.4.6.2) (where L = LAI). When these calculated values for k were substituted into the Beer's Law equation the resulting fit to the data accounted for 92% of the variance compared with 88% when a constant k(= 0.72) was used (Fig.4.4.6.1). Thus the data indicated that k was relatively lower at lower leaf area indices, earlier in the season. Differences in leaf angle which may occur during the season would obviously affect the light interception characteristics of the canopy, but such differences were probably confounded with other changes for example leaf distribution, and individual effects could not be determined, from these experiments.

The PAR interception data (Fig.4.4.6.1) was obtained from all the treatments of Experiments: F1, F2, F3, F4 and although LAI varied, the relationship between LAI and PAR interception did not vary systematically with any of the agronomic treatments.

4.4.6.2 Dry matter production

Daily incoming PAR data was obtained from a site within one km. of the experiments (courtesy of H. Bateman, Environmental Physics Section). On a few occasions when instruments failed, total solar radiation (ST) values were obtained from a nearby Meteorological Station and PAR was calculated as PAR = 0.53 (ST), from the relationship shown in Figure 4.4.6.3.

A significant linear relationship was found between cumulative total dry weight (TDW) (TDW, used in the chapter is adjusted see Chapter 4.4.5) and cumulative PAR intercepted in both years, and the 1980 data are shown in Figure 4.4.6.4. When forced through the origin, total dry weight (TDW) = 2.49 (PAR) and 3.42 (PAR) for 1979 and 1980, respectively, indicating that conversion of light to dry matter was more efficient in 1980. Although such an effect may be explained in terms of water stress in 1979 (Chapter 4.4.5), relationships based on cumulative data are not entirely satisfactory since other variables, and time, may be confounded with the apparent effect.

The photosynthetic conversion efficiency (g dry wt MJ^{-1} PAR intercepted) for the canopy was calculated for each growth analysis period. In general, the experimental treatments had no significant effect on photosynthetic efficiency and therefore the general temporal patterns for varieties in 1979, and individual experiments in 1980, are shown in Figure 4.4.6.5. In general, photosynthetic efficiency was higher in 1980 compared with 1979, probably as a consequence of differences in water stress. The variety Record had a higher conversion efficiency than Pentland Crown, during early August, and it may be that Record was less affected, since neutron probe data indicated that Record had a slightly deeper root system. Later in August the photosynthetic efficiency of Record was lower than that of Pentland Crown due to earlier canopy senescence.

Crop growth rate (CGR) as a function of PAR interception is shown in Figure 4.4.6.6. A linear relationship was evident for 1980, while CGR was severely restricted under the drought conditions of 1979. Calculation of intercepted PAR, assuming constant k = 0.7, from LAI values resulted in a similar relationship between CGR and PAR.

However the relationship with measured PAR accounted for 91% of the variance in CGR while that with calculated PAR interception accounted for 84%. The difference was due to the fact that k was not constant throughout the season as discussed previously.

Although CGR and total dry matter production are important the factor of major concern in potatoes is tuber yield. The relationship between tuber yield and intercepted PAR is shown in Figure 4.4.6.7. Although photosynthetic conversion efficiency (g tuber dry wt MJ^{-1} PAR intercepted over the whole season) for tuber weight was slightly different for two years: tuber dry weight = 1.97 (PAR) and 2.37 (PAR) for 1979 and 1980 respectively, but still a significant linear relationship between tuber dry weight and total PAR intercepted over the whole season existed (Fig.4.4.6.7). Between two varieties in 1979, Record was 13.4% more efficient than Pentland Crown in converting light to tubers.

4.4.7 Experiment F5

Soil temperature, at 10cm depth and screen, max. and min. air temperature and rainfall from April to October 1981 are given in Figures 4.4.7.1 and 4.4.7.2.

4.4.7.1 Emergence and stem number

The cold treatment took 45 days to reach 50% emergence compared to 31.7 for apical, a difference bigger than the one found for Exp. F2 (1980). This may be explained by the difference of temperature at the time of planting of two treatments in this experiment. Similarly

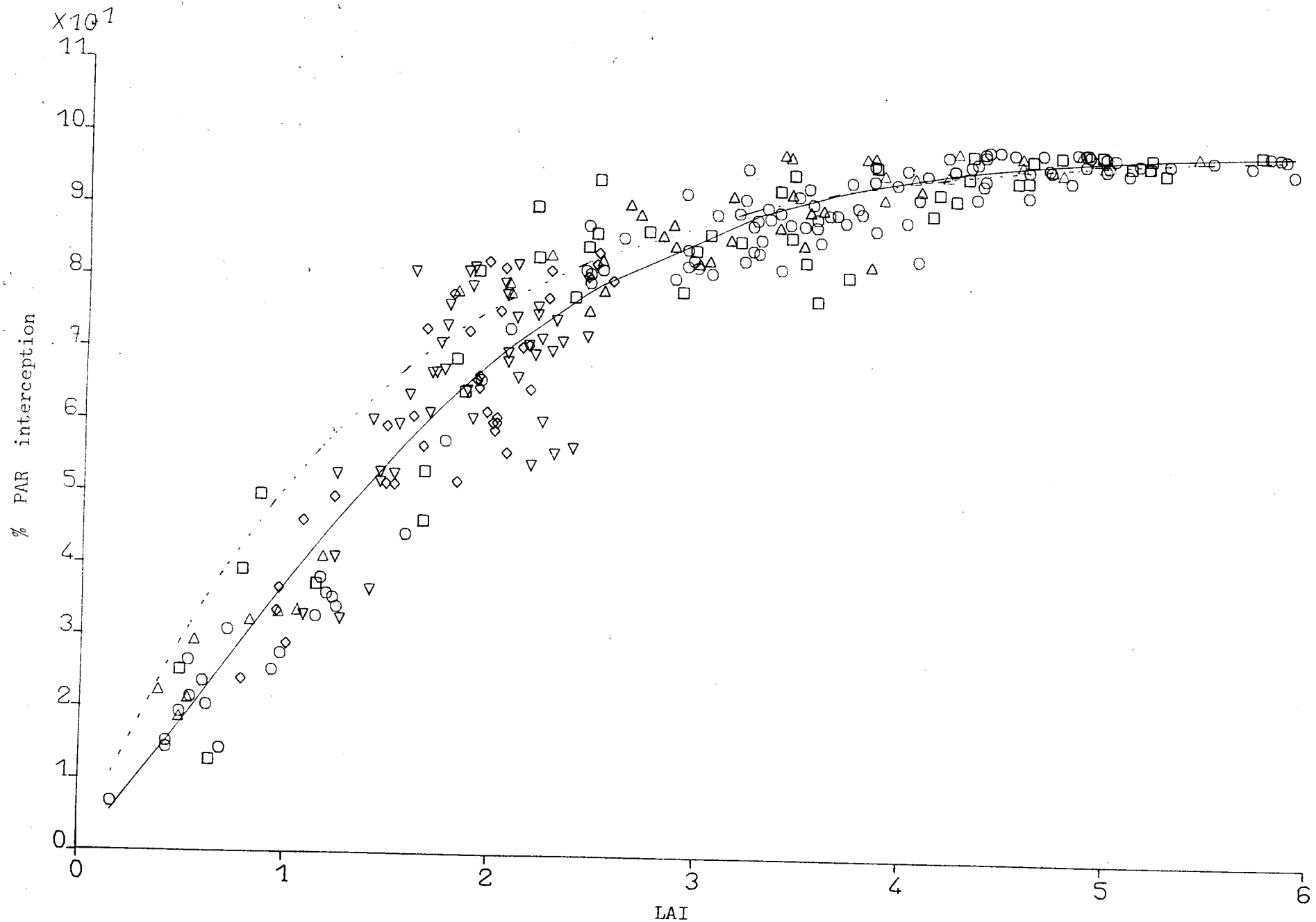
Figure 4.4.6.1 The relationship between LAI(L) and intercepted PAR in 1979 and 1980. Each data point is the mean of replicates for a particular treatment. Excludes data from late in the 1980 season when LAI was declining and stems were intercepting a higher proportion of radiation (total number of points 278).

(a) PAR interception = $1-e^{-kL}$, where k = 0.72 (----)
residual standard deviation (RSD) = 7.90
% variance accounted for 88.26.

(b) PAR interception = $1-e^{-{}^{1}kL}$ (------) ^{2}
where ${}^{1}k = 0.335\ (\pm\ 0.038) + 0.151\ (\pm\ 0.030)\ L - 0.013(\pm 0.005)L$

RSD = 6.49
% variance accounted for 92.1

Key: ○, Experiment F2; △, Experiment F3; □, Experiment F4; ◇, Record /Experiment F1); ▽, Pentland Crown (Experiment F1).


X10-1
11
10
9
8
7
6
5
4
3
2
1
0
% PAR interception
0
1
2
3
4
5
6
LAI

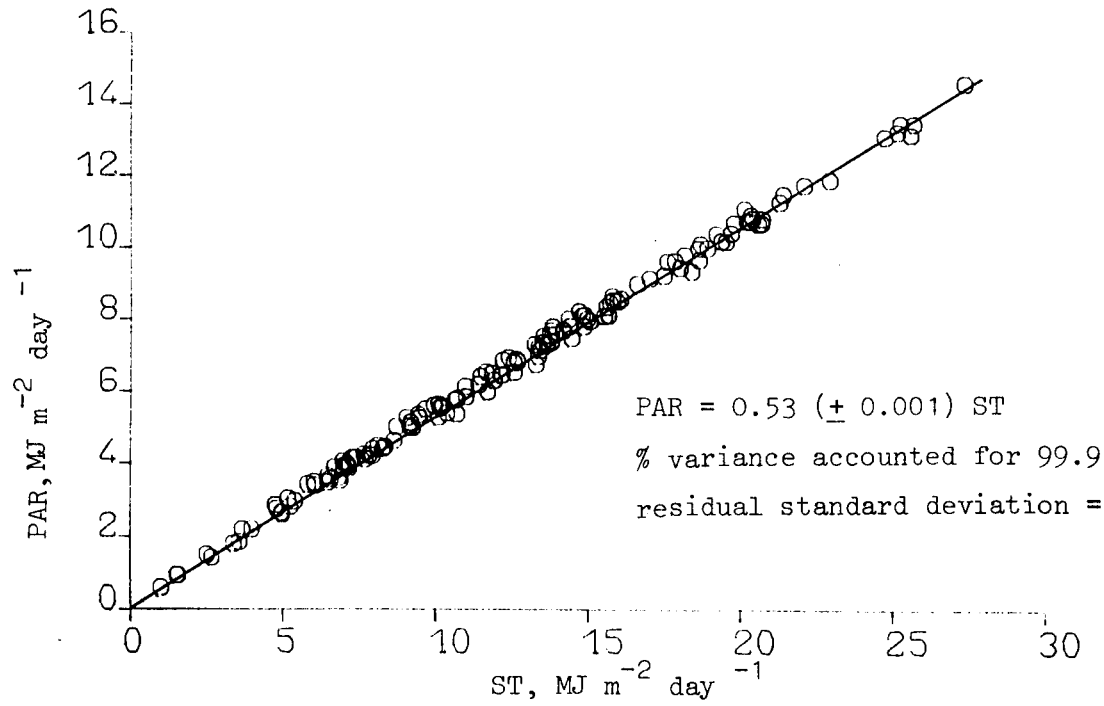


Figure 4.4.6.3 The relationship between photosynthetically active radiation (PAR) and total incoming radiation (ST) on a horizontal plane. Data from 144 days between May-October, 1979.

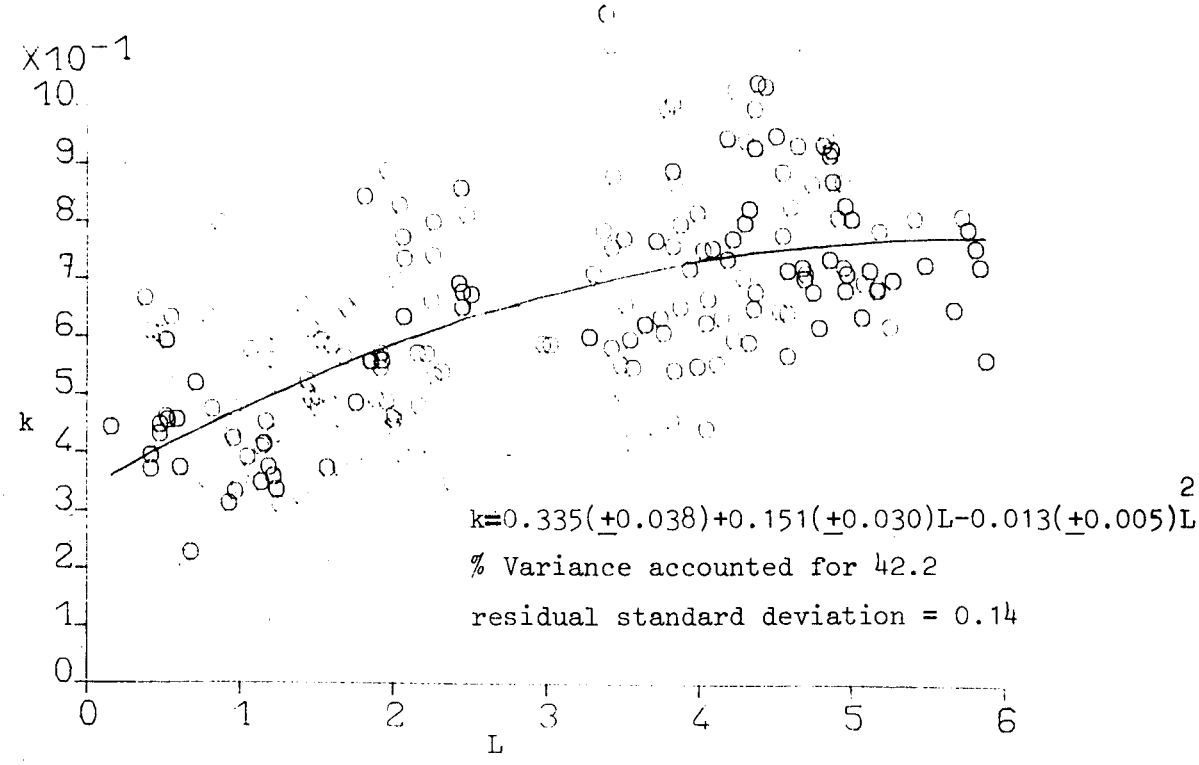


Figure 4.4.6.2 The relationship between k and leaf area index (L). Data from experiments: F1; F2; F3; F4. Excludes data from late in the season when LAI was declining and stems were intercepting a higher proportion of radiation (total no. of points 195).

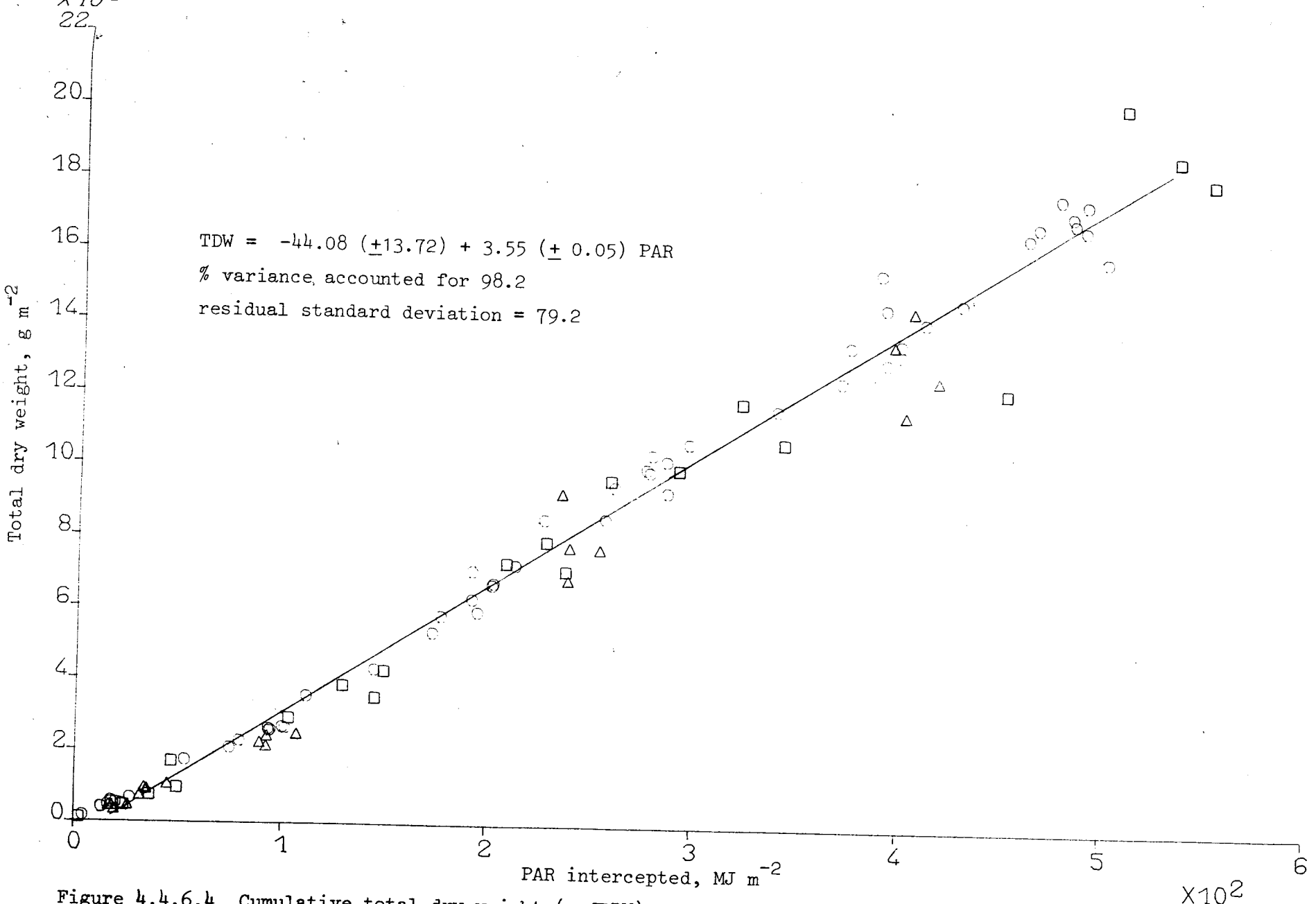


Figure 4.4.6.4 Cumulative total dry weight ($\overline{T}$DW) as a function of cumulative total PAR interception for all experiments in 1980. Each data point is an average for replicates (total number of points 94). For meaning of symbols see figure 4.4.6.1.

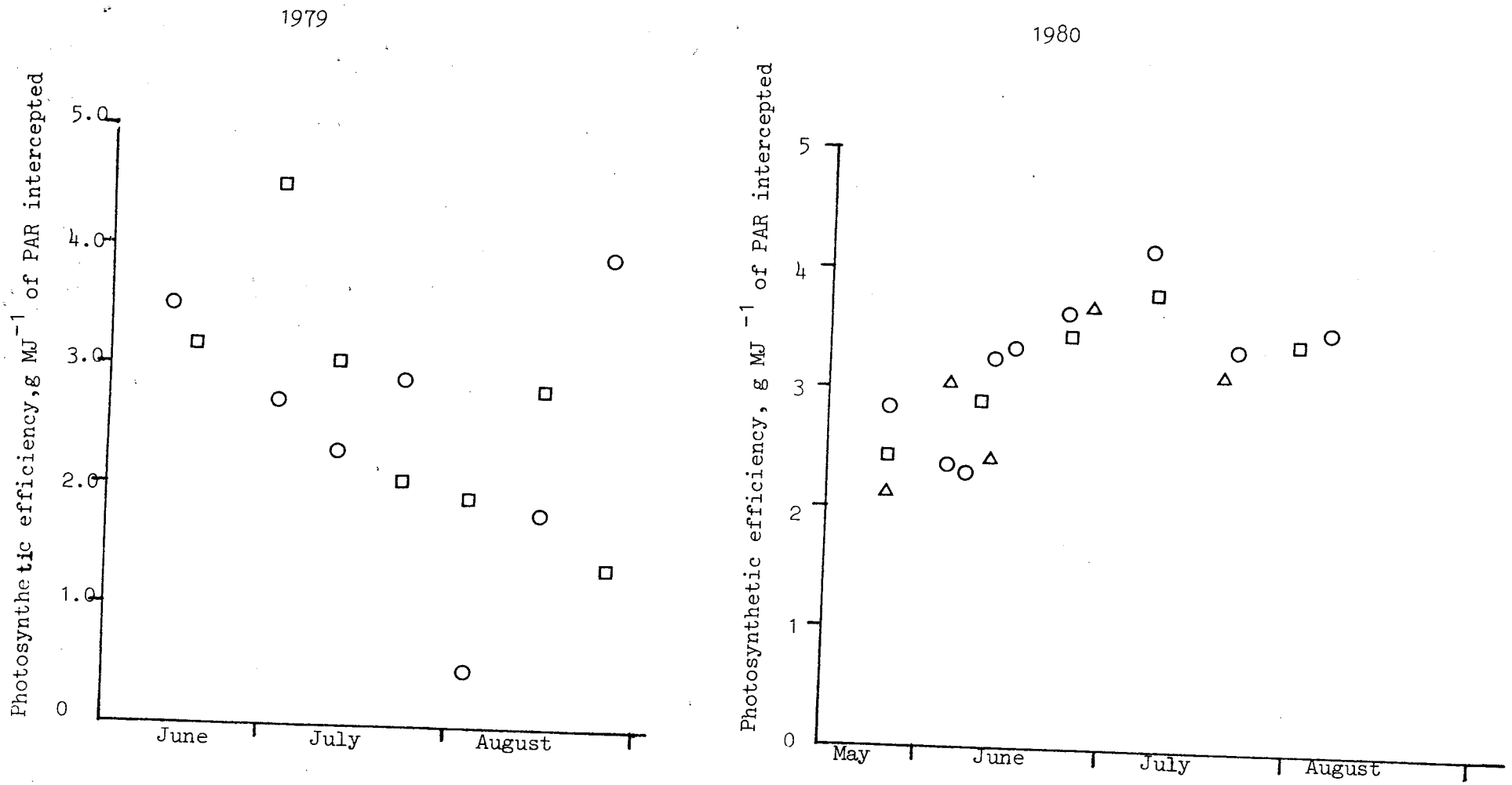


Figure 4.4.6.5 Changes in net photosynthetic efficiency during 1979 and 1980. For meaning of symbols see figure 4.4.6.1.

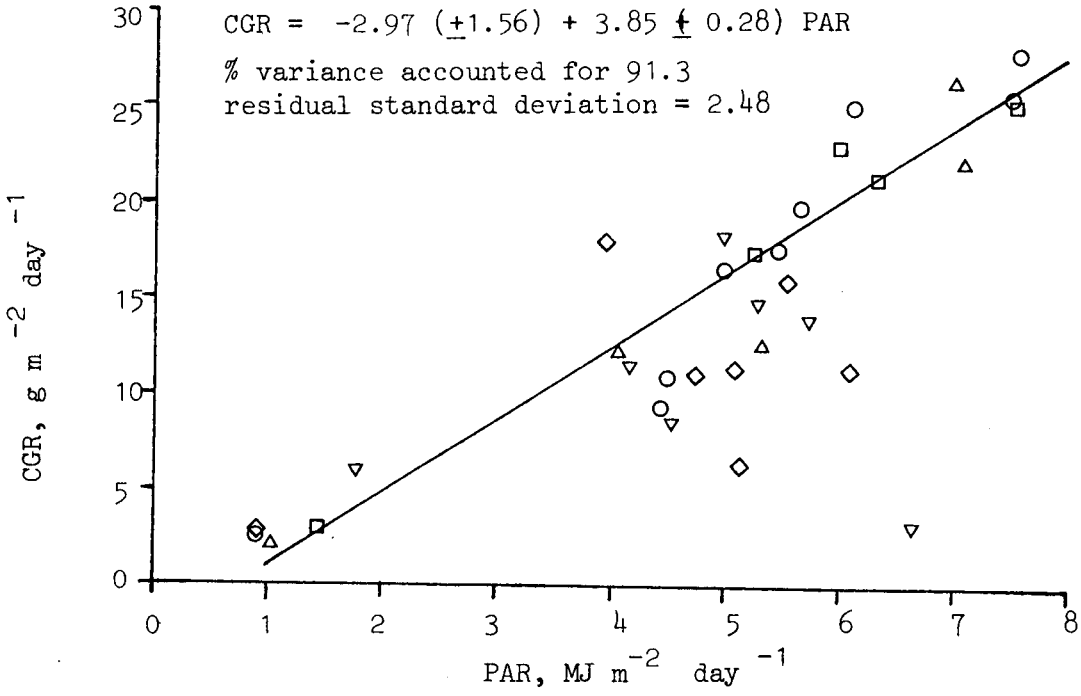


Figure 4.4.6.6. Crop growth rate (CGR) as a function of PAR interception for three experiments in 1980 (each data point is a mean for total number of plots in that experiment) and 2 varieties in 1979 (each data point is a mean for 12 plots). Regression line fitted through 1980 data only (see text).

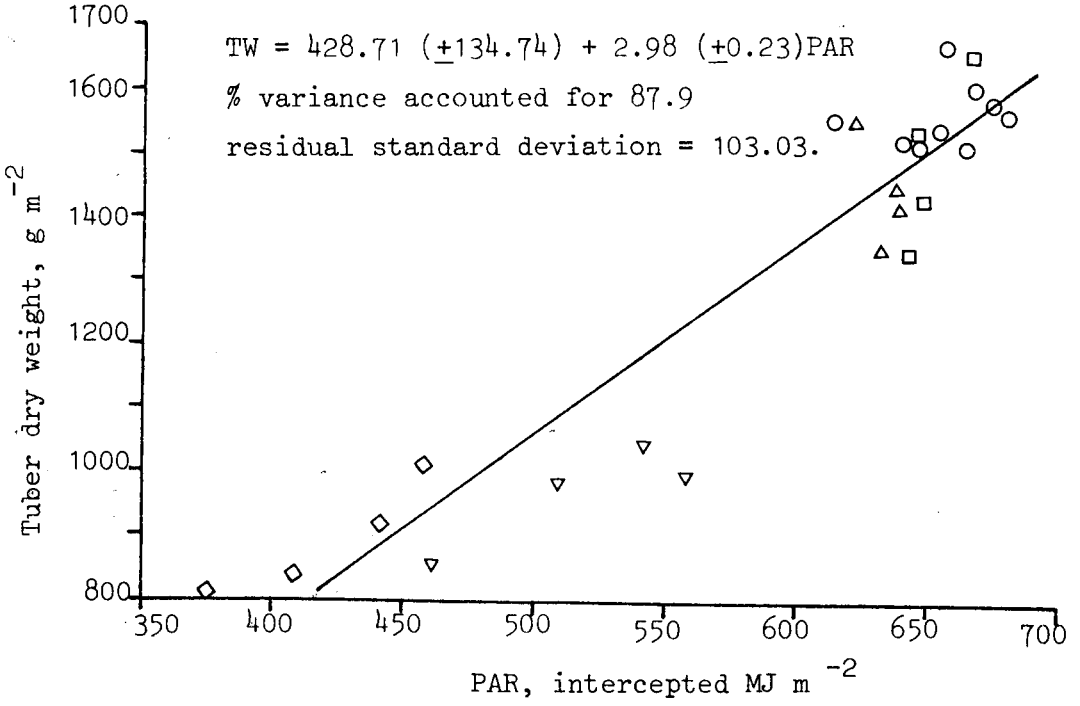


Figure 4.4.6.7 Total tuber dry weight produced during 1979 and 1980 as a function of PAR interception. Each data point is a mean for replicates.

Note: For meaning of symbols see figure 4.4.6.1.

early planting also took more days to reach 50% emergence compared to late due to difference in temperature. (Table 4.4.7.1.). Unlike Experiment F2, cold took more days (8.7) from appearance of the first stem to reach 50% emergence compared to apical (6.4), this may be due to the reason that apical in Experiment F2 increased total stem number. Stem numbers were averaged for all dates of growth analyses, as there was no difference between different dates and they were not affected by any treatment (Table 4.4.7.1.).

4.4.7.2 Growth and development of stem and leaf.

Cold emerged later and thus had lower LAI early in the season (Fig.4.4.7.3) but when considered from the date of 50% emergence cold had slightly higher LAI compared to apical. For example after 14, 21 and 28 days of 50% emergence, cold had LAI of: 0.42; 1.14; 1.65 and apical: 0.40; 0.86; 1.34 respectively. Late planting had lower LAI early in the season but when considered from the date of 50% emergence there was no difference. For example after 12, 19 and 26 days of 50% emergence late had LAI of: 0.53; 0.97; 1.51 and early: 0.43; 0.87; 1.54 respectively.

As found for Experiment F2, mixture gave significantly lower LAI early in the season compared to apical. Specific leaf area was not affected, thus leaf dry weight was proportional to LAI. Effects on stem weight was similar to LAI. Leaf to stem ratio decreased during the growing season as was found in the previous two years and was not affected by any of the treatments (data for leaf and stem weight is not presented).

4.4.7.3 Tuber growth and development.

Tuber initiation (TI) was calculated by interpolation as in previous years. Unlike 1980, TI was not delayed by cold (Table 4.4.7.1.) when considered from the date of 50% emergence, but when considered from the appearance of first stem, it was 2.7 days later in cold compared to apical; still the difference was slightly less then the Experiment F2 (4.3 days). Tuber weight was lower in cold and early planting (Fig.4.4.7.5) but when considered from the date of TI there was no difference. For example after 5, 15, 36 and 57 days of TI cold yielded: 36.7; 92.4; 442; 561g m^{-2} and apical: 12.1; 102.8; 378; 600g m^{-2}, respectively. Similarly in case of date of planting (data used only from mono plots as date of TI for mixture was not worked out), after 6, 21, 37 and 58 days of TI, late planting yielded: 33.6; 110.5; 416.5; 580.5g m^{-2} and early planting: 28.7; 122.7; 422.8; 611.2g m^{-2} respectively. As found for Experiment F2 (1980) tuber weight in mixture was significantly lower than apical early in the season.

As far as tuber size grades are concerned cold did increase the percentage of medium size tubers (Fig.4.4.7.6) but the difference was not significant. Late planting had a higher percentage of medium sized tubers, but maybe because it was trailing about 4 days behind (difference in time to reach 50% emergence), early planting.

As found in 1980 (Exp. F2) cold had slightly higher LAI (1.30) at the time of TI then apical (0.98) and initiated a higher number of tubers (Fig.4.4.7.4). Planting date did not affect the tuber number. More tubers were found in mixture compared to apical, maybe due to presence of cold in the mixture.

4.4.7.4 Total dry matter accummulation.

During this year roots present on the stolons and stems were not removed. Leaves started to fall off, by the middle of July and were not collected. Like LAI and tuber weight, total dry weight (TDW) was also lower in cold and late planting (Fig.4.4.7.7) due to difference in time of emergence (Table 4.4.7.1.). Percentage of tubers out of TDW were lower in cold and late planting (Fig.4.4.7.7) but when considered from the date of TI there was no difference. For example, after: 5; 15; 36; 57 days of TI cold had: 16.2; 35.3; 60.5; 68.6 percent and apical: 9.25; 32.94; 57.38; 68.3 percent tubers out of TDW, respectively. Similarly in the case of date of planting after: 6; 21; 37; 58 days of TI, late planting had: 16.4; 34.5; 59.3; 67.0 percent and early planting had: 14.7; 37.0; 60.4; 70.6 percent tubers out of TDW, respectively (data used from the mono plots only).

4.4.8 Experiment F6

This experiment was specially designed to study the effect of physiological age on emergence. There was no difference in time to reach 50% emergence between 8OD and 92OD suggesting that once the sprouts had become visible (about 2 to 3mm) after that longest sprout or physiological age has not much to do with emergence (Tables 4.4.8.1. and 4.4.1.6.). Time between appearance of first stem and reaching the 50% emergence varied from 2 to 6 days and was 4.0 for 4D and 5.5 for 92OD.

All the plants were harvested after 64 days of planting. Although LAI was higher in treatment 92OD it did not differ significantly from

the treatments which emerged with it (Tables 4.4.8.1; 4.4.8.2.). Similar results were obtained for stem weight, leaf weight and total dry weight (TDW) (Table 4.4.8.2.). Tuber weight, tuber number and percentage of tubers out of TDW, were higher in treatment 920D (Table 4.4.8.2.) probably because it initiated tubers earlier. But all other treatments of those which emerged at the same time did not differ significantly (Table 4.4.8.2.).

Table 4.4.7.1. The effects of physiological age and time of planting on: stem No., emergence and tuber initiation (TI).

Treatment.	Total stem number m^{-2}	Days taken to reach 50% emergence	Days taken to TI from planting	Days between appearance of 1st stem to reaching 50% emergence
Cold	14.9	45.17	68.17	8.69
Apical	13.6	31.67	54.33	6.35
A + C	13.4	40.0		
SED	0.68	1.322	1.139	1.139
Early	13.3	40.78	63.33	8.19
Late	14.7	37.11	59.17	6.85
SED	0.55	1.088	1.344	1.139

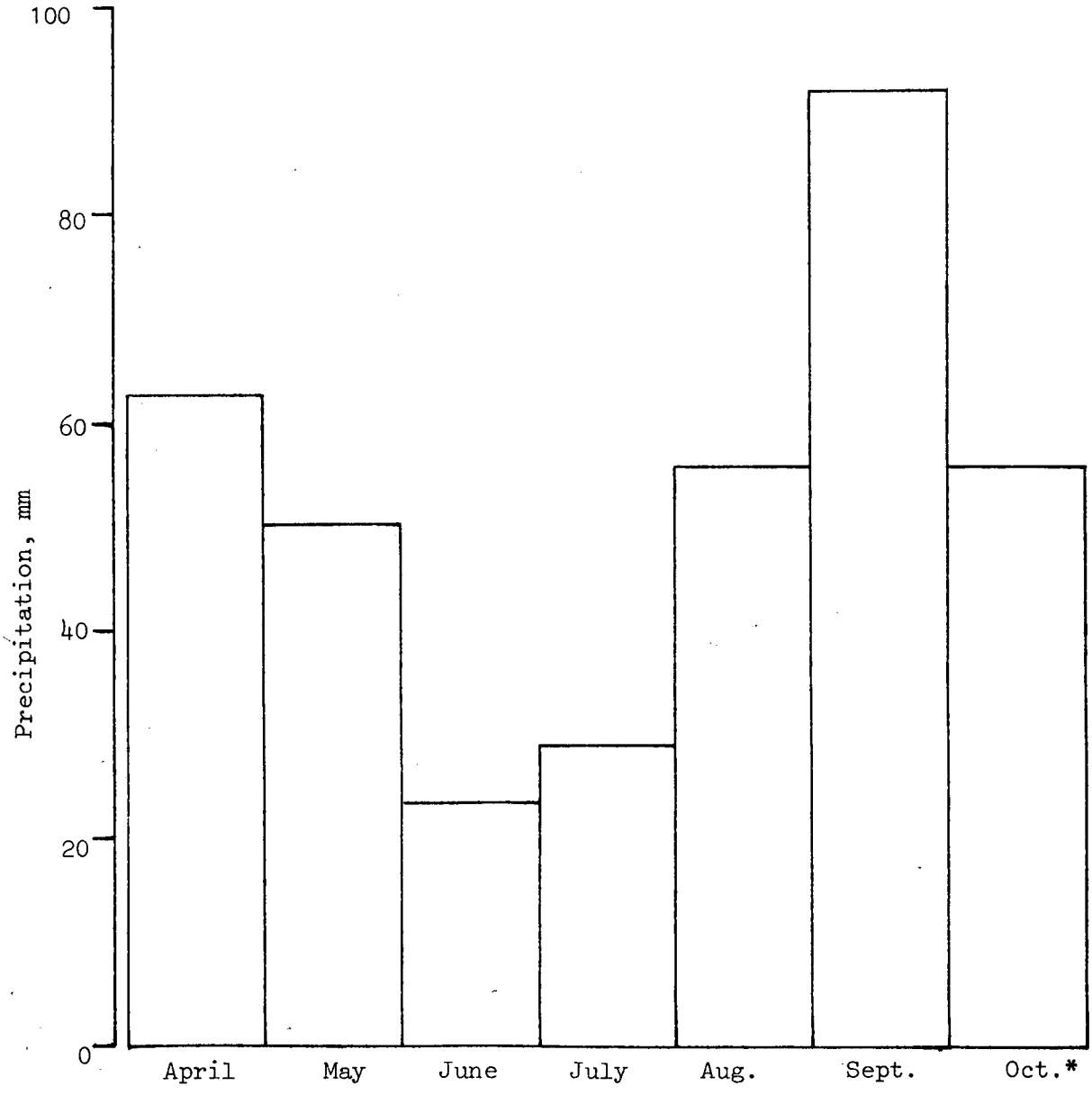


Figure 4.4.7.1 Monthly rainfall from April to October 1981.

*only for first 25 days for October.

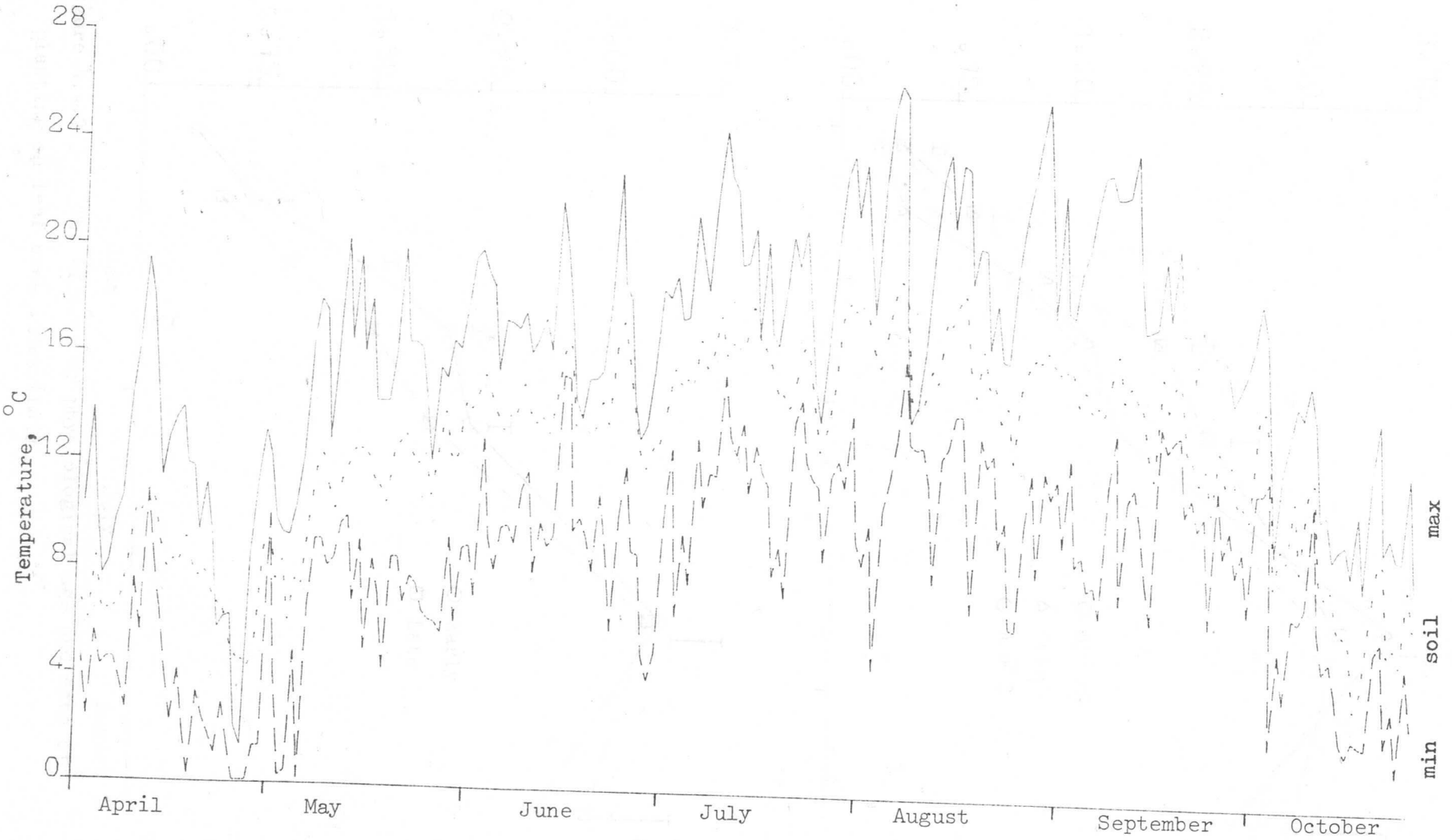


Figure 4.4.7.2 Screen maximum (_____) and minimum (- -) and soil (----) temperatures at 10cm depth from April to October, for the year 1981.

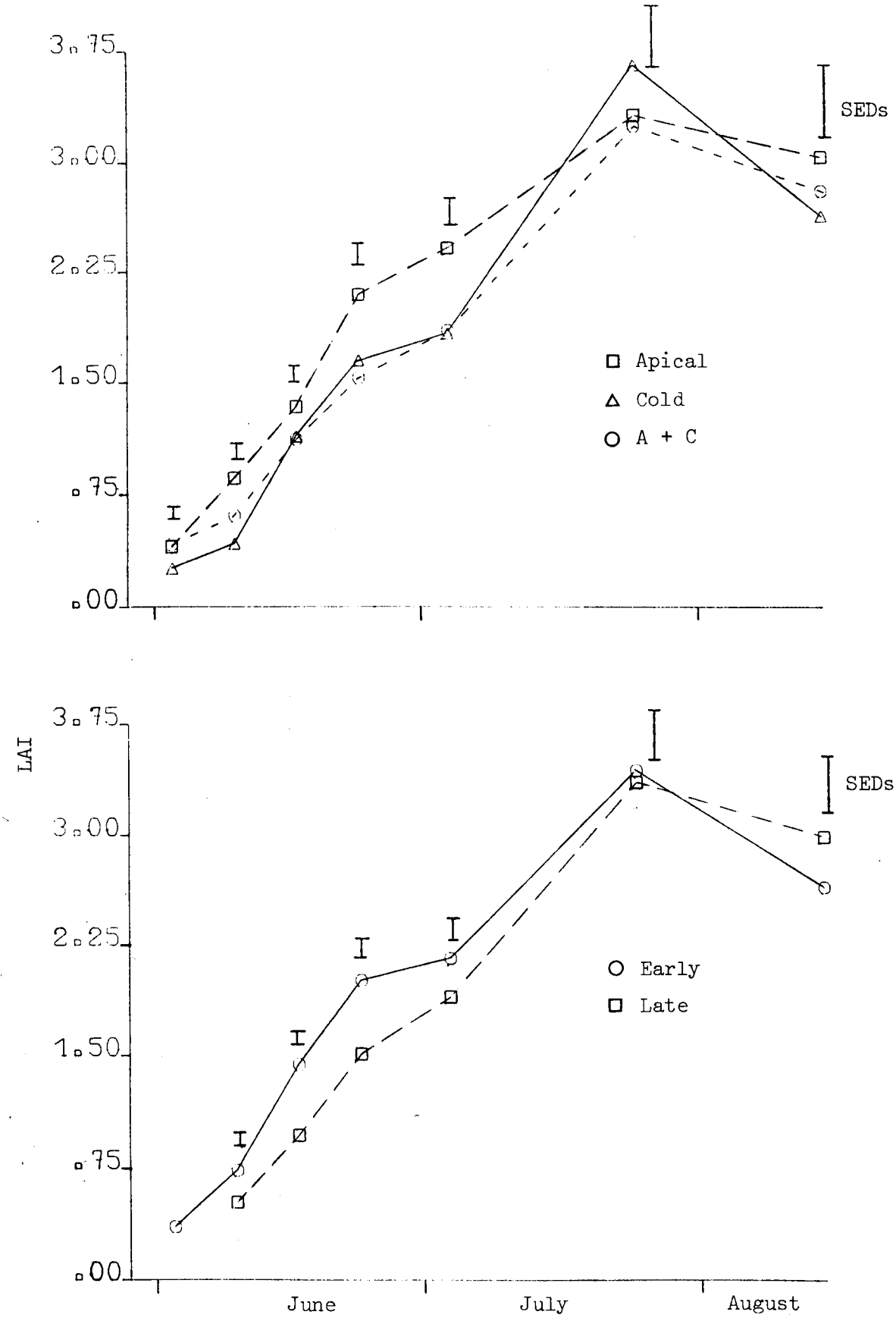


Figure 4.4.7.3 The effects of physiological age and date of planting on leaf area index (LAI).

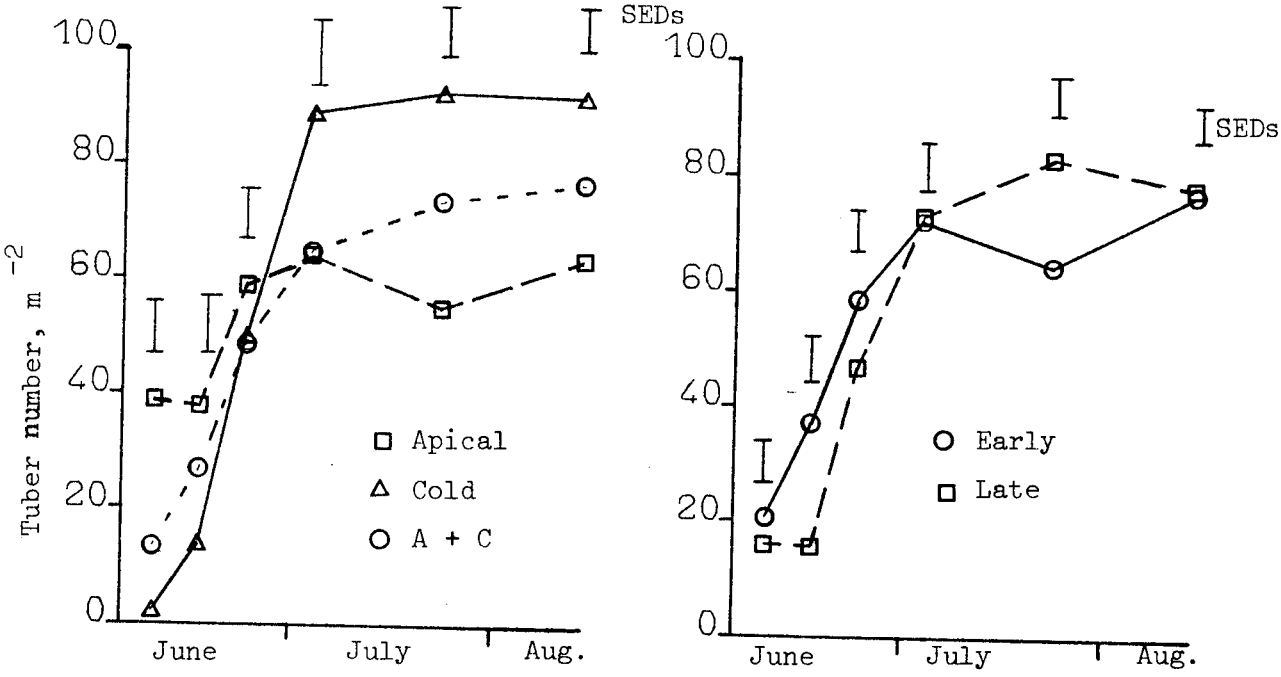


Figure 4.4.7.4 The effects of physiological age and date of planting on tuber number.

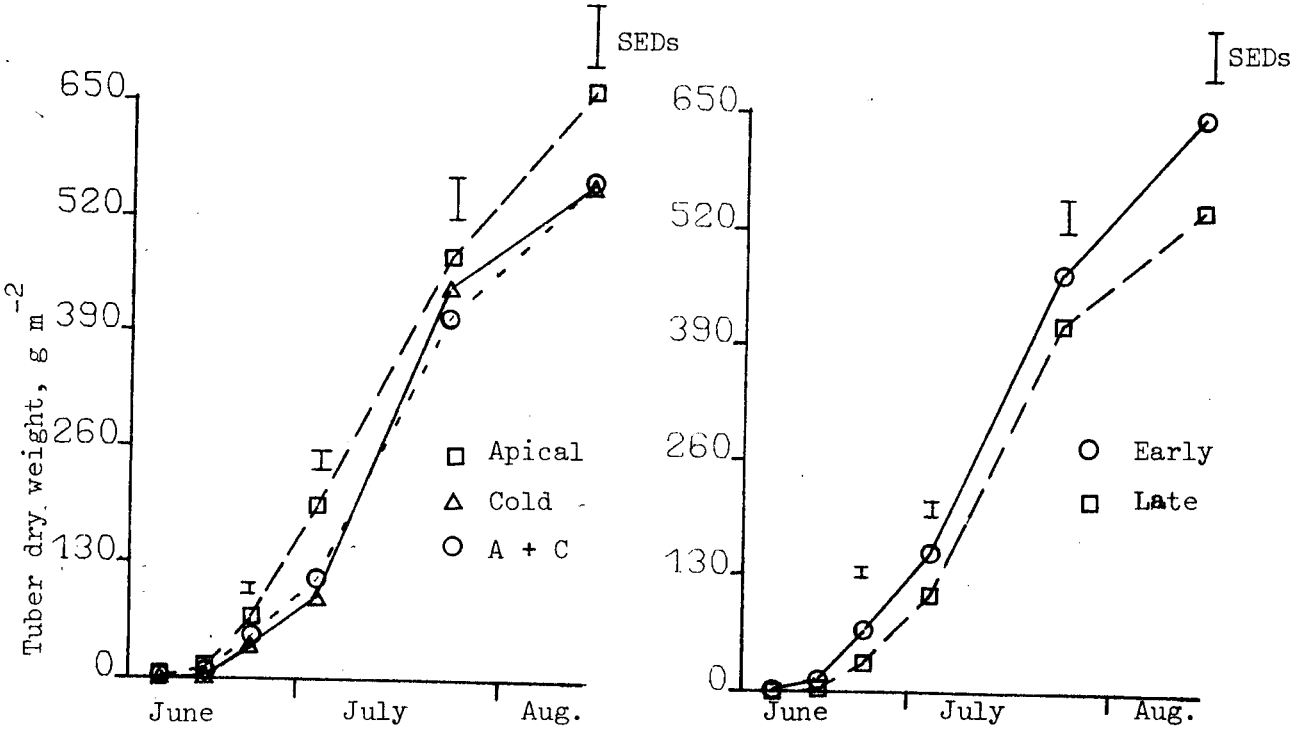


Figure 4.4.7.5 The effects of physiological age and date of planting on tuber dry weight.

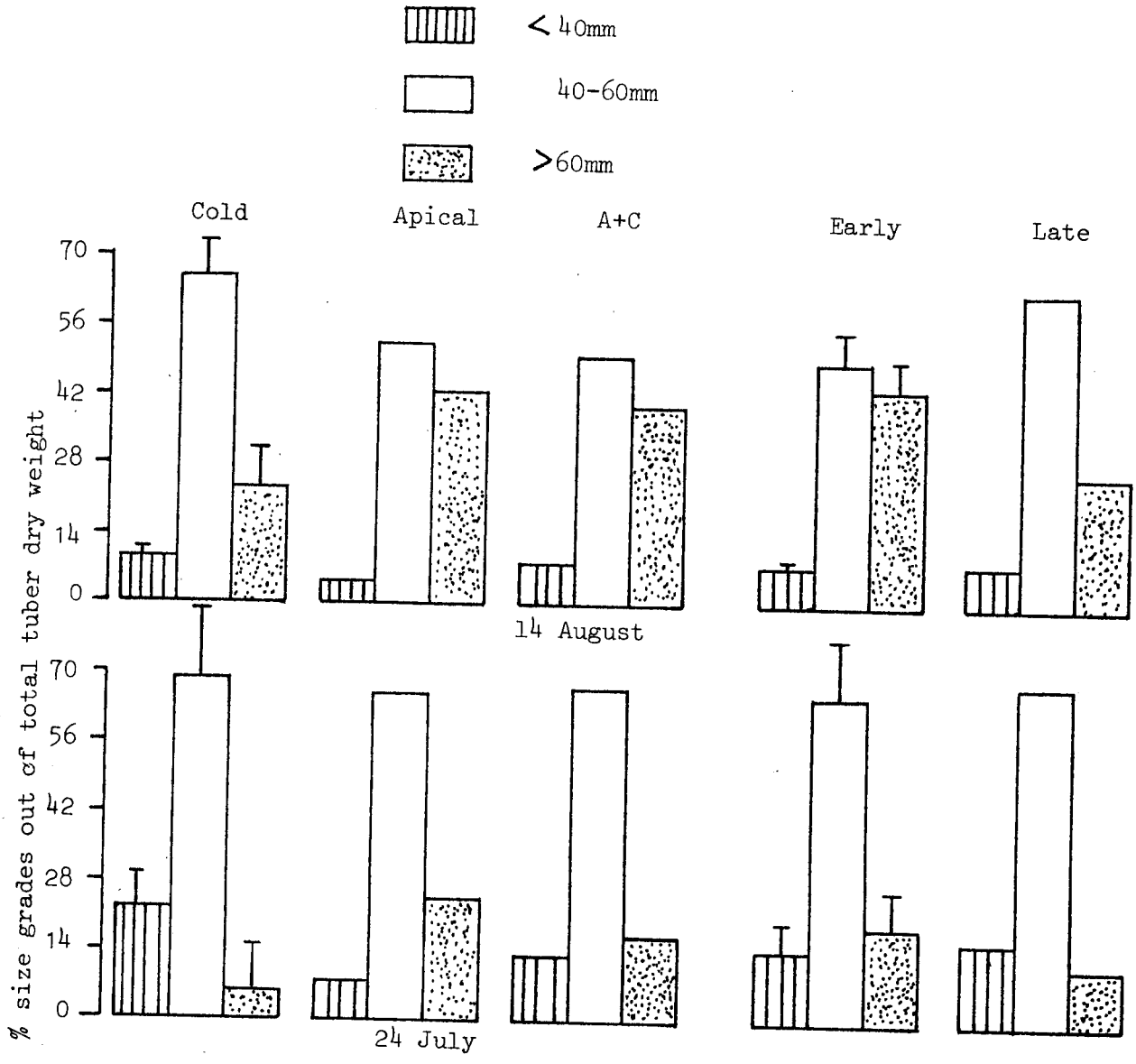


Figure 4.4.7.6 The effects of physiological age and date of planting on percentages of tuber size grades out of total tuber weight (dry weight basis). Vertical bars are the SEDs.

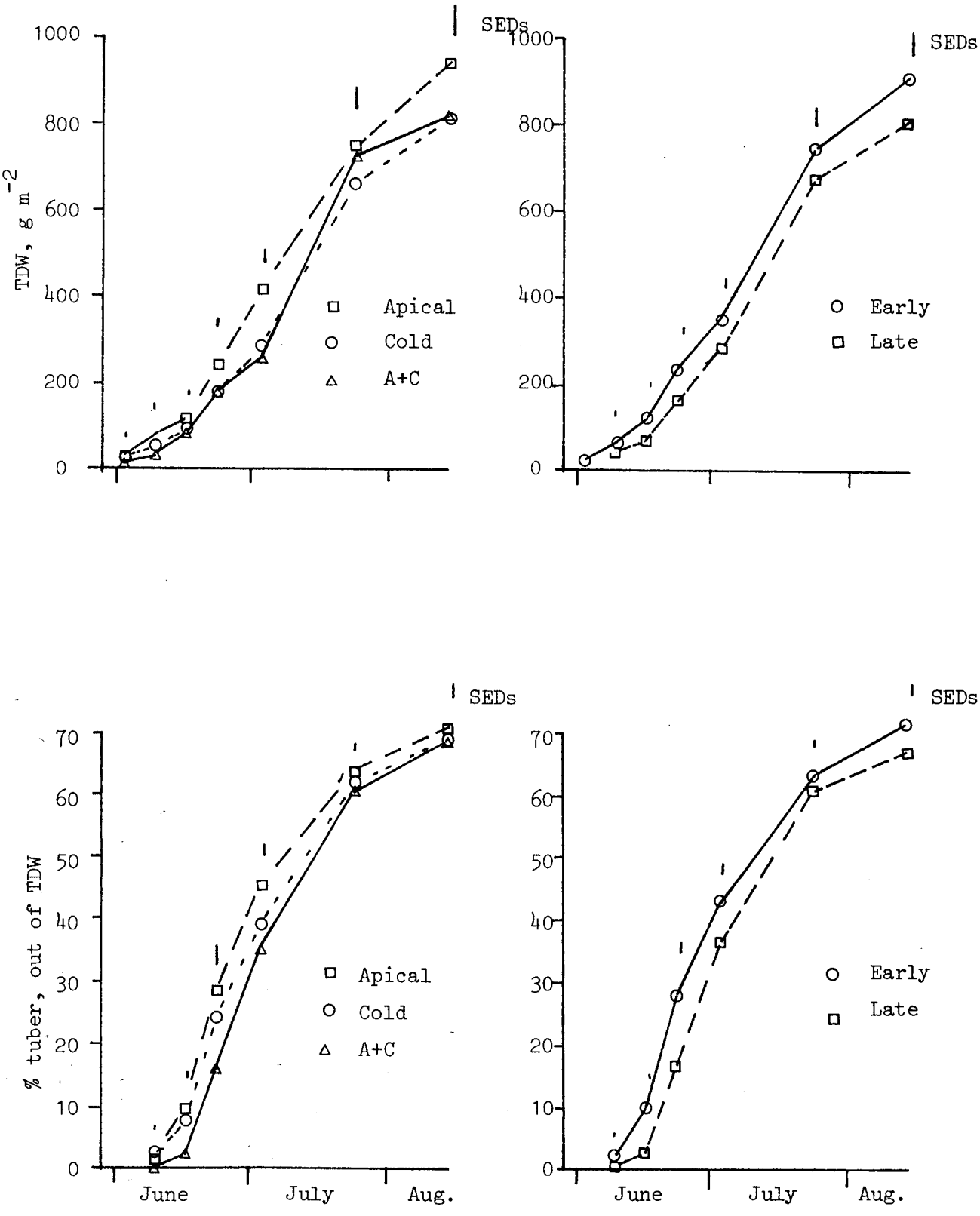


Figure 4.4.7.7 The effects of physiological age and date of planting on total dry weight (TDW) and percentages of tubers out of TDW.

Table 4.4.8.1. The effects of physiological age on emergence.

Days after planting / Treatment	Number of stems m^{-2}										Days taken to reach 50% emergence
	28	30	32	34	36	38	40	42	45	50	
4D					1.2	5.7	7.8	11.9	16.4	16.4	40.3
24D				2.5	5.5	8.3	10.5	13.8	15.7	16.6	37.8
48D				1.5	9.2	13.8	15.4	15.4	15.9	15.7	35.8
80D	0.8	1.2	2.9	7.4	11.1	11.9	12.3	12.7	13.5	15.2	34.0
128D		2.5	5.2	8.6	12.0	13.2	13.6	14.8	15.7	16.0	33.8
184D		1.2	4.3	9.8	12.0	14.5	14.5	15.1	15.4	15.1	33.3
232D		3.7	5.8	7.4	9.8	12.9	13.8	14.8	15.4	16.0	33.0
280D	0.6	1.2	3.1	7.4	9.2	11.7	13.2	13.5	14.5	14.5	34.3
352D		0.3	0.9	6.2	8.0	11.1	11.4	12.6	12.9	14.8	34.5
920D	1.2	4.6	6.8	11.1	15.4	18.8	19.4	20.0	20.3	22.5	33.5
SED	0.75	1.62	2.57	2.86	2.16	2.49	2.65	2.72	2.47	2.54	1.21

Table 4.4.8.2. The effects of physiological age after 64 days of planting on, tuber, LAI, TDW and its components.

Treatment	LAI	Tuber no.m^{-2}	Dry weight, g m^{-2}					% tuber out of TDW
			Tuber	Leaf	AGS	UGP	TDW	
4D	1.03	0.9	0.01	42.3	27.5	14.0	83.8	0.01
24D	1.26	13.5	1.9	52.4	33.5	15.6	103.4	1.8
48D	1.36	31.7	7.6	59.9	38.5	17.3	123.3	6.2
80D	1.80	23.4	10.6	73.7	47.1	21.4	152.7	5.5
128D	1.79	35.5	21.9	75.7	47.9	21.0	166.5	11.2
184D	1.70	20.9	10.9	71.1	45.8	18.4	146.2	6.0
232D	2.09	40.0	30.8	87.8	57.4	23.4	199.5	13.8
280D	1.65	26.9	11.5	72.6	47.1	21.4	152.5	6.0
352D	1.62	21.1	10.6	68.5	42.3	22.3	143.7	6.8
920D	2.25	52.3	47.6	95.0	59.3	25.8	227.7	20.4
SED	0.237	12.06	9.38	9.67	7.25	2.95	25.02	4.34

4.5 DISCUSSION

4.5.1 Sprout growth during storage

Similar results were obtained over three years for sprout growth during storage. Total sprout length per tuber as well as growth of the individual sprout increased with increase in initial tuber weight and there was a significant linear relationship between total sprout length per tuber and initial tuber weight. This may reflect the availability of substrates (Morris, 1966, 1967; Wurr, 1978a). Total sprout length per tuber increased with increase in day degrees above $4^{o}C$ after dormancy break for a similar type of treatment (sprout growth rate was different for different types of treatments e.g. apical, multi, fast and slow). When lines of cumulative total sprout length per tuber as a function of cumulative day degrees above $4^{o}C$ from dormancy break over three years for apical treatment from the experiments: F1 (both varieties); F2; F3 were compared, they differ in intercept and slope which was related to initial tuber weight. Thus for these lines multiple regression was done in which day degrees above $4^{o}C$ from dormancy break accounted for 70% of the variance (significant, P = 0.001) in total sprout length per tuber and when tuber weight was included the variance accounted for increased to 80% and this increase due to initial tuber weight was significant (P = 0.001). So the total sprout length may be represented by the equation,

$$SPL = 2.25(\pm 2.08) + 0.31(\pm 0.002)DD + 0.118(\pm 0.023)TW$$

Where, SPL = Total sprout length, mm $tuber^{-1}$, DD = day degrees above $4^{o}C$ from dormancy break and TW = initial tuber weight, g and residual standard deviation = 4.58 and residual degrees of freedom = 53.

When data from the experiment F3 was also included in the multiple regression the variance accounted for decreased from 80% to 70%; perhaps the dormancy of this seed lot had already broken before it was received, for this seed had many damaged sprouts which increased the number of growing sprouts and eventually the total sprout length per tuber. Increase in sprout length with increase in day degrees, when stored at different temperatures during storage immediately after dormancy break has been reported by several workers, Rawi, 1981; Ali, 1979; Wurr, 1978b. When tubers were under ideal conditions for sprouting immediately after dormancy break, apical dominance established within the sprout population, larger sprouts inhibiting the smaller ones as reported by Goodwin (1963), for the variety Arran Pilot. Storing tubers in cold (3 ± 1°C) stimulated more sprouts to grow, as reported by Wurr and Allen, 1976, and total sprout length per tuber per day degree increased as reported by Krijthe, 1962 and Wurr, 1978a. Thomas and Wurr (1976) reported a build up of the gibberellins in potato tubers following cold storage for 14 days, which may have increased sprout number and thus the total sprout length per tuber. Although total sprout length per tuber increased due to greater number of sprouts following cold storage the extension rate of the longest sprout was not changed. When tubers were stored in the dark extension rate of the sprouts was increased , this confirms the report of Rawi (1981).

If the physiological state of the tuber is to be judged from the state of the sprouts present then tuber weight must be taken into consideration. If tubers were stored at conditions ideal for sprout growth immediately after dormancy break, then total sprout length or length of the longest sprout may be a good indicator of the physiological

state of the tuber. But if tubers were stored for different periods in the cold (3 ± 1°C) then length of the longest sprout alone appears to be the parameter for judging the physiological state of the tuber. Mean sprout length as used by Morris (1966), may not be the useful parameter especially in the case of apically sprouted tubers where some sprouts stopped growing.

4.5.2 Emergence

In these experiments the longest sprout in the case of apical treatment was 7 - 16mm longer than that of multi and in three out of the four cases, apical emerged a day before multi but this difference was not significant and may not be of much practical importance, similar but slightly different results have been reported by other workers e.g. Wurr and Allen (1976), could not find differences in time to emergence in seed lots sprouted either from 15th September, 15th November or 15th January until planting. Ali (1979) found a difference of 1 - 4 days in appearance of 50% plants in various experiments where difference in length of the longest sprout varied from 6 - 30mm. Younger (1975) found a difference of 4 days in one year (planted on 23rd April) and 1 day in another year (planted on 3rd May) between two treatments, LS (sprouted for 12 - 13 weeks at 12°C before planting) and SS (sprouted for 18 days at 12°C before planting), in time to reach 50% emergence. Rawi (1981), reported that 50% of plants appeared 4 to 5 days earlier in physiologically old seed (longest sprout over 100mm) compared to physiologically young seed (longest sprout 32mm in one experiment and 62mm in another). However tubers with such long sprouts may be impractical to be used for commercial planting.

Harvesting before emergence showed that after planting, with the availability of moisture and nutrients, the extension rate of sprouts increased many fold and it was 2.8mm day^{-1} $sprout^{-1}$ between 7 to 14 days of planting (Experiment F3, 1980) and this may have further increased before emergence with increase in soil temperature (Headford, 1962; Bremner and Radley, 1966; Borah, 1959). Furthermore it is not only the longest sprout which has to emerge and in the case of apical sprouting some branches had already initiated in the store on the main sprouts, and these developed as branch stems. Branch stems usually emerged later than the main stems. In one experiment (F2) where apical had a higher proportion of branch stems compared to other experiments 50% emergence was one day later than the multi treatment. Thus greater differences in emergence due to differences in the length of longest sprouts may not be expected especially when planting is done late e.g. after the middle of April.

Experiment F6, which was taken for emergence showed that when at least 80 day degrees above $4^{\circ}C$ were given just before planting emergence was only delayed for a day or so and the difference was not significant but less than 80 day degrees above $4^{\circ}C$ did sugnificantly delay the emergence. Depending upon the time of planting in different experiments and different treatments in the same experiment, cold emerged 4 - 14 days later than the seed which had at least 80 day degrees above $4^{\circ}C$ before planting. Similar results were reported by Younger, (1975). It was seen that about 50 day degrees above $4^{\circ}C$ were required to have sprouts of about 2.3mm in the store. About 50% to 60% of the sprouts were either removed or damaged in mechanical planting from seed lots which were either stored at $12^{\circ}C$ for, 12 - 13 weeks or 18 days, before planting (Younger, 1975). If further tuber development is not affected

(discussed later, 4.5.3), then tubers given about 50 day degrees before storage may be of practical importance for commercial planting where mechanical handling is necessary, although emergence may be delayed for about 2 to 3 days. Results may vary from one variety to another as in Experiment F1, where two varieties had little difference in sprout length but Record started emerging ten days later than Pentland Crown. Similar results were obtained in 1980, when few tubers with similar physiological state of two varieities were planted to see the effect on emergence. The period between planting and emergence reduces as planting is delayed (Bremner and Radley, 1966). The variety Pentland Crown took 24 days in 1979 (planted on 1st May) and 33 to 34 days in 1980 and 1981 (planted on 15th or 16th April) from planting to reach 50% emergence. Similar results were found by Younger (1975). These results were confirmed by date of planting experiment (F5) in 1981.

4.5.3 Tuber growth and development

New tubers may form on mother tubers during longer storage period in the dark without foliage being produced (Claver, 1975; van Staden and Dimalla, 1977). Van Loon and Houwing (1981) reported reduction in incubation period (peiod between the appearance of the first sprout on the tuber and formation of tubers on the sprout when stored in darkness (Claver, 1951)) by storing at 12°C compared to 4°C. Rawi (1981), reported failure in emergence due to 'little potato' disorder in physiologically very old seed. In the present experiments no difference between tuber initiation (TI) or later tuber growth was found among apical, multi, fast and slow treatments of various experiments,

but cold (seed stored at 4°C until a day before planting), did delay the TI even when considered from emergence. This confirms the report of Raquf (1979). LAI at the time of TI was higher in cold compared to apical and multi as found by Raquf, (1979). Thomas and Wurr (1976), reported an increase in gibberellins following cold storage for 14 days. Wurr et al., (1980), found higher concentrations of cytokinin and gibberellins in 'little potato' compared to normal tubers and further they stated that 'little potato' initiation may have occurred at low gibberellins levels but that gibberellin activity subsequently increased with tuber growth. It may be that during storage at 12°C concentrations of cytokinins in the sprouts may have increased while in cold stored tubers concentrations of gibberellins were increased, so the ratio of cytokinins and unknown tuberization stimulus to gibberellins may have been more in sprouted tubers (apical or multi) compared with unsprouted (cold) at the time of emergence. This resulted in differences in time to TI (Chapter 2.5). Although there were differences in physiological age between apical and multi treatments, TI was not affected. Possibly the ratio of cytokinins and the unknown tuberization stimulus to gibberellins increase at higher rates immediately on transfer to warm conditions (12°C) following cold storage and after that it increases at a slower rate, thus differences may not have been big enough between apical and multi to affect the TI. It appears that certain aspects of tuberization are varietal characteristics as Record took less time to initiate tubers and further it allocated more assimilates to the tubers, compared to Pentland Crown.

In the apical treatment a slightly higher percentage of assimilates were allocated to the tubers compared to the multi treatments in Experiments F1 and F3 but not in Experiment F4, although this was not

significant. This effect appears to be due to competition between stems rather than physiological age, as total stem number were higher in multi of Experiments F1 and F3 and decrease in spacings between plants did slightly decrease the percentage of assimilates allocated to the tubers. No difference in percentage of tuber by weight out of total dry weight was found between cold and apical or multi when considered from the date of TI. So it appears that once the TI had occurred the effect of physiological age disappeared and major factor affecting the tuber growth may then have been the environment. An effect of photoperiod could not be detected as the difference in emergence between early and late planting of Experiment F5 was only four days and day length, during mid-May, when plants were emerging, was increasing at the rate of 20 minutes per week. It is accepted that there is a balance between growth of tubers and rest of the plant anything which favours the growth of one will retard the growth of others (Moorby, 1978; Ivins and Bremner, 1965). In 1979 due to water-stress haulm growth was reduced and this resulted in allocation of a higher percentage of assimilates to the tubers compared to very wet year of 1980. For example after 36 and 47 days of 50% emergence percentage of tuber dry weight out of total dry weight was 36 and 53% in 1979; (average of apical and multi for Pentland Crown only) 28 and 47% in 1980 (Experiment F2, average of apical and multi); 30 and 48% in 1981 (Experiment F5, for apical, average of two dates of planting) respectively. Although a higher percentage of assimilates was allocated to tubers in 1979 the overall growth of the crop was very much reduced (4.5.4 q.v.) which reduced the bulking rate per unit area. For example after 36, 47, 57, 69 and 81 days from 50% emergence tuber weight gm^{-2} was 107, 227, 362, 432 and 525 in 1979 (mean of apical and multi for Pentland Crown); 154,

349, 557, 795 and 1091 in 1980 (mean of apical and multi for Exp. F1) and 88, 234, 359, 503 and 637 for 1981 (for apical, mean of two planting dates, Experiment F5) respectively. These figures appear to be related to rainfall data for three years (Figs.3.3.1 and 4.4.7.2). Similar results were found by Chowdhury, 1980. Llewelyn (1967) increased tuber bulking by irrigation. McDermott and Ivins (1955), found a linear relationship between total tuber yield and the May - September rainfall over eight years (1947-54). There was increase in yield of 1.4T/ha for each cm of rainfall, which Harris (1978), states is similar to yield responses found in irrigation experiments in Britain. Mixing of two type of seed tubers did not affect the bulking rate as their yield was not significantly different from that expected i.e. average of two types of seeds when grown alone. But sprouted seed had the advantage over cold early in the season as found by Chowdhury (1980). In general senescence (4.5.4 q.v.) was not affected by any treatments within experiment, so final yield did not differ due to treatments, but final yields of 1979 were much lower than 1980, as the crop was affected by drought in 1979. Significant linear relationship was found between final tuber yield and leaf area duration (LAD) as reported by several workers (e.g. Gunasena and Harris, 1968, 1969, 1971). Several workers (e.g. Gunasena and Harris, 1968, Bremner and Radley, 1966; Bremner and Taha, 1966) have reported improvement in the relationship between LAD and tuber yield, when leaf area indices above three were assumed as three, but this was not the case in the present investigation even assuming LAI over 4.0 as 4.0 did not give any relationship with tuber. Probably light interception increases with increase in LAI over 3 and further efficiency of the canopy was increasing with increase in LAI (4.5.4 q.v.). In fact later Gunasena and Harris (1971)

also could not improve relationship between LAD and tuber yield by assuming leaf area indices over 3 as 3 or over 4 as 4 or over 4.5 as 4.5. A linear relationship between tuber number and total stem number was found as reported by Allen, 1972; Moosey, 1962; Wurr, 1974. Since stem number does not take any account of the size of different types of stems the relationship between LAD accumulated over a period of 30 days from the date of TI accounted for more variance. This confirms the mechanism discussed in Chapter 3.5 that tuber numbers which develop depend upon the assimilates available at the time of TI and a period after that. Sizes of the tubers depend upon the total assimilates available for their growth from TI until harvesting. Since LAD was much greater in 1980, there were higher percentages of bigger sized tubers in 1980 compared to 1979. The number of axillary branches (AB) decreased with an increase in stem numbers per unit area (Ifenkwe, 1975), which in the present investigation were related to leaf area duration (LAD) for a period of 30 days from emergence (i.e. speed of ground cover). Tuber numbers increased with decrease in spacing so their average size decreased (Ifenkwe, 1975) thus the proportion of bigger sized tubers may be related to the AB. In the present investigation tuber yields of relatively bigger sized tubers were significantly linearly related to the LAD contributed by the axillary branches.

4.5.4 General crop growth

Stem number is now considered as the unit of population in the potato crop (Allen and Bean, 1978). Apical treatment increased the proportion of branch stems compared with multi and cold treatments in all the experiments as earlier found by Younger (1975). Main stems were much bigger than their counterpartbranch stems. It may be that because branch stems emerged later they were suppressed by the main stems. Hence the type of sprouting treatment given to the seed tubers must be taken into consideration when calculating plant populations. Water stress may inhibit the formation of new leaves (Munns and Pearson, 1974; Zaag and Burton, 1978) and so may reduce the LAI (Boyer, 1976; Munns and Pearson, 1974). In the present experiments due to more rain fall in 1980, stems were much longer than those in 1979 and leaf numbers were increased. This resulted in higher LAI values when compared with 1979 and 1981. Increase in LAI or ground cover with irrigation has been reported by Llewelyn, 1967; Mohindra, 1975. In the absence of any apparent water stress, higher LAI in 1980 resulted in higher radiation interception and thus total crop growth was higher in 1980 when compared with the other two years. It may become more clear if light interception and crop evaporation are taken into consideration. In general different treatments within a particular year did not differ in their photosynthetic efficiency or evaporation rates thus the results are discussed in general for two different years.

The fraction of radiation intercepted by a canopy depends mainly on LAI (Shibles and Weber, 1966; Horie and Udayawa, 1970), and transmission of individual leaves and their geometrical arrangements. Light interception (LI) increased linearly until LAI was about 2.25 and

thereafter LI increased at a diminishing rate, due to inter-leaf shading. Furthermore, leaf angle may vary with an increase in leaf size and so may affect the geometrical arrangment within the canopy. In the present investigation these combined effects were detected as a change in k as LAI increased. The efficiency of conversion of light to dry matter can be estimated from the linear relationship between accumulated total dry weight and accumulated intercepted radiation (Littleton et al., 1979; Milford et al., 1980). When forced through the origin (Smillie, 1966), the relationships found here indicated that for every 1.0MJ of PAR intercepted, the crop produced 3.42g of dry weight in 1980 and 2.49g in 1979. The 1980 results are comparable with results reported for other crops, for example; 3.2g/MJ PAR for barley and wheat grown at Sutton Bonington and Rothamsted (Gallagher and Biscoe, 1978); 3.5g/MJ PAR for sugarbeet (Biscoe, and Gallagher, 1977). The conversion efficiency in 1979 was much lower than that in 1980, probably because 1979 was a dry year. Reduction in photosynthetic efficiency due to water stress has been reported for potato (Shekhar and Iritani, 1979; Chapman and Loomis, 1953; Moorby, et al., 1975), barley (Legg et al., 1979; Biscoe et al., 1975; Gallagher and Biscoe, 1978), maize (Verdun and Loomis, 1944), apple (Schneider and Childers, 1941), soybeans (Schibles and Weber, 1966) and wheat (Gallagher and Biscoe, 1978). A reduction in water supply will frequently cause stomatal closure (Moorby et al., 1975) and thus increase the resistance to CO_2 uptake. Also decreased crop evaporation may result in higher respiration rates, associated with higher leaf temperatures and consequently net photosynthesis may be decreased (Lomas et al., 1972), (evaporation mesurements for the present investigation are discussed later). Another factor which may have affected the photosynthetic efficiency of the canopy is the irradiance

level in relation to the light saturation point of individual leaves. Changes in LAI result in differences in the degree of inter-leaf shading and consequently alter the irradiance level required to saturate the leaf canopy. Individual leaves may be light saturated at irradiance of 100w m^{-2} for wheat (Marshal and Biscoe, 1977) or 850 UEM$^{-2}S^{-1}$ for potatoes (Ku et al., 1977). However, although incident irradiance may reach 2000 UEM$^{-2}S^{-1}$, in summer, the canopy as a whole is seldom light saturated. In 1980, in the absence of any apparent water stress, the photosynthetic efficiency of the canopy increased slightly with increasing LAI, up to LAI values of around 5 (Figs.4.4.6.5; 4.4.3.16; 4.4.3.18; 4.4.3.19). Further evidence for increased photosynthetic efficiency of the canopy with increasing LAI comes from the relationship between CGR and mean leaf area index ($\bar{L}$) (Fig.4.5.1). Up to LAI values of 2.5 - 3 the relationship between CGR and $\bar{L}$ was similar to that between light interception and LAI. However at values of LAI greater than 3 total light interception increased at a slower rate than CGR i.e. the conversion of light to dry matter was more efficient per unit area when LAI was higher than 3. Puckeridge and Ratkowsky (1971) reported a similar effect in wheat although the values of LAI were higher due to the characteristics of a grass type canopy.

At LAI values of 4 or more around 95% of the incoming radiation was intercepted and it may be expected that for some of the lower leaves the rate of respiration would exceed gross photosynthesis. However at these values of LAI the total dry weight of the canopy was over 1000g m^{-2} and consequently the contribution to total canopy respiration, by the minor proportion of lower leaves, would have been small. As has been shown in other crops (e.g. Gallagher and Biscoe, 1978), crop growth rate was found to be linearly related to PAR intercepted by the leaf

canopy. The relationship was clearly influenced by water stress as in 1979. Although the efficiency of light conversion to total dry matter was much reduced by water stress in 1979 the percentages of tuber dry matter out of total dry weight were increased (4.5.3 q.v.). A linear relationship between tuber dry weight and total PAR intercepted over the whole season was found for both years data as reported by Scholte Ubbing (1959).

Soil moisture studies of the present investigation showed that in 1979 due to water stress and lower LAI crop evaporation was much lower than the potential evaporation (Penman, 1956). These differences were greater than the differences detected for peas (Dawkins, pers. comn.) for the same year but the peas were planted earlier than the potatoes and so they were better established than potatoes by the commencement of the dry spell. Fulton (1970) described potatoes as much more sensitive to water stress than maize or tomatoes. Burrow (1969) demonstrated that the ratio of actual to potential evaporation fell more rapidly in potatoes compared to sugarbeet. Shepherd (1972) reported a greater reduction in crop evaporation of potatoes compared to mixed crops of grass and clover. He related this to the greater sensitivity of potato leaf diffusion resistance to a decrease in leaf water potential. Fuehring et al., (1966) reported considerable reduction in crop evaporation if irrigation was not given at 75% available soil moisture. Potatoes are considered to have shallow root systems compared to other crops e.g. sweet corn, tomato, sugarbeet and barley (Corey and Blake, 1953; Durrant et al., 1973). In the present investigation roots extracted water from a depth of 90cm in one year and 80cm in another i.e. in the orders found by French, et al., 1972; Durrant et al., 1973. Arkley(1963) showed that there was a linear relationship between the amount of dry

matter produced and the amount of water evaporated. Penman (1963) related tuber bulking to the adjusted potential evaporation. In the present investigation crop growth rate was linearly related to the crop evaporation. Although there was a difference between years, within any year, physiological age or storing tubers in the dark before planting did not affect the overall total growth of the crop when considered from the date of 50% emergence. However the proportion contributed by different types of stems was different for different physiologically aged tubers, as apical treatment increased the number of branch stems. When total stem number were increased either by decreasing spacing or using bigger seed, LAI and total dry weight were increased early in the season, and this resulted in more tubers being initiated. The average tuber size was reduced as found by Ifenkwe, 1975. General growth of the mixed plots, where two types of seeds (i.e. sprouted and unsprouted) were mixed within rows was not different from expected (i.e. average of sprouted (apical or multi etc.) and unsprouted (cold) when grown alone). Sprouted occupied more space than allocated to it, this confirms the report of Chowdhury (1980) but both treatments senesced at the same time.

One way of increasing the interception of total radiation is by increasing the longevity of the crop. In 1979 senescence of the crop was not affected by the physiological age or spacing but the variety Record senesced after 138 days of planting and Pentland Crown after 160 days of planting. In the case of Pentland Crown it was observed that small seed (34g) emerged later and senesced later than bigger seed (62 or 105g). In 1980 there was no difference in senescence among the various treatments of Experiments F2 and F3; all senesced after 162 days of planting. Treatment S25 of Experiment F4 senesced 16 days

later than other treatments of that experiment and 12 days later than the Experiment F2 or F3. Differences in LAI due to different treatments of Experiment F5 (1981) disappeared from the middle of July and light interception measurements showed that about 93% of the incoming radiation was being intercepted on 30th. September and 90% on 13th. October, with no difference between treatments. It now appears that senescence in 1979 was affected due to water stress. As large seed emerged first it may have been affected more by the water stress than the later emerging small seed. This hypothesis agrees with Bagley (1971) who foung than an early developing crop suffered more from the drought in July than the less advanced crop. Younger (1975) reported that cold treated seed emerged later and senesced later than the sprouted seed. Senescing in 1980 was affected by the very humid weather as stems were over a metre long, lodging occurred and rotting of stem tissues was observed from the middle of August onwards. Another factor could be the depletion of nutrients especially the N (Ivins, 1963; Ivins and Bremner, 1965; Gunasena and Harris, 1969, 1971), as crop grew at a very fast rate. Due to higher stem numbers total dry weight of all treatments of Experiment F4 but S25 was higher than the treatments of Experiments F2 or F3, so they might have depleted the soil before others. Another factor which may have affected the senescence is the transmission of wavelengths above 700nm (Holmes and Smith, 1977; Scott et al., 1968), which may have affected the physiological status of the plants as LAI was very high in that year. Another evidence for this come from Chapter 3, where the pp333 treated plot in 1980 had a close canopy compared to other treatments and this may have affected the transmission and it senesced before others. It can not be the temperature as some individual guard plants were seen green for at least ten days after

the crop had senesced. Now, since 1981 has been the medium year for rainfall and LAI did not reach above 3.5 and growth rate has been much lower than 1980, thus soil may not have been depleted for nutrients and as there was no severe drought like 1979 the crop did not senesce until the middle of October.

For delaying leaf senescence in a wet year, application of nitrogen later in the season may be helpful (Gunasena and Harris, 1969, 1971). Later application of N may slightly affect the bulking rate, but if LAI of over 3 or so is maintained during September and the middle of October could be very useful as due to short days most of the assimilates produced may be used for tuber growth only. In a dry year like 1979, if irrigation is given in such a way that crop does not suffer from drought and LAI stays around 4.0, may be helpful in increasing the duration of the crop.

Any of these techniques to extend leaf persistence by delaying leaf senescence could be frustrated by blight disease and of course blight control in itself extends leaf persistence and the period of tuber bulking.

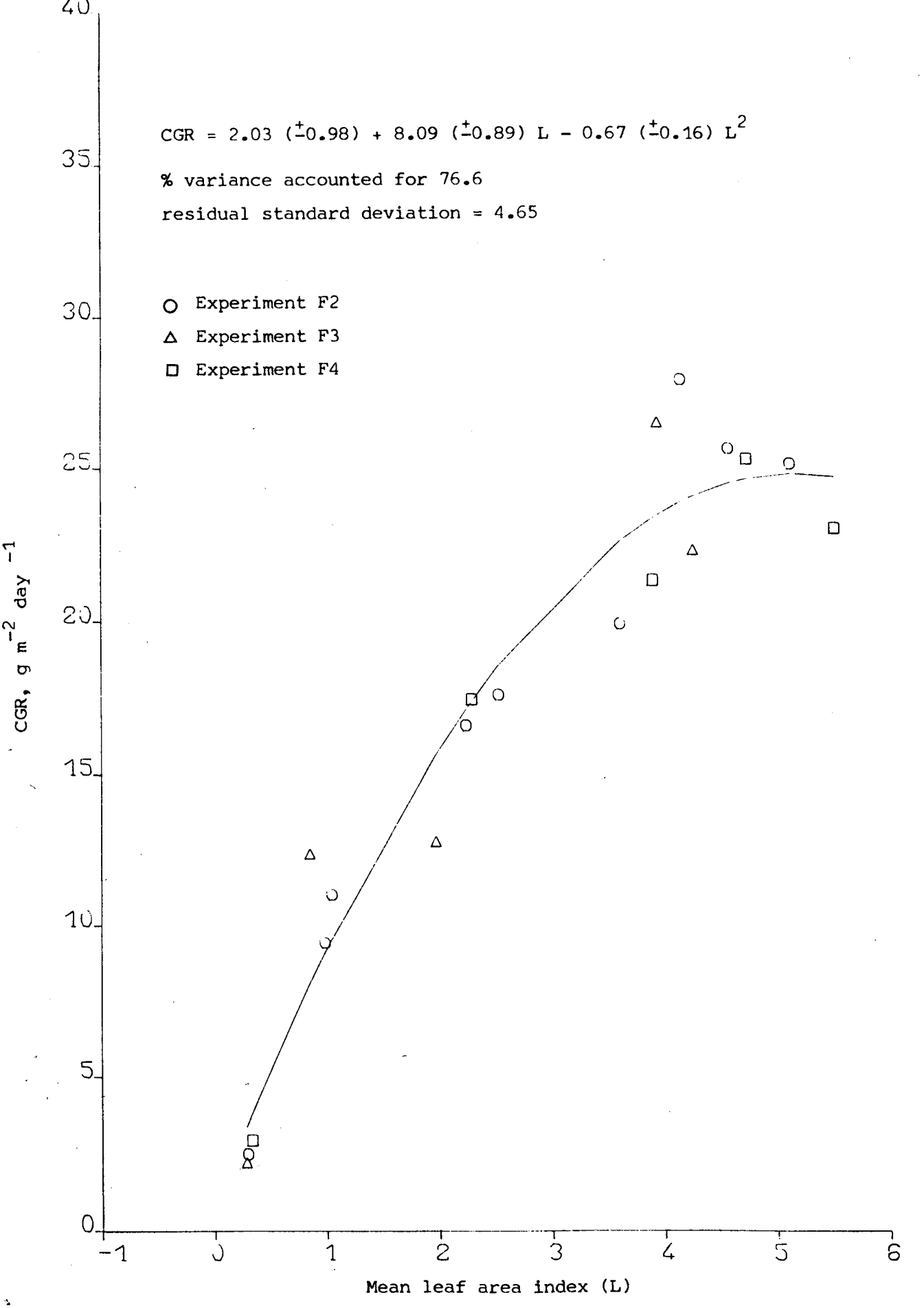


Figure 4.5.1. The relationship between crop growth rate (CGR) and mean leaf area index for all experiments in 1980. Each data point is an average for number of plots in that experiment.

SUMMARY AND CONCLUSIONS

In the majority of the field experiments, final tuber yields were not significantly different over a wide range of treatments which included (a) different physiological ages (b) different sprout growth rates at planting time (c) different stem populations obtained by adjusting plant spacing and seed tuber sizes (d) a mixture of seed tubers of different physiological ages or even (e) the two different varieties. In 1979 drought in early summer affected all treatments but there was some recovery when rain fell later, but because of this all yields were lower than in 1980. The photosynthetic conversion efficiency of the canopy (g dry weight MJ^{-1} PAR intercepted) was 2.49 in 1979 compared with 3.42 in 1980 when there was no apparent water stress.

Final yields are multiples of tuber numbers and mean tuber weights and these two components, together with stem numbers, were significantly different with different plant spacings, seed tuber sizes and storage treatments. Record produced more tubers than Pentland Crown. The relationship between seed tuber numbers and stem numbers was linear and significant.

In treatments which gave higher stem numbers in the crop L.A.I. and general crop growth rate were higher early in the season but other treatments caught up later. PAR interception increased linearly with increases in L.A.I. up to LAI = 2.25 when over 70% of the incoming radiation was intercepted.

Above LAI = 2.25 the rate of PAR interception slowed down until LAI = 4.0 when around 95% of the incoming radiation was intercepted. Final tuber yields were significantly related to the PAR intercepted by the canopy over the whole season.

No treatment other than varietal differences hastened leaf senescence which was later than anticipated and this probably explains why final tuber yields were not significantly different for several different treatments. Growth analysis studies showed how different aspects of plant growth were affected, but in each case it appears that the crops arrived at similar final yields but by different pathways, i.e. bulking rates x duration. Growth analysis results also showed that had the crops been burned off or lifted earlier for final yield then the different effects of many treatments would have been much larger. Hence seed treatments are of vital importance with early crops and probably second early crops where lifting occurs before mid-August. However, with maincrops which are allowed to mature late, by favourable environment, absence of blight and by production treatments such as irrigation or higher N levels, then a great deal of catching up takes place and at final harvest there are not likely to be great differences in yield from a range of seed treatments. The major effects are likely to be on tuber numbers and sizes which can have implications for quality for various purposes.

Drastic effects on leaf growth resulted from treatment with a growth regulator PP333. Although this investigation was no

more than observation plots with no replication, it was evident that leaf area per plant was reduced and higher tuber yields resulted. It proved possible to plant closer without enhancing interplant competition and PP333 appeared to increase the allocation of assimilates to the tubers. The result was more medium sized tubers. This preliminary trial suggests that there might well be a future for plant growth regulators with the potato crop and gives encouragement for further investigations to be carried out.

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APPENDICES

Appendix A

John Innes potting compost number 1 was prepared by mixing loam: peat: Grit; 7:3:2 (volume basis). 372g of J.I.B (5% N, 7.2% P_2O_5 soluble, 1% P_2O_5 insoluble and 10% K_2O) fertilizer and 70g of chalk was added per 100Kg of mixed compost.

Appendix B

Seed used for experiments: GR1 (growth room); F1; PP333 trial 1979, was obtained from UCW, Aberystwyth, where it was grown at Rhayader, Powys, from Scottish FS3 (Pentland Crown) and FS2 (Record) stocks. It was planted on 10 May, defoliated on 4 August and harvested on 5 September

Appendix C

Seed used for experiments: GR2 (growth room); GH1 (glasshouse); F2 was also obtained from UCW, Aberystwyth, where it was grown at Dyfed, near Llanarth from a once-grown Scottish VTSC stock (Multiplied in 1978 at high altitude seed site near Rhayader, Powys). It was planted on 22 May, defoliated on 10 August and harvested on 17 September.

Seed used for experiments: F3; F4; PP333 trial 1980 was grown at Bunny (University of Nottingham Farm) from Scottish AA1. It was planted on 7 May, defoliated by the end of August and

harvested from middle to end of October.

Appendix D

Seed used for experiments F5 and F6 was obtained from UCW, Aberystwyth, where it was grown at Dyfed near Llanarth. It was planted on 17 April, defoliated on 21 July and harvested on 4 September.

Appendix E

Main stem - The stems directly originating from the mother tuber.

Branch stem - The stems originating from the underground stem i.e. not straight from the mother tuber.

Axillary branches - The stems originating from the leaf-axis above ground.

Main stolons - The stolons originating straight from the stems.

Branch stolons - The stolons originating from another stolon i.e. not straight from the stem.

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