"GROWTH ANALYSIS OF c.v. PORRILLO SINTETICO (Phaseolus vulgaris L.)"

by

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A report of results from studies conducted while a trainee in bean physiology

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CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL
Palmira, Colombia

1976

INTRODUCTION

The objectives of this experiment are to understand the basic pattern of growth and development of the bean plant through growth analysis techniques using a standard variety, c.v. Porrillo Sintetico, (growth habit type II, indeterminate). This research is especially focused on an understanding of the pattern of pod set and the evaluation of the main factors controlling pod set. The variety chosen has proved widely adapted at altitudes from 1900 m to 13m in the tropics and has yielded consistenly above 2.5 t/ha in experiments at CIAT. The grwoth analysis reported here forms part of a larger set of experiments on the same variety in the same season and in the same field in which manipulation of crop growth conditions was carried out to evaluate further the physiological conditions controlling yield potential in this variety.

MATERIALS AND METHODS

Cultural practice

Porrillo Sintetico was sown in rows on beds on March 16th, 1976. Bed width center to center and including irrigation furrows was 1m, two rows were sown at intervals of 35cms on the crest. Seedlings emerged on March 21st, 1976. At the three trifoliate leaf stages, the stand was thinned to 30 plants/m^2 (300 x 10^3/ha). The crop was harvested on June 2nd, 1976.

Two hundred kg/ha of compound fertilizer (30:30:30 = Nkg/ha: P_2O_5 kg/ha: K_2O kg/ha), 25 g/ha of $ZnSO_4$ (5kg Zn/ha), 5 kg/ha of Rayplex Fe (0.5 kg Fe/ha) and 5 kg of Borax (0.5 kg B/ha) were broadcasted at seeding time. At 24 and 32 days after germination, a 0.5% solution of $ZnSO_4$ (0.2 kg ZN/ha) sprayed to prevent Zn deficiency.

Plants were supported from both sides of planted rows by horizontally stretched wires at 20cm and 40cm height. However, plants lodged after flowering and this support system did not work effectively.

Control of pests and diseases and irrigation were conducted by following the common practices in CIAT and plants were kept in a healthy condition throughout the growing season.

Experimental design and plot size

Randomized block design with four replications was chosen. Site for each sampling stage (total 9 stages) randomized within each replication. Plot size within each replication was 84 m^2 (4m x 21m). Four adjacent 1m x 2 row beds were used , the two central beds being sampled for growth analysis. Subsamples for leaf area, pod number, pod and bean weight, pod growth, nitrogen analysis, sugar and starch analysis and bean yield samples at harvesting time were taken. For growth analysis $1m^2$ samples were taken from each replication every seven days at nine growth stages commencing 12 days after emergence. At harvest 9 m^2 were taken for final yield and samples of 1 m^2 were analyzed for yield components. Each sampling site was bordered by 50cm of crop to avoid border effects between sampling dates.

Sampling of growth analysis plot

Every seven days starting 12 days after emergence all the plants within 1m length of bed ($1m^2$) were sampled. Canopy height was measured in the field. Plant number, node number on mainstem and branches, three types of pods were classified according to size and counted. Pods were classified as follows. Small pods: pod length less than 5cm

and flowers still blooming at the time of sampling; large pods: pod length more than 5cm with significant bean filling not yet recognized; fruited pods: significant bean filling recognized and mature pods: fruited pods at final harvest. After counting the various characters, plants were separated into five parts; viz. green leaves, pods, beans (mainstems and branches separately), roots and the rest (yellow leaves, petioles and stems). After drying in a ventilated oven at 60°C for two days, each part was weighted separately.

Subsamples for leaf area per node, pod number per node and total pod weight per node

1. Sampling

Two plants per replication were taken at random from adjacent border rows of the central two beds near to sampling plot for each stage. Eight plants (two plants per replication x four replications) were combined and treated as one sample.

Leaves and pods on the mainstem were grouped according to their node of origin. Leaves and pods on branches were also grouped for each branch separately and identified according to the node of origin on the mainstem.

2. Leaf area per node

Leaf area per node was measured separately according to the node of origin using a leaf area photometer (Hayashi Denko AAM40°). Leaves were then combined and dried at 60°C for two days, and weighed. The ratio of total leaf area to total leaf dry weight was calculated. This ratio was used for calculation of leaf area of the growth analysis samples of that stage.

Leaf areas per node were summed for the whole plant and relative percentage of total leaf area per node within plant was calculated. This relative percentage and the leaf area index of the growth analysis plot (mean of four replications) were used to calculate the leaf area distribution pattern per node (m^2/node/m^2 land area) at each growth stage.

3. Pod number per node

The pod classifications were counted separately according to their node of origin. Pod number of three types was summed for each node and then for the whole plants. The relative percentage of pod number per node within plant and within each node and the relative percentage of each pod type was calculated.

The relative distribution and total pod number from

the growth analysis plot (mean of four replications) were used to calculate pod distribution pattern per node (within each node, each pod type separately) for that growth stage.

4. Total pod weight

Nodes were stratified by node of origin and beans were removed by hand. Beans and pods were oven dried (60°C 2 day) and weighed. Bean weight was expressed on a moisture content adjusted to 14%. Beans and pod weight were summed for each node and for the whole plants. From the grand total of whole plants, relative percentage of bean and pod weights within plants were calculated. Pod and bean weight distribution were then calculated in the same manner as for pod number per node.

Subsamples for flower and pod retention

Four plants per replication (total 16 plants) were tagged at random within the plot with no border effects. For each flower of each plant, the dates of flowering, fruiting, physiological maturity and abortion were checked almost every day during the post flowering period. These data were summed and adjusted to final plant number/m^2 basis (about 30 plants /m^2).

Subsamples for pod growth

On the day of flowering of the 7th node raceme, two flowers of that node were marked. Twice a week ten pods which were similar to the above marked pods in pod length and growth stage were sampled from border rows. The data for pod length, fresh weight of pod wall and beans and dry weight of pod wall and beans were recorded.

Sampling at harvesting time

1. Sampling

Sampling at final harvest consisted of two parts, (a) yield plot ($9m^2$) and (b) growth analysis plot ($1m^2$). From the yield plot, only data of bean yield and plant population were taken. From the yield component plot, data on plant number, node number, bean yield, mature pod number, bean number, pod weight, stem weight, and root weight were measured.

2. Calculation

Moisture content of all bean yield and yield component were adjusted for 14%. The final bean yield was calculated as the mean of the sum of yield plot and yield component plot across replications. Final plant number at harvest was calculated in the same way.

The ratio (k) of the final bean yield to the bean yield of the yield component plot was calculated. Mature pod number, bean number, pod weight, stem weight and root weight of the yield component plot were multiplied by K to calculate these components on a larger yield plot basis.

Subsamples for bean yield per node and each yield component per node

Ten plants per replication were taken at random from adjacent border rows of the central two beds and combined with other replications (total 40 plants). Pod number, bean number and bean yield were measured separately according to node of origin for mainstem and branches. Moisture contents of beans were adjusted to 14%. These data were adjusted to the mean final plant number at harvest (about 30 plants/m^2). Bean yield per node and each yield component per node were then calculated.

Analysis of nitrogen and sugar and starch

Nitrogen determinations were conducted on green leaves pods and beans and whole plants (included roots). Sugar and starch analyses were conducted on stems, pods and beans and

whole plants. The subsamples were taken at each sampling stage from the growth analysis samples every seven days.

For nitrogen analysis, 2-8 plants (depending on the plant size) per replication were taken from the adjacent border rows of central two beds at each sampling time of growth analysis and were combined for the four replications. These samples were divided into two parts. Whole plants (included roots) were washed and dried at 60°C for two days. Green leaves and pod plus beans were removed separately and washed and then dried at 60°C. After drying, each plant was ground and nitrogen determined by the standard micro Kjeldahl technique.

For sugar and starch analysis, 2 to 8 plants (depending on the plant size) per replication were taken as for nitrogen analysis. Plants were separated into three parts; whole plants (included roots), stems and pods plus beans. After fine two stage grinding, the samples were analysed for sugar and starch.

The method of Yoshida et al (1971) was slightly modified in that the total amount of sugar and starch extracted by $HClO_4$ twice for 15 minutes was measured.

Measurement of light transmission ratio (LTR)

Every two weeks starting from two weeks before flowering to four weeks after flowering the light transmission ratio was measured in the field.

Every 20cm from the soil surface light intensity was measured and compared with the intensity above the canopy.

For light measurements linear MONTEITH type solarimeter was used as a sensor and EIKO type TDP-1 millivoltmeter was used as a detector. These data were calibrated into lux using a TOSHIBA photocell illuminometer.

RESULTS

1. Competition between vegetative organ growth and reproductive organ growth after flowering

The increase of vegetative organ weight (VOW) levelled off at eight days after flowering commenced (eight days from flowering commenced will be expressed as FL8) and after FL15 gradually decreased. On the other hand, reproductive organ weight (ROW) increased rapidly after FL8. That is, it seemed that there was competition between VOG and ROG from FL1 to FL15, and after FL15, growth shifted from VOG to ROG (Fig. 1).

After this shift of growth phase, the increase of vegetative node number stopped as did any further increase in leaf area index (Fig. 1). Leaf area was also measured individually for each node at each stage (Fig. 2). Up to FL15, new leaves unrolled at upper nodes and hence leaf area increased. However, once new leaf development stopped, leaf area decreased rapidly with the senescence of old leaves.

Light transmission ratio (LTR) and canopy height were shown in Fig. 3. At 19 days after germination (expressed as G19), canopy height was low and LAI was about 1.2 (Fig. 1). At this stage, canopy could maintain good light condition, that is, 50% of light was intercepted by about 1/2

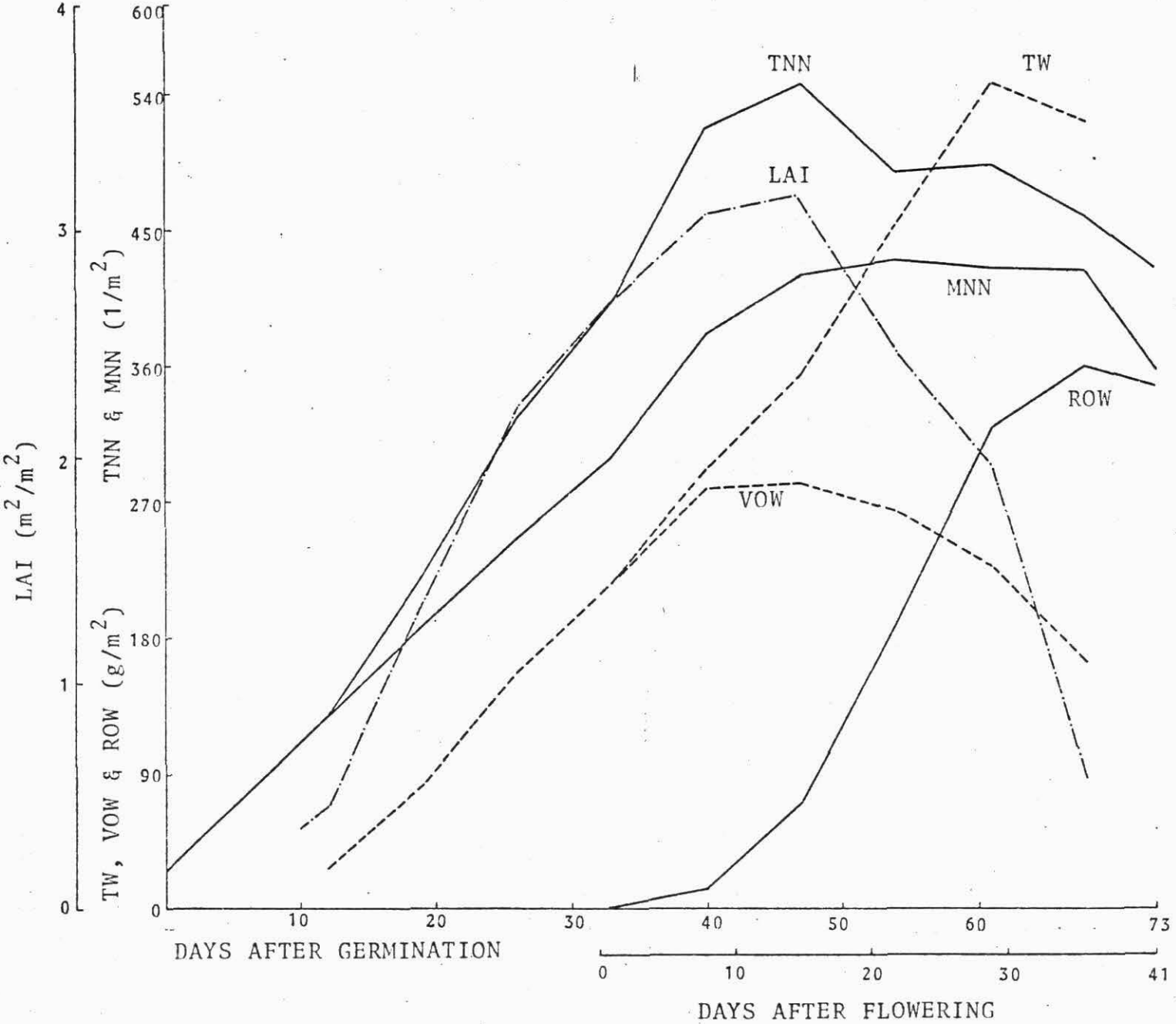
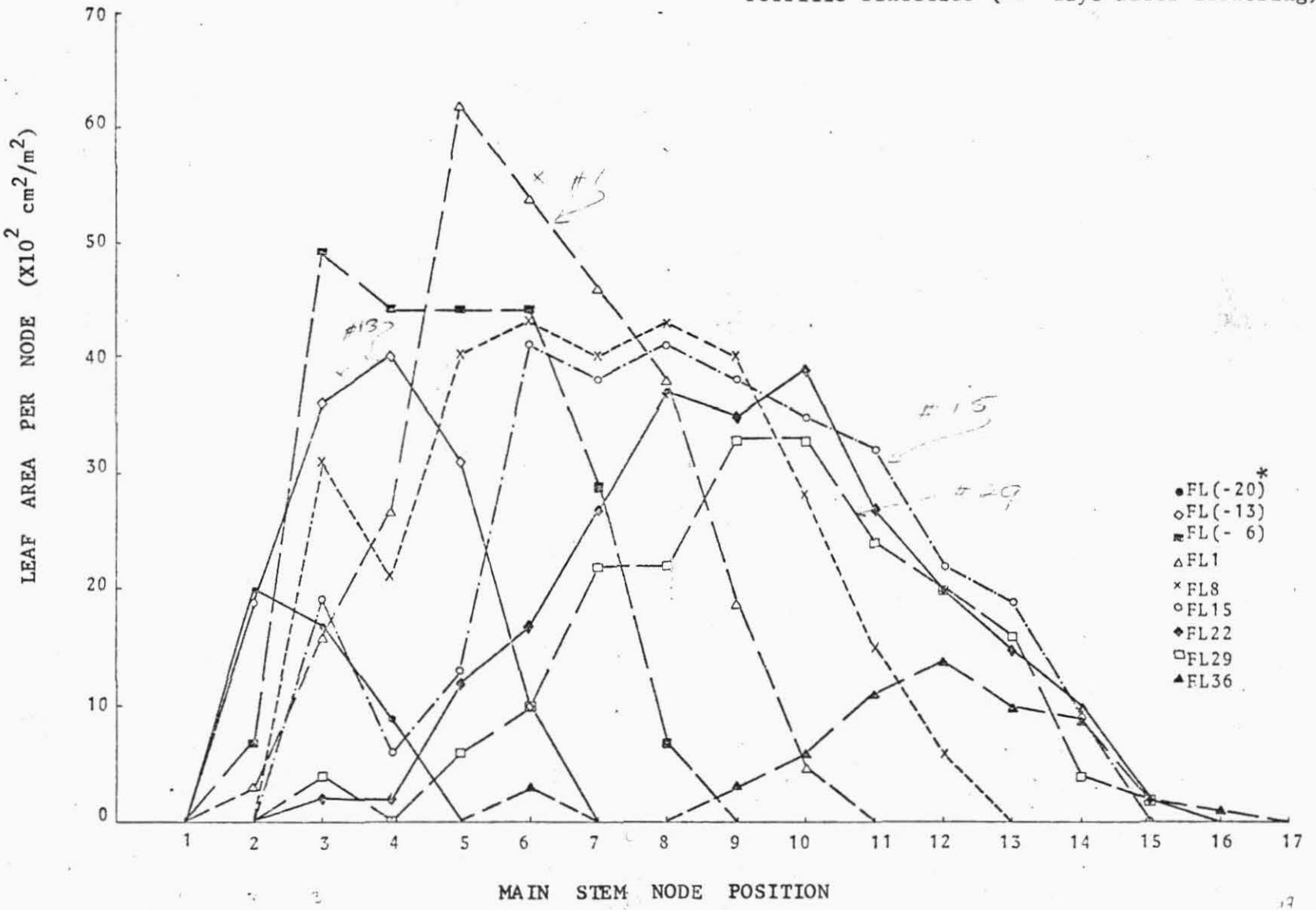


Fig.1 Total weight (TW), vegetative organ weight (VOW), reproductive organ weight (ROW), total node number (TNN), mainstem node number (MNN), and leaf area index (LAI) at different growth stages in Porrillo Sintetico.

Fig. 2. Leaf area per node (branch leaf area included at each node position) at different growth stages in Porrillo Sintético (*: days after flowering).



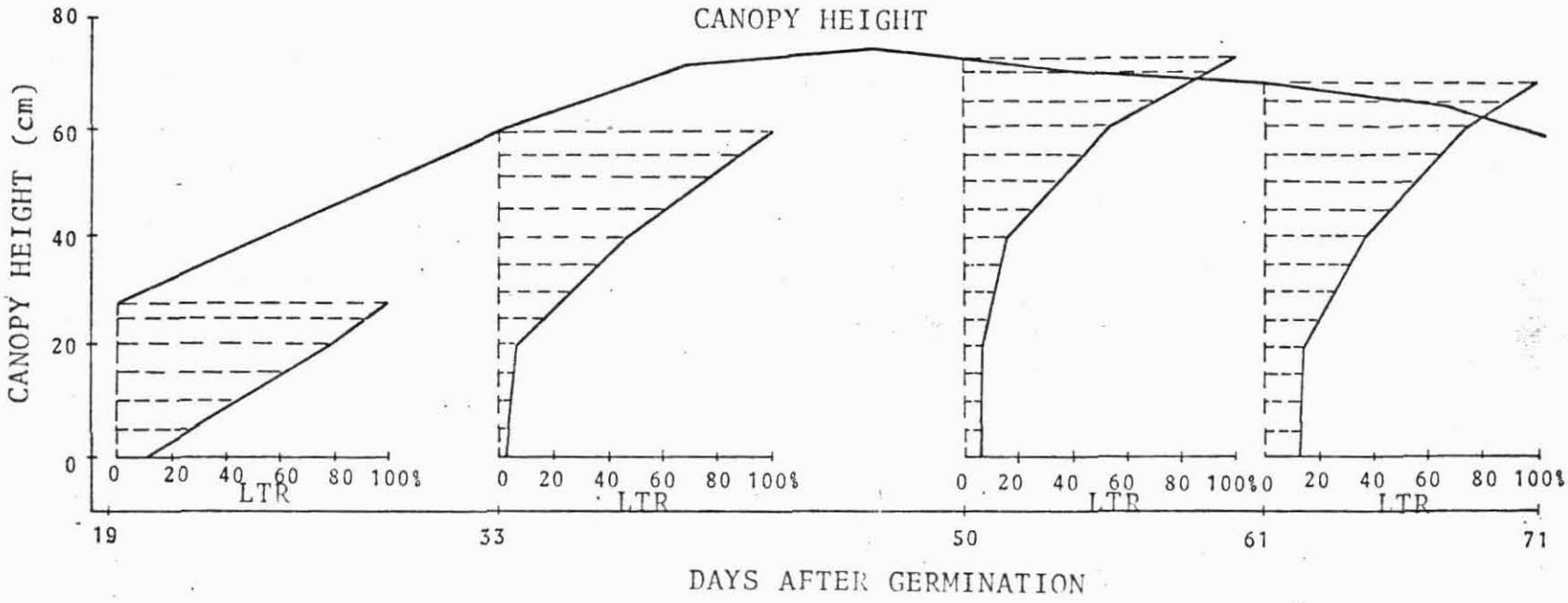


Fig. 3 . Light transmission ratio (LTR) and canopy height at different growth stages in Porrillo Sintetico

of canopy stratum from canopy surface and 10% of light reached soil surface.

At G33 (FL1), canopy height increased and LAI was about 2.5. Light conditions were not as favourable, that is 50% of light was intercepted by the first 1/3 of canopy stratum from the canopy surface.

At G50 (FL18), canopy height had levelled off and LAI reached about 2.8. At this stage light conditions had further deteriorated, that is, 50% of light was intercepted by about only 1/5 of the canopy stratum and less than 20% of light was shared by 1/2 of leaves at the bottom of canopy.

At G61 (FL29), canopy height decreased slightly and LAI decreased to about 2.0 caused by senescence of lower leaves. This drop of lower leaves was reflected in improvement of light conditions. At this stage, 50% of light was intertepted by about 1/3 of the canopy stratum, and about 15% of light reached the soil surface.

2. Reproductive Growth Phase

A. Flowering pattern and pod set

There were big differences in the ratio of mature pod number at harvest to total flower number (pod set ratio), in relation to node position. However, there was no relation between this pod set ratio and total flower number for each node (Fig. 4).

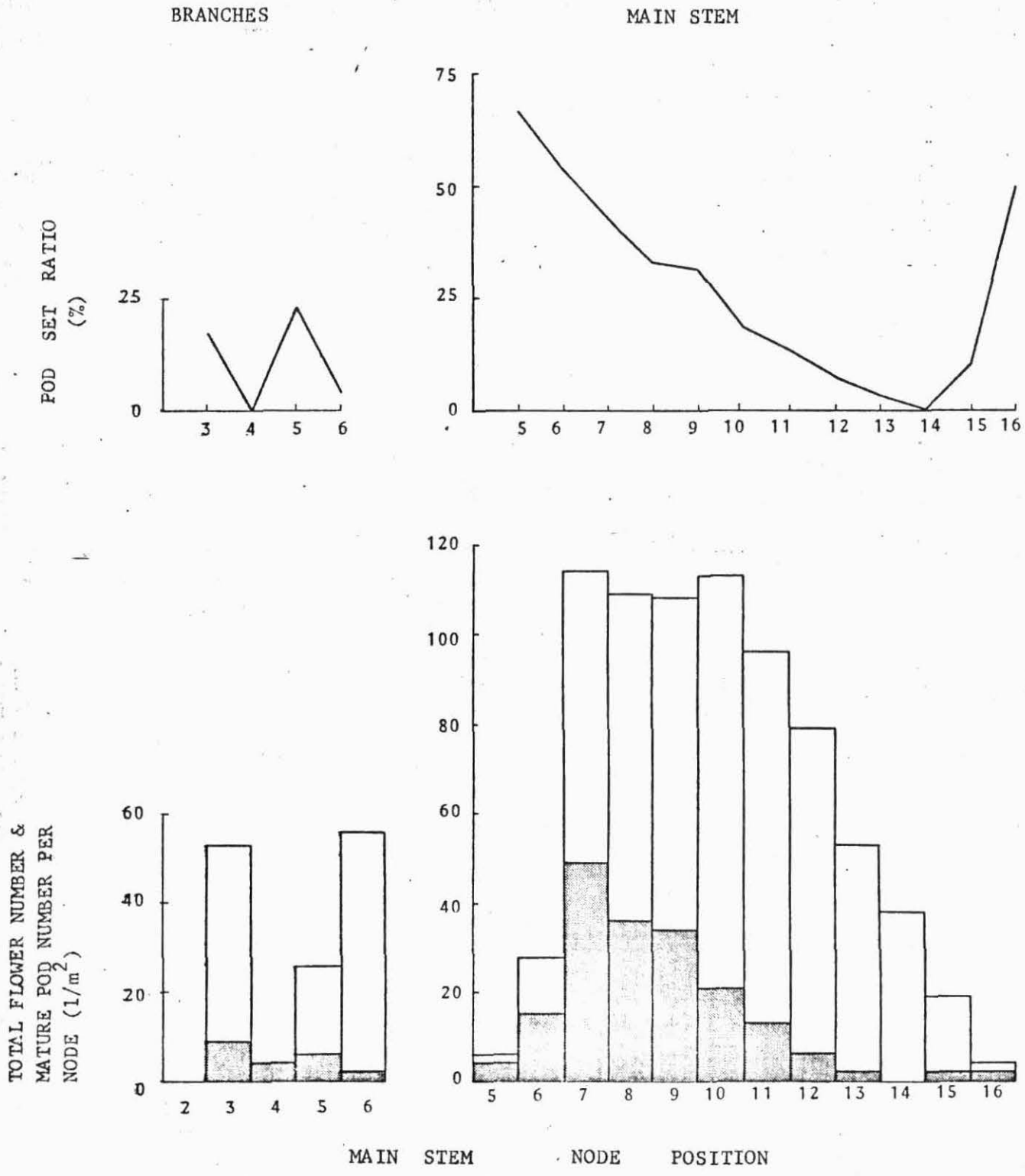


Fig. 4 Relationship between node position and the pod set ratio (ratio of mature pod number to total flower number) for each node of mainstem and branches (branches differentiated by node of origin) for Porrillo Sintétito.

Generally speaking, within each raceme, two flowers bloomed as a unit on the same day with about three days interval from bottom unit to upper unit sequentially on the raceme. The lowest unit of two flowers at the bottom of the raceme was defined as the first unit and the second lowest unit of two flowers was defined as the second unit and so on.

On the mainstem, the relationship between the flowering days of each unit within raceme of each node and the pod set ratio of each node was investigated. The results are shown in Fig. 5. Usually the lower the node position the higher the pod set ratio. If the flowering day of the second unit of a lower node raceme and that of the first unit of a higher node raceme were the same, the flowers of the first unit were usually set. That is, pod set ratio was controlled principally by the earliness of the flowering day of each flower bud and secondarily by the position within racemes (Fig. 6). In other words, the location of mature pods was determined mainly by earliness of the flowering day of each pod and not by the balance within each source-sink unit.

The same relationship was found among nodes within each branch. Comparison between each branch resulted in wide fluctuations and data for branches were not discussed here.

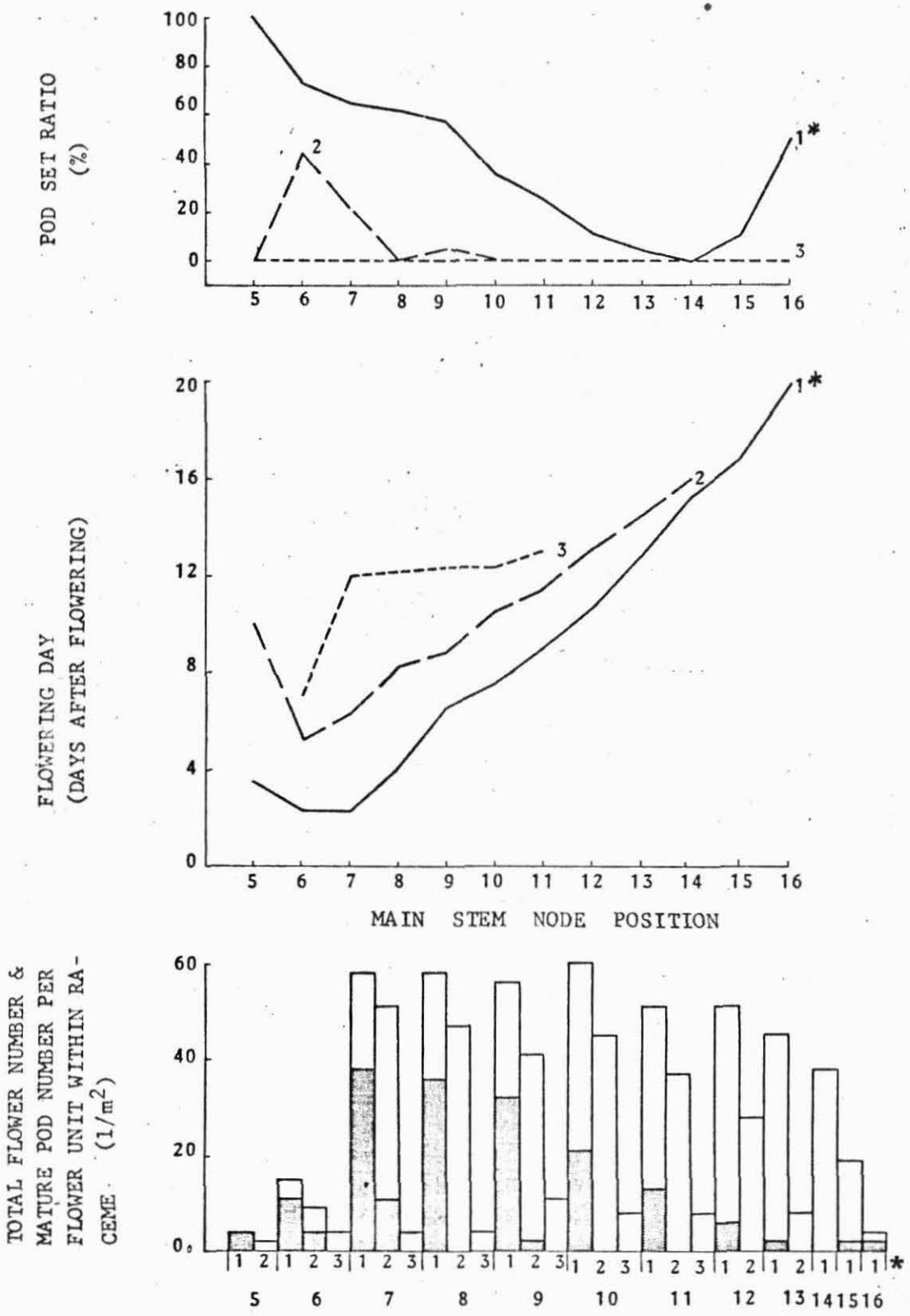


Fig. 5 Relationship between flower unit within each raceme at each node position and flowering day of each flower unit and the pod set ratio for each flower unit on the racemes on the mainstem for Porrillo Sintético. (Data of branches excluded).
*: the order of flower unit within each raceme).

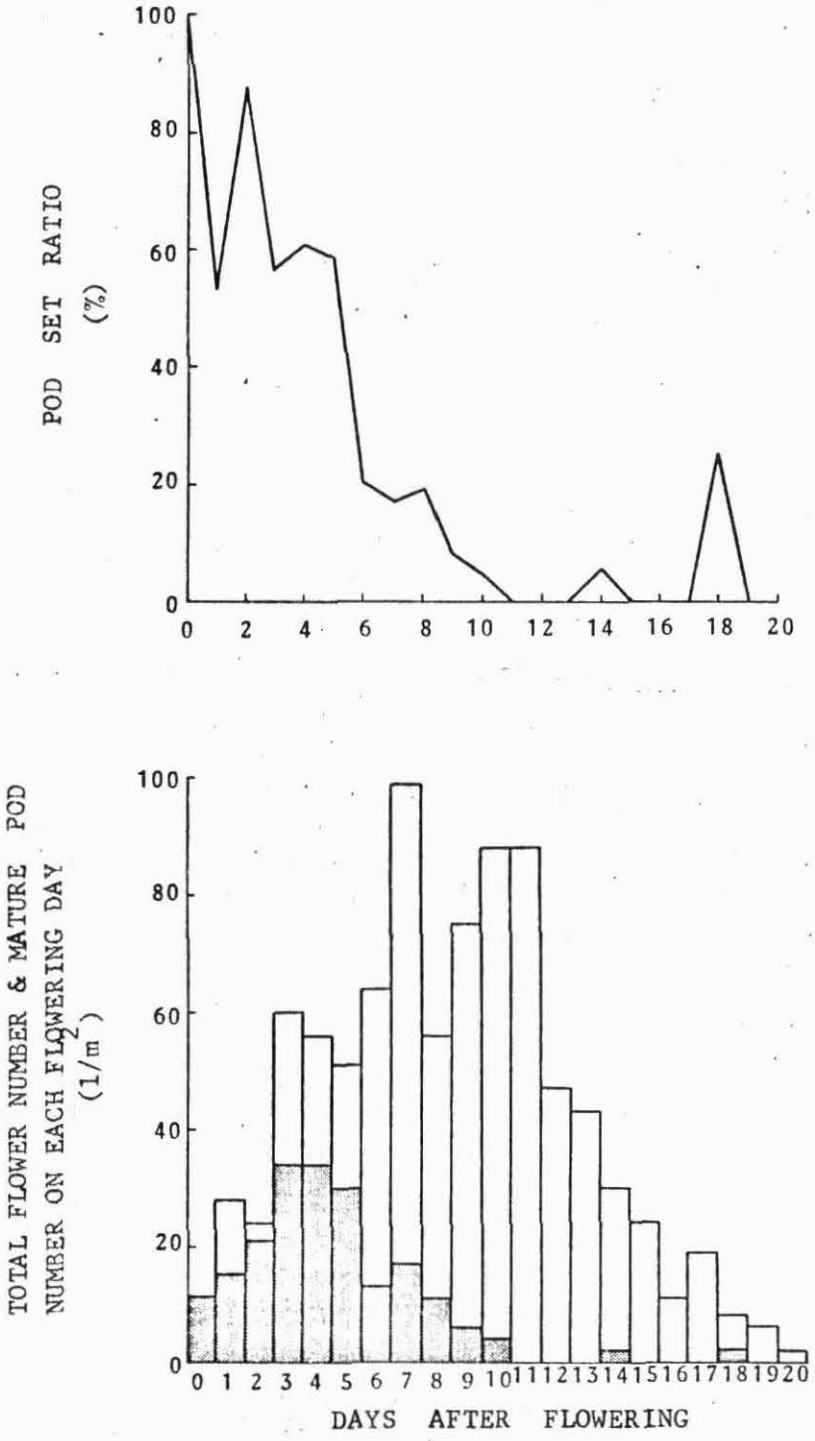


Fig. 6 Relationship between flowering day and pod set ratio (the ratio of mature pod number to total flower number blooming on each day of the flowering period) for Porrillo Sintético.

B. Pod growth

i) Growth and development of single pod on the 7th maintem node position

At FL12 pod length reached at constant level (FIg. 7). Pod wall weight attained its maximum value of about .65 g per pod at FL22 and gradually decreased till about .45 g per pod at maturity, loosing its weight of about .20 g per pod (about 30% of maximum pod wall weight).

Significant bean filling started at FL15 and after that bean weight increased rapidly and reached its maximum value of about 1.7 g per pod at FL33 and levelled off.

Reproductive organ weight (ROW; pod wall weight + bean weight) increased rapidly after the start of significant bean filling at FL15 and reached its maximum value of 2.2 g per pod at FL33 and slightly decreased in accordance with the decrease of pod wall weight. At maturity, bean weight (about 1.6 g per pod) shared about 75% of ROW (about 2.1 g per pod). The decrease amount of pod wall weight (about .20 g per pod) was equivalent to about 10% of bean weight.

As the water content of pod wall and beans decreased rapidly at FL33, when bean weight and ROW showed their maximum value, FL33 seemed to be the stage of physiological maturity of the pod of this node position.

ii) Pod growth (plant basis)

Pod growth stages are defined as follows

(a) small pod: pod length less than 5cm

(b) large pod: pod length more than 5cm, with significant bean filling not yet observed.

(c) fruited pod: significant bean filling observed

(d) mature pod: fruited pod at harvest

Pod number and reproductive organ weight were investigated for each node at each stage (Figures 8 and 9).

Up to FL15, small pod number and large pod number increased in parallel with fruited pod number. However, at FL22, the increase of fruited pod number levelled off and the mature pod number at harvest looked to be determined by the fruited pod number at this stage (Figures 8 and 10).

After FL8, reproductive organ weight increased rapidly with the commencement of bean filling (Fig. 10). After the final pod number was determined (about FL22), bean filling was concentrated in those fruited pods (Fig. 9). After FL36 bean filling was completed.

The analysis of yield components for each node at harvest (Fig. 11) revealed that the upper nodes of the mainstem suffered from an apparent shortage of assimilate during the pod set stage; bean yield, pod number and bean yield per pod showing lower values. This lower bean yield per pod was

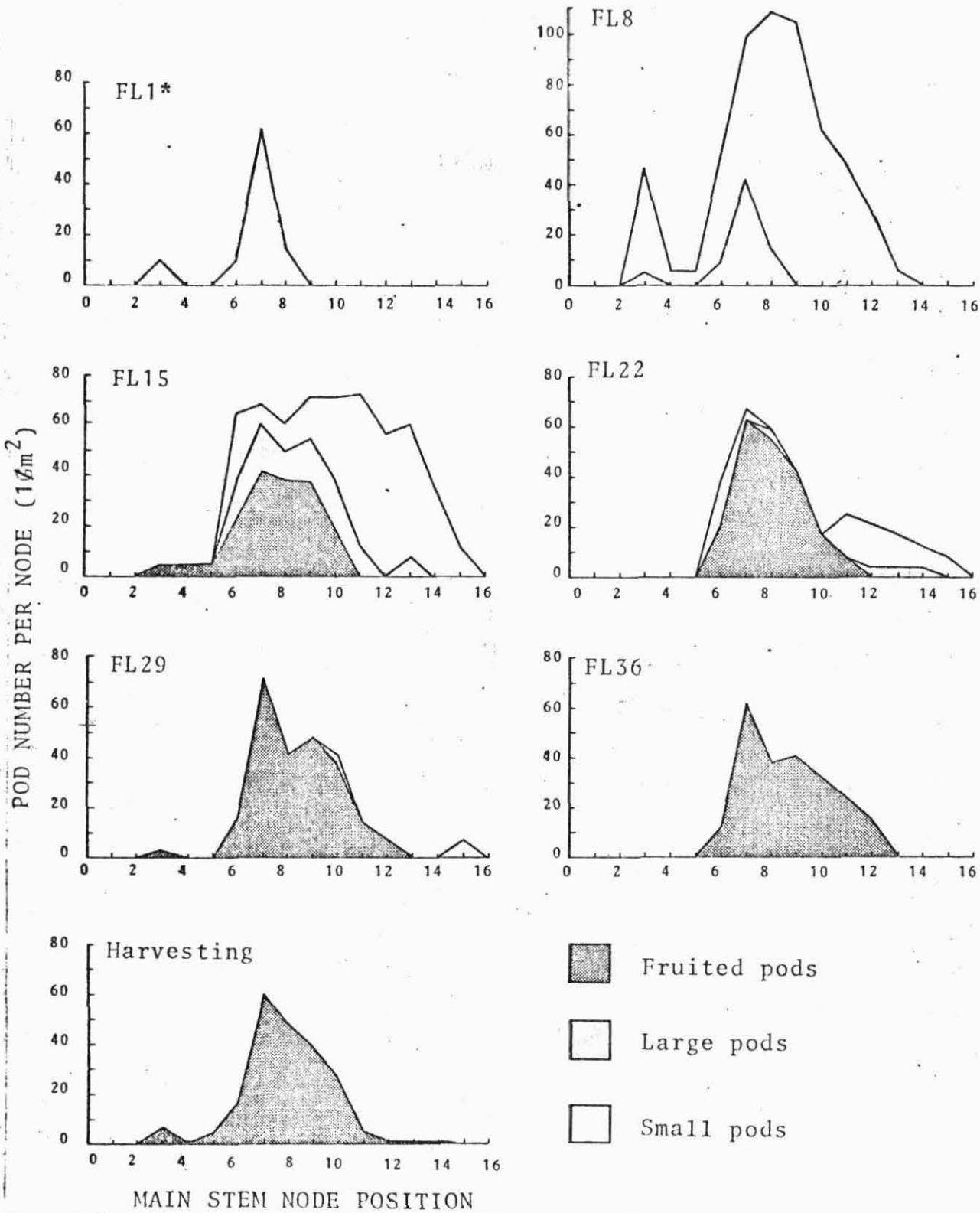


Fig. 8 Small pod number (pod length <5cm), large pod number (pod length ≥5cm, significant bean filling not observed), and fruited pod number (significant bean filling observed) at different growth stages after flowering (* days after flowering).

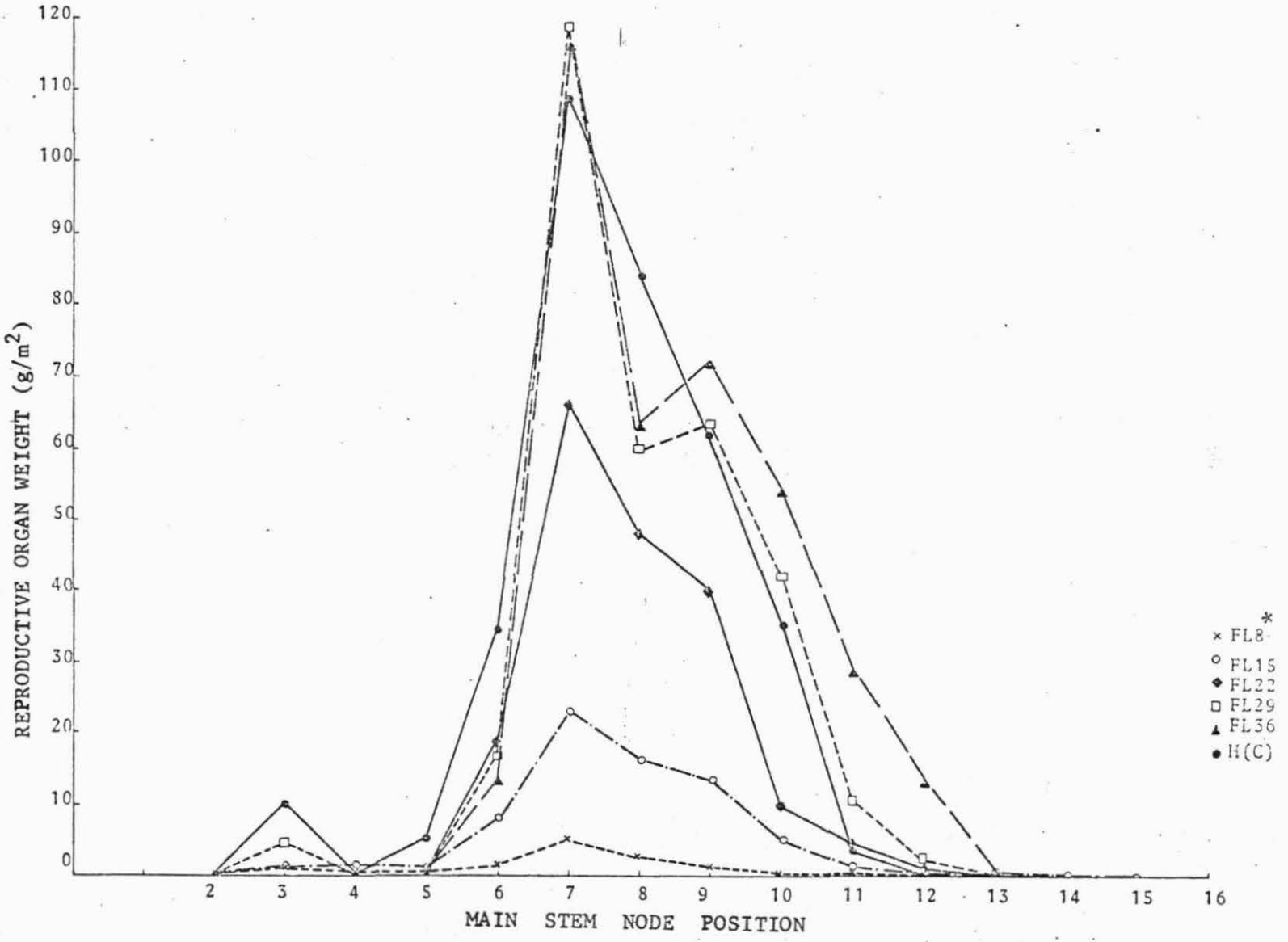


Fig. 9 Reproductive organ weight (pod wall weight + bean weight) per node at different growth stages in Porrillo Sintético.
(*: days after flowering H: Harvest).

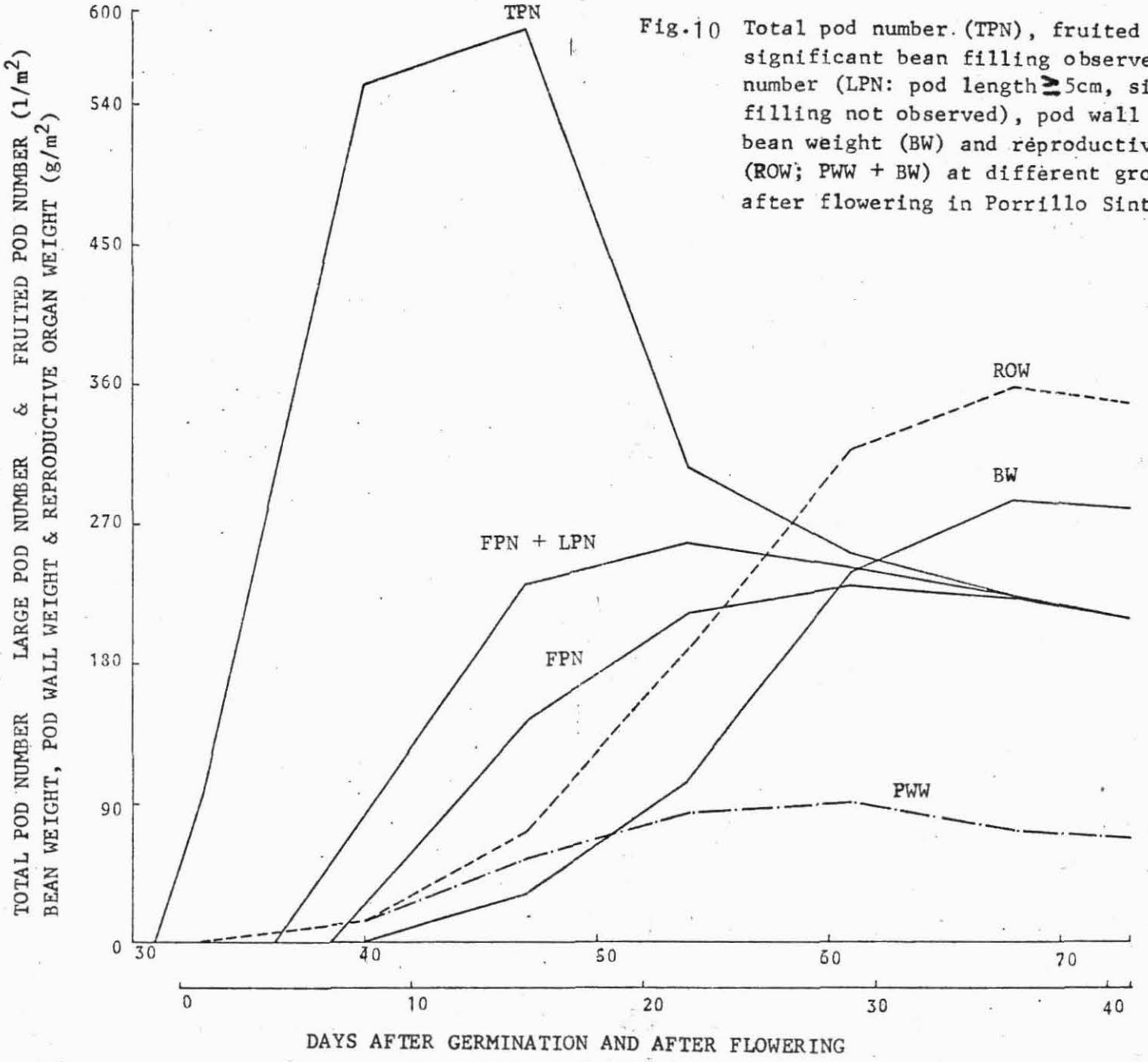


Fig.10 Total pod number (TPN), fruited pod number (FPN; significant bean filling observed), large pod number (LPN: pod length ≥ 5cm, significant bean filling not observed), pod wall weight (PWW), bean weight (BW) and reproductive organ weight (ROW; PWW + BW) at different growth stages after flowering in Porrillo Sintético.

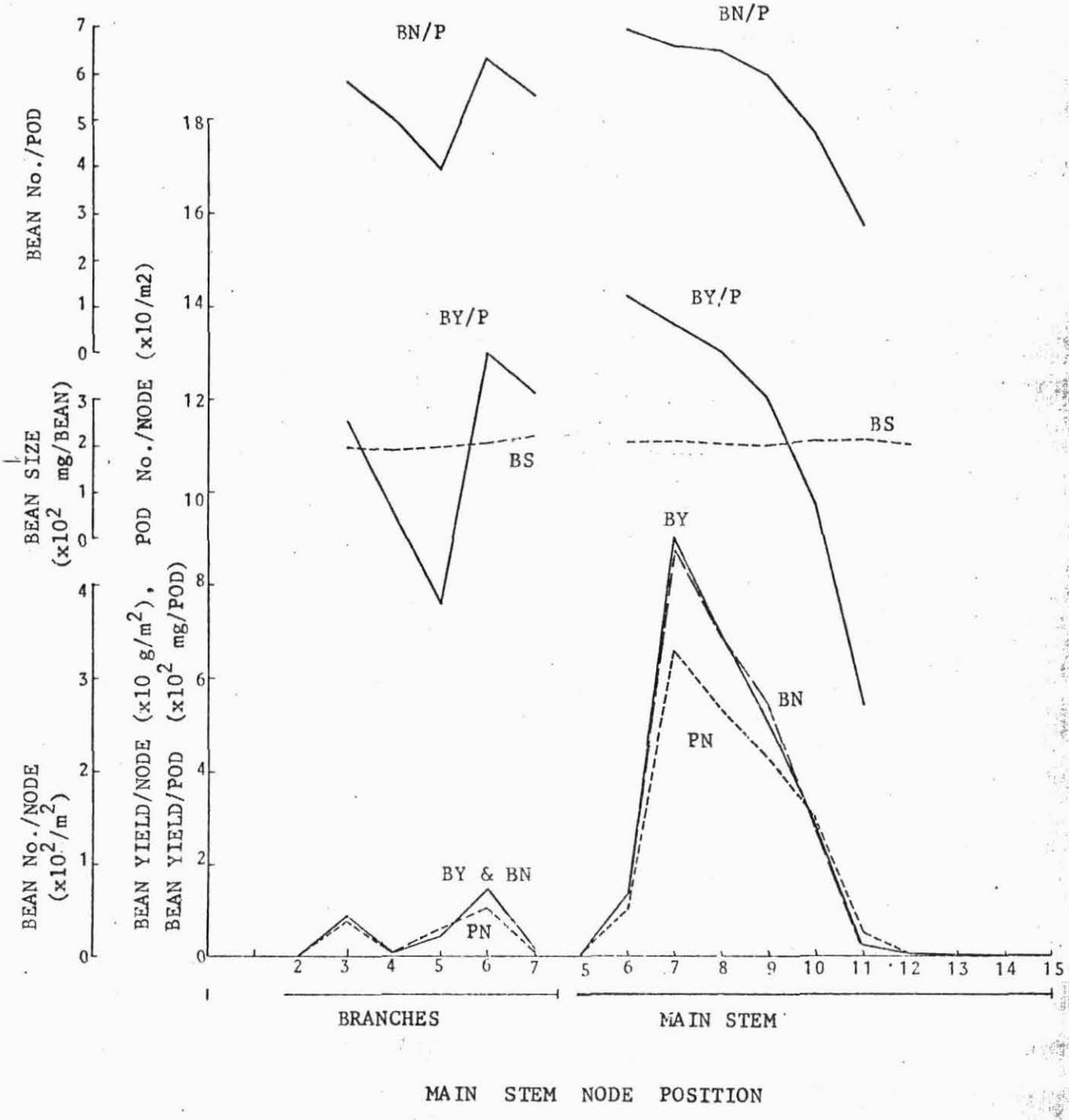


Fig.11 Bean yield per node (BY), pod number per node (PN), bean number per node (BN), bean number per pod (BN/P), bean yield per pod (BY/P) and bean size (BS) of mainstem and branches (branches differentiated by node of origin) in Porrillo Sintético.

caused by lower bean number per pod. While bean size showed little difference among node positions. The shortage of assimilate caused firstly a reduction in pod number and then bean number per pod. Bean size would be determined by the balance between bean number and the amount of available photosynthate during later stage of bean filling. Under these experimental conditions, it seemed that there was sufficient photosynthate for bean filling during the later maturing stage.

The amount of sugar and starch accumulated in whole plant at FL1 was 19 g/m^2 and the amount accumulated in vegetative organs at FL36 (almost physiologically mature) was 17 g/m^2 (Fig. 12). Hence, almost all of the sugar and starch which had been accumulated in beans was considered to be produced after flowering. Also, the fact that sugar and starch content of stems had decreased after the start of significant bean filling suggests the translocation of sugar and starch from stems to filling beans.

3. Nitrogen status

The amount of nitrogen accumulated in whole plants increased continuously up to maturity, with accumulation increasing rapidly in the reproductive organs after flowering

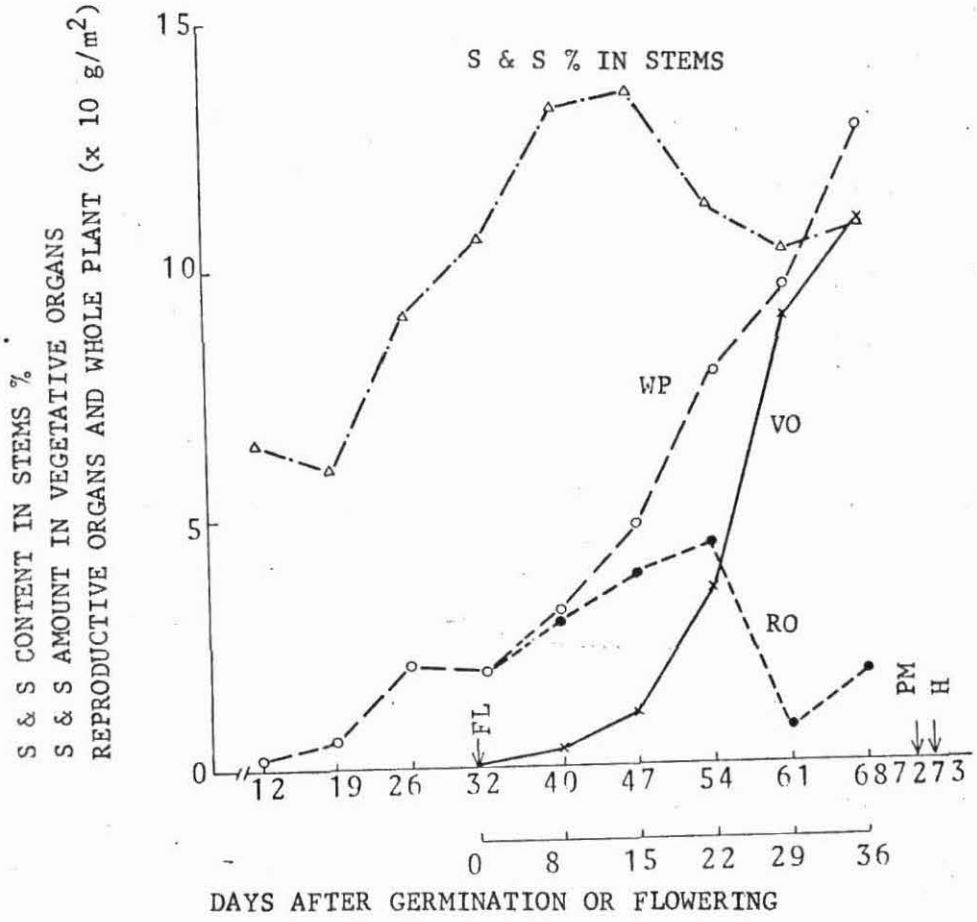


Fig. 12 Sugar and starch (S & S) content in stems, S & S amount in vegetative organs (VO), reproductive organs (RO), and whole plant (WP) at different growth stages in Porrillo Sinfético.

(FL: flowering; PM: physiological maturity; H: harvest).

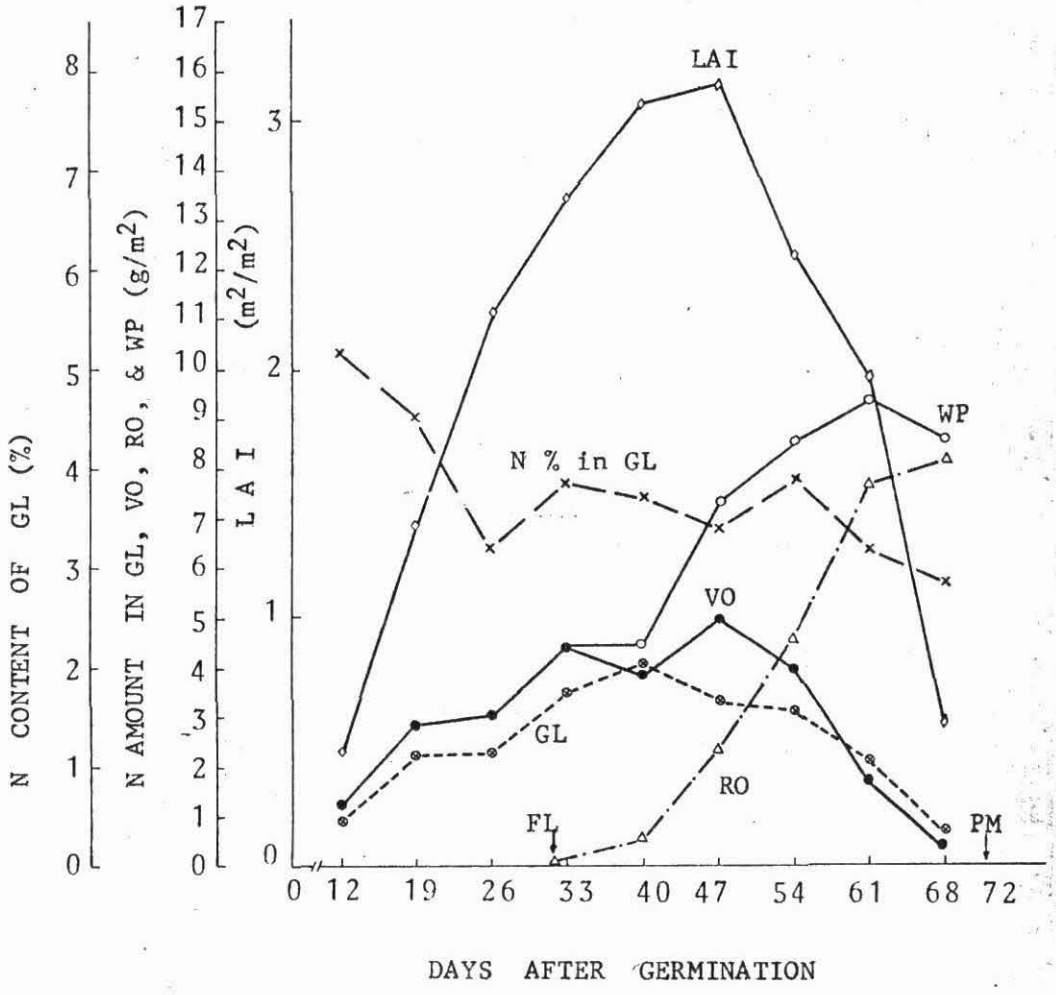


Fig. 13 LAI, nitrogen (N) content of green leaves (GL), N amount in GL, vegetative organs (VO), reproductive organs (RO), and whole plant (WP) at different growth stages in Porrillo Sintético.

(FL: flowering; PM: physiological maturity)

(Fig. 13). On the other hand, the amount of nitrogen in green leaves gradually decreased in parallel with the reduction of LAI after the commencement of significant bean filling. The nitrogen content of green leaves was maintained between three to four percent after flowering. The nitrogen amount in green leaves showed the highest value of 4.1 g/m^2 at FL8 and 0.7 g N/m^2 at FL36 (almost physiologically mature). The nitrogen amount which was lost from green leaves by translocation or leaf drop during bean filling period was thus estimated at about 3.4 g N/m^2.

C. Discussion

The growth pattern of this variety will be interpreted as follows.

After flowering commenced, competition between VOG and ROG for assimilate was apparent. After the start of significant ROG, VOG terminated and maximum LAI was determined (i.e. two weeks after flowering). Also, light condition of canopy was deteriorated in parallel with the increase in LAI.

Two weeks after flowering commenced, LAI decreased rapidly resulting in a reduction in the total amount of currently available photosynthate. On the other hand, one week after flowering commenced, crop growth rate (CGR) of reproductive organs (RO) increased rapidly (Fig. 14.) resulting in a probable shortage of photosynthate. The priority in utilization of this limited amount of available photosynthate seemed to be given to the early bloomed fruited pods to complete their bean filling: remainder of the photo synthate being shared among some late bloomed small pods. In other words, the location of fruited pods within plants was determined mainly by the earliness of flowering of each pod, and not by the source-sink balance of each nodal unit. The number of mature pods was determined by the available photosynthate which in turn is controlled mainly by the leaf

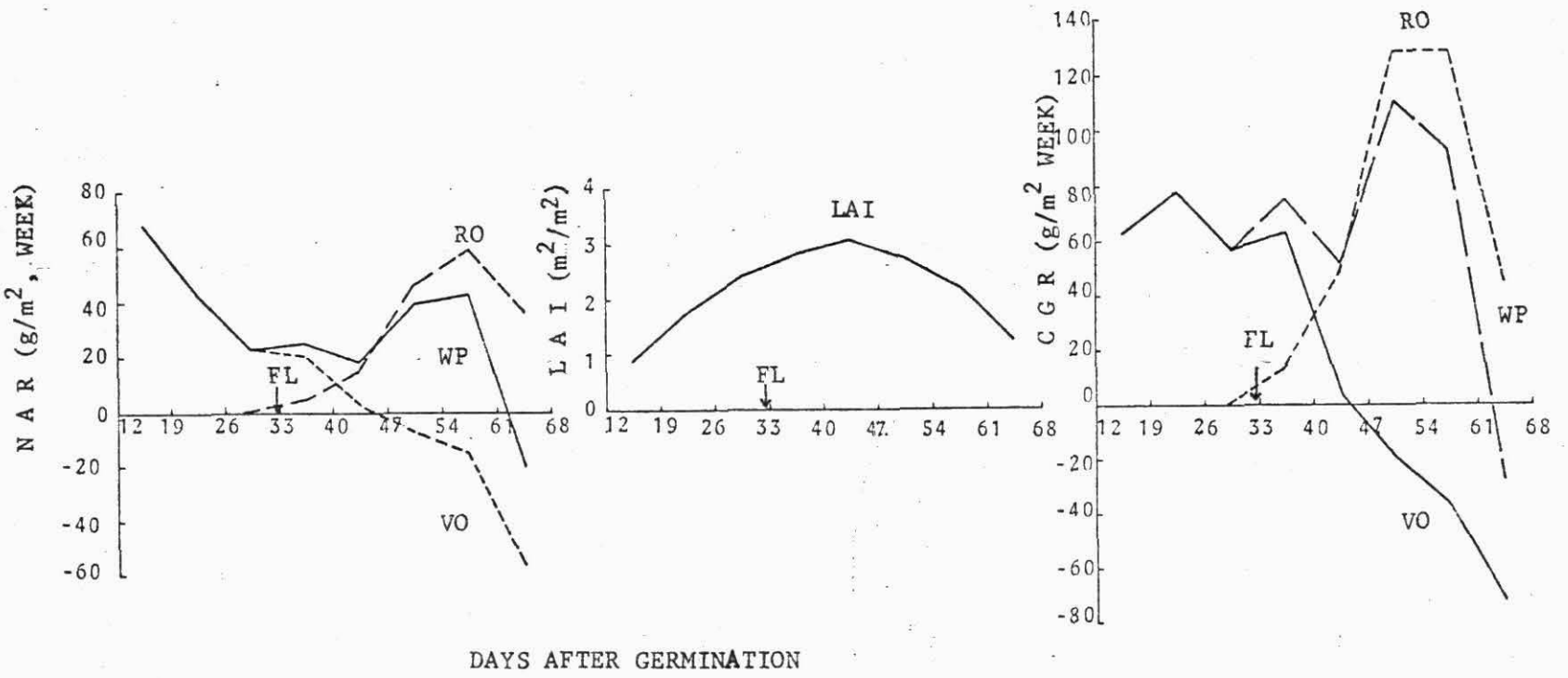


Fig.14. Net assimilation rate (NAR), leaf area index (LAI) and crop growth rate (CGR) of whole plant (WP), vegetative organs (VO) and reproductive organs (RO) at different growth stages in Porrillo Sintético. (FL: flowering).

area. Over the period from two to four weeks after flowering the CGR of RO showed the highest value, with photossynthate being concentrated in fruited pods. Up to the stage at which bean number per pod was determined, there seemed to be a shortage of assimilate. However, during the bean filling stage, there appeared to be sufficient assimilate for final bean filling probably caused partially by the translocation of assimilate from stems.

Maximum LAI and maintenance of LAI up to the stage of significant bean filling seemed to be determined by the balance between new leaf development and senescence of old leaves. After significant bean filling had commenced, it was determined by senescence of old leaves. There is a possibility that the nitrogen status of green leaves will have some influence on the senescence of leaves and maintenance of leaf area. The question of whether this loss of nitrogen from green leaves after significant bean filling could be the primary cause of leaf drop and reduction of LAI or that nitrogen loss was simply the result of leaf drop needs to be determined.

It was previously observed that each node could constitute a source-sink unit. The relationship between maximum leaf area of each node after the commencement of flowering and bean yield per node is shown in Fig. 15. This

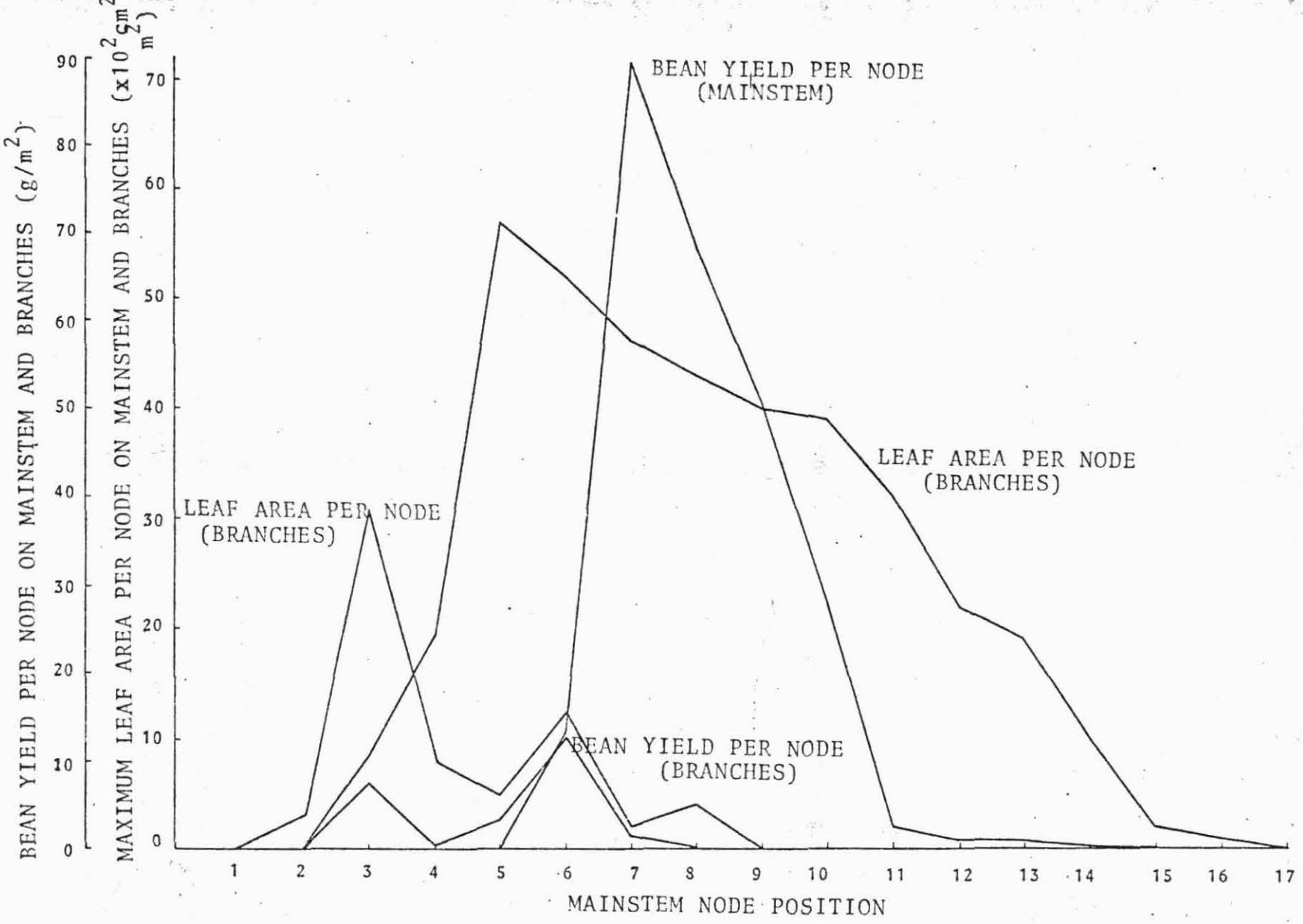


Fig. 15. Relationship between maximum leaf area of each node after flowering and bean yield per node for Porrillo Sintetico.

result suggests that there is no clear independence of each node as a source-sink unit.

From the above results, the following conclusions can be drawn.

The key factor increasing yield potential is increasing the amount of assimilate available during the pod set stage when pod number is being determined.

One direction would be to increase the amount of leaf area during the pod set stage, i.e. an increase in maximum leaf area index (LAI) and leaf area duration (LAD). The other way could be through an improvement in the efficiency of leaf layers in the canopy.

For many bush bean types where the maximum LAI does not reach ceiling LAI (the order of about 3.5, under CIAT conditions), node number increase could lead to leaf area increases and higher bean yield. However, for the bush types varieties where maximum LAI values are already exceeding the ceiling LAI, node number increases may not result in bean yield increases. An improvement in lodging resistance should be the first step to improve the light condition of canopy and thus the efficiency of all leaf layers.

The determinate bush varieties are usually more resistant to lodging (due probably to thicker and shorter

mainstems). However, they have fewer nodes and hence a smaller maximum LAI than the indeterminate bush varieties. If the node number of the determinate bush varieties can be increased to be able to reach the ceiling LAI (the order of about 3.5), yield potential of the determinate bush varieties could be comparable to or exceed that of indeterminate bush varieties.

For indeterminate bush varieties which maximum LAI already exceeding ceiling LAI, the main factor controlling the lodging resistance seems to be the status of the mainstems. Thicker and shorter mainstems should be favorable. However, many nodes will be needed to exceed ceiling LAI, so short internode length will also be essential.

The ability to maintain high levels of LAI for longer duration (LAD) seems to be determined by the balance between vegetative node growth after flowering and senescence of old leaves. Among growth habit types I, II, and III, the degree of vegetative node growth after flowering differs, i.e. in type I: small (mainly on branches), in type II: medium, in type III: large. Most varieties of growth habit type III are more favorable with respect to the maintenance of leaf area at high level after flowering. For the determinate bush variety, the character of heavy branching habit which provides vegetative node growth after flo-

wering could also be effective in maintaining reasonably high levels of LAI after flowering. There are obviously many combinations of maximum LAI, LAD and lodging resistance among the three growth habit types. The relative importance of each factor and the effect of these combinations on bean yield are still unknown.

The other direction could be to increase the efficiency of pod set by mitigating the competition between VOG and ROG after flowering. Decreased VOG after flowering will also cause the reduction of post flowering LAI which may not lead to increased pod set. Another way could be to change the pattern of the distribution of assimilate among large and small pods. In other words, if the assimilate which is usually concentrated in large pods is shared with small pods, it would result in more pod set by more fully utilizing assimilate available during the bean filling stage. The movement of assimilate during the pod set stage seems to be controlled by endogenous growth substances and further study is needed to clarify these points.

As a first step, increasing the amoung of leaf area during the pod set stage seems to be the most practical alternative.