USING ORGAN GROWTH POTENTIALS TO IDENTIFY PHYSIOLOGICAL AND HORTICULTURAL LIMITATIONS TO YIELD

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Abstract

For the last several years research in my laboratory has focused on identifying physiological and horticultural limitations to yield based on source-sink interactions and the concept that plants grow as collections of semi-autonomous but interacting organs. This concept assumes that plant genotype, triggered by internal and environmental signals, determines current organ specific growth potentials and that environmental conditions specify conditional growth capacity and maintenance requirements (sink capacity) of each organ at a particular point in time. The availability of resources for organ growth and maintenance (source capability) then interacts with the conditional growth capacity to determine the realized organ growth for any given time period. In this paper I will discuss how this concept has permitted identification of periods during fruit development when fruit growth tends to be source-limited or sink-limited. Furthermore the use of the concepts for studying how nitrogen and water stress affect fruit growth capacity and crop yield will be demonstrated.

Résumé

Au cours des quelques dernières années, la recherche dans mon laboratoire s'est focalisée sur l'identification des limitations physiologiques et horticoles du rendement basées sur les interactions source-puits et sur le concept que les plantes poussent comme des collections d'organes semi-autonomes mais en interaction. Ce concept assume que le génotype de la plante, sollicité par des signaux internes et environnementaux, détermine des courants potentiels de croissance spécifique des organes et que les conditions du milieu spécifient les capacités conditionnelles de croissance et les besoins de maintenance (capacités puits) de chaque organe à un moment donné. La disponibilité des ressources pour la croissance des organes et leur maintenance (capacité source) interâgit alors avec les capacités conditionnelles de croissance pour déterminer la croissance réalisée de l'organe à une période donnée. Dans cet article, je discuterai comment ce concept a permis l'identification de périodes au cours du développement du fruit quand cette croissance tend a être limitée par l'effet source ou l'effet puits. Par ailleurs, il sera démontré comment l'utilisation des concepts peut permettre d'étudier comment les effets des stress azotés ou hydriques affectent les capacités de croissance du fruit et le rendement.

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1. Introduction

Source-sink relationships and the regulation of resource allocation determines crop yield in plants. The growth of individual plant organs may be restricted by resource availability (source limitation) or by the organ's ability to utilize resources (sink limitation, Wareing and Patrick 1975). Furthermore, the organ's ability to utilize resources are thought to be dictated by the plant genotype, environmental and endogenous thresholds, and prevailing environmental conditions (DeJong and Grossman, 1994). The bases for the organ's ability to utilize resources are maintenance respiration and the maximum organ growth potential, the genetically determined growth attained when an organ is grown under optimal environmental conditions in the presence of a non-limiting supply of carbon or other resources (Warren Wilson, 1972; Wareing and Patrick 1975; Ho, 1988). In 1989, DeJong and Goudriaan reported that seasonal patterns of peach fruit growth potentials are apparently governed by developmentally determined patterns of fruit relative growth rates. Later Grossman and DeJong (1995b) documented that when peach fruit did not attain their growth potential for specific growth intervals due to source limitations, those fruit grew according to a developmentally determined RGR pattern subsequent to relieving of the source limitation.

This paper will discuss experiments which were conducted to determine a) periods of source and sink limitations to fruit growth and yield in peach trees, b) differentiate the effects of nitrogen deficiency on fruit growth potentials and resources available for fruit growth, and c) determine if reduced fruit size in response to water stress is primarily a result of lack of resources available for fruit growth or on fruit growth potential.

2. Materials, methods and results

2. 1. Source-Sink study

The fruits analyzed in this study were grown in 1990, on two peach cultivars, 'Spring Lady' and 'Cal Red' with fruit maturity date in late May and mid-August, respectively. Trees were planted at high density (1250 trees/ha) and trained to a central leader system. Apart from fruit thinning treatments, trees received routine horticultural care suitable for commercial fruit production.

Maximum fruit growth potential was determined using fruit grown on heavily-thinned trees from which most of the flowers were removed at bloom. Fruit were further thinned one month after bloom. Other trees were left unthinned to approximate conditions of maximum resource demand for fruit growth. Mean crop loads on heavily thinned and unthinned trees were 33.2 and 240.0 and 60.9 and 288.0 fruits/tree for 'Spring Lady' and 'Cal Red' trees, respectively. Fruit dry weight was monitored weekly and relative growth rates analysis was done to determine when fruit relative growth rates differed significantly as a result of the thinning treatments (see Grossman and Dejong, 1995a, for further details).

Differences in mean individual fruit dry weight developed rather quickly in response to thinning treatments (Fig. 1). In spite of the rather large differences in mean individual fruit dry weight, the thinning treatments caused significant differences in fruit relative growth rate only during specific periods of fruit development, particularly in the late maturing cultivars (Fig. 2). These data clearly show that although the fruit loads of the unthinned trees were very heavy, fruit growth on these trees was resource limited only during specific time intervals. Interestingly when total crop resource usage was calculated for the trees in these treatments, the unthinned 'Spring Lady' and 'Cal Red' trees partitioned equal amounts of fruit growth during the first five weeks after bloom (Fig. 3). This indicates that in spite of large differences in fruit development patterns, trees of these two cultivars had similar amounts of resources available to support early fruit growth.

This study clearly shows that differences in crop yield, when trees are provided adequate water and nutrients, are primarily a function of crop load and the relative lengths of periods of sink versus source limitations to fruit growth. Large individual fruit sizes are attained by minimizing periods source limitations, whereas maximum yield is attained by minimizing periods when collective crop growth is developmentally (sink) limited.

2. 2. Nitrogen stress study

'O'Henry' peach trees trained to a perpendicular V system with 1055 trees/ha received no fertilization for more than a year prior to this study. In fall, 1993, four N-fertilization treatments were established. Treatments consisted of: Fall N, receiving 200 kg N/ha on October 5, 1993; Split N treatment receiving 100 Kg N/ha on October 5, 1993 and April 10, 1994; Spring N, receiving 200 Kg N/ha on April 10, 1994 and a Control, which received no N fertilizer. Additionally three thinning treatments were imposed within each N treatment subplot. The three thinning treatments were heavy thinning (~100 fruits/tree), commercial thinning (~210 fruits/tree), and unthinned (~450-500 fruits/tree). Trees received other tree care appropriate for commercial orchards.

Time of full bloom was carefully estimated from bloom count data and fruit growth was monitored at 4-14 day intervals on the heavily thinned trees in each of the 4 N treatments. Fruits were harvested in several harvests using commercial maturity standards and a mean harvest date was calculated based on weighted means of each harvest (See Saenz *et al.*, for further details).

The N treatments resulted in clear differences in tree nitrogen status, particularly between the control trees, which showed symptoms of marginal N deficiency, and the other N treatments. Trees receiving fall fertilizer attained full bloom 2 days earlier than trees in the other treatments. On the other hand, fruit matured 8-12 days later on all treatments receiving N fertilizer than on the Control trees, depending on the crop load. Fruit on trees with heavier crop loads tended to mature later than fruit on trees with light crop loads. Contrary to expectations, estimated maximum fruit growth potential tended to be higher on Control trees compared to all other N treatments (Fig. 4) but mean fruit size at harvest were lower because of the shorter development period (Fig. 5, Table 1). Fruit size and crop yield were significantly enhanced in treatments receiving N fertilizer relative to the Control treatment because of longer periods available for fruit development and larger amounts of resources available for fruit development (as indicated by the unthinned treatments Table 1) but not because of effects N availability on maximum fruit growth potential.

2. 3. Water Stress Study

Five-year-old 'Elegant Lady' peach trees growing in a high density perpendicular V training system (909 trees/ha) were subjected to irrigation treatments during the last 7 weeks of the fruit development period. Control treatment trees received 120% of estimated replacement evapotranspiration (ETo) whereas the water stressed treatment received no irrigation for 2 weeks and then only 25% of estimated ETo for the final 5 weeks of fruit growth. Trees within each irrigation treatment received one of three fruit thinning treatments: light crop load (~60 fruit/tree) moderate crop load (~260 fruit/tree) and heavy crop load (unthinned, ~560 fruit/tree).

Mid-day bagged-leaf, xylem water potential measurements were made (McCutchan and Shackel, 1992) made at regular intervals to track the development of water stress. Fruit were harvested on July 14 and mean and total fruit fresh and dry weight were determined per tree (see Berman and DeJong 1996 for further details).

The water-stress treatments resulted in substantial reductions in mid-day xylem water potentials, indicating the development of water stress (Fig. 5). Trees with heavy crop loads experienced higher degrees of water stress than light-cropped trees. Although the mean individual fruit fresh weight was significantly reduced by water stress in all thinning treatments mean fruit dry weights were significantly affected only in the heavily cropped treatment (Fig. 6). Similarly, although the mean crop fresh weight was significantly reduced by water stress across all thinning treatments, the mean crop dry weight was only significantly affected by water stress in the heavy cropped treatment (Fig. 7).

These data indicate that the primary effect of water stress on peach growth and yield in this experiment was on peach fruit hydration and not fruit dry matter growth potential. Furthermore water stress appears to have relatively minor effects on availability of resources for dry weight growth (source limitations) until crop loads are excessive.

3. Discussion

These three studies demonstrate how the concept of organ growth potential can be used to identify developmental, physiological and environmental factors that affect crop growth and yield. Identification of these specific effects can be used to develop more definitive and efficient horticultural practices as we continue to move in the direction of optimizing horticultural crop production with increasingly scarce resources.

References

Berman M. E. and DeJong T. M., 1996. Water stress effects on fruit fresh and dry weight. Tree Physiol. (in press).

DeJong T. M. and Goudriaan J., 1989. Modeling peach fruit growth and carbohydrate requirements: reevaluation of the double-sigmoid growth pattern. J. Amer. Soc. Hort. Sci. 114:800-814.

DeJong T. M. and Grossman Y. L., 1994. A supply and demand approach to modeling annual reproductive and vegetative growth of deciduous fruit trees. HortScience 29:1435-1442.

Grossman Y. L. and DeJong T. M., 1995a. Maximum fruit growth potential and seasonal patterns of resources dynamics during peach growth. Ann. Bot. 75:553- 560.

Grossman Y. L. and DeJong T. M., 1995b. Maximum fruit growth potential following resource limitation during peach growth. Ann. Bot. 75:561-567.

Ho L. C., 1988. Metabolism and compartmentation of imported sugars in sink organs in relation to sink strength. Ann. Rev. Plant Physiol. 39:355-379.

McCutchan H. and Shackel K. A., 1992. Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). J. Amer. Soc. Hort. Sci. 117:607-611.

Saenz J. L., DeJong T. M. and Weinbaum S. A., 1997. Nitrogen fertilization increases peach fruit growth potential, increases resources availability and prolongs the fruit development period. J. Amer. Soc. Hort. Sci. (submitted).

Wardlaw I. F., 1990. The control of carbon partitioning in plants. Transley Review No. 27. New Phytol. 116:341-381.

Wareing P. F. and Patrick J., 1975. Source-sink relations and the partitioning of assimilates in the plant. In : Photosynthesis and Productivity in Different Environments Cooper, J. P. ed., Cambridge Univ. Press, Cambridge, pp 481-499.

Warren Wilson J., 1972. Control of crop processes. In : Crop Processes in Controlled Environments Rees, A. R., Cockshull, K. E., Hand D. W. and Hurd R. G., eds. Academic Press, New York, pp 7-30..

Table 1 - Relationship between thinning severity and fertilization on fruit number per tree at harvest, final fruit dry weight and fresh weight. Different letters indicate significant difference (P-0.05) using Tukey test.

Severity of Thinning (*)	Nitrogen treatment (**)	Crop Load	Weight per fruit		Fruit weight per tree	
		# fruit tree^{-1}	Dry weight (g fruit-1)	Fresh weight (g fruit -1)	Dry weight (kg tree-1)	Fresh weight (kg tree-1)
Heavy	No N	98.6 a	33.7 a	196.9 a	3.3 b	19.4 b
	Spring N	101.1 a	39.3 b	240.7 b	4.0 a	24.3 a
	Split N	99.5 a	38.1 b	231.2 b	3.8 ab	22.9 a
	Fall N	105.4 a	39.0 b	235.4 b	4.1 a	24.8 a
Commercial	No N	223.0 a	23.2 a	142.5 a	5.2 b	31.7 b
	Spring N	199.4 a	29.5 b	201.3 b	5.9 ab	40.1 a
	Split N	217.8 a	29.7 b	192.8 b	6.4 a	41.8 a
	Fall N	213.7 a	30.0 b	191.4 b	6.4 a	40.9 a
Unthinned	No N	460.2 a	15.6 a	99.1 a	7.1 b	45.5 b
	Spring N	466.4 a	21.5 b	147.0 b	10.0 a	68.3 a
	Split N	541.4 a	18.3 b	129.1 b	9.8 a	9.8 a
	Fall N	498.9 a	20.1 b	133.6 b	10.0 a	66.1 a

(*) Thinning treatment applied April 4-7, 1994. Heavy thinning consists of 100 fruits/tree, Commercial thinning consists of 210 fruits/tree and Unthinned consists of 450-550 fruits/tree.

(**) N-fertilization treatments applied September 28, 1993 (fall application) and April 9, 1994 (spring application). Spring N consists of 200 kg N/ha in the spring, Fall N consists of 200 kg N/ha in the fall and Split N consists of 100 kg N/ha in the fall plus 100 kg N/ha in the spring.

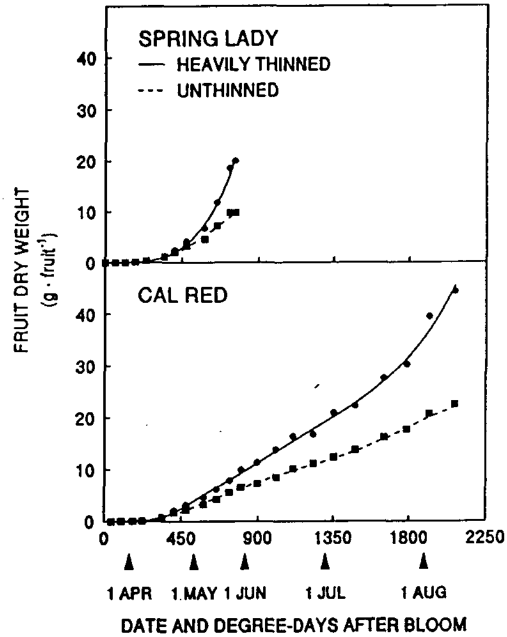

Fig 1. Seasonal patterns of mean individual fruit dry weight on heavily-thinned (—) and unthinned (- - - -) trees of two peach cultivars. (Adapted from Grossman and DeJong 1995a).

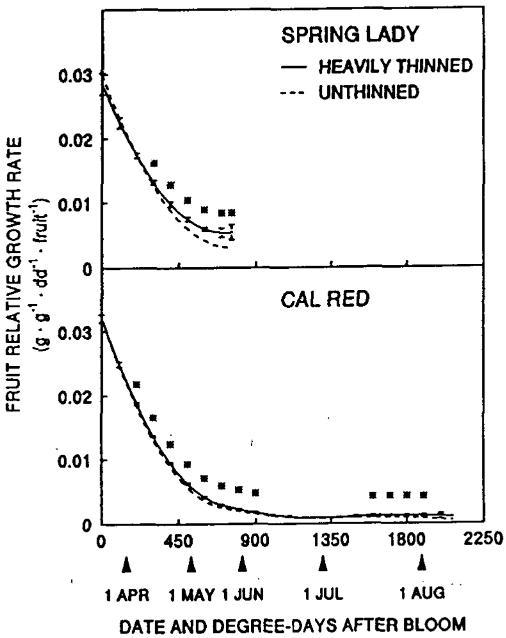

Fig 2. Seasonal patterns of fruit relative growth rates for fruits on heavily-thinned (—) and unthinned (- - - -) trees of two peach cultivars (Adapted from Grossman and DeJong 1995a).

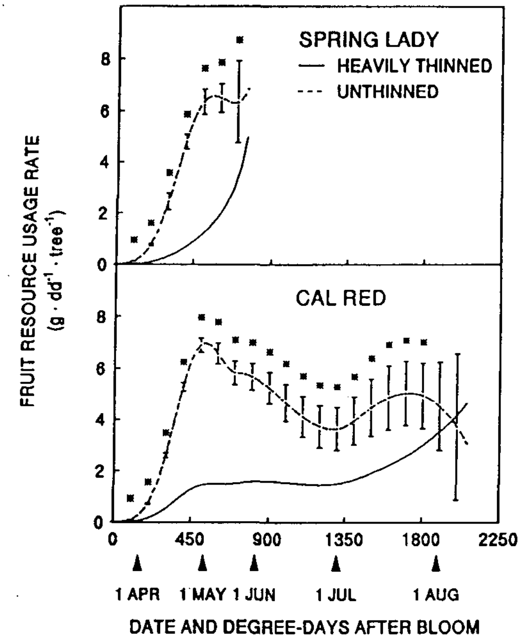

Fig 3. Seasonal patterns of crop resource usage rate on heavily thinned (—) and unthinned (- - - -) trees of two peach cultivars (Adapted from Grossman and DeJong 1995a).

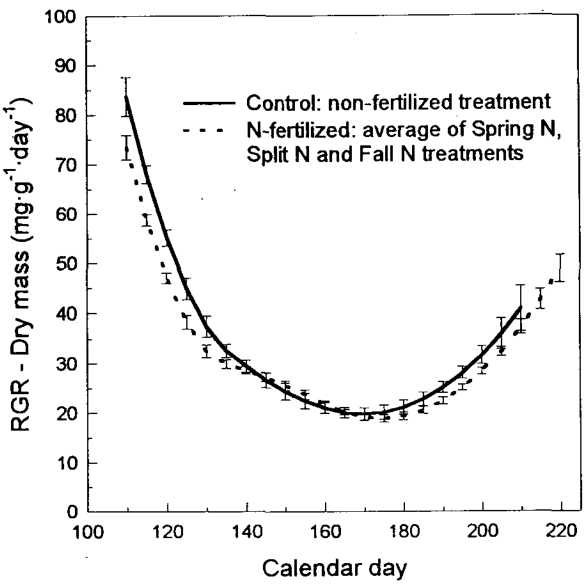

Fig 4. Seasonal patterns of fruit dry weight relative growth rate for N-fertilized and non-fertilized 'O'Henry' peach trees. (Adapted from Saenz et al. 1997).

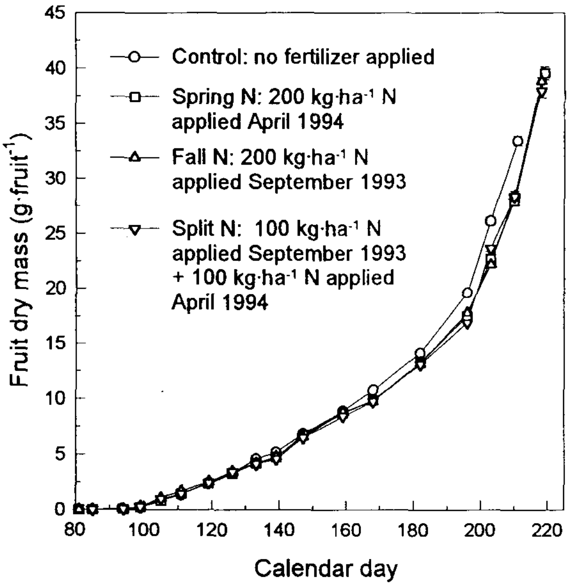

Fig 5. Seasonal patterns of average fruit dry weight accumulation of 'O'Henry' peaches as influenced by nitrogen fertilizer treatments (adapted from Saenz et al. 1997).

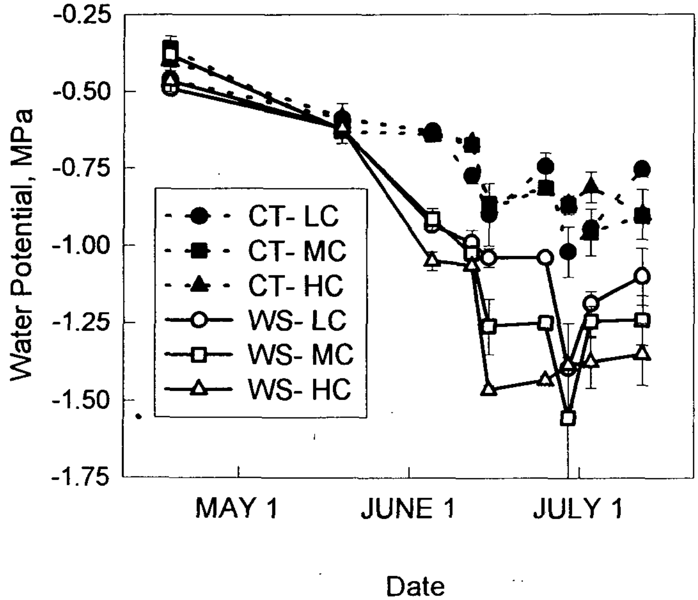

Fig 6. Seasonal patterns of mid-day xylem water potential for 6 irrigation/thinning treatment combinations. Irrigation treatments were control treatment (CT) and water stress (WS) treatment. The thinning treatments were light crop (LC), moderate crop (MC) and heavy crop (HC) (adapted from Berman and DeJong 1997).

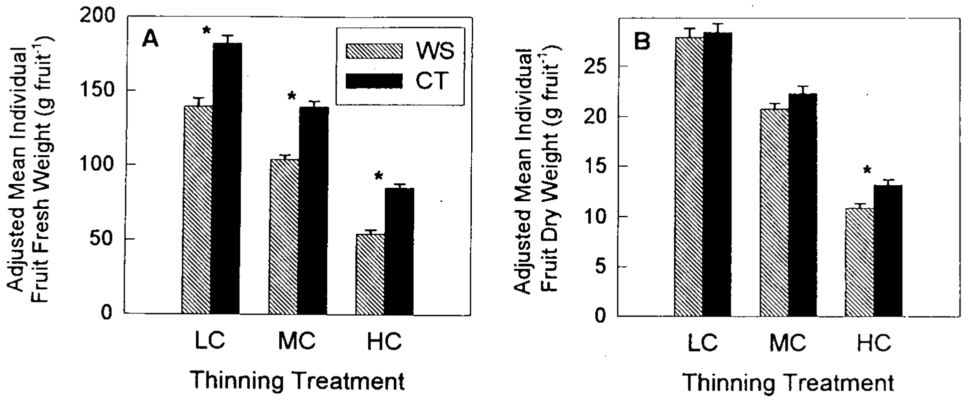

Fig 7. Mean individual peach fruit fresh and dry weights in response to irrigation and thinning treatments (see Fig 6 for treatment details)(adapted from Berman and DeJong 1997)

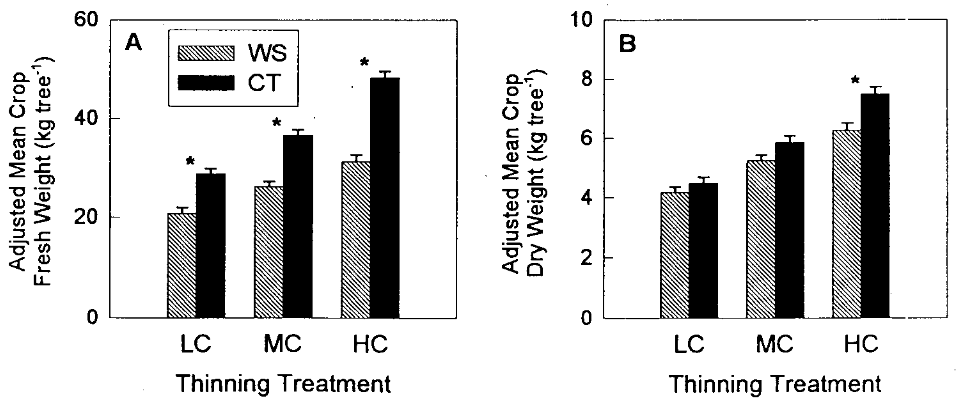

Fig 8. Mean peach crop fresh and dry weights in response to irrigation and thinning treatments (see Fig 6 for treatment details) (adapted from Berman and DeJong 1997).