

## Canopy Development, Carbohydrate Partitioning and Yield Characteristics of Pistachio

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The primary emphasis of this project was to understand the vegetative growth differences between ‘Kerman’ trees grown on *Pistacia atlantica* (Atl), Pioneer Gold I (PGI) and UC Berkeley I (UCB) rootstocks and to determine how those differences affect canopy development, yield characteristics and the carbohydrate balance of the tree. This has been a very broad project that has spanned four years. The data are currently being composed for publication in scientific journals, but this document is designed to serve as a summary for growers.

Our first objective was to determine why trees on UCB and PGI rootstocks are larger than those on Atl. It is easy to simply say that UCB and PGI trees are more vigorous, but we were interested in understanding why they are more vigorous. Our approach to answer this was to look at how the trees grow. Fundamentally, temperate deciduous trees produce two basic types of vegetative growth: **preformed** and **neofor**med. These terms refer to when leaves are formed in their embryonic state in a bud relative to when they are expanded and seen on the tree. In preformed growth, leaves are formed in a bud during one season (call that season x), but the bud does not grow, and thus you do not see the leaves, until the following season (x+1). Exactly how many leaves are formed in a bud depend on things such as the species, the position of the bud in the canopy, the size of the shoot that the bud is formed on, environmental conditions and other factors. In contrast, neofor

med growth has leaf development and expansion occurring in the same season, without the formation of a bud. This is sometimes referred to as “free” growth because it is not constrained to a “fixed” number of leaves as is the case for preformed growth.

We determined that for ‘Kerman’ pistachio every bud on a tree, regardless of the rootstock, crop load, canopy position or parent shoot size, has 8-9 leaves preformed in it (Table 1).

Table 1. The number of preformed leaves in dormant buds from ‘Kerman’ trees on three rootstocks following an on- and off-year.

Rootstock	crop	No. of preformed leaves
Atl	on	8.3
	off	8.4
PGI	on	8.3
	off	8.4
UCB	on	8.5
	off	8.8

for some reason that shoot began to grow from a bud, which had 8-9 leaves preformed in it, but something triggered it to continue to grow beyond that preformed or fixed point. Thus, a shoot with neofor

med growth also has a section at its base that is preformed. This is illustrated in Figure 1. By understanding this, we can logically conclude that a tree that produces more shoots with neofor

med growth will have 8-9 nodes. However, as you know there are frequently shoots in a canopy that have more than 8-9 nodes on them.

This is the result of neofor

med growth. That is,

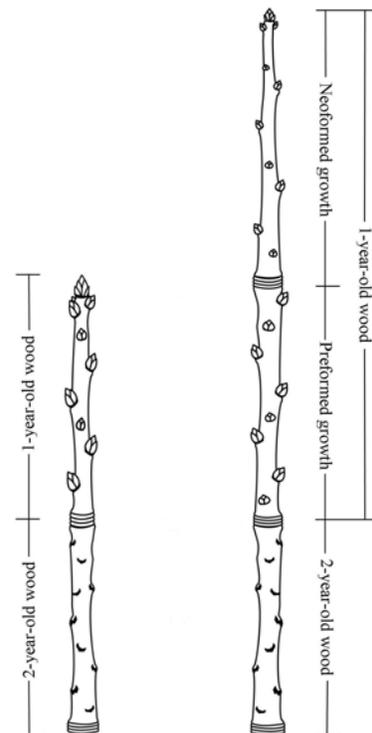


Fig. 1. Two typical shoots from a ‘Kerman’ pistachio tree. The 1-year-old wood of the shoot on the left is entirely preformed whereas the 1-year-old wood of the shoot on the right is both preformed and neofor

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neoformed growth than trees on Atl, thus their larger size. We also observed that on mature trees neoformed growth is generally found only in the top of the canopy, suggesting that light may be a factor important to the development of neoformed growth.

Once we understood the source of the growth differences among rootstocks we could begin to determine how neoformed growth affects yield, canopy development, pruning and other horticultural practices.

We initially assumed that this greater growth of trees on UCB and PGI must explain why these trees are generally much higher yielding than those on Atl. However, as we studied the neoformed shoots we found that they did not have very many more inflorescence buds than their much shorter, preformed, counterparts (Table 2). This is because inflorescence bud development

Table 2. Inflorescence bud set and retention of shoots composed only of preformed growth and those with neoformed growth from 'Kerman' trees on three rootstocks.

	Rootstock		
	Atl	PGI	UCB
	No. of inflorescence buds set		
Preformed	8.4	8.2	9.3
Neoformed	12.8	11.7	13.2
	No. of inflorescence buds retained		
Preformed	6.5	5.3	6.6
Neoformed	8.0	6.8	8.6
	Percent inflorescence bud retention		
Preformed	77.1	64.8	70.7
Neoformed	60.5	56.0	63.9

primarily occurs at the preformed nodes of a shoot with neoformed growth. We found that typically only the earliest formed neoformed nodes, that is those closest to the preformed portion of the shoot, developed into inflorescence buds (Fig. 2). Thus, a shoot with neoformed growth that may have 40 nodes may only have 11 or 12 inflorescence buds on it. In further studying these shoots we found that a higher percentage of the set inflorescence buds aborted on shoots with neoformed growth than on shoots with only preformed growth, but because the shoots with neoformed growth started with 4-5 more inflorescence buds more than preformed shoots they ended up retaining about 1-2 more buds (Table 2).



Fig. 2. A shoot with both preformed (between the vertical lines) and neoformed (to the right of the second vertical line) growth. The circles indicate the only inflorescence buds on the neoformed portion of the shoot. The other buds on the neoformed portion of the shoot are vegetative. All of the buds on the preformed portion of the shoot are inflorescence buds.

These differences translated into an overall yield difference between preformed and neoformed shoots of about one cluster of nuts more on the neoformed shoots at harvest time. This small increase did not explain the large differences in yield between UCB and PGI trees and those on Atl. The differences in yield are simply a matter of larger tree size with more shoots and more clusters per tree (Table 3). Furthermore, when we investigated the relationship of shoots to canopy position we found that the greater number of clusters on shoots with neoformed growth was more related to the position in the canopy and not the shoot type. That is, a shoot with only preformed growth will yield just as well as a shoot with neoformed growth if they are in the same position in the canopy. This meant that we could investigate ways to eliminate or control neoformed growth in mature trees without significantly affecting yield.

Our first investigation into controlling neoformed growth was

Table 3. Total number of clusters per tree, number of nuts per cluster and average cluster weight for three normally cropping mature 'Kerman' trees grown on three different rootstocks.

Rootstock	tree yield (kg fresh)	no. of clusters per tree	no. of nuts per cluster	cluster fresh weight (g)
Atl	20.8	482.0	19.7	44.8
PGI	49.4	1105.0	18.4	46.7
UCB	65.5	1608.0	16.5	41.5

with regulated deficit irrigation (RDI). Because the preformed growth is what develops first in the spring of each year (i.e. the spring flush) and because California receives winter rainfall it is very difficult to develop significant water stress during the initial burst of spring growth. Therefore, under California conditions, it is nearly impossible to alter preformed growth with water stress, unless there is a very dry winter. This is good, since the preformed growth is where our crop develops. However, the neoformed growth begins a bit later in the season, after the spring flush has extended. At this time the winter rainfall stored in the soil has been depleted and the trees are relying on irrigation so we have the opportunity to affect neoformed growth with water stress.

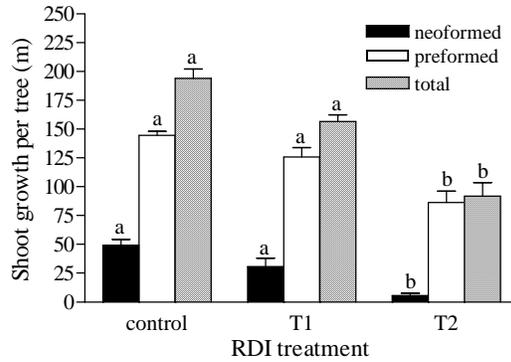


Fig. 3. The average total shoot growth per tree and the portion of the total growth that was preformed and neoformed for 'Kerman' trees on UCB rootstock grown under three RDI treatments: control – fully irrigated, T1 – mild stress, 50% irrigation during stage I, and T2 – high stress, no irrigation during stage I and 50% during stage II.

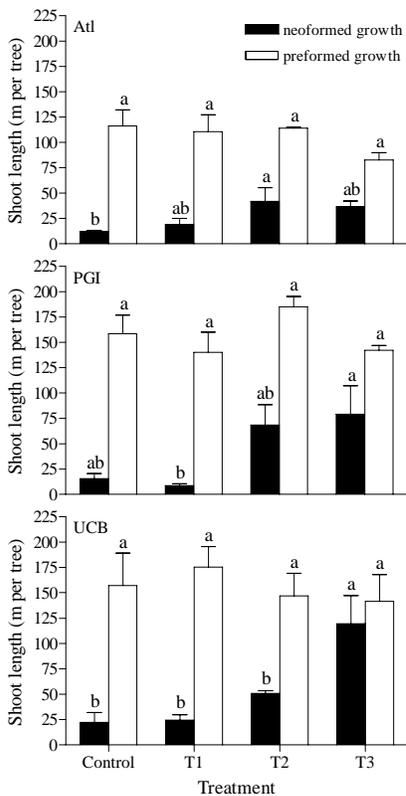


Fig. 4. The length of preformed and neoformed growth produced by 'Kerman' trees on three different rootstocks when trees were pruned according to four different treatments: control – no pruning, T1 – only the neoformed portion of 1-year-old shoots was removed, T2 – all 1-year-old wood was removed, T3 – 1-year-old wood plus half the length of the subtending 2-year-wood was removed.

This is exactly what our data showed (Fig. 3). Only under high water stress (T2) where the winter rainfall had been prevented from filling the soil profile were we able to affect preformed growth. Under mild stress (T1) we could reduce neoformed growth without significantly effecting preformed growth. However, we did not reduce the length of individual shoots with neoformed growth; rather we reduced the number of shoots with neoformed growth per tree. Therefore, there were still some very long shoots in the canopy that needed to be dealt with by pruning. Because of this and because of the difficulties in applying irrigation stress uniformly without stressing the trees too much we do not feel that this is a viable method for growers to control neoformed growth.

Our second investigation into controlling neoformed growth dealt with pruning. Our observations were that many shoots with neoformed growth grew very near to a pruning wound. This coupled with the observation that these shoots were often found only in the top of the canopy led us to investigate the influence of topping on the production of neoformed growth. We found that when pruning cuts removed only a portion of 1-year-old wood (T1) the resulting new growth was no more likely to produce neoformed growth than when it arose from un-pruned control shoots (Fig. 4). However, if a pruning cut removed all of the 1-year-old wood (T2) or was made back into 2-year-old wood (T3) then there

was a much greater increase in the stimulation of new shoots with neoformed growth. The reason for this response is that if the new growth arises from 1-year-old wood there is a bud there with 8-9 preformed leaves in it that will tend to restrain the new growth. However, on older wood the physical structure of the bud has been lost due to secondary thickening of the shoot and only a meristematic region remains, what is commonly referred to as a “latent bud.” These latent buds no longer have leaves preformed to restrain their growth and therefore produce a neoformed shoot.

It is interesting to note that the trees responded similarly to the pruning treatments regardless of rootstock. However, the degree of response was vastly different depending on the vigor of the rootstock. No matter how heavily pruned trees on Atl were they did not respond to the same extent as trees on PGI or UCB. This emphasizes that our horticultural practices must be tailored to the rootstock we are using.

Our final endeavor on this project was to understand how the differences in vegetative growth of trees on the three rootstocks affected tree carbohydrate status and what impact, if any, this has on alternate bearing. Because of the preformed nature of most of the shoots in a pistachio canopy the very early growth of shoots is the same, whether the tree is in an on- or off-year (Fig. 5). However, once nut growth begins we see that the shoots from on-year trees grow more slowly than those of off-year trees, suggesting a strong competition for carbohydrates between reproductive and vegetative growth. It is very interesting to note that the patterns of both shoot and nut growth shown in Figure 5 are virtually identical across rootstocks and in an off-year, when apparently there is little competition for the available carbohydrates, specific stem dry weight does not simply continue to increase all season, suggesting a genetically determined maximum dimension that is unaffected by rootstock.

When we analyzed stem tissue throughout the growing season from both on- and off-year trees we found a very interesting pattern in carbohydrate storage and mobilization (Fig. 6). The 1-year-old and 2-year-old stems of trees on the three rootstocks had virtually identical storage at the beginning of the season, again supporting the idea of a genetically fixed capacity. As the spring flush of growth began storage levels declined similarly in both on- and off-year trees, but once very early nut development began the storage of on-year trees declined more quickly compared to off-year trees. Very interestingly, after stage I of nut development ended, the on-year trees began to quickly accumulate carbohydrates in the current season, 1-year-old and 2-year-old stems. At the end of stage II of nut growth (early July) both the on- and off-year trees had accumulated similar levels of carbohydrate in the three ages of stem tissue. But in the on-year trees this storage was quickly mobilized during kernel fill, apparently because the demands

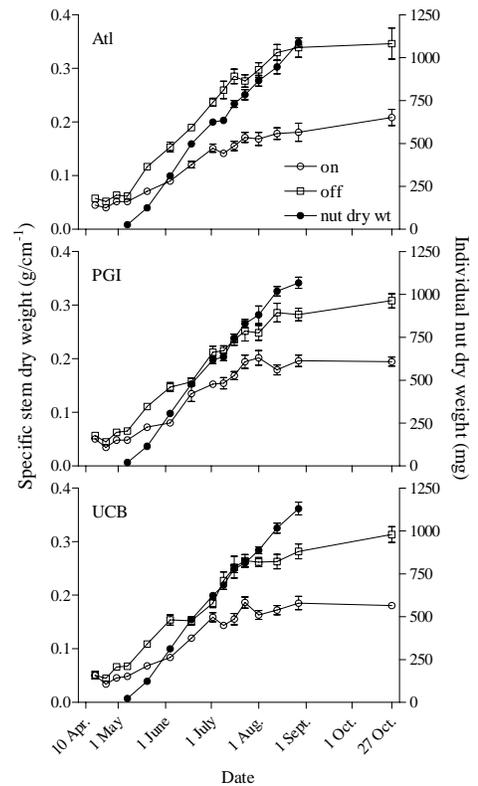


Fig. 5. Specific stem dry weight of current season stems from on- and off-year ‘Kerman’ trees (left axis) and average nut dry weight of the nuts subtending the current season stems from on-year trees (right axis).

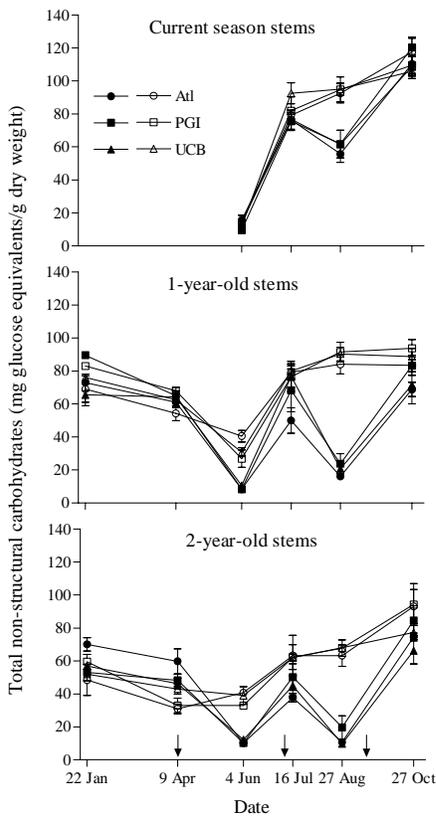


Fig. 6. Annual changes in total non-structural carbohydrate concentration for stems from on- (solid symbols) and off-year (open symbols) 'Kerman' trees on three rootstocks. Arrows indicate, from left to right, bud-break/bloom, start of nut-fill and harvest.

of nut growth are greater than can be met by current photosynthesis. After nut growth finished, the on-year trees quickly stored carbohydrates again, reaching similar levels to the off-year trees by the end of October. Note that in the off-year trees storage appears to level off by early September at a point that is roughly equal to what it was at the beginning of the season, again there is that apparent genetically fixed capacity.

The mid-season decline in storage in on-year trees is coincident with the period of inflorescence bud abscission. While these data don't definitively indicate that carbohydrate competition between developing nuts and inflorescence buds is the cause of abscission, they do indicate that carbohydrate competition is involved. We believe that the strong demand for carbon by the developing crop during this period triggers an internal change in plant hormones which then leads to the bud abortion.

Additionally, the theory that the off-year is biologically necessary to accumulate carbohydrate reserves which are then used to support the development of the crop during the following on-year appears to be disproved by these data. Both on- and off-year trees started the season with similar reserves, despite having had different crop loads during the previous season. Also, the reserves that were carried over from the previous off-year were completely depleted by early June of the on-year, prior to kernel development. Therefore, there was no reserve

carbohydrate left to support kernel development during July and August. The carbon that was mobilized during kernel development had been stored during June when there is very little nut growth taking place. Thus, it is likely that if the bud abortion phenomenon can be solved (by breeding, biotechnology, chemical spray or other means) the tree has sufficient carbon available each year to produce a crop.

Lastly we investigated the preformed status of shoots in young trees and how this influences training and canopy development of young trees. The primary difference between mature trees and young trees is the number of vegetative buds that can potentially grow and produce a shoot. In mature trees most lateral buds become inflorescence buds but on young trees the lateral buds remain vegetative. We looked at preformation in both terminal and lateral buds of young trees on PGI rootstock (Table 4). We found that the terminal bud of young trees, like mature trees, had 8-9 leaves preformed in it. But as you move along the shoot from the terminal to the base the number of preformed leaves declines by 2-3, becoming quite constant at 5-6 leaves. The number of leaves preformed in the lateral bud is very indicative of the shoot that will grow from it, except at the first five nodes below the tip where neoformed growth was quite common (Table 4).

Table 4. Number of preformed leaves in terminal and lateral buds of shoots from dormant 2-year-old and 5-year-old 'Kerman' trees on PGI rootstock and the number of nodes per shoot that grew on similar shoots from buds in the same position as those dissected (2-year-old trees only). ND = no data collected.

Node position	2-year-old shoots		5-year-old shoots
	No. of preformed leaves	No. of nodes on the shoot that grew	No. of preformed leaves
Terminal	8.5	25.6	9.3
1	7.1	13.3	7.1
5	6.6	6.9	6.1
10	6.4	6.4	5.7
15	6.4	7.6	6.3
20	6.4	6.8	6.0
25	6.3	6.4	5.0
30	6.4	6.6	6.1
35	6.1	6.1	5.5
40	5.8	6.0	ND
45	5.6	5.3	ND

produced neoformed growth to produce more of it (Fig. 6). The effect was so great that in the 50 and 75% pruning treatments more than 75% of the lateral growth that came from the pruned parent shoot was neoformed. But again, this was concentrated within the first five nodes below the pruning wound.

Based on these experiments with young trees and the data from the pruning trials conducted on mature trees we believe that we have developed enough of an understanding about pistachio's response to pruning in both the immature and mature stages to make pruning recommendations. In young trees, where the goal is to produce a large tree as quickly as possible we believe it is beneficial to make heading cuts that remove about 50% of the length of the shoot. This will sufficiently shorten the parent shoot so that it does not bend under its own weight and it will sufficiently stimulate neoformed growth to develop additional canopy branches quickly. However, as trees approach bearing age heading cuts during the dormant season should remove as little as possible of the length of the parent shoot, if any at all. This will prevent the over-stimulation of neoformed growth and allow numerous lateral buds to push and produce short "spur" shoots that will become the fruiting wood of the tree. This practice may result in some long shoots that will not sufficiently support themselves. It is possible that these may be dealt with by summer pruning or even "circle-tying" at a young age; however, we have not tested these ideas experimentally.

This led us to want to understand how pruning influences the growth of lateral buds. Would pruning stimulate neoformed growth as it did in mature trees and thus help to increase the vigor of young trees and produce a larger canopy more quickly? We found that pruning young shoots in general did not increase the number of lateral shoots that produced neoformed growth. However, it did stimulate those that

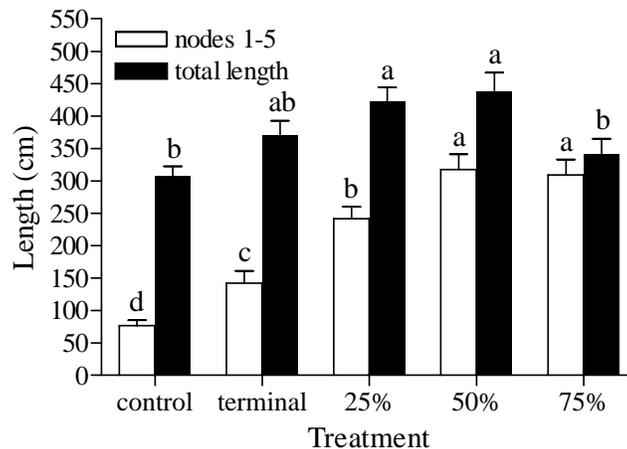


Fig. 6. The total length of all lateral shoots that grew from a un-pruned control shoots or pruned shoots on 3-year-old 'Kerman' trees on PGI rootstock. The treatments were: terminal – only the terminal bud was removed from the parent shoot, 25% - 25% of the length of the parent shoot was removed, 50% - 50% of the length of the parent shoot was removed, and 75% - 75% of the length of the parent shoot was removed.

In mature trees the goal is to minimize vegetative growth such that fruit wood spurs are renewed but the canopy is not over stimulated. Our data show that random heading cuts, particularly those into wood older than one year like are made by hedging and topping, are the most likely to stimulate neoformed growth that will then require additional remedial pruning. Selective pruning to remove overly vigorous shoots by making thinning cuts back to a lateral shoot are best. To stimulate new fruit wood, heading cuts should be made to a “knuckle” so that a number of shoots are stimulated from the same location. This will result in competition among the shoots and prevent them from becoming too vigorous.

Pruning can be used to rejuvenate older, poorly producing trees. However, as the data presented here indicate, the response to pruning is extremely localized, within a few nodes of the pruning cut on young trees and usually within about 12 inches of the pruning cut on mature trees, even when large diameter (4 or more inches) limbs are cut. This means that if you are attempting to lower the canopy of an old tree you must cut the tree lower than you want it to be when it re-grows. For example, if you are trying to lower a canopy from 20 to 15 feet and you top at 15 feet most of the re-growth will come from the 14-15 foot range. By the time this wood develops lateral fruit wood your canopy will probably be in the 18 foot range. The bottom line is that the new canopy you produce by pruning will basically be on top of the limbs you cut, not down in among them.