Developing optimal nutritional and irrigation requirements for almonds.

Prof. Raphael Assaf
Almond Board of Australia

Project Number: AL06004

AL06004

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DEVELOPING OPTIMAL NUTRITIONAL AND IRRIGATION REQUIREMENTS FOR ALMONDS

Project AL06004
Final Report

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Scientific Director, Principal Investigator and the leader of the project.

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I.D.M. Principle Technician. — **Almond Board of Australia.**

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Report n. 3, 2007.

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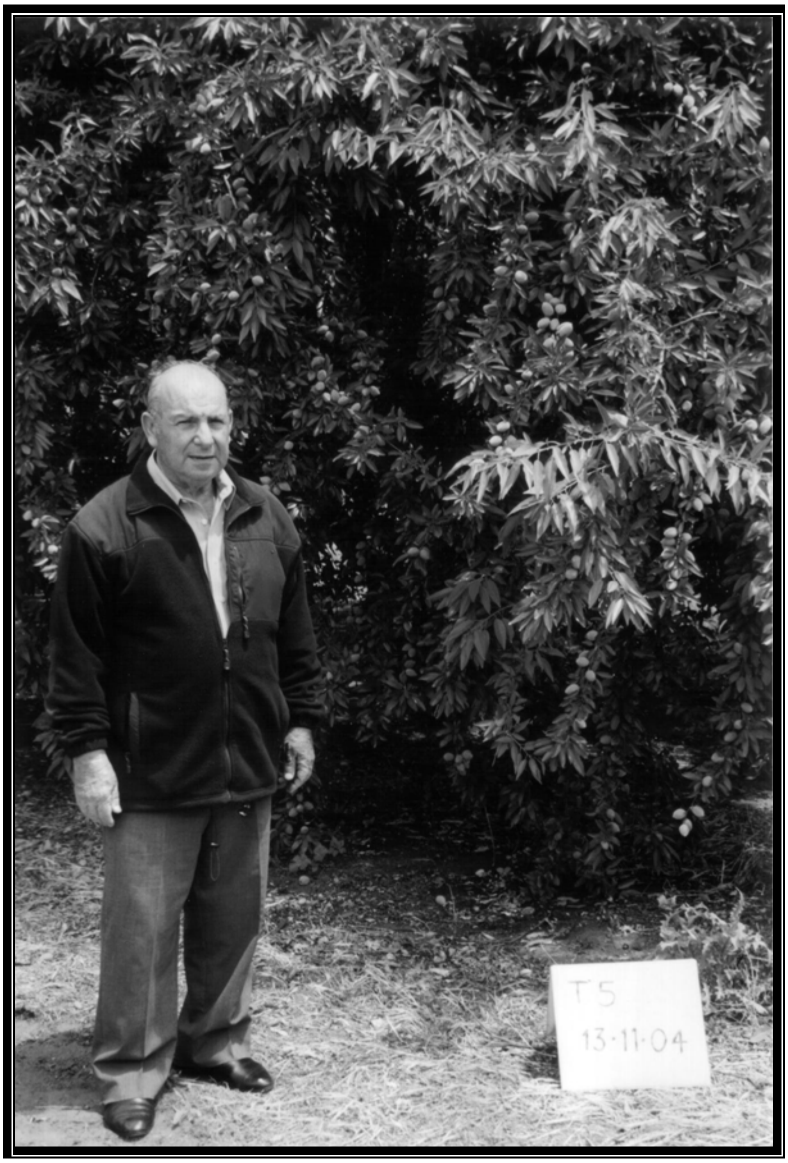

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ACKNOWLEDGEMENTS

The Australian almond industry was built on innovation and lead by risk-takers considered “crazy” in their time. It has thrived and can continue to lead the world if we dare to maintain this courageous attitude. We hope this work on optimization of almond growing will continue this way.

We acknowledge the Prof. ASSAF Israeli Teams of Research and his colleagues especially the late Levin I. and Bravdo B.; To ARO. (Agriculture Research Organisation Volcani Centre Beth-Daganm, Israel.) Institute of Horticulture, the Ministry of Agriculture Israel, and their heads that allow Prof. ASSAF to cooperate with Australia and use some of the results. The trial would not be possible without his direct guidance and his involvement in every decision in the scientific trial since all the concepts are totally new in Australia.

This trial has the support most importantly of the Clark and Taylor families. The ongoing support of the owners and their staff has been crucial and is very much appreciated.

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3. Voluntary contributions from the Clark Taylor Family
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MEDIA SUMMARY

As the Australian almond industry expands, many new and important challenges must be addressed. These include:

- the need to be internationally competitive in production and product quality
- the need to maximise the value of limited resources, particularly land and water
- the need to be sustainable, particularly from an environmental perspective in the long term

This project aims to address and have a positive effect on all of the above issues.

Fundamentally this project encompasses a wide range of management disciplines and brings them together in a unique way in order to provide almond trees with the best possible conditions for long-term production.

This project uses Israeli management technologies and adopts the unique concept of ‘optimisation’ to maximise production efficiencies, which has been developed by Professor Raphael Assaf, a Scientific Director with the Volcani Centre , in conjunction with many of his collegues through more than 40 years of intensive trial work.

The concept of optimisation revolves around:

- Feeding the trees with their daily nutrition and water needs.
- Supporting the trees at each of the pheonological stages throughout the seasonal cycle.
- Supplying inputs in a way that enables effective uptake by the tree

- Providing stable and optimal nutritional and moisture level in the soil so that the trees can adapt to these conditions

Importantly, this trial is identifying limits to almond orchard performance that were previously unknown. A critical outcome from this trial has been the development of a far better understanding of the efficiencies that are achievable.

At this stage, results from this project are preliminary, with further work required to confirm them.

ABSTRACT

A trial on Optimization of almond growing is currently being conducted in Berri SA. The almond trees were planted in June 1999, on a sandy loam soil, under a desert climate. The fundamental basis of the trial is the large Israeli research of many Teams, conducted in this field over many years. In fruit crops, (apples, stone fruit, grapes and nuts) very extensive work was undertaken by the main investigator of this trial and his colleagues over 38 years. The Optimization of almond growing trial is continuing this research and aims to provide optimal growing conditions in the cycles of growth and fructification of the tree, the optimum in nutrition, irrigation and pest management etc. It adopts the best training and pruning systems in order to support high quality yields of almond kernal. The irrigation system adopted is the best from the Israeli apple and almond research actuated in this trial by: on-line button drippers, 4 l/h, pressure compensated, (Netafim). Drippers are spaced 1m, with 2 laterals per row 1m distance either side of the trunk of the tree. The application of water approaching closely the consumptive use by the trees, is daily by pulses, 1hour water on, 1hour water off (calculated as the best for this soil type). The daily amounts of water applied are by coefficients of the Pan Class A. Evaporation, elaborated in Israeli trials in stone fruit and almond. In nutrition, the best application is inspired and based on results from the Israeli Mahanaim apple trial. Most of the nutrition is used in spring 2/3 and the rest in the fall with the aim to build reserves for the following season. Nutrition is delivered via solution by the drippers with the consumptive use of the trees, applied in the last two pulses of that days irrigation. We complete the needs of the trees in macro and microelements by applications of injections of solutions to a depth of 40cm (in the main active root-zone) and by foliar sprays. The irrigation treatments consist of 3 levels of water, T4, standard – 100%, T5, high -160% and T6, low- 60%. The Standard is the best found in our trials in Israel. Similarly in nutrition, we work with 3 concentrations in water: T1, poor - 240N and 400K, T2, standard, 320N and 600K and T3, rich, 480N and 800K. The six treatments are in 4 replications of 2 rows (Nonpareil and Carmel cultivars) randomized in 4 geographic blocks. They are compared to treatment 7 that emulates the best commercial management practices in Australia. T7 is one plot, consisting of 16 rows that are a continuation of rows in block 1 & 2 (with the same soils, area 0,69ha). At the start of the

trial, trees in all 7 treatments had the same volume and trunk circumference (in the same population). We succeeded to build a Y shaped canopy, without pruning and only bending in years 3, 4, and 5. In years 6 and 7, a light pruning was adopted to maintain the original Y structure and the light penetration. We have achieved outstanding results each year and get a very large number of strong flower buds and new growth of 1 – 2m with thick, double size leaves. The operation of the irrigation system has improved with time. Pulses allow us to achieve a soil profile with maximum lateral distribution of humidity and adequate air in the soil. As a result of these effects we get more than 10 times the volume of dense, fine active roots than in T7 (irrigation amount and interval are determined by the Australian Enviroscan. Installation is 2.2 l/h in line drippers, spaced at 75cm with 2 laterals per row). For all irrigation treatments the development of the humidity in the soil profile that occupied all the surface of the rows, was measured weekly by Neutron probe. In our applied irrigation treatments (T7 excepted) we discovered an important and new finding as no water losses occurred beneath the layers under the root system. Findings in nutrition were the same with no migration of N, NO3 and NH4 with very small deviations and no accumulation of salt beneath the root-zone. Current measurements show us that the coefficients of Pan Class A Evaporation, we use in the irrigation treatments T2 & T4 (standard treatments) are working well with the continuous consumptive use of the trees. Planned changes in crop coefficients are determined by fruit and tree growth cycles. Preliminary results are impressive, however they are preliminary and many changes allowing further refinements are needed to complete the adoption from apples to almond. The amount of water applied to the standard treatment T2, was 1500mm in 2005 and 1670mm in 2006, 80-87% of the Pan Evaporation for the season. This good result is supported by the previous work in Israel in many deciduous fruit crops and in cultivars with late maturity in September (In Israel 900mm is applied in the season giving, 80% of the pan, 600mm less than almond in South Australia). High quality yields achieved in the trial have been fed well by the nutrition. Throughout the years of the trial, the total predicted amounts of water and nutrition have changed very little, yet only in 2005 we began to see differences and effects of the different treatments. It will take more years to reach the conclusions we achieved in the Israeli research. For Nonpareil variety, the cumulative yields of kernal, achieved by year 8 (3 full seasons yields) were excellent, 17.6 t/ha by the best treatment

T3 and 16.2t/ha for the lowest yield in T6. The other treatments were found to be statistically in between. The annual cumulative yields of the 6 treatments are 189% of T7 that achieved 9.0 t/ha. In Carmel variety, accumulative yields were equally impressive, with smaller differences between the treatments T 1, 2, 3, 4, 5. A cumulative yield of 18.4 t/ha. was achieved in T1 compared with 15.6 t/ha in T6 (the lowest). The average results from the 6 treatments are 172% of T7. The annual yields of almond kernal in Nonpareil variety, in 2006, (8th leaf) are reduced on 2005 yields, 4.2t/ha in the best treatment T5. T1,2, 3, 4 are in between and T6 is the lowest, 3.6t/ha. All the treatments give 340 % of T7, the commercial control with 1.1t/ha. In Carmel CV the highest yields in 2006 are 5.2t/ha for T1 and 4.0t/ha for T6 the lowest. These yields achieved more differences between the treatments and are 234% of T7, the commercial control with 2.0t/h. In the year 2006 we achieved in NonPareil an average yield of 3.9t/ha , the qualities of the almond kernal produced in the trial were found to be excellent with no pinching and only small differences between the 6 treatments: in relation of almond kernal weight, 1.53grs in size in ounce 18.5 and crack out 31% in Nonpareil. In Carmel variety we achieved an average yield of 4.7t/ha with the qualities 1.4grs in kernal weight, 20.3 size in ounce and 31 % of crack out. In the measurements of tree trunk cross-section area increment (equal to the canopy and root new growth) T5 gave the largest and T6 the lowest. The average from all the treatments equalled T7 in the gain of trunk section area and about 1m more in the height and volume of the trees. The extraordinary results we have accomplished in this trial provide the opportunity of increasing profitability. We are around twice the yield of quality kernal allowing a near doubling in the net income of the average almond orchard. Our results are preliminary and must be confirmed in further years of research. Changes must be effectuated to some of the new agrotechnics adopted to almond from apples. Along with the high yields, we have begun to find the emergence of alternate bearing. This phenomenon will oblige us to change the future strategy of growing trees mainly the pruning serving us as a thinning agent renewing and pushing the growth it must be done very well as programmed with firm decisions and perfect execution. The development of plant and fruit indicators is very important in this work to help us optimize almond growing in our research and in the field.

1.0 OBJECTIVES OF RESEARCH, AND ABBREVIATIONS

The aims of this research project are:

To double the commercial yields of the almond orchards and their profitability.

To determine the optimal conditions for the almond trees and work on their Optimization

To determine especially the irrigation, the nutrition working with consumptive use of the trees.

To determine the best training and pruning systems.

To determine the rate of water and nutrition uptake by consumption use for optimal almond production.

To test the efficacy of the irrigation system and the nutrition used by each Treatment in this trial.

To explore the possibility of saving water and increasing efficiency in cultivation and harvesting practices in almond trees.

1.1. Key of Abbreviations:

NP	Nonpareil	FC	Field capacity
C.	Carmel	SP	Saturation point
NPU	Ne plus Ultra	WP	Wilting point
SWC	Soil water content	E-Pan	Pan class A Evaporation
CV.	Cultivar or variety	WA	Water applied
T1 – T7	Treatments 1 -7	Tr.	Treatment

2.0 INTRODUCTION

The trial on Optimization of almond growing is continuing the research work done in Israel in this field. The major objective is to double the quality yields of almond orchards in Australia. The entire trial is based on results obtained in Israel in apple, stone fruit and nuts, adopted to almond growing started in Neve-Yaar Research Center Israel. All the planning programs in the Berri S.A. trial are guided by apple Optimization works. Most of it has been investigated and published by Assaf R. et al., with his colleagues working with him 38 years. See lists of some publications classed by principal subjects given in report No. 1 2006.

Optimization of crops requires application of optimal environmental conditions to the roots as well as to the canopy. High production in fruit crops and others such as tomatoes is presently achieved in greenhouses under controlled conditions. It is difficult to achieve complete control under field conditions, but recent developments in irrigation technologies have enabled the root environment to be controlled in terms of root volume, root aeration, concentrations of minerals and water at various stages of growth and development of the tree and the fruit. Once the optimal concentration of minerals is determined, application at the rate of **consumptive use** through fert-irrigation systems is possible. It should be borne in mind that the application of water and minerals at the rate of **consumptive use** can be implemented at a rate according to the desire of the grower or by the Optimization research. For example once it has been decided to maintain a certain water content in the root zone, frequent application of decided water amounts will implement it. The plant will then adjust its growth, leaf area and productivity to that soil water potential in the root zone which determines the availability of the soil water. Such an adjustment has been well demonstrated in drip irrigated apples (Assaf et al., 1974, and others, see publications lists; Proebsting et al., 1977; Levin I., Assaf R. et al., 1979; Middleton et al., 1979; Elfving, 1982, see all the lists of publications in the report number 1 published in 2006)

Drip irrigation is the most appropriate method for irrigating at the rate of consumptive use because of its **slow rate of water emission**. This irrigation method also enables **soluble fertilizers** to be applied through the irrigation water at the rate of consumptive use. In this case, the rate of application is adjusted so as to maintain a constant nutrition concentration in the root zone. A constant gradient of minerals is then formed within the irrigated soil volume.

The automatic irrigation and fertilizing we use in our trials in Israel. (See Assaf et al., publications) was not possible to organize in Australia for the Berri trial. In our experimental plot, Assaf was obliged to correct the installation they built for us. All the compounds were changed even the drippers and the computerized controller in order to deliver an irrigation installation with a perfect water distribution. (Will be discussed in materials and methods)

The best training system, we adopt is from our work on stone fruit and almond. The Y shape canopy was found to be the more appropriate to the Optimization of almond growing concepts (Assaf et al., see publications lists). We get two walls in the trees, 4-8 productive units in each side, full of flower buds, fruits, a very good interception of radiation and net photosynthesis production, a maximum of new growth of branches 1-2m with double size thick leaves. (See publications list Assaf et al. giving in full details in the Report number 1 published in 2006)

The best irrigation system adopted from our previous work in almond is: Two lines of 4 l/h button drippers, (Netafim) pressure compensated, spaced 1m, placed on 2 laterals, each 1m from the trunk of the trees. The amounts of water by the consumptive use of the trees are applied by coefficient of the Pan Class A Evaporation measured automatically and processed with daily readings and adjustments, keeping no small deficit of water in the soil. They are adopted from stone fruit and almond formulas elaborated in our previous work (in Neve-Yaar Research Center, Israel Vallee, Israel, local variety selection by Assaf, grafted on GF677 root stock in hot climate) and are elaborated and refined in the Berri trial.

The best application of water that approaches consumptive use is daily by pulses (calculated for the soil of the trial specially, 1hour on 1hour off). Preliminary results show that the profile of soil used by the roots is totally wetted, yet keeps a high concentration of air. These conditions enable us to get a very intense root system like in the previous work

The best nutrition regimes adopted are derived especially from our apple trials in Mahanaim Israel and from other fruit crops. In our studies we get very high quality yields in many fruit crops (see publication lists Assaf et. al.). In the Berri work, planning of applications is from the apple procedure and is all the time checked and changed by analysis. It will take years to elaborate and refine it. The application of fertilizers was completed by injections to a depth of 40cm (the main active root-zone) and via foliar sprays like in Mahanaim, permitting us to feed the extraordinary high yields while getting very healthy trees and good growth. We also learn from the work done in the PhD. Thesis of ASSAF and use it to get strong and new buds, trying to influenced their formation in the different stages of bud differentiation.

In our trial on Optimization of almond growing, all the results are preliminary and more years are needed to confirm them. A lot of parameters must be changed to be more scientific based and to be more precise as we have been in our previous work.

3.0 MATERIALS AND METHODS

The trial was set up in the Mallee area of Southern Australia with a desert climate. Winter rainfall averages 273.5mm. The orchard was planted in the Clark-Taylor farm near Berri SA., in July, 2001. A section of 3-year old commercial almond orchard was selected for the trial. Trees are spaced at 6.7m between rows, 6.1m within the rows, giving 245 trees per ha. The area assigned to the trial is 7.64 ha containing 1870 trees in total. The cultivars are: Nonpareil, Ne Plus Ultra and Carmel, all grafted on Nemaguard rootstock. The ratio is 50% Nonpareil, 33% Carmel and 17% Ne Plus Ultra. The Ne Plus Ultra trees were excluded from the statistics of the trial as there were insufficient rows. However, limited data was collected in this criteria and observations made regarding the yields and kernel qualities to allow conclusions to be drawn about the influences of the new techniques like a special hedging/pruning of the trees etc.

Soils are typical to Southern Australia; sandy to light sandy loams varying in depth from 50cm to 1.6m. Soil texture is: 24% of clay. The pH (in water) is 8.5 to 9.5. The soil is very heterogeneous with three different top soil types very difficult to work with. The most important points when working with soil humidity are Field Capacity, Saturation Point and Wilting Point. In CT soil we have a very small holding capacity of water and nutrients. These points will be verified through further calibrations at three sites with 4 replications. Wilting point will be determined using the sunflower method and we will try to use new kits to perform rapid analysis of pH and Ece to solve the problems of acidification under the drippers (in T3 mainly). The hydraulic conductivity is 5cm per hour very fast. The soil is not cultivated and only contact herbicides are used: Pest management is conducted as in the commercial orchard. The irrigation system for the six treatments was converted over to a design copied from Neve-Yaar Research Centre Israel, using Netafim 4l/p pressure compensated, no drain button drippers spaced at 1m. Two laterals per row, 1 meter from the tree trunk. The drippers were installed 5cm below ground with a short micro-tube to bring the water to the surface. Where the slope exceeded the dripper design, Netafim in line TNL valves were installed. Sand filters will be installed to overcome problems in water quality. Treatment 7 (the control) is irrigated with the original above ground dual laterals with 2.2 l/h in-line, pressure compensated drippers, spaced at 75 cm.

Precipitation rates as measured on total planted surface are, 1.19mm per hour for T1, T2, T3, T4 and T6, 1.79mm for T5 and 0.87mm for T7.

The six treatments in four replicates were arranged at random in 4 geographic blocks with 2 rows in each replicate. The “control” (referred to as “Treatment 7”) constituted by a single block of 0.69 hectares, emulates the best orchard management practices typical to Australia. The 16 rows are a continuation of block 2 and 3, planted on the same soil. Irrigation in T7 is conducted by the Australian Enviroscan. The trees have been built in the standard vase shape. For technical reasons such as canopy spraying and the need for 2 rows of borders, (different volume and shade in border trees) we decided to have the structure described upon to allow the possibility of a comparison between the trees and fruit behaviour. The results of T7 are not statistically analyzed to the six treatments but are still available and important. Further analysis is required in T5 as this treatment is the upper limit in relation to irrigation and helps greatly in the weekly decision making process. We plan for this treatment to have less drainage and runoff in the future by replacing the existing installation with 8 Litre drippers.

The six treatments consist of 3 levels of nutrition, (T1 - 240N 400K, T2 - 320N, 600K and T3 - 480N, 800K) and 3 levels of irrigation, (T4 - 100%, $T5^{+}$ - 160% and $T6^{-}$ - 60%) (**Table 1**). Irrigation application is controlled via a Motorola computerized controller and monitoring by water meters, allowing us to conduct a perfect accuracy in the irrigation. Water is applied in pulses of 1hr on 1hr off calculated specially for this sandy soil, every day, beginning at 8.00 exactly and corrections made to the daily deficit in the water application for each treatment. The nutrition delivery system is such that: each treatment is provided with a dedicated 220L pressurized injection tank. Fertilizer is introduced into the tank in the required quantities at the two last pulses of the daily irrigation.

All the measurements and the monitoring effectuated in the trial are always done by statistically elaborated protocols. Pan Class A Evaporation is read daily at 9.00. Soil moisture monitoring is by a neutron probe (CPN Hydro probe in Australia). Readings are elaborated by 50mm aluminium access tubes installed at 0, 20, 40, 60, 80, and 100cm distances from the dripper on one side of the lateral from the drippers in T4, T5, T6 and T7. They are the leading plots. We have a single tube in every replicate, 20cm from the dripper (found as representative of the soil in the plot). Readings are performed weekly, with the same walk between the trees in the orchard, starting Friday at 5.30 after 6 hours of water being stopped. All readings are completed by 8.00. A circular steel plate, 60 cm in diameter and 6 mm thick is used to minimize neutron escape from the 0-30cm layer (see details in publications of Assaf et al., lists). Trenches will be dug every year to evaluate the root systems in different treatments and in the control from the farm.

In relation to the amounts of water to use and the timing of irrigation, we operate the trial exactly the same way as the Assaf Israeli Teams had done on their Optimisation work on apples. In relation to nutrition, the planning is totally based on apple; the fertilizer application is very complex, and many subjects are involved: all is based on many trials done in Israel especially by Assaf Research Teams. The main trial providing orientation for our work is the Israeli apple trial in Mahanaim; in applications of nutrition made within the season, in the total quantities applied, the different compounds utilised, the equilibrium of cations and anions etc. and of N and K. The other macro and micro elements required are injected equally to a depth of 40cm (within the main root system) or sprayed directly on to the foliage in all 6 treatments. Hoagland solution forms the basis of the composition of the solution used, but it is changed and enriched to the needs of our trees and fruit (see our research work, for many years on hydroponics in containers and in lysimeters). Every year, we make substantial changes to the planning, (particularly the formulas) and we will change in response to leaf and soil analysis results continually because we work with special soil sandy with pH 9. We will also develop in next years more advanced leaf analysis and will weigh 100 leaves, extracting the level of chlorophyll etc. Assaf is against any early publication of this work. This would be premature as we need more years to get this knowledge totally different from Australia. Our opinions are the same for the coefficients of the Pan Class A Evaporation used to calculate the amounts of water for each application in the season, to meet consumptive use in the orchard.

We analyse the mineral content of the soil 6 times in the season, the leaves and fruit 3 times yet must perform these tasks more frequently to improve our knowledge.

The volume of the tree, its total and new growth, the productivity and the potential yield of every tree in the trial are evaluated. 12 equal trees in evaluation (trunk circumference and history) were selected from the start of the work to determine weight in gross yield and from which samples are collected for precise measurements of all the different qualities of the kernel in each replicate: (400 fruits) allow measurements to be taken including weight, size, % of crack-out, evaluations of appearance, sensorial tests etc. The growth of every tree in each of the plots is evaluated each winter using a tape to measure the tree circumference at a fixed point, 20 cm above the ground. We will develop indicators of plant and fruit growth as developed in Israel for fruit crops. These indicators will provide assistance to our research work and help us to operate more closely to the consumptive use while assisting in the successful transfer of optimisation concepts to commercial farms.

Table 1

Design of the Different Treatments in Optimization of Almond Growing in the Trial, Berri SA

Treatment			Irrigation	Nutrition N:K un/ha	Remarks
1	low	nutrition	100% ETc + daily pulses *	240 : 400	Eq app of P Zn B Mg Fe
2	stand	nutrition	100% ETc + daily pulses	320 : 600	Eq app of P Zn B Mg Fe
3	high	nutrition	100% ETc + daily pulses	480 : 800	Eq app of P Zn B Mg Fe
4	stand	water	100% ETc + daily pulses	320 : 600	Eq app of P Zn B Mg Fe
5	high	water	160% ETc + daily pulses	320 : 600	Eq app of P Zn B Mg Fe
6	low	water	60% ETc + daily pulses	320 : 600	Eq app of P Zn B Mg Fe
7**			Continuious irrigation ***	2005/06: 180: 87 ****	

* pulses of 1 hour on, 1 hour off

** T7 is best commercial practice in 2000 as determined by the farms consultant, it is concentrated in one plot of similar soil type and consists of 16 rows.

*** water is scheduled using the Australian Enviroscan and best practice technicques in Australia, it is not calibrated to the Neutron Probe, soil analysis and correlation curves.

**** nutrition application quantities and frequency are determined by the farms consultant.

4.0 RESULTS AND DISCUSSION

4.1. Short Report of work from July – February 2006/07

In the last 6 months of 2006 we have continued to apply all the 6 treatments as determined with statistical protocols. The program commenced in autumn where we applied 3 sprays of urea to feed the buds prior to defoliation with urea, at this point we didn't achieve the expected results with the buds being very small and few in number. It was only after a special trial of different concentration spray that achieved a result with strong buds.

Over winter an extensive pruning program was planned with the aim of opening up the tress and reducing the disease susceptibility of the tress. The four step process involved removing all dead wood, cutting a one meter wide strip down the centre of the rows, removing limbs and water shoots which were shading the Y in the centre of the trees and finally to remove limbs from the walls of the canopy so that we had approximately 8 productive limbs on each side of the tree. The two last steps were not accomplished due to a lack of organisation we only partly achieved the desired results and this will influence heavily our work on alternate bearing and on our crop and future crops. More detailed work will be required in 2007 to ensure we maximise light interception and reduce this potential for lower crops. We have completed the kernel qualities in each treatment and prepared all the data in the tables and curves. We also try to solve the Heterogeneity of the soil by doing more work on saturation point and field capacity

In late July we applied foliar sprays of KNO_3 in order to break dormancy and synchronise flowering, the sprays are combining with the results of chilling hours experienced over winter. The sprays were successful opening most flower buds with a strong coincidence of flowering occurring. We commenced our irrigation program in August by filling the profile with 150mm of irrigation; this followed an exception dry period over winter which depleted our reserves of soil moisture. In late August we started our irrigation treatments and followed the statistical protocols outlined in the 2005 and 2006 reports. Our Nutritional program commenced at the same time, again applications we applied as per the statistical protocols.

Professor ASSAF visited twice over this time once in July and a second time in December for 6 to 8 weeks each visit with a third visit during harvest period. He conducted a number of field days and open days. The first series of field days (held during the July visit) was conducted at sites in Angle vale, Loxton and Mildura where over 100 growers from the various regions attended. The field days provided an opportunity for the Professor ASSAF to visit local farms and discuss with growers their individual problems they experienced on their properties, analyse them and allow for regional growers to ask questions about the management of these problems

An extensive Open day with two sessions was run during the second visit at the Clark Taylor Farms Trial site where just over 80 growers attend. At this event we demonstrated to all the growers present the work done over the past 12 months through a series of sites and speakers. The growers had the opportunity to see in detail what we have achieved in terms of tree performance, tree crop, growth, and quality, comparing the trial site to the to the conventional farm plots. During the discussion we explained in detail how we achieved the results in a step by step process. Topics covered included a over evaluation of the trial site differences between treatments, a detailed explanation on how we use the Neutron Probe Data and how we deal with the issues of consumptive use of irrigation and nutrition. The groups also had the opportunity to here Professor Assaf discuss the water restrictions and hear some of the options open to growers. Professor Assaf discussed the restrictions in detail and drew on his experience as well as thoughts from his over seas colleges authorities in the world in almonds and irrigation to enlighten growers on the realities of the restrictions putting forward as little work had been done in almonds to deal with the circumstances now faced by growers with restrictions occurring in the middle of the season.

A copy of the abstract of the items brought in this open day is sent to the growers with the March Newsletter.

4.2. Water applications

In order to achieve optimum results in relation to irrigation application, daily applications of water by pulses 1 hour on 1 hour off are made to the root system to cover the consumptive use of the tree. Use is determined using crop factors (coefficients) and the Pan Class A Evaporation daily readings.

Information required for irrigation decisions to meet consumptive use at CT Farms

1 Crop factor/coefficient example 1.0-1.2 at peak use

2 Daily Pan reading in mm of water that evaporates from the surface of the pan

3 Irrigation system output is 1.19mm/hr at CT farms

4 Neutron Probe readings

Calculating consumptive use in irrigation for the trees of the standard treatment in the CT Trial. Example for the day of 14/6/06

Daily irrigation requirement at CT = Crop factor Coefficient 1.1x Daily Pan reading, 9.6

Application required to meet consumptive use = 10.5mm

Method of application of irrigation to meet consumptive use at CT Farms

Consumptive use 10.5mm÷Application rate of the irrigation system 1.19mm/hr

Number of hours irrigation required to meet consumptive use = 8.82 hrs

This equates to 9 hours rounded up to the nearest hour.

Applications are made via a series of ‘pulses’ which are 1 hour on 1 hour off starting at the same time every day 8:00am.

The trial has been operating for five seasons. The first year, 2002/03, was a year of conversion from the previous irrigation, nutrition and canopy management systems. Up until September 2004 there were ongoing issues of design limitations and equipment failure.

The aim of the irrigation applications is to supply the consumptive use of water by the trees during day light hours throughout the season. In our previous apple research, we developed this principle further through daily drip irrigation by pulses (these are capable of giving very small quantities of water). We achieved a very large profile at high moisture levels in the soil. This profile contained good aeration, and therefore developed a full and very dense root system filling the area between the trees down to a depth of 80cm. This very dense system consists of fine, white, active roots with few anchorage roots growing down. Moisture levels throughout the profile are kept constant throughout the season within prescribed limits. The **0-30 cm** layer is kept at +- 5% of Field Capacity, (in sandy soil it will vary). The aim is to keep infiltrating water in the upper profile of **0-30cm** (i.e. moisture above Field Capacity which will permeate throughout the profile). In the main active root-zone, the mid-layer of **30-80cm**, a moisture level of 75% of the available water is aimed for (this has found to be optimal, without tree stress). In the lower layer of **80-160cm** around 75-50 % of available water is desired as the aim is to keep this layer drying. This is difficult due to the lack of roots in this zone. For the 2006 data, in the **30-80cm** layer (active root-zone), **Field Capacity** was 12.5% humidity by weight and **Saturation Point** 13.8-18%. The **Wilting Point** usually accepted for sandy loam is 3.6% of humidity by weight.

Previous work on Optimization and automated irrigation showed that the water applied between 08:00 and 10:00 in the day, (in Israel these pulses were for 10 minutes) was half used in the beginning then almost fully utilised by the tree, then the uptake of the water increases to around double until 14:00 when this reduces to levels similar to early Morning and finishing at around one third by the end of the day. From this point the deficit accumulated during the peak demand period is replaced. At the end of a hot day of around 10-12mm evaporated by the Pan, in S2 (cycle of the development of the cells of the fruit) all the water applied is absorbed by the tree. Optimal levels must be returned prior to restarting again. Many other examples are figured in our publications.

The drip system design used is based on our multi annual trials in apples. These trials evaluated various dripper discharge rates, lateral numbers and application frequencies with and without pulsing (see Assaf et al. publications). The system we adopted in Berri consists of two laterals, each installed 1m from the trunks of the trees, with 4 l/h drippers placed every 1m. Water application is by pulses theoretically giving full coverage of the soil (root volume) profile. Pulses give 80 to 100% more coverage (see Assaf et al. publications). The best possible pulse regime in our case is 1 hour on and 1 hour off (as determined by the hydraulic conductivity of the soil and the observations in field). During the “off” phase of the pulse cycle the effect of the gravitational forces are reduced and stopped and the water moves more laterally. Theoretically, we can control the level of the moisture in the soil where we need and want it.

The daily quantities of water given to the root system to cover the consumptive water use are determined by crop coefficients and the Pan Class A Evaporation. These have been determined for apples, stone fruit and almond in different cultivars and different areas of Israel (see Assaf et al. publications). We started the work on almond in South Australia with the same procedure, using very accurate daily pan readings. Coefficients are checked and adjusted where required using the weekly neutron probe readings. Any minor deficit or surplus in water in the soil is corrected daily, with the weekly moisture balance being checked and corrected every Monday, as required. All daily irrigations commence exactly at 8:00 (this is important for root adaptation, organisation and dispersion in the soil).

The computerized irrigation controller allows us to commence the correct irrigation as described and based on coefficients of Pan Class A Evaporation that change with the climate, the crop load, the cycle of tree and fruit growth. The results for 2005/06 are described in **Table 4** which gives the water applications by crop stage for each treatment. **Table 5** clearly shows that 2005/06 was a hotter season. The Pan Class A Evaporation was 75mm higher than the prior season. Overall water applications rose by 152mm from the previous season resulting in a total application of 0.87% of the Pan Class A Evaporation. **Table 3** gives the phenology data collected for Nonpareil and Carmel in 2006. This data was very similar to that collected in 2005 and shows a very good co-incidence in the flowering of the two cultivars.

At the commencement of the season we prepare the orchard to work with the small daily amounts of water needed for the consumptive use of the tree and the fruit growth through the season. The first step at the end of the winter and before breaking dormancy is filling the soil profile to achieve moisture levels close to field capacity down to **<u>160cm</u>**. The Neutron Probe is the key to water monitoring in the CT trial, it is the primary tool due to its ability to accurately measure the quantity of water in the soil profile. The Neutron Probe works by emitting neutrons from a radioactive source. These neutrons slow down when they come in contact with hydrogen atoms (H2O). When these neutrons bounce back to the probe they react with a gas and release an electrical pulse, this is then expressed as a number that once calibrated gives a highly accurate measure of soil moisture (see soil moisture monitoring).

Profile filling is used to optimize soil humidity conditions at the start of the season. It is the process of providing enough water to fill the profile to field capacity. Profile filling removes wet dry interfaces from the soil, sets up perfect soil humidity conditions for flowing and fruit set and provides a well buffered system to protect against potential irrigation breakdowns at critical points in the season. Profile filling is a substitute for winter rainfall, in most almond growing regions around the world winter rainfall is quite substantial, however here we have an average annual rainfall of less than 300mm, winter being only a part of that, and effective being a smaller part again. In order to determine and quantify the amount of water required to compensate for the lack of effective winter rainfall we use the Neutron Probe combined with the calibration equations to calculate the % soil moisture at the start of the season generally in mid July With this information at each depth through the profile we generate how many mm of irrigation is needed to be applied to fill the profile. This process is replicated until the profile is full. There is no set figure to give regarding how much water should be added as this final amount will vary each year depending on the amount of effective rainfall occurs over winter. In the trial we give 120-150mm in 2-3 applications. This profile building is very important at the start of the drip irrigation season to achieve a very uniform and large distribution of moisture and prepare the soil for the optimal development of the root system in the coming spring. After the filling of the profile, we have the optimum conditions and the best moisture conditions in the soil for the flowering stage, fruit set and for the first steps of the growth of the branches. No water is then applied until the trees start growing (elongation of the tips of the growth and the fruit set is finished). The application of water found the best in previous work for this stage called S1, cell division of the fruit; see **Table 2** describing the different stages in fruit and tree growth and **Table 3** giving the phenology of the different varieties in the trial. We use a coefficient of 0.3-0.5 of the pan Class A evaporation until pit hardening of the fruit. This allows some drying of the soil to increase aeration further and therefore maximize root growth. The next stage is cell development S2, requiring varying a cycle of higher coefficients (0.8-1.0-1.2-1.0-0.8) depending on the fruit load. Four to five weeks before harvest the fruit is fully prepared and the drying stage is commenced whereby we assist hull-split and the development of the fruit abscission layer prior to harvest. The stress induced with this drying is also used to assist flower bud differentiation. During this final stage, up until harvest, the amount of water given is 0.6 of the Pan Class A Evaporation. After this stage comes post harvest S3, and reduction of the coefficients to 0.3 of the Pan Class A Evaporation. It will take many years to get more accurate calculations.

We have used Pan Class A Evaporation for more than 40 years in our trials and adopted it throughout Israel with great success for all the crops. Every orchard has 1-3 pans in different positions in fruit crops. The data is distributed to all the growers for comparison purposes and in order to gather more information about the climate on individual farms.

In the Berri trial we use a Pan Class A Evaporation incorporating an automatic data logger, built and established with the protocols published by the USA Weather Bureau. Figure 1 gives the data collected at Century Orchards in years 2005 and 2006. We have placed a more sophisticated pan closer to the trial site with more representative exposure for the 2006-2007 season. The differences between the years are important, sometimes more than 10% for the same period. In the Upper Galilee of Israel the ETp. is 1200mm, approximately 35% less than in Berri.

Table 4 shows the amount of water applied in the different treatments, in the season of 2005-06 with the cycles of growth of the tree and the fruit as a percentage of the Pan Class A Evaporation. The season was significantly hotter with 152mm more evaporation than 2004-05. In T4 (and T2) the standard, best found in Israel, we applied 0.87 %. (normally 0.80-0.82)of the Pan Class A Evaporation over the season, similar to that obtained in Israel in middle to late season varieties of stone fruit and in almonds.

The commercial treatment irrigated by the Australian Enviroscan received 0.72 n 2005-6 and 0.65 in 2004- 5 of the Pan Class A Evaporation. Table 5 shoes that while water applications in T6 (the dry treatment) which received 0.52 of the Pan Class A Evaporation were lower, T6 out-performed T7. For the scientific researchers involved,

this was a very early and important realization of the high level of efficiency of water application in the trial.

Table 2.

<u>Different Stages in the Annual Fruit and Tree Growth Cycle, in Different Fruit Crops, in the Optimization of Almond Growing Trial, Berri SA</u>

	JULY	AUGUST	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
Apple: Golden Delicious				Stage 1	Stage 1 / Stage 2	Stage 2	Stage 2	Stage 2	Stage 2 / Stage 3	Stage 3	Stage 3	
Nectarine: Fantasia			Stage 1	Stage 1 / Stage 2	Stage 2	Stage 2	Stage 2	Stage 2 / Stage 3	Stage 3	Stage 3	Stage 3	
Almond: Nonpareil		Stage 1	Stage 1 / Stage 2	Stage 2	Stage 2	Stage 2	Stage 2 B	Stage 2 B	Stage 3	Stage 3	Stage 3	

Stage		Process
1.	(red)	**Fruit set & cell division.** Follows flowering. Fruit grows by cell division, determining final number of cells in fruit, (and thus maximum potential size). Root system develops. Canopy growth starts. Period of high demand on tree reserves.
2.	(blue)	**Cell expansion.** Existing cells from stage 1 develop and expand fruit & Kernal size. Kernal concentration of nutrients. Canopy new growth start, bud initiation commences.
2B.	(brown)	**Special stage in almonds.** Cell expansion completed. Hull and Kernal begins to mature and dry and ready to harvest. Bud initiation continue. No canopy or root growth exist.
3.	(green)	**Post Harvest.** (After fruit fully mature, split hull and dry ready to mechanical harvest) Second root flush growth exist. Bud initiation continues. Building of tree reserves in nutrients that return to branches and roots for the next season.

Table 3

Phenology of Nonpareil in 2005-06, in Optimization of Almond Growing Trial in Berri SA

Stage	Phenology		25%	50%	75%	100%
S1	Bud burst (Stage B)		7/08/2005	9/08/2005	12/08/2005	15/08/2005
	Flowering (% at stage F)		18/08/2005	20/08/2005	22/08/2005	24/08/2005
	Fruit set (% at stage G)		22/08/2005	24/08/2005	26/08/2005	30/08/2005
	Rosette (Fully developed)		24/08/2005	27/08/2005	29/08/2005	31/08/2005
	2 cm Elongation		5/09/2005	9/09/2005	11/09/2005	19/09/2005
	4 cm Elongation		11/09/2005	16/09/2005	21/09/2005	23/09/2005
S2	Pit Hardening	14/10/2005				
	Beginning of spilt in fruit	11/01/2006				
	Hull split	8/02/2006				
S3	Harvest	27/03/2006				
	Leaf drop	29/05/2006				

Phenology of Carmel in 2005-06, in Optimization of Almond Growing Trial in Berri SA

Stage	Phenology		25%	50%	75%	100%
S1	Bud burst (Stage B)		7/08/05	9/08/05	12/08/05	15/08/05
	Flowering (% at stage F)		18/08/05	20/08/05	22/08/05	24/08/05
	Fruit set (% at stage G)		22/08/05	24/08/05	26/08/05	30/08/05
	Rosette (Fully developed)		24/08/05	27/08/05	29/08/05	31/08/05
	2 cm Elongation		5/09/05	9/09/05	17/09/05	21/09/05
	4 cm Elongation		14/09/05	19/09/05	23/09/05	27/09/05
S2	Pit Hardening	30/10/05				
	Beginning of spilt in fruit	26/01/06				
	Hull split	23/02/06				
S3	Harvest	26/04/06				
	Leaf drop	29/05/06				

TABLE 4.

Water Application in mm, in % of E-pan in 2006, in Different Stages, in Different Treatments, in Optimization of Almond Growing Trial , Berri SA

	S1			S2			S3			Total		
Date	26/8/05-13/10/05			14/10/05-27/3/06			28/3/06-28/5/06					
Days	**54**			**169**			**66**			**289**		
Treat.	Water mm	E-pan mm	E-Pan %	Water mm	E-pan mm	E-Pan %	Water mm	E-pan mm	E-Pan %	Water mm	E-pan mm	E-Pan %
1	139.2	224.2	62	1446.1	1477	98	84.9	220.5	39	1670.9	1921.7	87
2	141.1	224.2	63	1448.4	1477	98	82.6	220.5	37	1672.0	1921.7	87
3	140.5	224.2	63	1449.7	1477	98	80.3	220.5	36	1670.5	1921.7	87
4	139.0	224.2	62	1449.3	1477	98	81.4	220.5	37	1669.7	1921.7	87
5	225.7	224.2	101	2314.4	1477	157	133.9	220.5	61	2674.0	1921.7	139
6	88.0	224.2	39	862.2	1477	58	52.0	220.5	24	1002.2	1921.7	52
7*	56.4	224.2	25	1204.0	1477	82	120.1	220.5	54	1380.5	1921.7	72

*T7 is the commerical plot of 16 rows

Pit harding is the end of stage S1, Harvest is the end of stage S2, The end of irrigation is the end of stage S3

Table 5.

Total Water Application in mm and % of E-pan in the Trial Farm Site in Years 2004-05-06, in Different Treatments, in Optimization of Almond Growing Trial, Berri SA

		Treatment 4		Treatment 5		Treatment 6		Treatment 7*	
Season	Evap mm	W. A. mm	E-pan %	W. A. mm	E-pan %	W. A. mm	E-pan %	W. A. mm	E-pan %
2003/04	1810	1459	81	2334	129	882	49	1171	65
2004/05	1846	1518	82	2427	132	913	49	1117	61
2005/06	1921	1670	87	2674	139	1002.2	52	1381	72

*T7 is the commerical plot of 16 rows

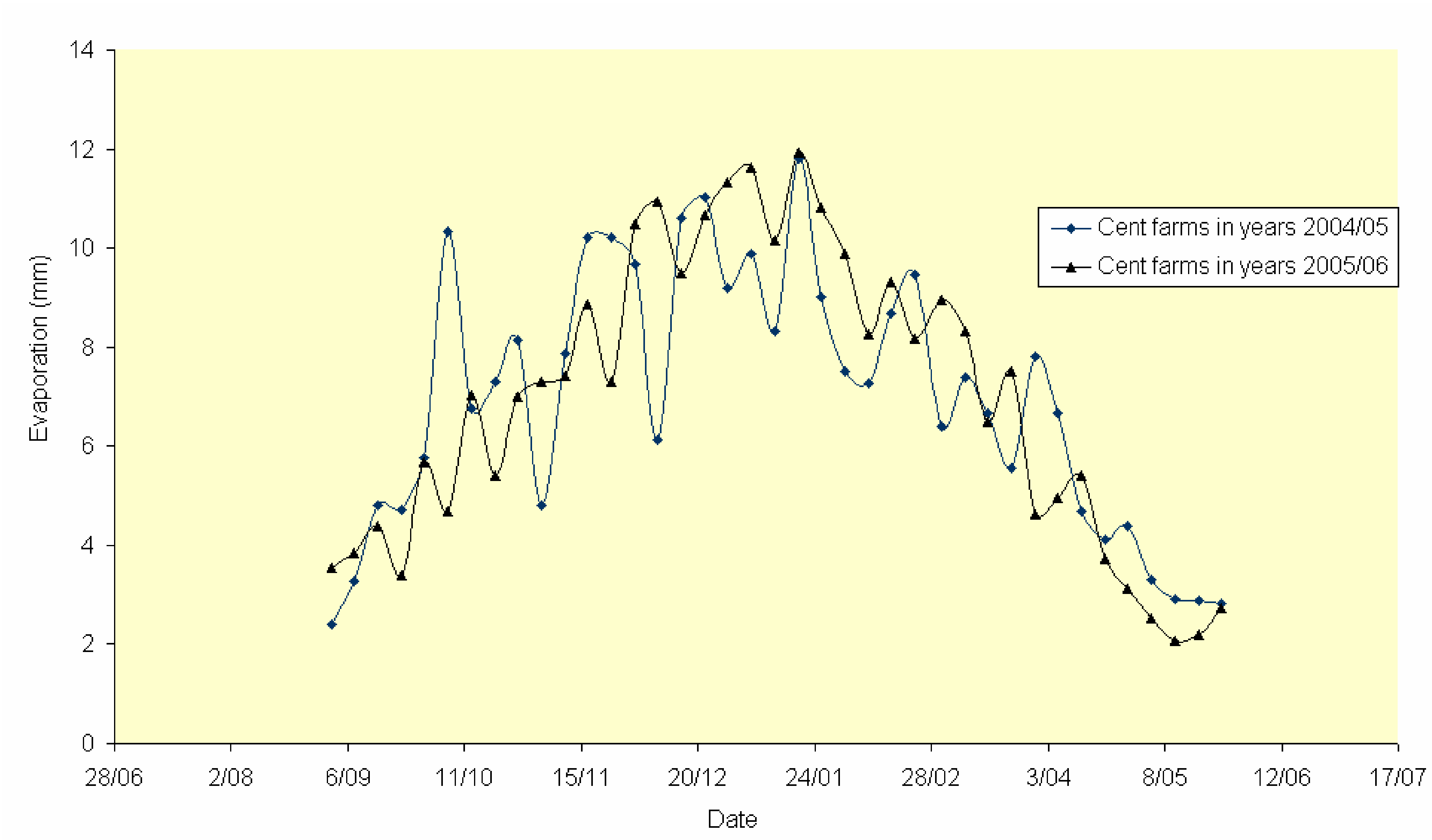

Fig. 1. Daily E-pan of the Century Orchards site in 2005 2006 used in Optimization of Almond Growing Trial, Berri SA.

4.3. Soil moisture monitoring

We read the moisture in the soil layers using the neutron probe (see USDA and Assaf et al. publications lists for all the details). The Neutron Probe is the key to water monitoring as used in the CT trial, it is the primary tool in irrigation monitoring due to its ability to accurately measure the quantity of water in the soil profile. The results are direct valid constant and very sensitive. The Neutron Probe works by emitting neutrons from a radioactive source. These neutrons slow down when they come into contact with hydrogen atoms ($H2O$). When these neutrons bounce back to the probe they react with a gas and release an electrical pulse, this is then expressed as a number that once calibrated gives a highly accurate measure of soil moisture.

In order to have the conversion of the readings from the Neutron Probe to real humidity by weight we have conducted extensive calibration work, this work has involved setting up bunded areas in the different soil types, filling the area with water 20 times in order to saturate the soil on the last fill we start reading as soon as we can no longer see water on the soil surface. We then take a reading every 10cm to a depth of 160cm and then immediately take a soil core every 10 cm. The soil samples are weighed wet and dry and corresponding percentages of moisture can be calculated for each depth at each time interval. We have taken over 5000 samples and are using the information to generate calibration curves that provide us with information such as field capacity saturation point and wilting point. This information enables us to generate % soil moisture for each reading from the neutron probe.

The soil moisture is read each week according to a set of statistical protocols with each of the 20 Neutron Probe aluminium tubes sites read starting at a set time each Friday morning at 6AM following the same path each reading. This information is charted at all depths and adjustments are made to crop factors to optimize the soil water conditions working around ± 5% of field capacity in the 0-80cm layer, (the main root system), without causing drainage and losses of water. The only exception to this process is Treatment 7. In this treatment (based on best commercial practices in 1999) we use the Australian Enviroscan to monitor soil moisture and work between full and refill points.

We have used the same process for more than 40 years obtaining successful correlations between soil readings by the neutron probe and the exact humidity of the soil. The neutron probe must be calibrated to the soil we work with. We act here exactly like we do in large trails throughout our previous work. The results are direct, valid, constant and very sensitive. We use them to convert the neutron readings to actual soil moisture in % by weight and by volume.

From the calibration these are:
Y=0.000010x + 0.029606 for **<u>0-30cm</u>** layer (Figure 2)
Y=0.000016x **-** 0.03568308 for **<u>30-80cm</u>** layer, (Figure 3) and
Y=0.00001944x – 0.07930267 for the **<u>80-160cm</u>** layer. (Figure 4)

Saturation Point in **0-80cm is 12.5%** humidity by weight and = 10075 Neutron Readings
Saturation Point in **80-160cm is 7.5%** humidity by weight and =11795 Neutron Readings

Field Capacity in **0-30cm is 8%** humidity by weight and =5400 Neutron Readings
Field Capacity in **30-80cm is 12.5%** humidity by weight and =10095 Neutron Readings
Field Capacity in **80-160cm is 15.7%** humidity by weight and =11785 Neutron Readings

Wilting Point in **0-160cm is 3.6%** humidity by weight and 5400 Neutron Readings

(More details figure in report No. 1, 2002-2005 in Figures 11,12,13)

Figure 5 shows the neutron probe readings 20cm from the dripper **in T4** (standard irrigation) **in 2005-06**. These are given in each of the three growing stages through the season (**S1**, **S2** and **S3**). The soil moisture readings at all depths show consistently that the soil moisture levels are **below Field Capacity** and thus no drainage has occurred. In relation to soil moisture this period shows the consistency and stability we desire.

Figure 6 show the neutron probe readings of **T5** (60% more water that T4) in **2005-06**. These are again given in each of the three growing stages through the season (**S1**, **S2** and **S3**). The soil moisture is consistently below Field Capacity. As expected, in the **<u>0-30cm</u>**

levels the readings are the highest, approaching FC close to the dripper before dispersing laterally through the root zone.

Figure 7 show the neutron probe readings 20cm from the dipper of **T6** (60% less water than **T4**) in **2005-06**. These are given in each of the three growing stages through the season (**S1**, **S2** and **S3**). Soil moisture levels generally are lower than **T4** and **T5** as expected. Moisture levels in **S1** and the early stages of **S2** are adequate for good flowering, fruit set and kernel development. These moisture levels are primarily a result of the initial profile building. Moisture levels decline through the later stage of **S2** until harvest, when reduced consumptive use (after completion of fruit development and commencement of leaf senescence) allows the soil moisture profile to be very dried and to plateau.

Figure 8 show the neutron probe readings 20cm from dripper of **T7**. This graph shows a clear moisture cycle reflecting the application of water every 2, 3 or 4 days. Moisture levels are generally similar to **T6** but without the stability. This extreme variability means that **T7** is close to Wilting Point for much of the time.

Figure 9 shows the neutron probe readings in 2005-06 in the root zone (**0-80cm**) at 20cm from the dripper and fig 10 at 40cm from the dripper (1.4m from tree trunk) for Treatments 4, 5, 6 and Treatment 7 in S1, S2, and S3.

In **S1** the moisture commences at similar high levels (to the 20cm distance from the dripper) for T4, T5, T6 and T7 after profile building. T4 and T5 are generally similar through the season, with some drying in T4 at the point of maximum consumptive use in **S2**. T6 moisture levels are consistently below those of T4 and T5 as expected and reflect the lower quantities of water applied. At no time does T5 reach Field Capacity in average of 0-80cm. Moisture levels of T4 and T5 show very good lateral development of a large and good moisture profile. T7 moisture levels are inconsistent cycles, particularly during the period of maximum uptake and after harvest where there is a rapid increase to 8000 and then decline to below Wilting Point till post-harvest.

Figure 11 shows the neutron probe readings in **2005-06** in the root zone **0-80cm** at **60cm from the dripper** (1.6m from tree trunk) for Treatments 4, 5, 6 and T7.

In **S1** moisture levels are slightly less than at 40cm as expected due to the profile 'draw-down' over distance. Moisture trends are similar to those at 40cm. These conditions remain consistent through the remainder of the season. Moisture levels of T6 and T7 are similar generally at or below Wilting Point with the exception of the latter half of **S2**, when T7 levels are higher, approaching those of T5. At this stage T7 is typically irrigated for in excess of 50 hours per application, causing some lateral dispersion into an area of soil which has no roots.

Figures 12 and 13 show neutron probe readings at **80cm** and **100cm** from the dripper respectively. Moisture levels and trends for T4, T5 and T6 are virtually identical to those at **60cm** from the dripper, indicating relatively even moisture levels from **60cm** to **100cm**. Moisture levels of T6 and T7 are similar, both being significantly less than either T4 or T5. Generally, soil moisture levels for T6 and T7 are at or below Wilting Point for the entire season at these distances from the dripper. Additional observations to note are that at these distances from the dripper, T4 is at or below **Wilting Point** from mid **S2** and T5 is at or below WP from the end of **S2**, ie from harvest (**S3**), when the crop factor is reduced and some reduction in soil moisture is desired to assist root growth during the Autumn season.

We bring here the same results without bringing the curves not yet completed. We find the same behaviour in Neutron Probe readings, **20cm** from the dripper, for **2005-06** for the different treatments during **S2** the **40 days of peak consumptive use**, 1.1 to 1.2 coefficient of Pan Class A Evaporation. In 2005-06 the season was very hot and accordingly consumptive was high. In T4 with water applications of **9.18 mm/day**, moisture levels are stable below Field Capacity with 75% of available water at **20–160cm** layers and ±5% FC in **0-20cm** layer (ongoing water infiltration). A gradient exists through the levels from **20cm** to **120-160cm**. This expected and desired gradient shows a consistent and stable reduction with depth. All levels with the exception being the surface near the dripper are below Field Capacity and Saturation Point, indicating that **drainage is not occurring and that the irrigation applications are being fully utilized by the tree**.

T5 with water applications of 14.59**mm/day** shows a similar situation but with slightly elevated levels (+-5%) at a depth of **<u>0-40cm</u>** and 80% of available water in the **<u>40-160cm</u>** layer. These are at or close to, but **do not exceed FC**. It was expected that T5 would approach and **be near Saturation Point**, giving drainage at depth. **This is not the case**.

T7 for which water applications are 5.81m**m/day**, a 2 week cycle has arisen causing variations in the soil from 70% of available water to WP in all the layers from **<u>0-160cm</u>**, a varying and unstable situation. The system used to lead the irrigation is very problematic, not constant and does not appear to be applicable for use in drip irrigation. Moisture levels are generally in a similar dry range to T6 (**5.81mm/day)** but variable. The **<u>0-20cm</u>** and **20-40cm** levels in particular vary in a range from Wilting Point to near Field Capacity

Fig 14 shows the graph of the monitoring of irrigation frequency using the Australian Enviroscan. The cycle is normally every 3 days or 4 days and we work exactly with the company protocols. Treatment 7 in our trial yields better than the trees in the surrounding commercial orchard under similar conditions. However, the strict adherence to the irrigation protocols does lead to more consistent soil moisture conditions and the consequent tree and root adaptation has given improved performance. In T7 the wetted bulb is under and very close to the drippers and has the form of a narrow carrot. The concept of using “full” and “refill” points to determine irrigation volumes and frequencies is problematic in drippers. This wet and dry cycle develops the moisture interfaces which limit lateral spread and exacerbates the normal “carrot” form of the wetted area, potentially leading to vertical drainage of water out of the root-zone. The Enviroscan is placed very close to the dripper in a position near to where the water runs as a tube. This position is very problematic and never used by us to schedule irrigation (see Assaf et al. publications). Enviroscan (or similar) technologies currently lead irrigation scheduling in many of Australia’s commercial almond orchards, particularly the larger ones. We have a lot of knowledge in the areas of irrigation and soil science and with the best of intentions have tried to truly help the growers by asking the company to calibrate their apparatus, providing real soil moisture readings (gravimetric and neutron probe readings). We are yet to receive the results.

In the following very important sections of the report we discuss many details that relate to the efficiency of drip irrigation using pulses to deliver the optimum level of water with the consumptive use of the almond trees. This has generated conditions that allow the achievement of high quality yields and the best growth. We have demonstrated that correct implementation of this strategy results in <u>no losses of water under the root-zone</u>. A very important innovation in this field, developed in Israel.

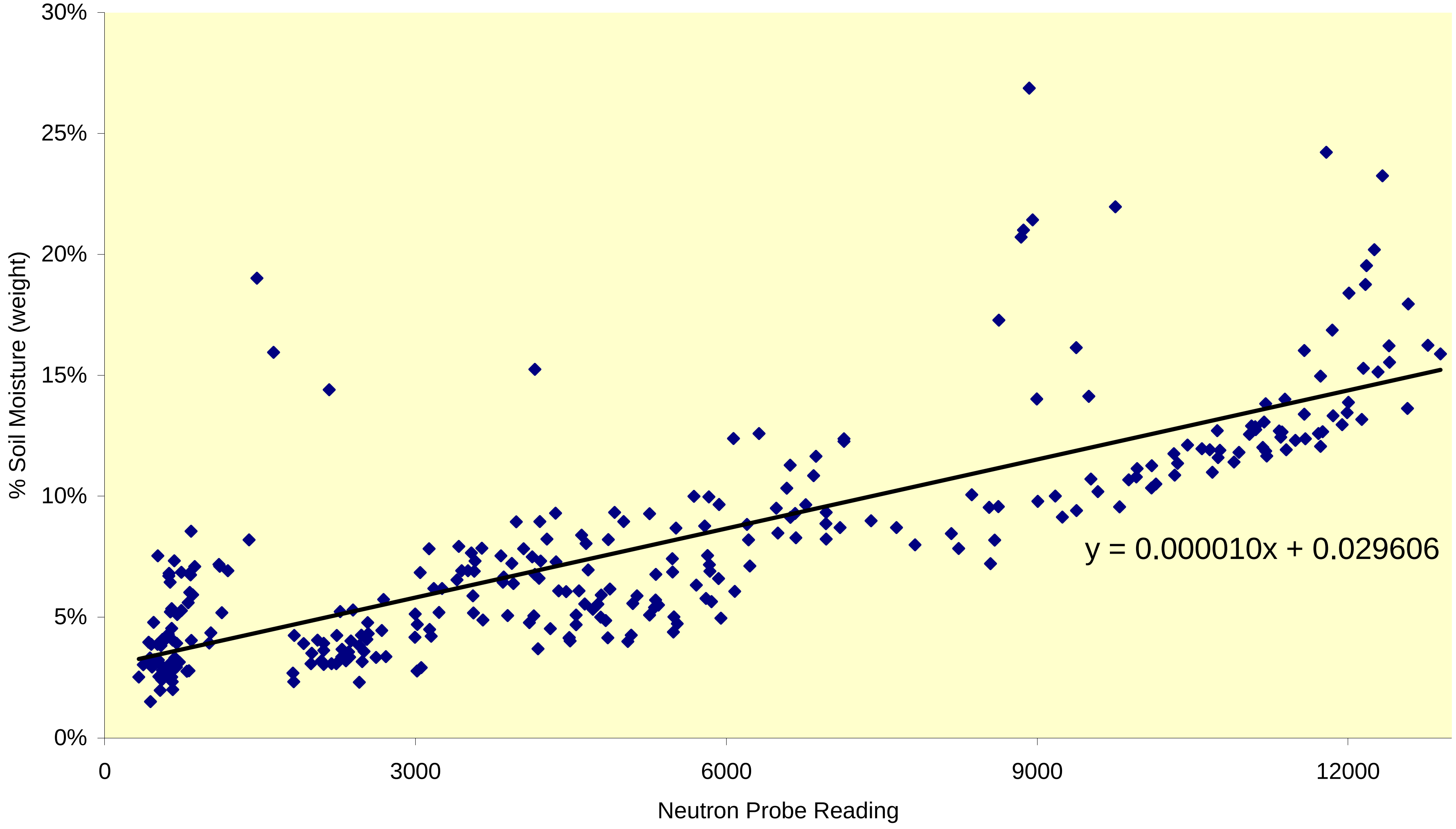

Fig. 2. Soil moisture retention by weight in %, in year **2002** in layer **0-30cm**, in Optimization of almond growing trial, Berri SA.

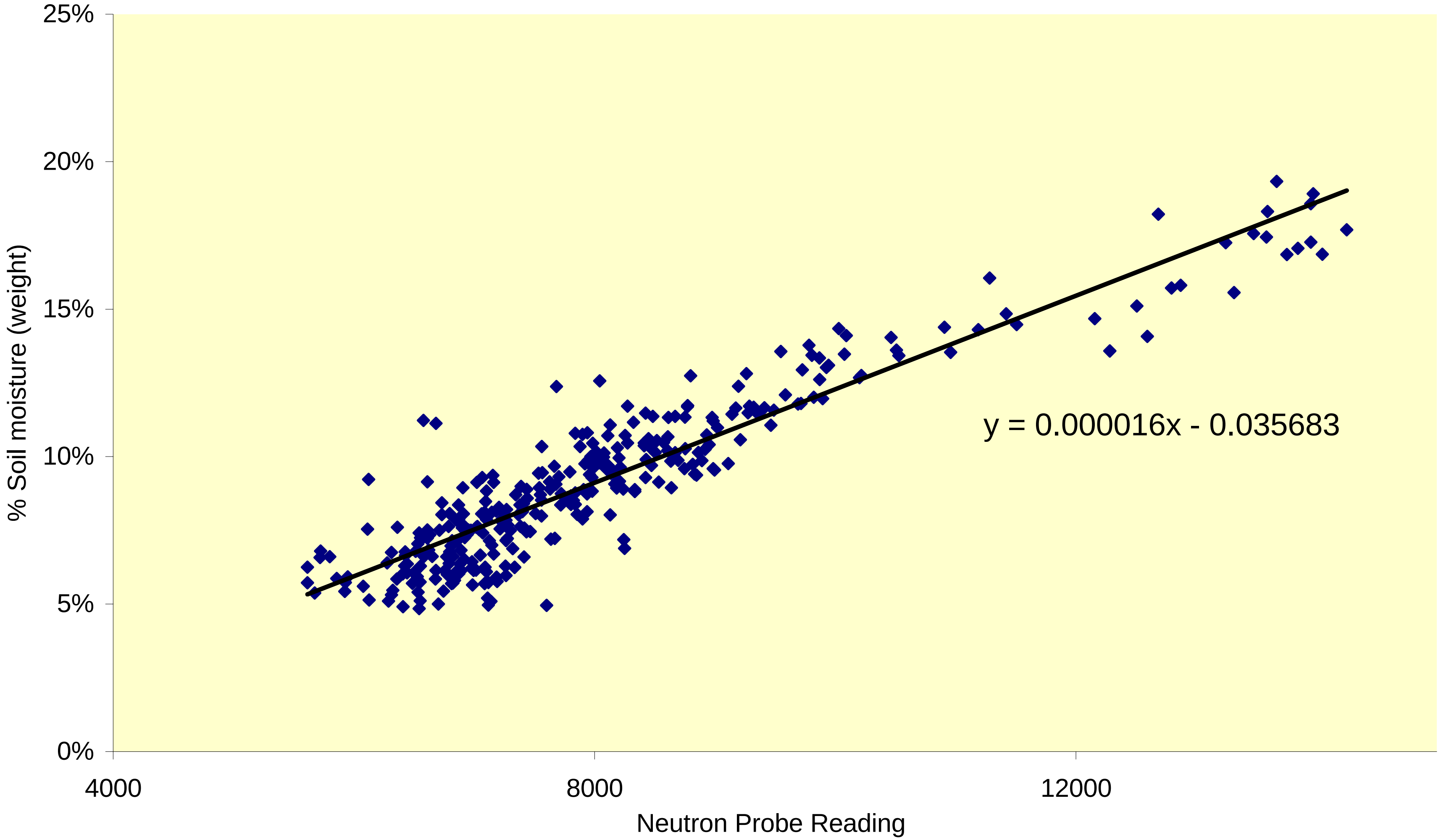

Fig. 3. Soil moisture retention by weight in %, in year **2002** in layer **30-80cm,** in Optimization of Almond Growing Trial, Berri SA.

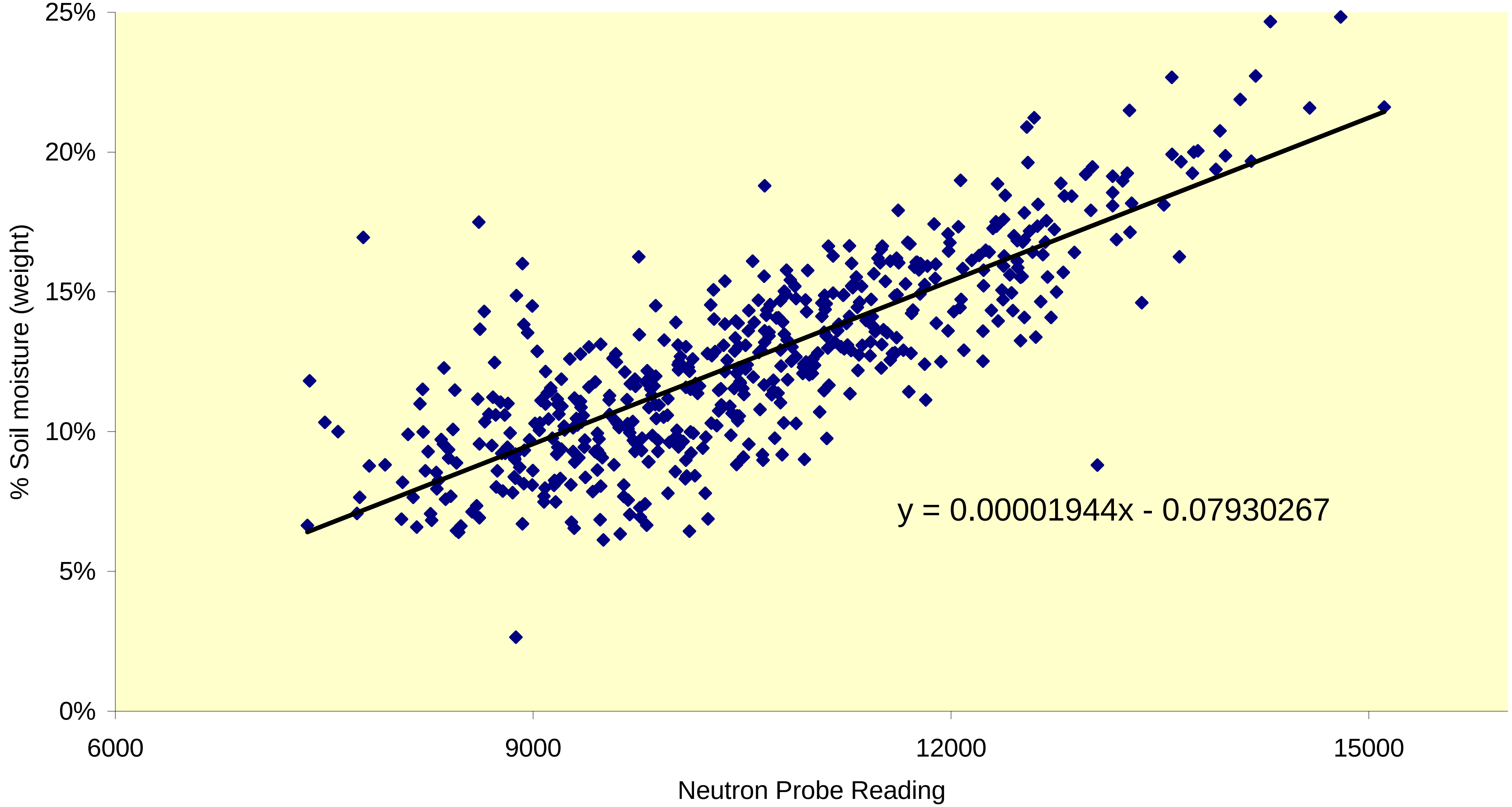

Fig. 4. Soil moisture retention by weight in %, in year **2002** in layer **80-160cm,** in Optimization of Almond Growing Trial, Berri SA.

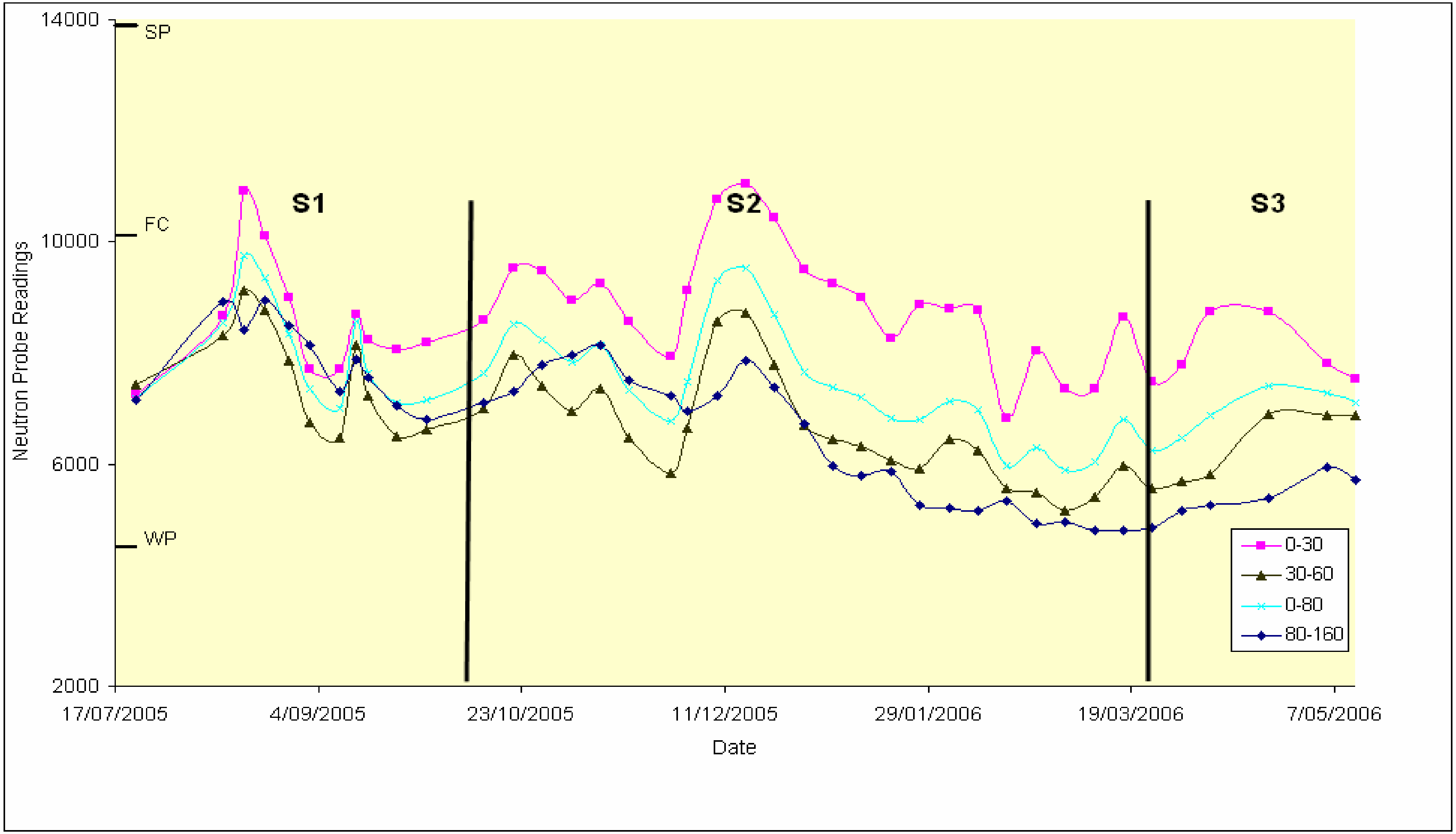

Fig. 5. Neutron probe readings in years **2005-2006**, in treatment **<u>4, 20cm</u>** from dripper, in different layers, in Optimization of Almond Growing Trial, Berri SA.

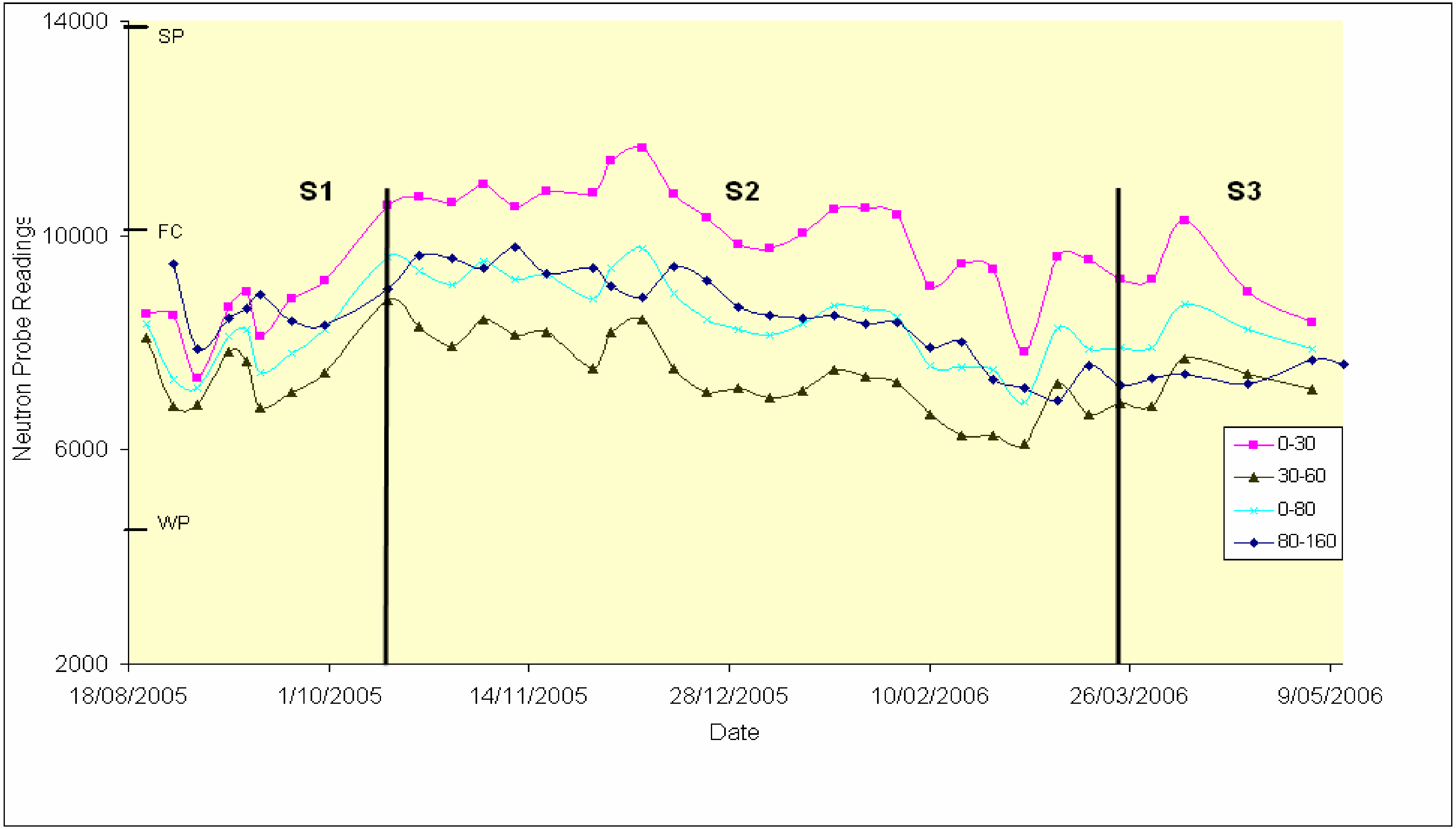

Fig. 6. Neutron probe readings in years **2005-2006**, in treatment **5, 20cm** from dripper, in different layers, in Optimization of Almond Growing Trial, Berri SA.

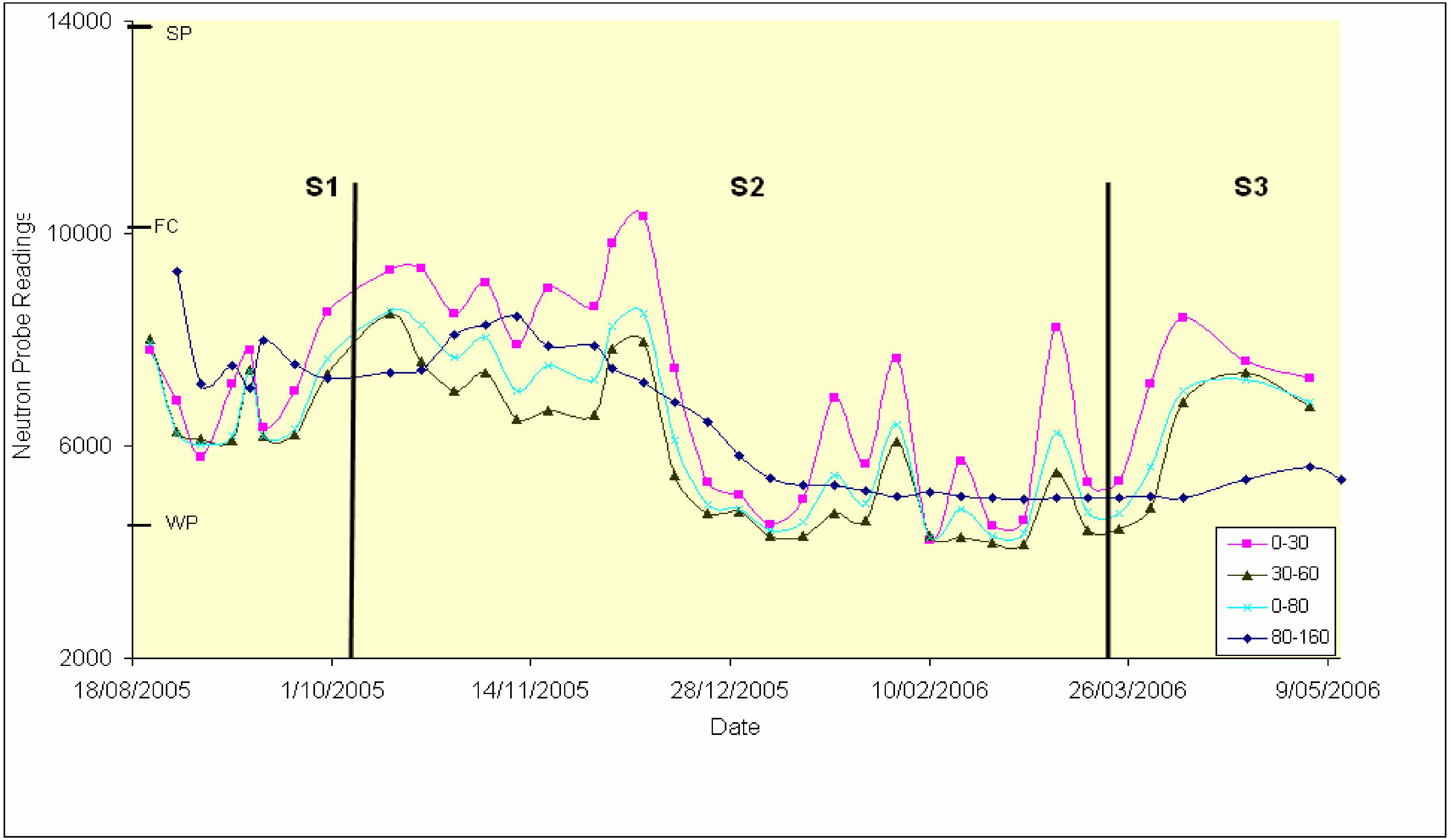

Fig. 7. Neutron probe readings in years **2005-2006**, in treatment **6, 20cm** from dripper, in different layers, in Optimization of Almond Growing Trial, Berri SA.

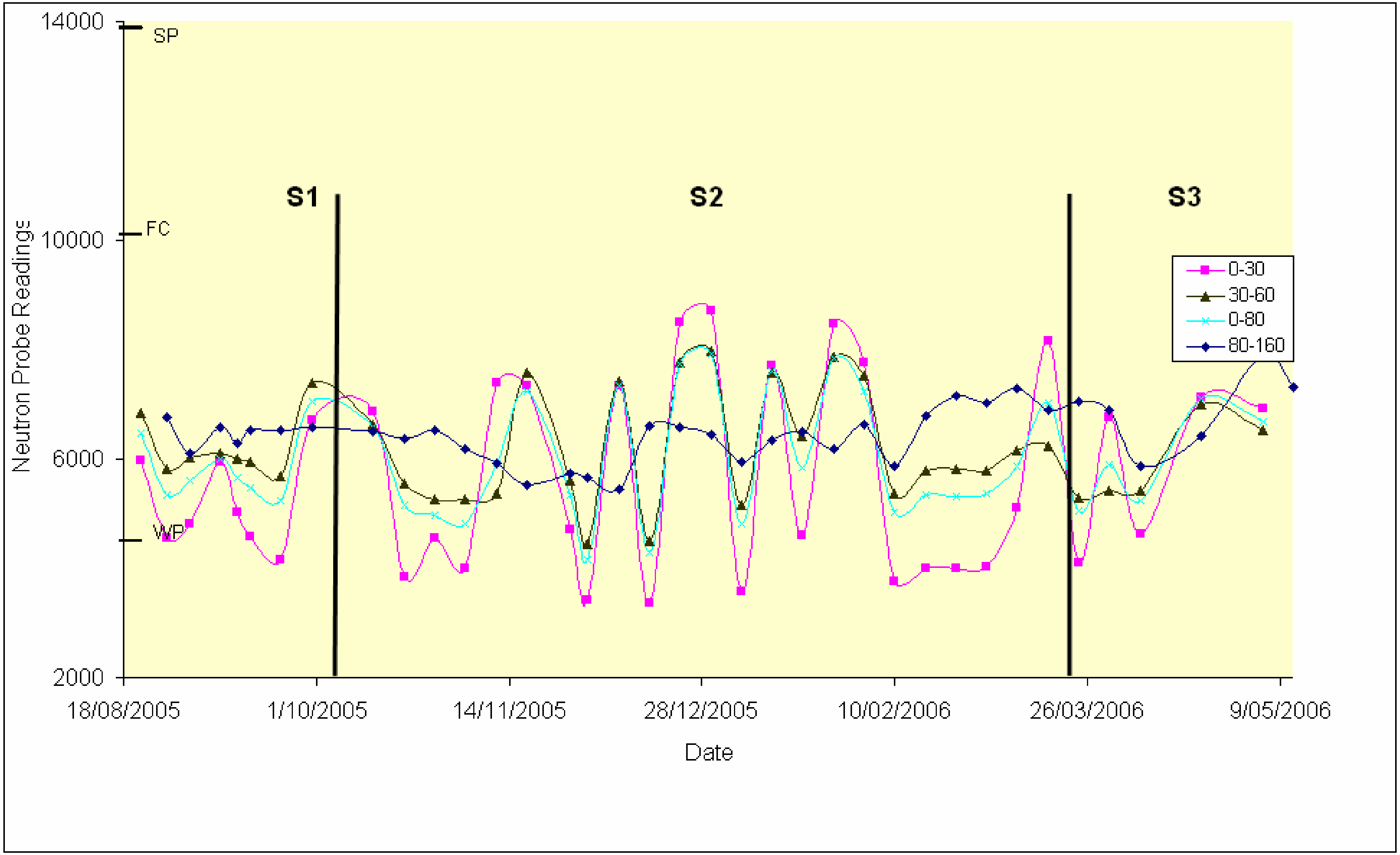

Fig. 8. Neutron probe readings in years **2005-2006**, in treatment **7, 20cm** from dripper, in different layers, in Optimization of Almond Growing Trial, Berri SA.

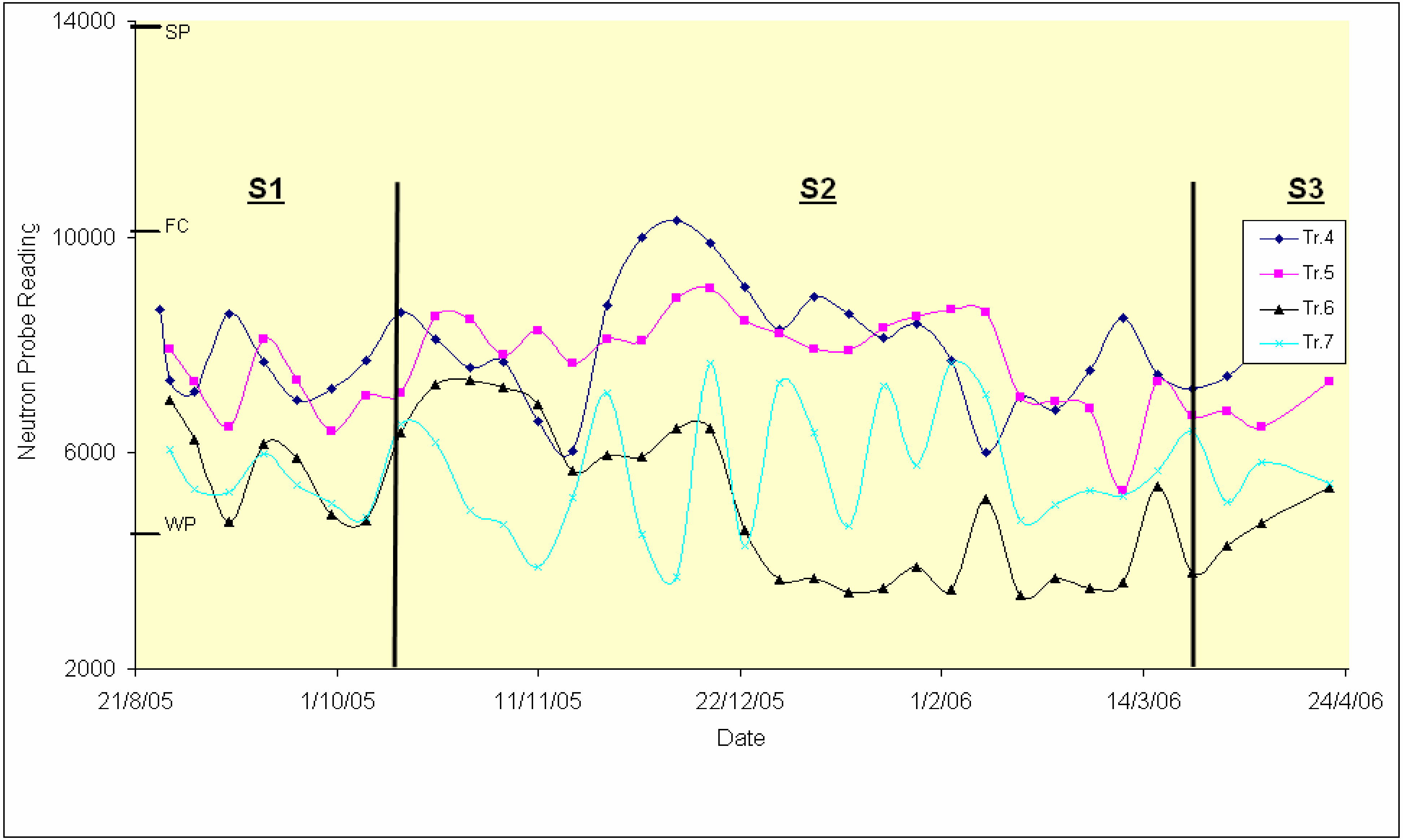

Fig. 9. Neutron probe readings in year **2005-2006**, in layer **<u>0-80cm, 20cm</u>** from dripper, in different Tr. in Optimization Trial.

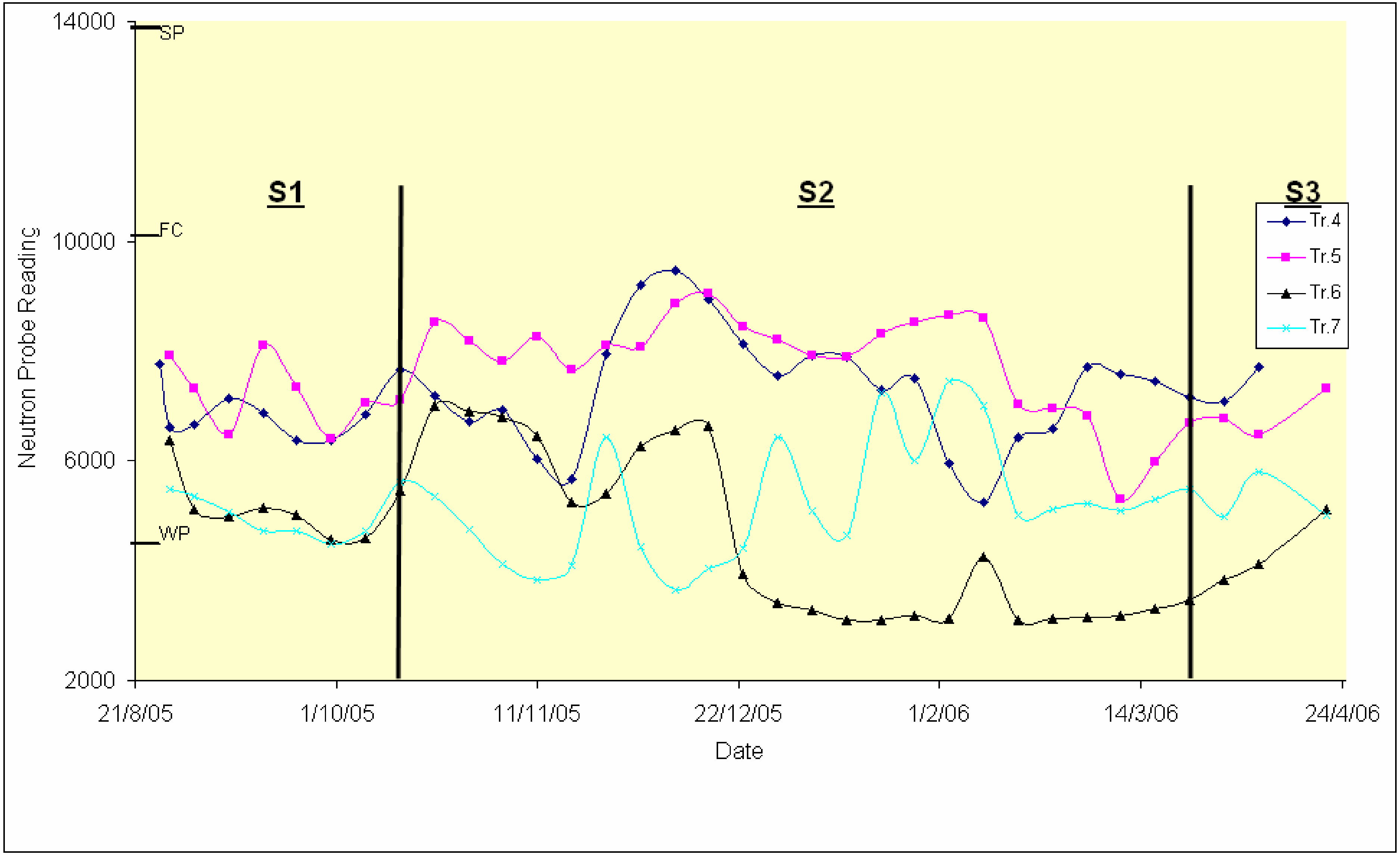

Fig. 10. Neutron probe readings in year **2005-2006**, in layer **0-80cm, 40cm** from dripper in different treatments, in Optimization of Almond Growing Trial, Berri SA.

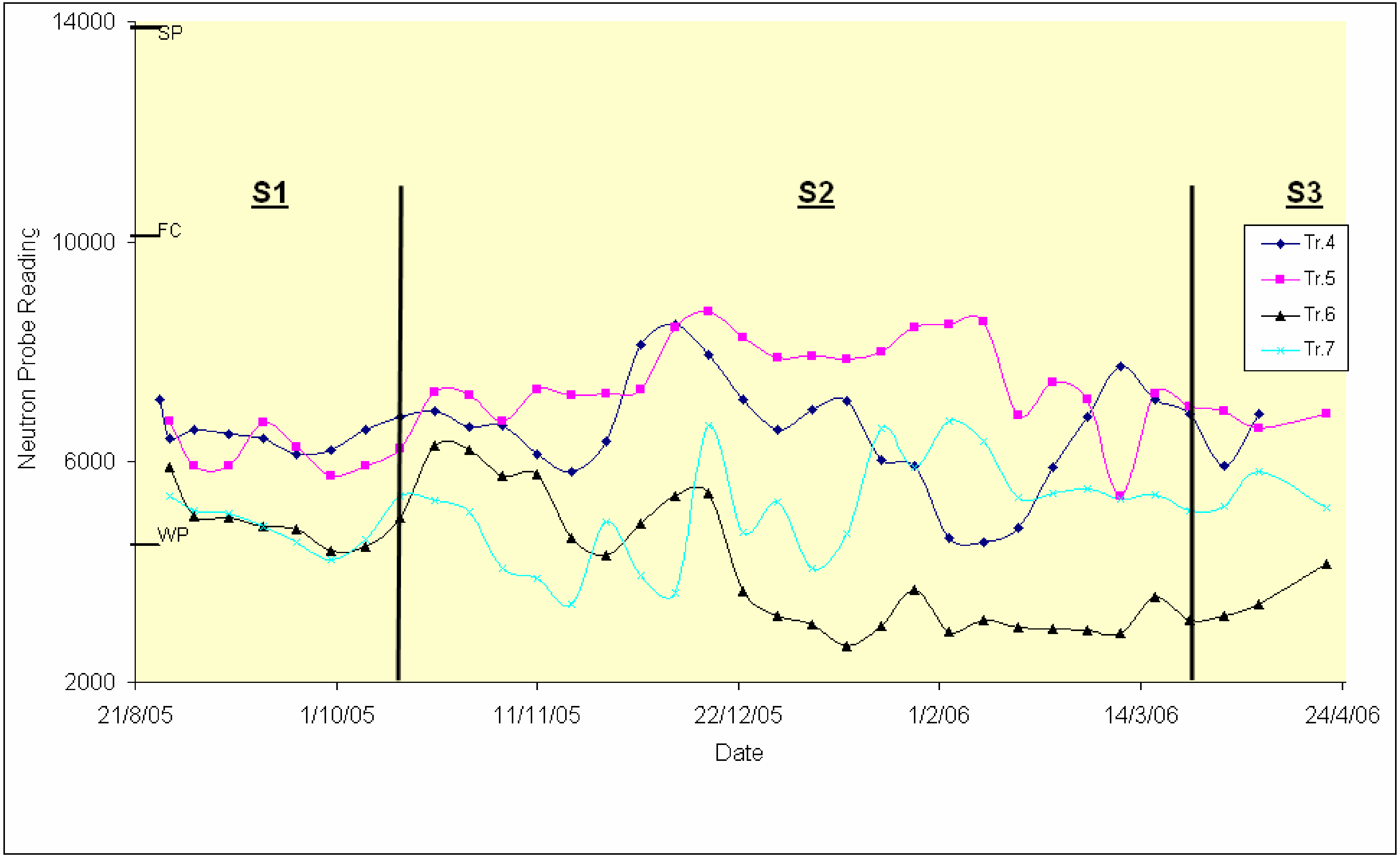

Fig. 11. Neutron probe readings in years **2005-2006**, in layer **<u>0-80cm, 60cm</u>** from dripper, in different treatments, in Optimization of Almond Growing Trial, Berri SA.

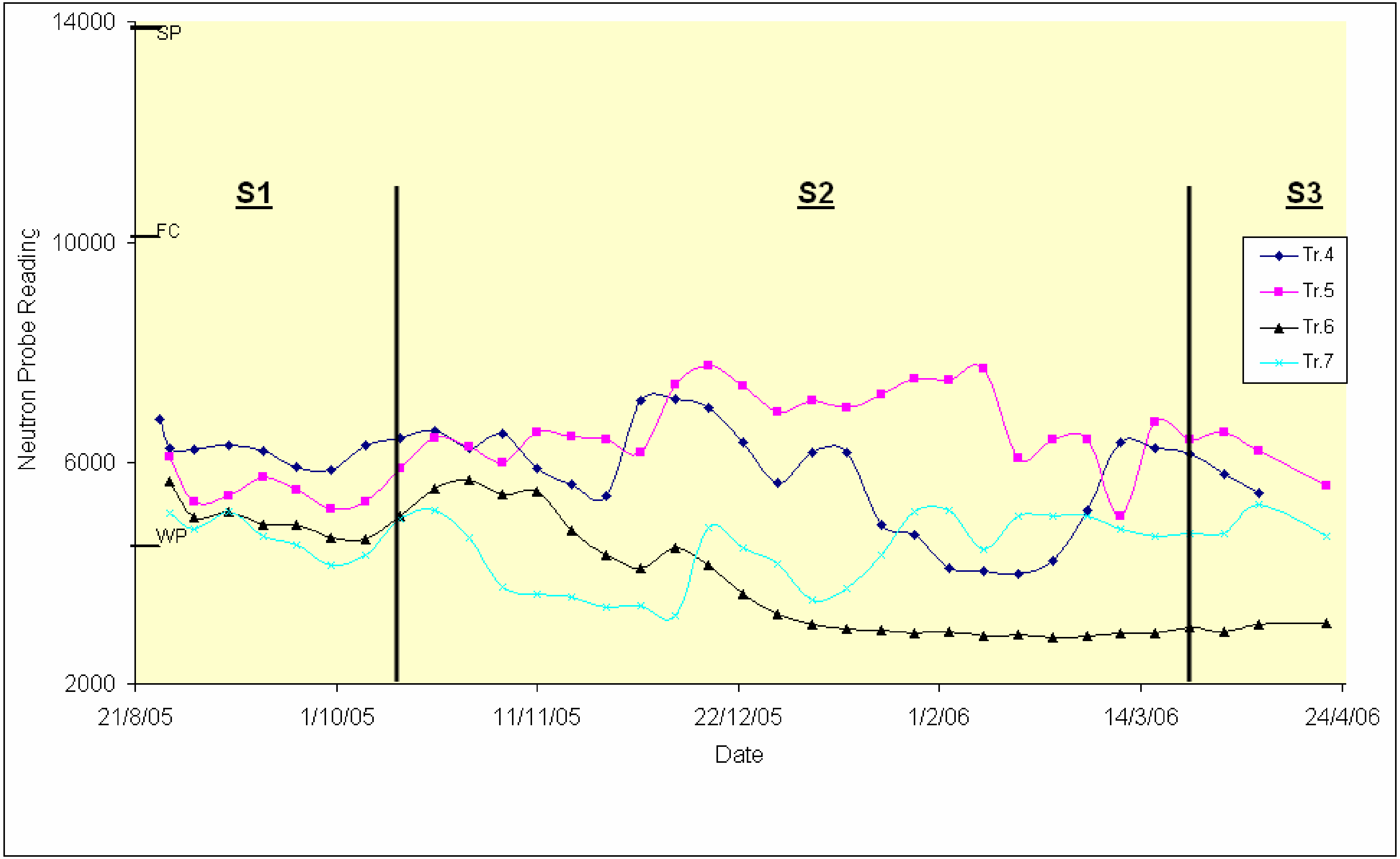

Fig. 12. Neutron probe readings in years **2005-2006**, in layer **<u>0-80cm, 80cm</u>** from dripper, in different treatments, in Optimization of Almond Growing Trial, Berri SA.

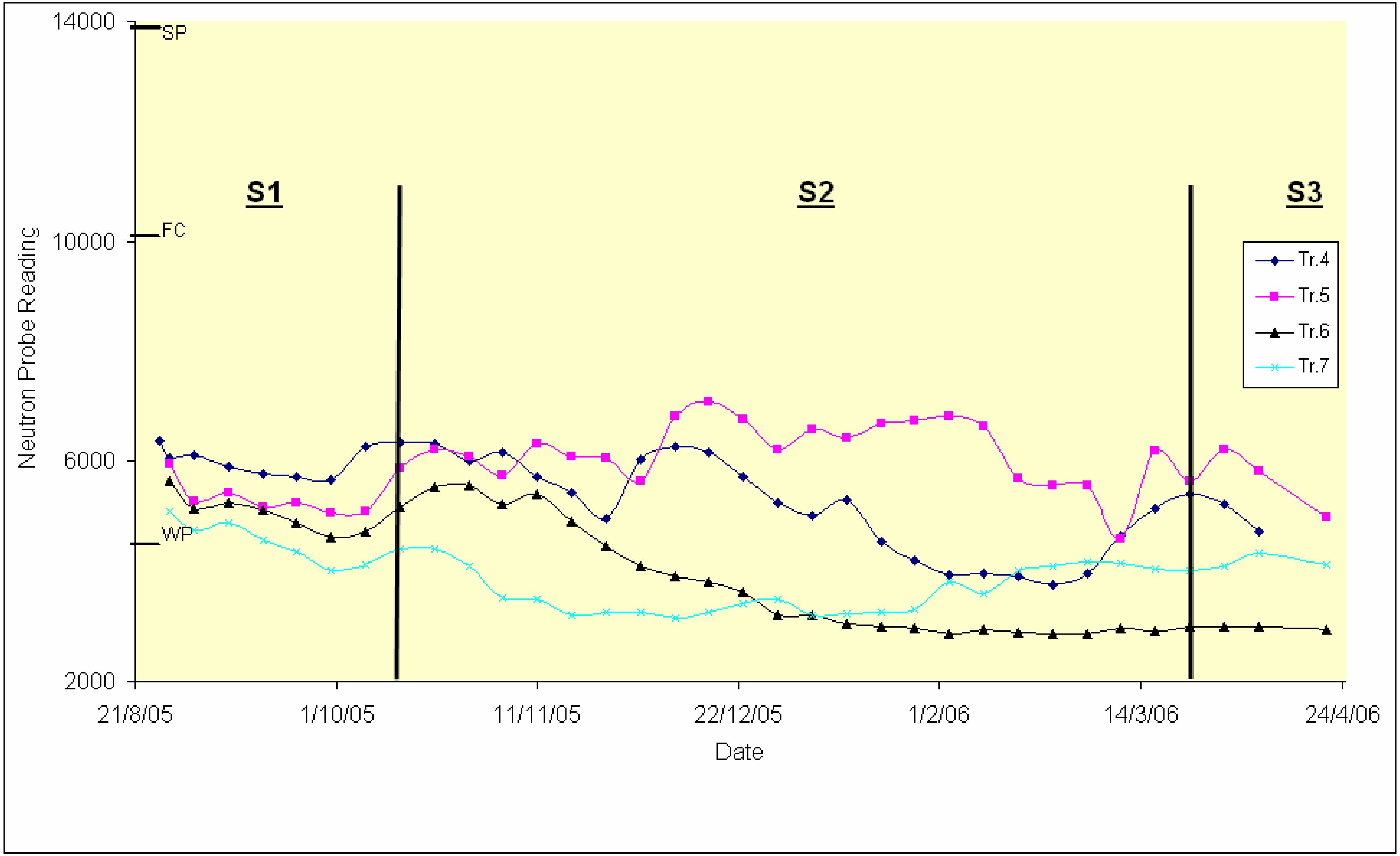

Fig. 13. Neutron probe readings in years **2005-2006**, in layer **<u>0-80cm, 100cm</u>** from dripper in different treatments, in Optimization of Almond Growing Trial, Berri SA.

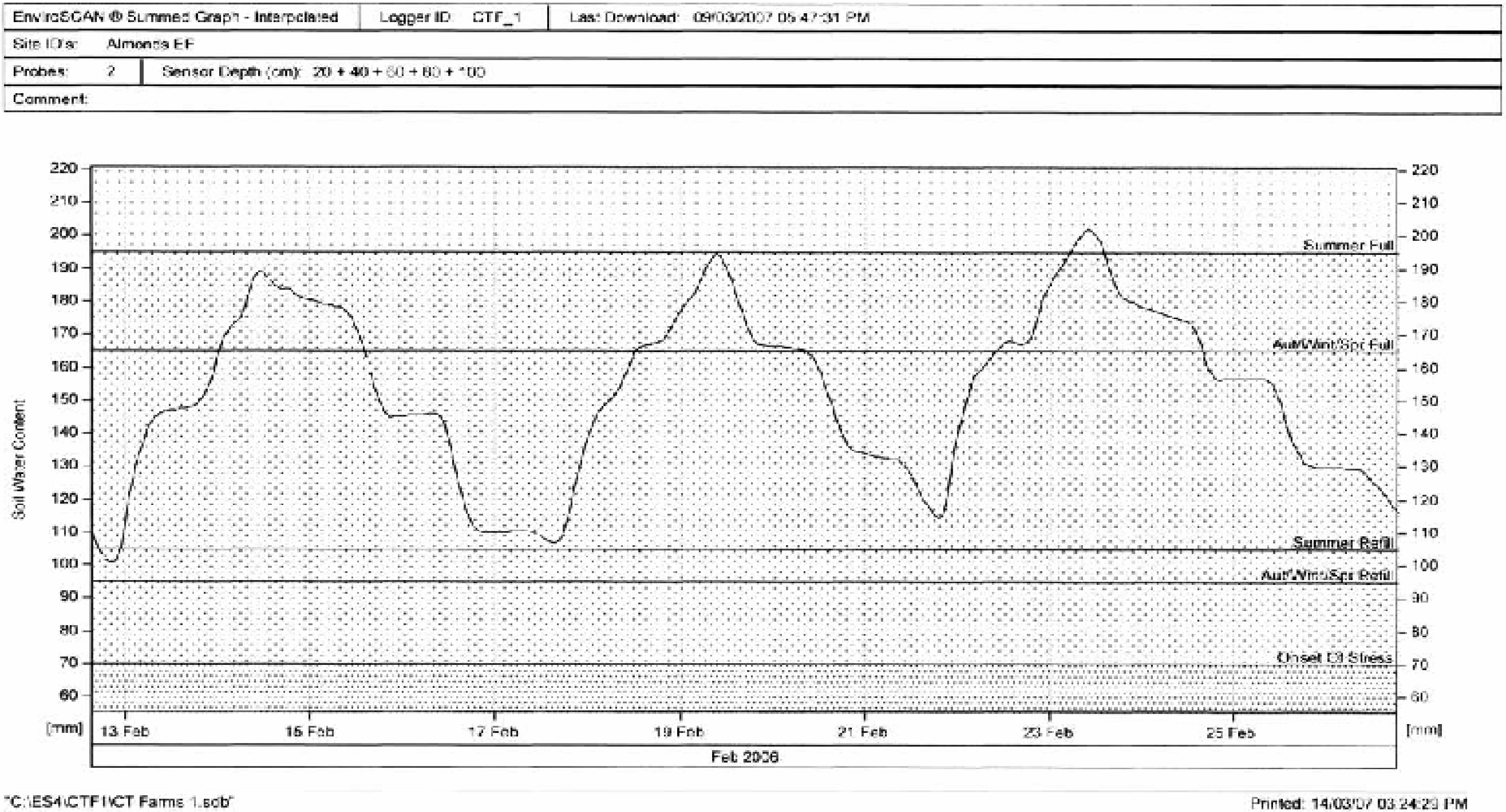

Fig. 14. Australian Enviroscan chart as used in Tr.7 (best commercial practice.) of the Optimization of almond growing trial, Berri SA

4.4. Root system

The most important results with the root system are obtained with pulses, the dynamics of which have been described previously. For more details see Assaf et al. publications list. Our results show that due to the very good conditions provided by irrigating with air the soil by pulses we have induced dense root proliferation. The lateral distribution caused by pulsing is very slow and always achieved without removing air from the soil (measured by us in previous work in medium soil finding that it is rich in CO_2 and oxygen). In our Optimization trials we have achieved over 10 times more roots compared to sprinkler irrigation and more than 4 times that obtained under daily continuous application of water by drippers. We achieved these types of root system in our work in the Berri trial also. The results have been demonstrated by digging trenches 40cm wide to a depth of 160 cm, between the trees, 2m from the trunks. The walls were washed by high pressure water, removing 5cm of soil from them. The roots are then visible, apparent and can be counted using a grid (20cm x 20cm). While this counting was not undertaken at the CT Trial due to a lack of resources, evaluations were made and photographic records were taken.

In Optimization, special attention is given to developing and proliferating the root system to ensure it is the best possible. The roots are never disturbed during the important growth flushes (one in spring, the other autumn); this growth being assisted and encouraged by the constant manner of irrigation and using specific fertilizer (N) compounds.

Trenches have been excavated to study the development of the root systems over time and across irrigation treatments. Fig 17 is the most recent photo of the root system we have generated in T5. Trenches dug for the almond conference one month earlier in T3 showed a similar intense root-system.

The very large root system developed in the Optimization trial forms the <u>basis of the high quality yields</u> and the outstanding performance of the orchard obtained like we get in our previous trials in apples.

Fig. 15. Dense fibrous root system development in December 2006, in Treatment **5** after 5 years of pulsing in the upper layer of the soil, in Optimization of Almond Growing Trial, Berri SA (photo of the site).

4.5. Canopy Management

Trials and studies have been undertaken for many years in Israel for different fruit crops. They form the basis of our fruit production systems and determine the equilibrium of fructification and vegetation for the best performance (see many publications on this subject by Assaf et al). We adopt for the Optimization Trial (the 6 treatments) in Australia the Y form studied for more than 30 years in stone fruit and 15 years in almonds. The basic tree skeleton is 4-8 productive units on each side, with an empty Y shaped centre of the tree. The Y shaped canopy is north-south in direction, which is preferable. This gives the best interception of light in the 2 walls of the tree. We grow the trees as fast as possible in the first 5years and all the new growth (2-3m a year as we get in the trial) is converted to productive wood by shaping the main limbs within defined angles or bending secondary limbs to a horizontal position. In these early years no pruning is undertaken, only training to the desired shape and angle. At the commencement of the trial, the three year old, vase shaped trees were converted over to this system

In season 2005/06, pruning was performed in 4 steps. 1 To prune and remove all the dead wood from the tree. This dead wood arises through shading and as a result of fungal infection (removal limits the level of inoculum). Step 2 occurs between the rows where we cut a 1meter wide section, free of branches and shade permitting the tractors work and passage. Step 3 is to clean the Y in the inside of the trees, removing mainly water shoots and crossed branches done partly. Finally step 4 the most important step is to have the two walls that build and form the tree equilibrated with no shade or crossed branches. In every dense corner we take out 2 or 3 limbs.

These final two steps were not accomplished in the trial, due to a great lack of organization and misunderstanding. This is disturbing our planning and our strategy with the alternate bearing and has affected heavily on yields and future harvests.

It is crucial to develop a tree structure capable of supporting the significantly increased weight of the higher yields and canopy (branches and leaves). To achieve this goal, strong, well placed limbs with wide angles are required and chosen.

4.6. Nutrition

Nutrition of fruit trees is complex and involves a very large knowledge. There has been considerable research work undertaken on this subject in the disciplines of soil science, soil physics, and physiology of fruit trees, biochemistry and biophysics to help us to progress. Many books have been published on this item. ASSAF works more than 40 years on nutrition and on Optimization Trials with colleagues, authorities in the world in this specialization. We start like in all the world trials giving different treatments (levels of N, K, P etc) to the different fruit crops by surface application of the fertilizer on the soil (quantities, combinations, timing, type and distribution). We get results after many years and learning all the influences of each element by different treatments tried on the soil, analyzing the physiology of the plant, the yields and the qualities of the fruit effects etc. This large body of information continues to be of great help in our new more sophisticated work. See many Assaf publications et al. lists and published report 2006.

When we first started applying the fertilizers by injection with the water mainly through drip irrigation (i.e. fertirrigation), we obtained results that were a revolution in all the nutrition of the plants.

In order to achieve optimum results in relation to the application of nutrition, regular applications of fertilizer are made to the root system to meet the consumptive use of the tree. It is very complex and we are trying new combinations in our formulas every season. Our work is preliminary with more years needed to determine the best formula in sandy soils of 9 pH with the aim of getting high yields.

Calculating consumptive use in nutrition for the trees of the standard treatment in the CT Trial's (best from previous work on apples).

1. Whole, dried fruit is 2.5-3.0% Nitrogen (This is in addition to the requirements for the regeneration and growth. of the canopy, roots and leaves).

2. The requirement for Potassium is similar, however it has a low efficiency of uptake. Most of it most is blocked in the soil and as such, more is required (typically 1.5 times the amount required by the tree).
3. Therefore growers wishing to produce average annual yields of 4t/ha (12t/ha whole fruit) will need to apply around 400 units of N and around 600 units of K.
4. 1/3 of the annual nutrition program is applied in Autumn to fill the reserves in the tree, however the bulk of our nutrition program (2/3) is required in spring. In the standard treatment this equates to a 12 week period of application of an equilibrated and synergistic nutritional solution (based on half Hoaglands).
5. As in irrigation, to achieve the optimum, applications need to be matched to consumptive use of the tree.

Products utilized during the spring and summer period include Potassium Nitrate, Urea, Ammonium Nitrate and Potassium Chloride. Weekly applications change in response to variables such as soil temperature, crop load growth needs and the stop of the vegetative growth.

In hot climates with high radiation such as South Australia and in CT Farms, (different in different areas) we observe many deficiencies in microelements such as Zn, Mg, Mn & B. (Boron is not always existent and has to be considered with special precautions). For each element we must find the most effective formula to apply as a foliar spray targeted to the young leaves in the spring. Zn is the most frequent and NZn is used with the best response. Iron is applied as EDDHA chelate at a rate of between 6-12 kg/ha per year. Applications are made with the irrigation water in a solution over a 6 week period. 6 sprays of NZn +KNO3 and Urea are given in the season, 2 Mg as MgSO4 and 2 Boron sprays. We use special injections to the root system when needed of zinc plus penetrating agents like urea.

In the Optimisation Trial, the planned quantities of fertilizers were injected by the drippers exactly as programmed, see Table 1. The different Treatments are adopted from the Mahanaim apple trial: being a low (7 weeks of solution), a standard (12 weeks) and a rich (21 weeks).

In the leaf mineral content analyses, we don't use the standard levels that are based on averages of the leaf analysis results in the orchards of California, Israel, Europe and in Australia. In Optimisation work we never use averages and don't want to be average in our performance. We compare ourselves to the **best analysis found in the best plot**, with the highest quality yields. In our case this is the **almond plot in Neve-Yaar, Israel and the CT trial in the future**. The same strategy is used for the soil and fruit analyses.

In leaf analysis, we use the Israeli protocol for collecting samples (statistically built). **Only normal and standard leaves are used** (not spur leaves) in a similar method to that applied to pome and stone fruit (*Rosaceae*) and other nuts. This phenomenon demonstrates that our calculations and applications of fertilizers by the consumptive use of the trees in the growing season is working very well and that all the major elements like N, P and K are taken up and absorbed. Our special attention is given to the timing and type of fertilizer materials used and the subsequent changes in the levels of the elements in the soil.

The leaf mineral content analysis results in years05-06 are given in 3 **Tables 6, 7, 8**. In the spring (10-5-06), **Table 6** we realize that all the macro-elements are higher like 4%in N and the contrary less and low in micro-elements. With the time the macro elements are reducing and the micro elements are increasing. In **Table 8** results of the summer analysis, the most important stage to read the nutrition status and compare our results, we find that in N there is no differences between the 3 treatments of nutrition 1,2, and 3 each treatment is higher than the control T7. The same phenomena is found in K, Zn, Mn, Cl and Fe. P is consistent across all treatments while higher levels are found in Mg and Ca in T7 than T1,T2 and T3 we find in Ca that we must repair the low levels and apply a special formulation to correct this . Our concentrations in N PK are satisfactory but we have to try to improve our applications if we want to feed the high yields that we currently enjoy.

Table 9 gives the mineral content of the hull of the fruit. There are small differences between treatments 1, 2, 3, and as always T7 is lower. We see less concentration but normal average in T3 in N, P, Ca, Zn, and Fe.

Table 10 gives the mineral content of the kernel. All are very high in the 3 treatments like 5% in N and less in T7 but are low in K, P, Ca, and Mg.

Table 11 gives the mineral content in the shells of the fruit. All the concentrations are low with the exception of K that is here more needed and is very high. (In Pecan, K nut analysis of shells is very important in determining the mineral nutrition status).

All these fruit mineral content analysis serve use to evaluate how much is extracted by the crop as pure elements without considering the efficiency of the uptake and they are large quantities per tone of kernel.

Our leave analysis tell us that we are doing well and must maintain these higher level and more to feed the high yields. From the beginning we get all the time higher and better concentrations, more satisfactory.

In the soil mineral content and analysis we have investigate few and they are not finished in the laboratories. We plan to do a lot more frequent for better understanding the evolutions and the special phenomena's created by our fertirrigation in this sandy soil with Ph 9, very sensitive and with a very poor and small water and nutrition retention , a quarter of heavy medium soil. The first results give us the same behaviour we observe last years and all will be reported lately in the next report.

In this Optimisation Trial, our preliminary results, (realized also in other trials in Israel) allow us to conclude this most important outcome. Applications of high rates of fertilization performed responsibly, using procedures adopted in our trial on Optimisation of almond do not result in any problematic accumulation of N derivates or salts in the different layers of the soil until now.

Table 6

Leaf Mineral Content 10/2005 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Trial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	4.0	0.21	2.2	*	0.41	*	*	181	181	64	*
2	3.8	0.20	2.3	*	0.42	*	*	183	178	62	*
3	3.8	0.20	2.3	*	0.42	*	*	183	178	62	*
7*	3.9	0.20	2.3	*	0.39	*	*	178	212	68	*

*T7 is the commerical plot of 16 rows

Table 7

Leaf Mineral Content 11/2005 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Trial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	3.5	0.18	2.2	*	0.5	*	*	448	220	78	*
2	3.7	*	*	*	*	*	*	*	*	*	*
3	3.5	0.18	2.3	*	0.4	*	*	315	220	64	*
7**	2.6	0.20	1.7	*	0.6	*	*	46	127	52	*

*Missing Data ** T7 is the commerical plot of 16 rows

Table 8

Leaf Mineral Content 01/2006 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Trial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	3.1	0.15	2.4	2.9	0.50	0.04	0.33	305	238	79	8
2	3.2	0.15	2.4	2.5	0.48	0.06	0.45	353	216	85	6
3	3.2	0.14	2.5	2.6	0.43	0.05	0.35	419	227	79	5
7*	2.3	0.14	1.4	3.8	0.73	0.05	0.25	53	125	61	8

*T7 is the commerical plot of 16 rows

Table 9

Hull Mineral Content 01/2006 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Tial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	2.2	0.14	3.7	0.20	0.07	0.03	0.14	131	17	109	19
2	2.1	0.12	3.6	0.19	0.08	0.04	0.13	123	17	102	15
3	1.9	0.09	3.7	0.18	0.07	0.03	0.15	109	18	47	6
7*	0.5	0.11	2.0	0.17	0.07	0.02	0.13	31	8	54	4

*T7 is the commerical plot of 16 rows

Table 10

Kernel Mineral Content 01/2006 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Tial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	5.0	0.48	1.2	0.21	0.29	0.01	0.03	55	37	69	8
2	5.0	0.47	1.1	0.20	0.29	0.01	0.03	55	36	60	7
3	5.0	0.46	1.2	0.20	0.29	0.01	0.02	55	38	60	7
7*	3.6	0.49	1.2	0.29	0.28	0.01	0.03	49	28	63	8

*T7 is the commerical plot of 16 rows

Table 11

Shell Mineral Content 01/2006 for Nonpareil, in Different Treatments, in Optimization of Almond Growing Tial, Berri SA

Tr.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
1	0.8	0.07	2.3	0.09	0.03	0.03	0.11	51	9	36	11
2	0.7	0.06	2.2	0.09	0.03	0.03	0.12	41	8	17	4
3	0.7	0.04	1.9	0.09	0.03	0.04	0.11	39	9	44	11
7*	0.6	0.08	2.4	0.13	0.04	0.03	0.13	17	6	24	9

*T7 is the commerical plot of 16 rows

4.7. Yields and qualities of the almond Kernals in the Optimization Trial

Table 12 shows the Nonpareil yields and kernel qualities in 2006, in the 7 different treatments. The yields were very high last season (around 4t/ha). Last year a 7^{th} leaf world record of 5.6t/ha was achieved in T5 and this year 4.2 t/ha. As expected the results in 2006 are less but not to the same extent as experienced in commercial farms (normally around 1t/ha). In T7 we achieved only 1.1 t/ha whereas the trial produced 3.5-4.2t/ha. This was a very important result. The expected results obtained in T7 are similar to the Californian productivity average. The lowest yields (classified as group C⁾ were achieved in T6 which gave 3.5t/ha using 40% less water than the standard treatment, T2. T6 still represents an impressive 312% of the yield in T7. T1, T3 and T4 produced yields in the order of 336% of the control T7. T2 is an intermediate group of yields (ab), but still in the order of 355% of T7 and finally T5 is the highest at 367% of T7. In the same table we can see that the qualities of the kernel are very good, averaging 1.53g in weight, 18.5 kernels to the ounce and 32% crackout, all of which are higher than 2005. A sensorial test done partly with the Australian Optimisation Team and in Israel by a Team of Specialists **found that the kernel of the treatments are shinier with better color, better in overall appearance, more sweet, higher in taste of amygdalis** (old almond flavour) **and less dry woody taste**. In T6 these qualities were all less and in T7 the lowest.

In table 16 we see the results of the good yields achieved in Carmel for the different treatments; on average in 2006 the Carmel variety yielded 4.7t/ha **1 t/ha more than Nonpareil**. The differences between treatments are T1 T2 T4 and T5 at 5t/h (group a) or 248% of T7. T6 and T3 (group b) yielded the lowest at 203% of T7. In the same tables we can see that the other qualities of the kernel are excellent. The crop in Carmel in 2006 for T7 was 2t/ha higher than normally obtained in commercial orchards after a high yield season.

We have to emphasize that in the Australian almond industry, the average yield per tree in 1997 in the better orchards was around 8.0kg. Currently now 18kg is being achieved in the optimization trail, compared with 12kg in the best commercial orchards now.

Nonpareil Fig 16 shows the number of fruit in different years and different treatments compared to T7. For T5 we see that the number of fruit per tree have increased from 4,150 in 2002 to 7,154 in 2003, 12,832 in 2004 and 18, 500 in 2005 and decreased to 10,380 in 2006 (compared with 3,089 in T7). Figure 17 shows the same data for Carmel. These figures show that to this point the fruit number has been spectacular, **approximately doubling each year** from 2002. While there was a fall in 2006 it was not dramatic like in T7. This phenomenon was true for all six treatments with only small differences in yield being observed to date. Treatment 6 gives results that are lower in Nonpareil and appear to have reached a plateau in Carmel in 2004. T7 shows consistently lower increases in fruit numbers of approximately 30% each year until 2006 where total numbers were less than 1/3 of the year prior.

With these very high yields, we would have expected to get lower quality kernel; (this has not been the case). There has been no pinching of kernel (not well filled) and all the qualities of the fruit are very good, with high kernel weight and size and good crack-out percentage.

Table 14 shows the multi-annual yields of Nonpareil in the years 2004-06. Yields in all treatments increase significantly each year as the trees develop and mature and decease after the high yields of 2005. The differences overall are small with the exception of T7, which consistently has the lowest yields. In 2005 and 2006, T6 (lowest water level and the smallest trees) has a significantly lower annual yield, possibly indicating the onset of a production plateau and/or sharp biennial bearing.

Total yield accumulated from 2004 to 2006 in Nonpareil, we harvested 13.4t/ha (the highest) in T5 and 13.2t/ha in T3 and 12.20t/ha (the lowest) in T6. T1, T2, and T4 are in an intermediate position, around 204% more than T7 which produced only 6.3t/ha. This represents a large and important difference in the total harvest.

Table 15 shows the multi-annual yields of Carmel from 2004-06 with results being generally similar to Nonpareil. We have 4 groups T1 (14.8t/ha), T2 (14.4t/ha) a group of, T4 and, T5, (with 13.9t/ha) a group T3 with 13.2t/ha and a final group containing T6 at 11.7t/ha again with T7 consistently much lower. T6 has performed less than the other treatments. T6 experienced a production decrease in 2005 and again in 2006. Again this possibly indicates the production of a biennial bearing cycle.

The most important parameters that are considered in trials such as this are the levels of production and quality of the fruit achieved. In the optimization of almond growing trial we are harvesting the highest yields in the world with a very high quality of Kernel. Until now we have not experienced any pinching or other disorders in the kernel, which is normally apparent in this situation. The high quality kernel achieved with these yields gives us hope that in the future we will successfully achieve a multi-annual average of 4t/ha.

TABLE 12.

Nonpareil Almond Yields and the Qualities of the Kernel in 2006 (8th Leaf) in Different Treatments, in Optimization of Almond Growing Trial , Berri SA

Treatments	Yield/Tree Kg	Fruit/Tree No.	Yield Kg/ha	LSD	% of T7	Almond Kernel Wt grs	Almond Kernel No / Oz	Almond Crackout %
1	15.69^{b}	10326	3845^{b}	226	336%	1.520^{bc}	18.7	30%
2	16.56^{ab}	10897	4058^{ab}	"	355%	1.523^{bc}	18.7	31%
3	15.72^{b}	10212	3853^{b}	"	337%	1.535^{a}	18.4	31%
4	15.64^{b}	10159	3833^{b}	"	335%	1.543^{ab}	18.4	32%
5	17.12^{a}	11049	4196^{a}	"	367%	1.553^{a}	18.3	31%
6	14.54^{c}	9634	3564^{c}	"	312%	1.515^{c}	18.8	30%
Av 1-6	15.88	10380	3891		340%	1.530	18.5	31%
7*	4.67	3089	1144	—	100%	1.511	18.8	21%

*T7 is the commerical plot of 16 rows

TABLE 13.

Carmel almond yields and the qualities of the kernel in 2006 (8th Leaf) in different treatments, in Optimization of almond growing trial , Berri SA

Treatments	Yield/Tree Kg	Fruit/Tree No.	Yield Kg/ha	LSD	% of T7	Almond Kernel Wt grs	Almond Kernel No / Oz	Almond Crackout %
1	21.37[a]	15481	5236[a]	589	262%	1.38[b]	20.5	32%
2	20.44[a]	14603	5009[a]	"	251%	1.40[ab]	20.2	33%
3	16.82[b]	11848	4122[b]	"	206%	1.42[a]	20.0	30%
4	20.02[a]	14300	4905[a]	"	245%	1.40[ab]	20.2	32%
5	19.36[a]	13636	4744[a]	"	237%	1.42[a]	20.0	32%
6	16.34[b]	12109	4005[b]	"	200%	1.35[bc]	21.0	29%
Av 1-6	19.06	13663	4670	*	234%	1.40	20.3	31%
7*	8.16	5747	1999	—	100%	1.42	20.0	25%

*T7 is the commerical plot of 16 rows

Table 14.

Yield of Nonpareil, in 2004-2006, in kg/ha in Different Treatments, in Optimization of Almond Growing Trial,, Berri SA

Year	T1	T2	T3	T4	T5	T6	LSD	T7
2004	3591^{b}	3463^{b}	3890^{a}	3877^{a}	3609^{ab}	3950^{a}	351	2258
2005	5274^{b}	5337^{ab}	5439^{ab}	5194^{b}	5616^{a}	4714^{c}	324	2894
2006	3845^{b}	4058^{ab}	3853^{b}	3833^{b}	4196^{a}	3564^{c}	226	1144
Total	12710	12858	13182	12904	13421	12228	—	6296
% of T7	202	204	209	205	213	194	—	100

Significant differences by letter seperation p=0.05
*T7 is the commerical plot of 16 rows

Table 15.

Yield of Carmel, in 2004-2006, in kg/ha in Different Treatments, in Optimization of Almond Growing Trial,, Berri SA

Year	T1	T2	T3	T4	T5	T6	LSD	T7
2004	4636[a]	4468[a]	4356[a]	4489[a]	3939[a]	4062[a]	715	2711
2005	4892[ab]	4948[ab]	4775[b]	4516[b]	5265[a]	3672[c]	442	2875
2006	5236[a]	5009[a]	4122[b]	4905[a]	4744[a]	4005[b]	589	1999
Total	14764	14425	13253	13910	13948	11739	—	7585
% of T7	195	190	175	183	184	155	—	100

Significant differences by letter seperation p=0.05
*T7 is the commerical plot of 16 rows

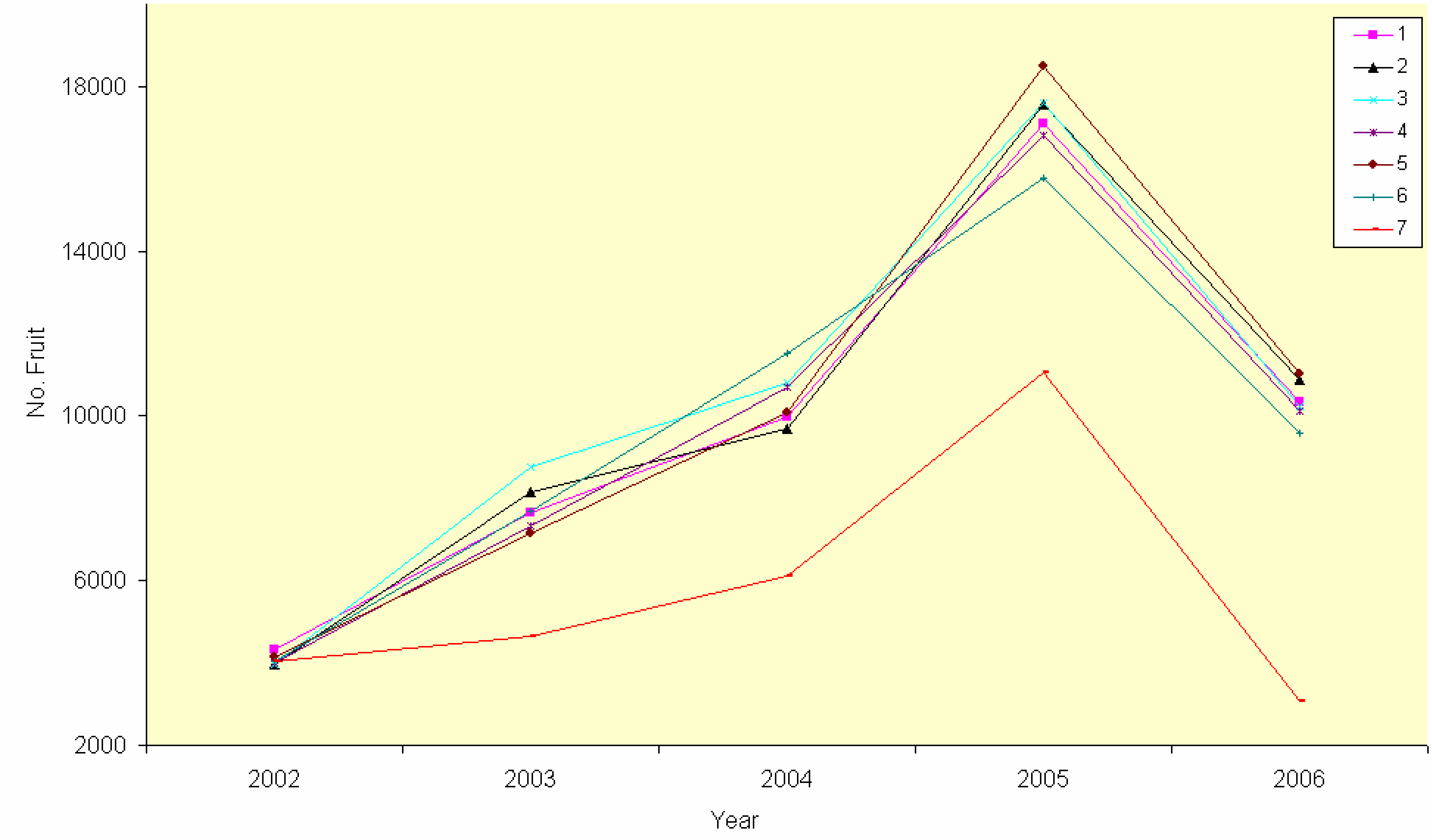

Fig. 16. Number of fruit per tree for Nonpareil in years **2002-2006** in different treatments, in Optimization Trial.

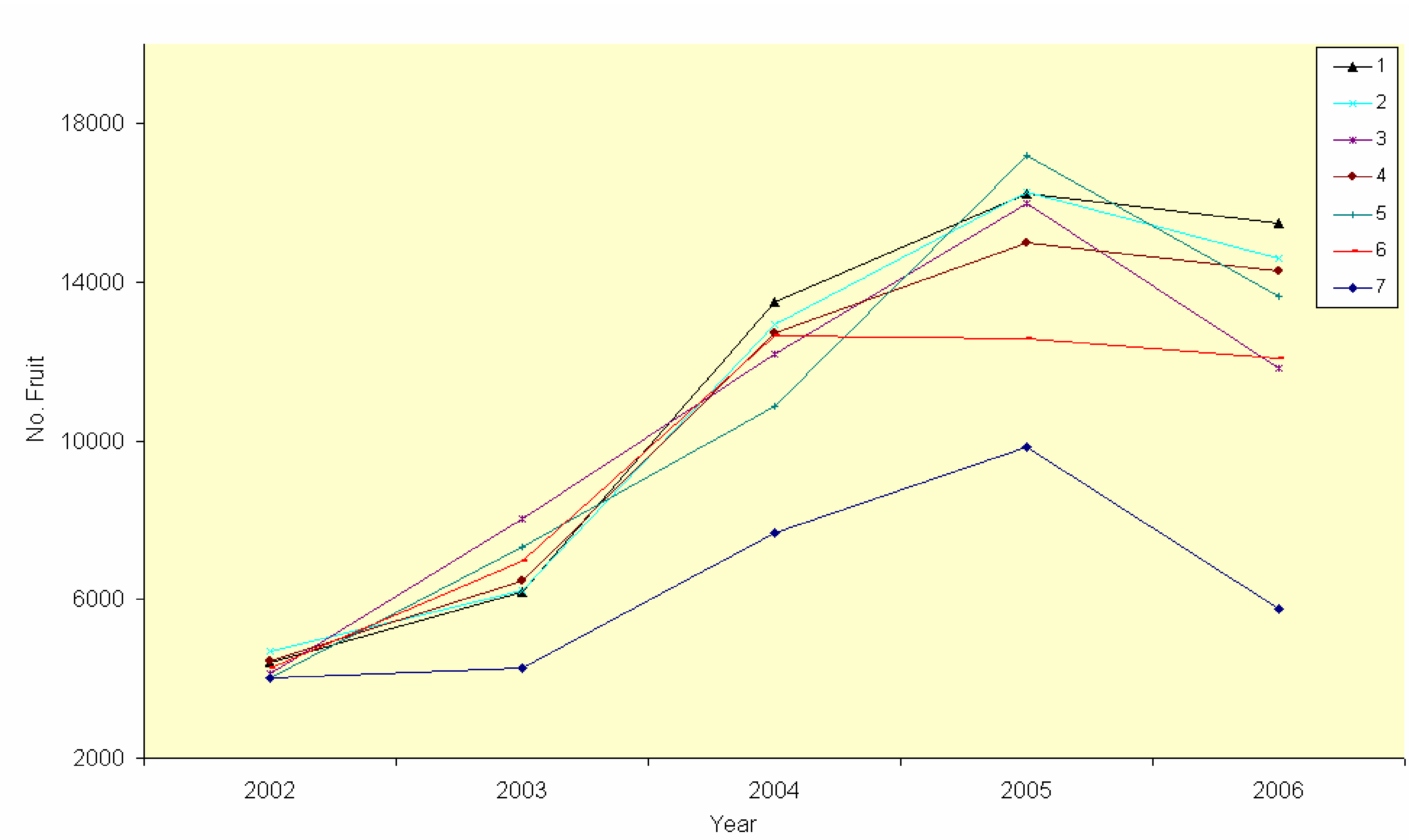

Fig. 17. Number of fruit per tree for Carmel in years **2002-2006** in different treatments, in Optimization Trial.

4.8. Tree growth in trunk cross sectional area and crop load of the trees

The growth of the trees in the Optimization Trial as expressed here in trunk cross sectional area has been spectacular each year to 2006. An important aim in the Optimization concept of almond growing is to achieve in each season new branches 1-1.5m long with thick, double sized leaves. The gains for each season (proportional to the total growth of the canopy and the roots) are reported in the Nonpareil variety in Table 16. These fall into two distinct groups. The highest growth was achieved in the treatment corresponding to the highest application of water **T5**. The lowest increase in trunk cross sectional area was found to have occurred in the lowest irrigation treatment **T6**. Treatments 1, 2, 3 and Treatment 4 were grouped in between. Increases in trunk cross sectional area for the Carmel variety are presented in Table 17. The effect is like in Nonpareil similar tendencies exist. Gains in the commercial plot **T7** are less than the lowest treatment **T6** in both Nonpareil and Carmel.

In our trial on Optimization we have developed a very important indicator that demonstrates the total effect and equilibrium achieved by the different water and fertilizer applications. Known as the charge, **kg of kernel per tree/gain in cm2,** this indicator relates to the load placed on the trees by the crop. The outcome of an application of this formula to the results of Nonpareil is displayed in Table 18. In the early years (2003 and 2004), the differences in charge were small. Only in **T6** did we begin to see an increase in charge due to crop load (less volume of canopy with a high crop). In 2005 and in 2006 like 2004 are moderate across all treatments. Differences in charge were minimal aside from T6 which continued to provide the highest value (greater charge). While not significant, the value for the highest yielding treatment in 2005, **T5** gave slightly lower charge (highest crop with the biggest volume canopy). This result becomes increasingly important once the behaviour of the commercial plot **T7** is considered. In 2005 **T7** the smaller volume of the trees combined with a low yield to give a charge not significantly different to that in the trial treatments. But in 2006, **T6** is the highest and **T7** is the lowest. This tells us that the higher yields in the trial have been obtained in tandem with adequate growth.

The results for the Carmel variety in relation to charge (Table 19) follow the pattern set in Nonpareil with **T6** having the highest crop load and **T7** the lowest.

The most important result we have achieved in the Optimization Trial in the six treatments in relation to charge is an equilibrated crop load. The high yields in 2005 resulted in charges that moved only a small amount and return to medium in 2006 from the average. This provides us with great hope by telling us that the affect of alternate bearing is less dramatic in our trial (excluding **T6**).

Future years work in this area will require large effort in order to maintain an equilibrated crop load. We have to adopt and work with a better strategy allowing more adequate canopy management. Only achieving better growth and some less crop through specialized pruning and thinning will allow us to maintain an equilibrium in relation to charge.

As discussed in the yield section of this report, we have achieved yields on 5.7t/ha in 2005 and 4t/ha in 2006 in the Nonpareil variety with no negative effect on the quality of kernel, crack-out percentages achieved and no pinching of the kernel. This result, replicated for Carmel, allows us to hope that by working well and maintaining an equilibrated crop load we may expect to achieve multi-annual yield of 4t/ha.

Table 16.

Nonpareil Gain of trunk cross section area in cm2 and %, in 2003-2006, in Different Treatments, in Optimization of Almond Growing Trial in Berri SA

Treatment.	2003 Gain cm^2	2003 Gain %	2004 Gain cm^2	2004 Gain %	2005 Gain cm^2	2005 Gain %	2006 Gain cm^2	2006 Gain %	Total Gain	Total Gain %
1	80	40	106	36	72	19	78	17	336	181%
2	73	37	103	36	70	18	78	17	324	170%
3	86	39	109	35	67	16	75	16	338	160%
4	81	39	111	37	67	17	76	17	336	176%
5	84	41	120	39	80	19	91	18	375	196%
6	68	36	78	27	55	16	58	15	259	134%
Average	79	39	104	35	69	18	76	17	328	169%
7*	47	20	75	24	38	11	71	20	230	129%

*T7 is the commerical plot of 16 rows

Table 17.

Carmel Gain of trunk cross section area in cm2, and %, in 2003-2006, in Different Treatments, in Optimization of Almond Growing Trial in Berri SA

Treatment.	2003 Gain cm^2	2003 Gain %	2004 Gain cm^2	2004 Gain %	2005 Gain cm^2	2005 Gain %	2006 Gain cm^2	2006 Gain %	Total Gain	Total Gain %
1	83	45	90	32	86	23	69	15	328	189%
2	86	47	94	33	79	21	63	14	322	172%
3	66	32	100	35	73	20	68	15	307	160%
4	85	45	93	33	76	21	67	15	321	181%
5	73	37	117	40	94	24	79	16	363	201%
6	71	39	54	20	51	17	46	13	223	128%
Average	77	41	91	32	77	21	65	15	311	172%
7*	51	22	66	22	52	15	59	16	229	132%

*T7 is the commerical plot of 16 rows

Table 18.

Crop Load of Nonpareil in 2004-2006, in kg/cm2, in Different Treatments, in Optimization of Almond Growing Trial, in Berri SA

Year	T1	T2	T3	T4	T5	T6	T7
2004	0.21	0.19	0.18	0.20	0.14	0.31	0.17
2005	0.23	0.26	0.27	0.24	0.23	0.29	0.23
2006	0.21	0.22	0.22	0.22	0.20	0.26	0.07
Average	0.22	0.22	0.22	0.22	0.19	0.29	0.15

*T7 is the commerical plot of 16 rows

Crop Load of Carmel in 2004-2006, in kg/cm2, in Different Treatments, in Optimization of Almond Growing Trial, in Berri SA

Year	T1	T2	T3	T4	T5	T6	T7
2004	0.14	0.14	0.14	0.14	0.13	0.21	0.12
2005	0.30	0.31	0.33	0.32	0.29	0.36	0.31
2006	0.32	0.34	0.25	0.31	0.25	0.36	0.14
Average	0.25	0.26	0.24	0.26	0.22	0.31	0.19

*T7 is the commerical plot of 16 rows

5.0 CONCLUSIONS AND EVALUATION OF THE ACHIEVEMENTS

We have succeeded to implement all the treatments in this optimization trial on almond growing in Berri SA, exactly as programmed. This allows great confidence that what we are reading in the trees is a real response. Because concepts on optimization have been adopted from the results of multi-annual and very successful research on apples and then on stone fruit and nuts in Israel over a 38 year period, the results are expected. The work is preliminary, requiring constant changes when we do not accomplish our goals.

The most important outcome of the work in progress has been the success in the fundamental strategic initiative of making the Australian almond industry the most productive in the world. The industry has moved from an emulator of the Californian techniques to the world leader in production technology.

The outcomes of the strategic plan as aided by the project are the following facts:

1) Almond production increased 34% from 7,704 tones in 1999 to 11,474 tones in 2004, to 16,178 in 2005 and to 15,917 in 2006.
2) The total almond planting increased by 72% from 6,100 ha in1999 to 10,490 ha in 2004 to 13,759 in 2005 and 19,020 ha in 2006.
3) The yields in mature almond orchards have improved from an average of 2.4t/ha in 1999 (like in California) to around 3t/ha in Australia in 2005 and in 2006.

The productivity of the trial trees, irrespective of the treatment, is significantly higher than treatment 7 (the industry best practice). The yields achieved in treatment 2 compared against industry benchmarks (Pocock 1999). The "benchmark average" is the average of a group of participating growers who were considered 'good growers' at the time. The "benchmark" is a selected grower acknowledged for his outstanding productivity at the time. Each season from the third year on we have achieved yields nearly double the yield of the "best benchmark". Compared with 2,500kg/ha for the best benchmark, T2 the standard in our trial producing in 2005, 5,337kg/ha and in 2006 4t/ha in 8th leaf trees.

A **significantly increased knowledge regarding almond production management** leading to significant improvement of on farm management practices regarding canopy management (training and pruning systems), irrigation systems and management of irrigation, nutrition and nutritive elements. This will provide more optimal use of input resources leading to greatly increased productivity, better fruit quality, improved profitability and greater improved environmental responsibility and sustainability. Most importantly, the key inputs of water and nutrition will have their efficacy significantly improved providing a significant competitive advantage over our main competitor, California. Results to date indicate water use efficiency gains of up to 70% are achievable and yield gains of up to 50% may be possible over current industry best practice.

The Optimization of almond growing trial has produced record yields and an economic revolution, however it is important to remember that the trial treatments were imposed on trees already in their third year. Our belief is that another revolution will occur, as we have achieved in previous work when we begin working with trees from the planting stage, in model plots.

Normally in almond and in other fruit crops it is expected that high yields will have a negative effect on fruit size. The contrary was found to have been the case in relation to the trial where fruit size, kernel weight and kernel numbers per ounce were excellent. Crack out percentages for the trial treatments were all above industry average. Sensory evaluations conducted by ASSAF (leader of sensorial teams in France and in Israel) on the almond kernel of our trial treatments found that we had produced better tasting almonds with sweeter, more aromatic kernel.

Prior to the establishment of the Optimization Trial at CT Farms in Berri (SA), ASSAF visited most of the orchards in Australia. At the time, drip irrigation systems were considered as not working and not robust, and generally thought to be not suited to almond production. Today after many visits in the optimisation trial and following participation in numerous field days the majority of growers are convinced that dripping is the best method of irrigation in the soils and conditions of SA. They have seen that using drip irrigation by pulses best meets the consumptive use of the trees allowing the development of the best root systems, (up to 10 times greater than those under sprinklers and other systems).

The importance of strong buds has been illustrated to the industry by the trial where we consistently cover the trees with very large numbers of buds of high viability. There is a big gap in the knowledge required to achieve this scenario under South Australian conditions. We have been inspired by the PhD theses of ASSAF, however if we are to fully understand the effect of the different compounds and concentrations involved and the different timings we will need many further years of investigation and special trials.

Using previous work performed in Israel we've been successful in completing and breaking dormancy in trees within the trial. While the procedures demand further refinement in specialising trials, we have accomplished a perfect coincidence in the flowering of different varieties within the orchard giving maximum opened flower buds and maximum fruit set.

Even given vast increases in the height and density of the canopies in the orchard of the trial, by maintaining the inside of the Y (clear of branches) we don't observe any additional disease problems, either fungal or bacterial.

Annual results achieved in the early stages of production are important and significant; however they normally tend to be altered after achieving such high results in relation to yield. Often high yields will produce alternate bearing in a crop. Tis year we did not execute most of the pruning work due to a lack of organisation. This occurrence will oblige us to develop entirely new strategies for growing the trees and managing the fructification cycle. As such, the long term effects of the Optimization Trial will need to be established with many parameters and procedures, adapted from apple Optimization work requiring further refinement. **The long term strategy in relation to fertilizer must be revised** in response to our success in seasonal applications and in building reserves in the soil. These decisions will require more specific and exacting analysis. Future samples may be sent to Cornell University to give the best analysis allowing more informed decisions. Future works will involve the organization by the Optimization Trial Research Team of Pan Class A

Evaporation data over a **regional spread of sites using a range of data collected from individual almond farm Pans**. Like in the upper Galilee of Israel it is expected that the exchange of information will be of great benefit to growers in meeting consumptive use by assisting them in decisions around irrigation Optimization, principally how much to apply and when to apply it. It is anticipated that this procedure will be accompanied with visits from the Research Team helping not only in programming and long term planning, but also the problems in individual orchards and how best to overcome them. **Leaf and soil analysis protocols will be developed** and distributed to Australian almond orchards. These will include the previously not performed tasks of washing tissue samples and selection of the best laboratories. The Australian Research Team will interpret the results of analysis using the new knowledge and concepts gathered in the Optimization Trial.

We must develop more indicators of plant and fruit growth as developed in Israel for many fruit crops. These indicators will provide assistance in our research work and for growers to help us perform more closely the Optimization concepts and continue the progression towards meeting the consumptive use.

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Prof Raphael ASSAF and his Teams
Relevant Publications within the years

6.4. List on Irrigation, Fertilization & Ferti irrigation Publications

* = Hebrew, ** = French, *** = English

1. * **Assaf R.**, Levin I. and Bravdo B. (1965)
Preliminary report on apple response to water regimes in Houlata. (1964-1965)
Upper Galilee Growers Organization, Bulletin No. 10: 1-12.

2. * Levin I., **Assaf R.** (1967)
Research report on apple response to water regimes in Houlata.
Upper Galilee Growers Organization, Bulletin No. 20: 1-20.

3. * **Assaf R.** Levin I. Hupert H (1967-1968)
First results obtained in Israel on trials with drip irrigation, done in Upper-Galilee in 4 experimental plots.
State of Israel, Minis. Of Agriculture.Volcani Center Report1968, monograph 3: 37p.

4. * **Assaf R.** Levin I. Hupert H. (1967-1968)
First trials in drip irrigation in Israel: 2 plots in the Upper Galilee and 2plots in the South of the Houlle.
Special publication of State of Israel, Volcani Center. Report 1968 n. 5.

5. * **Assaf R.**, Levin I., Bravdo B. and Shapira A. (1968)
Research report on apple response to water regimes in Houlata.
Upper Galilee Growers Organization, Bulletin No. 25: 1-50.

6. * Levin I., **Assaf R.**, Bravdo B. and Shapira A. (1969)
Research report on apple response to water regimes in Houlata.
Upper Galilee Growers Organization, Bulletin No. 40: 1-48

7. *** **Assaf R**., Bravdo B., Levin I. (1970)
Effects of different water regimes on yield quality of fruit and growth of apple trees.
<u>XVIII Int. Hort. Congress</u>, Volume I, Abstract No. 354: 178.

8. *** Levin I., **Assaf R**., Bravdo B. and Shapira A. (1970)
Water uptake from different soil layers in an apple orchard and in six irrigation treatments.
<u>XVIII Inter. Hort. Congress,</u> Volume 1, Abstract No. 354: 179.

9. *** Levin I., **Assaf R**. and Bravdo B. (1971)
Relation between apple root distribution and soil water extraction in different irrigation regimes.
<u>Ecological Studies, Analysis and Synthesis, Books</u>
Springer-Verlag, Berlin, Vol. 4: 351-359.

10. * **Assaf R**., Levin I. and Hupert H. (1971)
First observations on trickler irrigation in fruit orchards in Up. Galilee.
<u>Special publication No. 5, Division of Scientific publication</u> <u>Volcani Institute, Bet Dagan</u> (Summary English): 33 pages.

11. *** Levin I., **Assaf R**. and Bravdo B. (1971)
Relation between apple root distribution and soil water extraction in different irrigation regimes.
<u>Symposium on soil water physics and technology</u>, Rehovot, August 29-September 4.

12. *** Levin I., **Assaf R**. and Bravdo B.(1972)
Apple response to water regimes.
1. Effect of 6 irrigation treatments on water uptake from different soil layers.
<u>Journal of the American Soc. for Hort. Science</u>, 97 (4): 521-526.

13. * **Assaf R**., Levin I. and Bravdo B. (1972)
Research report on apple response to water regimes, final report. 1965-1971.
Upper Galilee growers Organization, Bulletin No. 53: 1-122.

14. * **Assaf R**., Levin I. and Bravdo B. (1972)
Preliminary report on the effect of sprinkler drip and mist irrigation treatments with different training systems of apple trees.
Upper Galilee Growers Organization, Bulletin No. 55.

15. * **Assaf R**., Spiegel-Roy P., Lavee S. (1972).
Fruit tree research, Matityahu Research Station.
Report on research studies in the station. Report on 28.6.72.
Agricultural Research Organization, Institute of Horticulture, Dept. of Pomology,

16. *** Levin I. and **Assaf R**. (1973)
Irrigation of deciduous fruit.
Ecological Studies, Analysis and Synthesis, Book.
Arid Zone Irrigation, Springer-Verlag, Berlin, Vol. 5.

17. *** **Assaf R**., Bravdo B., Levin I. (1974)
Effects of irrigation according to water deficit in two different soil layers, on the yield and growth of apple trees.
J. Hort. Sci., 49: 53-64.

18. *** Guelfat Reich S., **Assaf R**., Bravdo B. and Levin I. (1974)
The keeping quality of apples in storage as affected by different irrigation regimes.
J. Hort. Sci., 49: 217-225.

19. * **Assaf R**., Levin I. and Bravdo B. (1974)
Trials on apple response to water regimes Hulata 1965-1971.
Alon Hanotea, No. 9, July: 478-486.

20. *** Levin I., **Assaf R**. and Bravdo B. (1974)
Soil moisture distribution and depletion in an apple orchard irrigated by trickles.
Proc. of the 2nd Int. Drip Irrigation Congress, San Diego, California, July 7-14. .

21. *** **Assaf R**., Levin I. and Bravdo B. (1975)
Effect of irrigation regimes on trunk and fruit growth rates. quality and yield of apple trees.
J. Hort. Sci., 50:481-493.

22. * Guelfat Reich S., **Assaf R**., Bravdo B. and Levin I. (1975)
Effect of water regimes on the keeping quality of apples in cold storage.
Alon Hanotea, No. 4, January: 167-173.

23. * Levin I., **Assaf R**., Bravdo B. (1975)
Effect of irrigation regimes and hedgerow training systems on apple trees.
Preliminary report for 1972, 1973.
Upper Galilee Growers Organization, Bulletin No. 63: 1-73.

24. * **Assaf R**., Levin I., Bravdo B. (1976)
Apple response to water regimes and hedgerow training systems.
Research report for 1974-1975, Mahanaim and Ayelet Hashahar.
Upper Galilee Growers Organization, Bulletin No. 69: 1-195.

25. * **Assaf R**., Levin I. and Bravdo B. (1977)
Studies on apple response to water regimes and training systems of the trees.
Alon Hanotea, No. 2, November: 71-83.

26. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1977)
Fruit growing in shallow and stony soils -Beit Nekufa.
Preliminary report for 1977.
Volcani Center, Bet Dagan , Monograph No. 1.

27. * **Assaf R**. (1977) and every two years a similar report with more projects.
Deciduous fruit research report.
Regional Experiment Station Newe-Yaar, Research Center.
Izrael Valley Growers Organization, Monograph No. 55.

28. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1978)
Fruit Growing in Shallow and Stony Soils – Beit Nekufa.
Preliminary report for 1978.
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29. * **Assaf R**., Levin I., Bravdo B. and Slezinger E. (1978)
Fruit volume growth as an indicator for irrigation regime, mineral nutrition and vitalness of the orchard.
Upper Galilee Growers Organization, Monograph No. 71.

30. *** Levin I., **Assaf R**. and Bravdo B. (1979)
Soil moisture and root distribution in an apple orchard irrigated by tricklers.
Plant and Soil, 52: 31-40.

31. *** **Assaf R**., Bravdo B., Levin I. (1979)
An intensive hedgerow drip irrigation system for apples as developed in Israel.
Proc. Int. Dwarf Fruit Trees Association, March 1, 1978, Grand Rapids, Michigan.

32. *** Levin I., **Assaf R**. and Bravdo B. (1979)
Soil moisture distribution and depletion in an apple orchard irrigated by trickles (new results).
Int. Symposium of the Hort. Sci. Society, May 1978, Bet Degan, Israel.

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Effect of drip irrigation treatments and intensive nutrition on Yield Growth, Fruit Quality, Photosynthesis and Water relation of apples.
20th Int. Hort. Congress, August 1978, Sydney, Australia.

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Irrigation, water status and nutrient uptake in apple orchards.
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April 1-10, 1979 Canterbury, England, p. 255-264.

35. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1979)
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Preliminary report for 1979.
Volcani Center, Bet Dagan, Monograph No. 3.

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37. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1980)
Fruit Growing in Shallow and Stony Soils - Beit Nekufa.
Preliminary report for 1980.

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A.R.O. Volcani Center, Beth Dagan, summarized research results 1980: 65-68

39. * **Assaf R**. (1980)
Deciduous fruit research report for 1980.in Research Stations.
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Izrael Valley Growers Organization, Monograph No. 61

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Trials on fruit trees growing on a stony and shallow soil.
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41. * Levin I., **Assaf R**., Bravdo B. (1981)
Apple response to water regimes and hedgerow training systems.
Research report for 1978-80.
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42. *** **Assaf R**., Levin I., Bravdo B. (1982)
Apple fruit growth as a measure of irrigation control.
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43. *** **Assaf R**. (1982)
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45. * Levin I. **Assaf R** .Zur A. (1982)
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Preliminary report for 1982.
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48. * **Assaf R**., Levin I., Bravdo B. (1983)
The response of apple trees to Nitrogen fertilization regimes.
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49. *** **Assaf R**., Levin I., Bravdo B. (1984)
Effect of drip irrigation on the yield and quality of Golden Delicious and Jonathan apples.
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50. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1984)
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Preliminary report for 1983,Volcani Center, Bet Dagan, Monog. No. 7.

51. * Levin I. **Assaf R**. Bravdo B. And all. (1984)
Effect of different irrigation and different nutrition regimes on apple trees orchards, planted on volcanic tuff, in the Golan. (keshet)
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Board of Fruit Growing in Israel. Golan Research, report 1984:65-66

53. ** **Assaf R**. (1985)
Irrigation and fertirrigation of apple trees.
L'Arboriculture fruitiere, 371: 45-53. (French)

54. * **Assaf R**., Kalmar D., Dagan M., Mehari A. (1985)
Pecan trials in 1984 Preliminary report: on cultivars, training and pruning systems, Irrigation regimes trials. Izrael Valley Growers Organization, Monograph No. 87

55. * Levin I., **Assaf R**., Bravdo B. (1985)
Effect of drip irrigation regimes on Red Rosa plum.
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56. * Klein I., Levin I., **Assaf R**., Bravdo B., Geva S. (1985)
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57. * Klein I., Bar-Yoseph B., Levin I., **Assaf R**., Ben-Arie R., Bravdo B. (1985)
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58. * Levin I., **Assaf R**., Bravdo B., Nae B., Surkin B. (1985)
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59. * **Assaf R**., Levin I., Bravdo B. (1985)
'Sagiv' Plum trees - response to NPK fertilization regimes - Shaal. Preliminary Report for 1984-1985.
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60. ** **Assaf R**., Levin I., Bravdo B. (1986)
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61. *** **Assaf R**., Levin I., Bravdo B. (1986)
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64. * Klein I., Levin I., **Assaf R**., Bar-Yoseph B., Berkovich A., Melzman A., Surkin B. (1986)
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67. * **Assaf R**. Levin I. Bravdo B. (1986)
Optimization of water and nutrition regimes in apple fruit trees.
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70. ** Bar-Yosef B., Schwartz. S., Markovich T., Lucas B., **Assaf R**. (1988)
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72. * Levin I. **Assaf R**, Bravdo B. Meron M. (1988)
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75. *** Klein I., Levin I., Bar-Yosef B., **Assaf R.**, Berkovitz A. (1989)
Drip nitrogen fertigation of "Starking Delicious" apple trees.
Plant and Soil, 119: 305-314.

76. * **Assaf R.**, Ben-Tal I., Teichman B., Levin I. (1989)
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77. * **Assaf R.** (1989)
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78. * **Assaf R.**, Levin I., Bravdo B. (1989)
Optimization of water use by automated drip irrigation control for apple trees.
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79. * Klein I., Bravdo B., Levin I., **Assaf R.** (1989)
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Optimization of water application for deciduous fruit trees by automated drip irrigation control. Report for 1993.
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Optimization of water and nutrient regimes in deciduous fruit trees by Automated drip irrigation. State of Israel, Min. of Agri. Volcani Center Beth-Dagan, report 1994: 44-46

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Optimization of water application on apple trees by automated drip irrigation control.
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91. * **Assaf R**. Meron M. Levin I Bravdo B. and all (1995)
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Vth Int. Microirrigation Congress, Orlando, Fl, April 2, 1995: 6pp.

95. * Meron M. **Assaf R**. Bravdo B. and all (1996)
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Optimization of water application to deciduous fruit trees by automated drip irrigation. Hassade 63(6): 70

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