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Developing irrigation strategies for coffee under sub-tropical conditions

A report for the Rural Industries Research and Development Corporation

by David Peasley and Chris Rolfe

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Foreword

Australia grows only the higher quality Arabica coffees, which are used in the speciality or roast and ground market. Whilst present production is small (around 500 tonnes) there is potential to replace a significant proportion of the 12 – 15,000 tonnes of Arabica coffee imported into Australia annually. This section of the market is growing at a rate of over 6% per year, as the demand for instant coffee steadily declines. Expansion of Australia's coffee industry is limited by the area of suitable land for mechanised coffee production, the availability of irrigation water and competition with other crops.

With the cost of water set to escalate through water trading, it is imperative that a cost/ benefit analysis on the return per megalitre of water be carried out to assist investors in this industry make sound decisions on water use that will provide an acceptable return on investment.

This publication examines how efficient use of irrigation can assist the coffee industry to achieve quality production with minimum environmental impact. It looks at the optimum water requirements and likely returns/megalitre to grow coffee in the sub-tropics and establishes design criteria for irrigation and storage systems.

As part of this project an extension publication titled "***Best management Guidelines for Irrigation of Coffee in the Sub-tropics*"** is currently under production by NSW Agriculture.

This project was funded from RIRDC Core Funds which are provided by the Federal Government.

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Background

Consistent high yields and high bean quality are essential to the viability of the coffee industry in Australia. The sub-tropic region of Eastern Australia produces distinctive cup quality and superior bean size that is readily marketable throughout the world.

Rainfall variability and distribution make irrigation essential to producing this quality coffee consistently. In the sub-tropics, coffee is susceptible to over bearing and subsequent die back. Water stress and inadequate nutrition predispose trees to this die back affecting yields and bean quality.

Current suitable coffee growing areas are located in environmentally sensitive areas close to rapid urban and lifestyle expansion and the future of the industry will be determined by its low impact on this environment. The industry must produce hard evidence that it can use water efficiently and any diversions from the catchment will be kept to a minimum.

Water entitlements are now limited in NSW and the cost of water set to escalate through water trading. It is imperative that a cost benefit analysis on the return per megalitre of water be carried out to provide investors in this industry with a dollar value of water that will provide an acceptable return on investment.

This publication examines how efficient use of irigation can assist the coffee industry to achieve quality production with minimum environmental impact. It looks at the optimum water requirements and likely returns/Megalitre to grow coffee in the sub-tropics and establishes design criteria for irrigation and storage systems.

Methodology

In 1998, two sites were selected in northern NSW, one near the coast at Newrybar with mature trees that had not been irrigated since establishment and the other a new planting at Nimbin , away from the maritime influence, where summer and winter temperature ranges were higher and on a different soil type. The trees on the second site were drip irrigated from planting.

Trees at both sites were K7 variety from Kenya selected for its drought tolerance, its performance in local field trials and used extensively in current plantings in northern NSW. The tree spacings were 0.9 metres x 3.75 metres providing a density of 2963 trees/ha.

Both sites were laid out to three treatments. The first a non irrigated treatment (T1), the second irrigating to maintain a low stress level on the trees (T2) and the third treatment irrigating when a medium stress is induced on the trees (T3). The soil moisture at both sites was monitored by EnviroSCAN equipment with sensors at several depths to fully explore the fibrous root system. Automatic weather stations were installed at both sites to collect temperature, rainfall, humidity, wind and solar radiation data to calculate the daily evaporation rates. The irrigation was carried out with a single line of pressure compensated dripline applying about 7 – 7.5 mm/hour.

Irrigation, flowering and yield and quality assessment data was collected to compare treatments and determine water requirements, irrigation system design criteria and management techniques.

Results

The rainfall recorded, irrigation applied and irrigation requirements for each of the treatments over the period of the project are shown in Tables 1, 2, and 3. The drip irrigation system only applies water to 19% of the plantation area wetting a strip 700 mm wide in a row spacing of 3.75 metres. In 1999 there was 2994 mm of rainfall over 195 days and irrigation was not required for either treatment.

Table 1 - Newrybar site - 2000

Treatment	Rainfall	Applied irrigation	Water requirements
T1	1449 mm	-	-
T2	1449 mm	484 mm	0.92 ML/ha
T3	1449 mm	281 mm	0.53 ML/ha

Table 2 - Newrybar site - 2001

Treatment	**Rainfall**	**Applied irrigation**	**Water requirements**
T1	1760 mm	-	-
T2	1760 mm	938 mm	1.78 ML/ha
T3	1760 mm	326 mm	0.62 ML/ha

Table 3 - Newrybar site - 2002

Treatment	**Rainfall**	**Applied irrigation**	**Water requirements**
T1	1634 mm	-	-
T2	1634 mm	2164 mm	4.11 ML/ha
T3	1634 mm	647 mm	1.23ML/ha

Irrigation and storage requirements

Depending on the availability and cost of securing a water supply, even in a dry year (eg 2002), water requirements will vary between 1.23 (medium stress) and 4.11 megalitres/hectare (low stress) plus an allowance for seepage and evaporation in the case of an on farm storage.

If the water supply is a creek, river or a ground water supply then the daily extraction rate using a single dripline would be between 127,000 and 151,000 litres/ha/day in the month of highest usage.

Design criteria

The highest monthly irrigation application occurred in January 2000. Treatment T2 was 234 mm and T3 was 197 mm. These figures represent 31 and 26 hours of monthly irrigation per block.

Crop coefficient (kc)

The monthly crop factors have been averages for the two irrigation treatments and are shown in Table 4.

Table 4 – Monthly crop factors (kc) for irrigated treatments

Months	**Treatment T2**	**Treatment T3**
January	1.12	1.29
February	0.85	0.76
March	1.01	0.96
April	1.41	0.99
May	1.19	1.31
June	1.68	1.57
July	1.14	1.25
August	0.96	1.49
September	1.15	0.80
October	1.46	1.07
November	1.17	0.92
December	1.20	0.67
Annual Average	**1.20**	**1.09**

Plant water use

From the data generated by the hourly readings of the EnviroSCAN capacitance soil moisture sensors, coffee trees extract between 70% and 93% of their water requirements from the top 300 mm depth of soil. This is even during periods of moisture stress in non-irrigated trees. Irrigation operation should only allow sufficient time to replenish the top 300 – 400 mm of the soil profile.

Yield response to irrigation

Yield data from the years 2000 – 2002 measured in tonnes of cherry/ha have been compared for each treatment and the details are shown in table 5.

Table 5 – Yield in tonnes of cherry per ha

Year	Unirrigated T1	Low stress T 2	Medium stress T3
2000	11.690	16.313	15.815
2001	2.568	5.916	4.567
2002	20.530	28.684	26.256
Average	11.596	16.971	15.546

Within these three years, there was a significant variation in the yields of cherry, but consistently treatment 2 was higher than treatment 3, which was always higher than treatment 1. The additional yield from the two irrigated treatments in tonnes of cherry/ha is shown table 6.

Table 6 – Additional yield of cherry per ha from irrigated treatments

Year	Low stress T2	Medium stress T3
2000	6.8	6.1
2001	5.0	3.0
2002	12.1	8.5

The value of the additional yield/ha at $8.15/kg dry green bean is shown in Table 7.

Table 7 – Value of additional yield ($/ha) from irrigation

Year	Low stress T2	Medium stress T3
2000	$8861	$7906
2001	$6416	$3830
2002	$15629	$10975
Average	$10302	$7570

If water is the limiting factor then the additional tonnes/ML might be more applicable. This reverses the treatments so that although treatment 3 has a reduced yield when compared to treatment 2 it uses much less irrigation water, so the yield per megalitre is greater. The results are shown in Table 8.

Table 8 – Additional yield in tonnes of cherry per Megalitre

Year	Low stress T2	medium stress T3
2000	7.4	11.5
2001	2.8	4.8
2002	2.9	6.9

To fully evaluate the cost of providing additional on farm storage or constructing a bore to add groundwater supplies to improve the water security, the additional returns/ML at $8.15/kg DGB are shown in Table 9.

Table 9 – Additional returns ($/ML) for irrigated treatments

Year	Low stress T2	Medium stress T3
2000	$9,631	$14,880
2001	$3,662	$6,177
2002	$3,803	$8,923

Bean quality
Bean size and cupping quality were compared for each year that irrigation was applied.

Bean size
Year 2000 showed an 18% increase in size 18 bean for both the irrigation treatments when compared to the non irrigated treatment. In 2002 the comparison in bean size difference was insignificant.

Cupping quality
Over the period of the project an independent professional panel blind tasted each harvest. There was no significant difference in the cupping quality between the treatments.

Typical results as per the 2002 harvest as assessed under internationally recognised SCAA cupping form were:
- The non irrigated scored 69 –"*low acidity and mild smoky flavour and thin body*"
- The low stress irrigated treatment scored 73 –" *dull bakey aroma, nice acidity, sour, green apple flavour*"
- The medium stress irrigated treatment scored 75.5 – " *faint but sweet aroma, juicy, citrus flavour. Ok body.*"

Irrigation management
Unlike the climate of North Queensland coffee producing area, with its defined dry season which is favourable for managing flowering, rainfall events at both sites during the trial period showed conclusively that a defined dry season with little or no rainfall couldn't be relied upon in the sub-tropics. As a consequence flowering cannot be manipulated with irrigation in this region. A *publication* "***Best Management Guidelines for Irrigation of Coffee in the Sub-Tropics*"** is currently being prepared.

Drip irrigation of the trees at each site only provided water to between 19% and 21% of the total plantation area of the trees. The bulk of the roots are under water stress in a similar way to the non-irrigated treatments and flower blossoming was only triggered by rainfall, regardless of the water status of a small proportion of the root area. This means that irrigation to keep the trees healthy during crop development and ripening will have little effect on the blossoming pattern for next year's crop.

To achieve maximum yield irrigation should be available throughout the year and water provided when soil moisture in the top 300 – 400 mm profile reaches 50% of the readily available water supply for this section of the profile.

If water is limited then trees can be dried out to 100% of the readily available water supply in the top 300 – 400 mm of the soil profile with some reduction in yield but no change in quality or bean size.

Single row driplines with dripper spacings that provide a continuous wetted strip along the row with either 1.6 or 2.3 litre/hour dripper discharge will allow the trees to extract sufficient water to meet their requirements.

As coffee trees in full sun are gross feeders' fertigation is strongly recommended to provide adequate nutrition throughout the growing season to also assist in greater stomatal opening to provide additional photosynthesis. Even during 'the wet season' fertiliser can still be applied at higher concentrations in short irrigations to meet nutritional needs and minimise any nutrient leaching caused by excessive rainfall events.

1. Introduction

1.1 Background

Consistent high yields and high bean quality are essential to the viability of the coffee industry in Australia. The sub-tropic region of Eastern Australia produces distinctive cup quality and superior bean size that is readily marketable throughout the world.

Rainfall variability and distribution make irrigation essential to producing this quality coffee consistently. In the sub-tropics, coffee is susceptible to over bearing and subsequent die back. Water stress and inadequate nutrition predispose trees to this die back affecting yields and bean quality.

The current embargo on irrigation licenses and the introduction of the Water Reform package in NSW will limit the expansion of the coffee industry unless water is used at its optimum efficiency. As water will shortly only be available for purchase on the open market, the economic viability of the industry may be dependent on accurate information on water requirements and yield response to best management of water and nutrient.

Current suitable coffee growing areas are located in environmentally sensitive areas and the future of the industry will be determined by its low impact on this environment. This will also include hard evidence that the industry can use water efficiently and any diversions from the catchment will be kept to a minimum.

The review paper, "*The Water relations and Irrigation requirements of Coffee,*" by M.K.V.Carr (2000) details the following research needs to interpret the role that water plays in the growth and development of the coffee plant so that growers can plan and use water effectively for the production of reliable high-quality crops.

- Well-designed and managed field experiments should be conducted, over a range of typical sites, to quantify the yield responses of coffee to water.
- Adequate supporting measurements (crop, soil and prevailing weather conditions) must be taken to allow the results to be interpreted sensibly, and apply with confidence to other locations where climate and soil may be different.
- Need to develop further the understanding of the factors influencing the actual rates of water use of coffee, building on the work of Gutierrez and Meinzer (1994a) in Hawaii.
- The design and operating criteria for drip irrigation systems need to be specified with precision in order to optimise crop-yield: water use efficiencies.
- By linking the outputs from this research to a geographic information system, a method for assessing the benefits of irrigation, in crop and financial terms, could be developed and used to justify investments in specific locations and farming systems.

The research referenced in this review paper has been used in this report to both highlight previous findings and examine how they compare to the finding of this project.

2. Objectives

- Determine optimum water requirements to grow quality coffee in the sub-tropics
- Investigate the relationship between water and the phenological cycle
- Establish design criteria for irrigation and storage systems
- Develop a best management system for coffee irrigation to achieve quality production with minimum environmental impact
- Increase the viability of coffee growing in Australia as an export and import replacement industry with limited available water resources.

3. Methodology

3.1 Newrybar site

The trial area was set out in existing 5 year old coffee trees that were suffering some dieback in the top third of the canopy. The tree spacing was 0.9 m x 3.75 which provides a tree density of 2963 trees per ha. The variety is K7 a cultivar from Muhoroni, Kenya, which has a spreading habit with drooping primaries with copper coloured terminal leaves. Three treatments were employed as follows:

Treatment 1 unirrigated trees.
Treatment 2 irrigated to maintain soil moisture level half way between field capacity and refill point in the top fibrous root system.
Treatment 3 irrigated to maintain soil moisture level between field capacity and refill point in the top fibrous root system.

The layout of the randomised block design for the three treatments, replicated six times as follows:

Row			
1	T1	T2	T3
2	T2	T1	T3
3	T2	T3	T1
4	T3	T1	T2
5	T1	T3	T2
6	T3	T2	T1

EnviroSCAN tubes were located under marked trees in the first treatment area of each row, providing two-tubes per treatment. Capacitance sensors to measure soil moisture levels were located at 10, 20, 30, 50 and 80 cms depths in each tube.

Yield data was collected from 36 trees comprising the middle two marked trees per 6 tree plot.

An automatic weather station was located adjacent to the trial site recording hourly the air temperature, solar radiation, rainfall, wind and humidity. Daily recording settings were from midnight to midnight to align with the EnviroSCAN data. The data from these sensors are used to automatically calculate Eto using the Penman-Monteith equation as detailed in FAO 56 (1998).

3.1.1 Irrigation system

The irrigated plots are watered with a single line drip irigation system using Netafim RAM pressure compensated dripline with a drip rate of 1.6 litres/hour with drippers spaced at 30 cms. The system was measured to apply an average of 1.6 l/hr at a coefficient of uniformity of 93%.

Automatic solenoid valves separately controlled each treatment.

The wetted width of the drip line at a depth of 300 mm was 710 mm continuous along the tree row. This produced an application rate of 7.5 mm/hour and wet 19% of the area (row spacing 3.75m).

3.1.2 Soil moisture settings

Each EnviroSCAN tube sensors at 10,20 and 30 cm were used to determine the irrigation scheduling as the bulk of the fibrous root system was found in this section of the soil profiles. The full and refill settings were determined using the actual data collected in the first year of measurements. Details of these setting are shown at Table 10.

Table 10 – Moisture level settings for EnviroSCAN tubes, Newrybar site

Probe & treatment	Depth mm	Saturation % moisture	Field capacity % moisture	Onset of stress % moisture	Minimum % moisture
1	100	70			10
	200	67	50	22	21
Unirrigated	300	59			17
T1	500	61	41	27	23
	800	60	40	29	29
2	100	66			11
Irrigated	200	69	49	17	13
low	300	64			16
tension	500	66	43	26	23
T2	800	64	25	12	10
3	100	79			16
Irrigated	200	68	60	23	21
low	300	68			16
tension	500	64	52	24	19
T2	800	56	53	27	23
4	100	73			12
Irrigated	200	70	47	20	20
medium	300	68			18
tension	500	66	54	27	24
T3	800	65	51	26	21
5	100	77			8
	200	63	53	23	13
Unirrigated	300	60			16
T1	500	61	50	35	21
	800	56	44	35	34
6	100	73			10
Irrigated	200	66	53	19	18
Medium	300	61			17
tension	500	61	48	31	28
T3	800	62	47	29	28

3.1.3 Crop coefficients (kc)

These were determined by measuring the water used by the plants in the top 300 mm soil depth (where most of the water extraction roots reside) and dividing this by the calculated Eto, where rainfall is the main contributor to soil moisture. Where the drip irrigation system is only meeting plant water needs then the kc have been adjusted to take into account the root water extraction from a reduced wetted volume.

3.1.4 Yield determination

Various techniques for estimating yield were assessed against hand picking, but none proved reliable enough to give accurate results.

Prime cherry was harvested by hand (with up to 5 picks/season) from the 36 marked trees. These were wet processed using pectalytic enzymes, washed and sun dried to parchment then hulled to Dry Green Bean. Dry Green Bean samples were forwarded to independent professional taste panels for testing 3 months after final harvest.

3.2 Mountain Top site

This trial area was set out in a newly planted area in two locations on two different soil types and slope aspects with two irrigation treatments to be employed after the establishment period of three years. During this establishment period (2000 – 2002) all trees were irrigated under one treatment which maintained adequate soil moisture during this whole period.

The western plot site has a north- easterly aspect with a dark brown to black clay loam soil over a medium clay underlined by fine sandy clay loam and weathered sandstone.

The eastern plot site has a north- westerly aspect with a dark red-brown clay loam soil over a light to medium clay red to purple in colour underlined by red clays of volcanic origin.

The tree spacing was 0.9 m x 3.75 which provides a tree density of 2963 trees per ha. The variety is K7.

The block designs were the same for each plot site as follows:

x	x	x	x	x	x	x	x	x	x
A	A	A	A	A	A	A	A	A	A
x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x
B	B	B	B	B	B o	B	B	B	B
x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x
B	B	B	B	B	B o	B	B	B	B
x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x
A	A	A	A	A	A o	A	A	A	A
x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x
A	A	A	A	A	A o	A	A	A	A
x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x
B	B	B	B	B	B	B	B	B	B
x	x	x	x	x	x	x	x	x	x

Tree codes 'A' or 'B' are measured trees while trees coded as 'x' are buffers 'o' EnviroSCAN tubes.

Eight EnviroSCAN tubes were located under the sixth tree in the two middle A and B treatments (ie four tubes/site). Moisture sensors were located at 10,20,30 and 50 cms depths in each tube.

Yield data was collected from the first crop in 2002 when the trees were 2½ years old.

An automatic weather station was also located adjacent to the eastern trial site recording hourly the air temperature, solar radiation, rainfall, wind and humidity. Daily recording settings were from midnight to midnight to align with the EnviroSCAN data. The data from these sensors are used to automatically calculate Eto using the Penman-Monteith equation as detailed in FAO 56 (1998).

3.2.1 Irrigation system

The plots are watered with a single line drip irrigation system using Netafim Dripmaster pressure compensated dripline with a drip rate of 2.3 l/hour with drippers spaced at 40 cms. The drippers were measured and produced an average drip rate over the range of 2.3 l/hr at a Coefficient of Uniformity (Cu) of 96% to 2.1 l/hr at a Cu of 90%.

The wetted width of the 2.3-l/hr-drip line at 400-mm depth was 800 mm, at both plot sites, continuous along the tree row. This produced an application rate of 7.2 mm/hour and wet 21% of the area (row spacing 3.75m).

3.2.2 Soil moisture settings

After the trees were established, irrigation was applied at 45minute applications to effectively replace water in the 0 - 300-mm depth. This produced some drainage below the effective root zone and was later reduced to 30-minute applications. In summer these applications were daily representing a 3.6mm water application to 50% of the effective root zone. In January 2002 there were 25 irrigations, which indicates a total of 90mm was applied to these two-year-old trees. This represents a monthly application of 0.19 ML/ha.

3.2.3 Yield determination

All trees received the same irrigation treatment (low stress) in the first block planted in March 2000. In September 2002 preliminary yield data was collected to assess average yields and bean quality for 2½-year-old trees. Commercial yields are not expected from trees under 3 years of age.

Harvest on 24th September 2002 – A row of trees was selected at random adjacent to the EnviroSCAN logger station to be representative of the block. Twenty-five consecutive trees were selected in a single row selected at random. Cherry was fully ripe on all trees. Of the 25 sample trees, 10 (40%) were assessed as high yielding, 10 (40%) as low to medium yield and 5 (20%) had no crop. Two trees were again selected, one from the high yield group and one from the low to medium yield group. All cherry was strip picked from each tree.

Results - The tree from the high yield group produced 1.861 kg of cherry
The tree from the low to medium yield group produced 0.219 kg of cherry

Average yield was calculated as follows: -

1.861 x 10 trees = 18.61 kg
0.291 x 10 trees = 2.19 kg
Total yield = 20.8 kg
Ave yield from 25 trees = $\frac{20.8}{25}$
= 0.83 kg cherry/tree

4. Detailed Results and Discussion

4.1 Coffee's natural climate

The centre of origin of *Coffee arabica* L. is considered to be the cool, shady environment in the understorey of forests in the Ethiopian highland. At these latitudes (6-9^{0}N) and altitudes (1600 – 2000 m asl) the mean average air temperature is in the range 15-20^{0}C, the annual rainfall is 1600-2000 mm and there is a single dry season lasting three to four months (Carr 2000).

4.1.1 Climate of trial sites

Newrybar site

Located at latitude 28^0 44'S at an elevation of 140-m asl, 7 km west of coastline. The mean average air temperatures is 18.6^{0}C and the annual rainfall varied between 1367 – 2993 mm during the trial period with lower monthly rainfall generally between July and October.

Mountain Top site

Located at latitude 28^0 20'S at an elevation of 290 m asl, 43 km west of the coastline. The mean average air temperature is 17.9^{0}C and the annual rainfall varied between 965 and 2113 mm with lower monthly rainfall generally between July and November.

4.1.2 Temperature ranges

The coffee plant is an evergreen and leaves are produced throughout the year at rates that are dependent on temperature and water availability, but are shed during periods of drought. (Carr 2000) Temperatures below 12^{0}C for long periods inhibit growth and development and above 24^{0}C, net photosynthesis begins to decrease and is negligible at 34^{0}C. (Nunes *et al., 1968).* Prolonged exposure to high temperatures (c. 30^{0}C) accelerates leaf loss and induces a general decline in tree health (Drinnan and Menzel, 1995).

The temperature distribution at the trial sites over last two years was:

Table 11 – Temperature distribution Newrybar site

Year	2001	2002
% > 12^{o}C	8.9%	9.9%
% 12^{o}C – 24^{o}C	80.7%	78%
% 24^{o}C – 30^{o}C	10%	11.6%
% 30^{o}C – 34^{o}C	0.3%	0.4%
% > 34^{o}C	0.1%	0.1%

Table 12 – Temperature distribution Mountain Top site

Year	2001	2002
% > 12^{o}C	4.4%	10%
% 12^{o}C – 24^{o}C	70.2%	59%
% 24^{o}C – 30^{o}C	18%	23%
% 30^{o}C – 34^{o}C	4.4%	6%
% > 34^{o}C	3%	2%

Temperature charts for both sites and all years are shown in appendix.

4.2 Phenological cycle

Generally in non-equatorial areas flower and fruit development are phased to maximise the likelihood that the fruit will expand during the rains and after a flush of new leaves. Hence floral initiation occurs during the cool, dry winter period; the flowers then remain dormant during the dry season and blossom after the first showers that invariably precede the main rains. The 'pinhead' fruits remain dormant before expanding after the beginning of the rains by which time the new flush of leaves, triggered by the same 'blossom' showers, have expanded. Intense rainfall throughout the year (without a dry season) can lead to scattered harvests and low yields (Cannell, 1985).

The following field observations were made over the course of the project:

4.2.1 Newrybar site

1998

Tree health Trees were in a relatively poor state of nutrition at the start of the trial. This was evidenced by premature die-back of laterals. Significant leaf loss occurred in August 1998 through wind. Recovery of new leaf and shoot growth was poor, due to late maturity of the crop and the poor nutritional status of the trees. Following leaf analysis an improved nutritional program was initiated in 1999.

Crop Very late harvest 8th October, 6th November and 11th December (6 weeks later than normal). The delayed ripening was probably due to very cool spring and early summer (1997/98).

Flowering Blossoming triggered February 1998. This late flowering appears to have delayed the maturity of cherry and suppressed flower initiation for 1999.

1999

Tree health A wet year with a record number of wet days (2994 mm over 195 days). Trees recovered from die-back with improved nutrition program, lighter crop load and adequate soil moisture. Biennial bearing is evident sporadically throughout the block. Trees with a heavy 1999 crop are generally sparse in leaf growth and flowering, while trees that cropped lightly in 1999 and flowering heavier and have good leaf cover.

Crop Two harvest periods (17th, 20th 23rd September and 25th, 26th October).

Flowering Moderate blossoming on 20th December triggered by rainfall on 10th and 11th December, light flowering on 28th December from rainfall on 18th December, heavy flowering on 21st January 2000 triggered by 45 mm rainfall on 12th January 2000 (this is a very late flowering).

2000

Tree health **N**on-irrigated trees were under moisture stress from 4th September to 25th October while still carrying a crop load. The trees in both irrigated treatments showed a better shoot and leaf recovery from significant leaf loss over the whole block in October/November. The leaf loss could have been caused by heavy crop load while under stress, very late flowering (21st January, 2000), crop maturing during peak stress period (October/November) or strong winds during peak stress period.

Crop Three harvest on 12th September, 10th October and 7th November. This seems to correspond to the three main blossoming events in the previous spring/summer.

Flowering No significant blossoming occurred during 2000 spring as plants were under heavy crop despite good falls of rain on 12th October. This rainfall event triggered a major flowering on the same variety in the Tweed district, which had been completely harvested in September. Light blossoming occurred on 1st December from rainfall on 21st November mainly on top of trees. A further light and sporadic flowering on 20th December was triggered by rainfall on 10th December.

2001

Tree health All trees were well leafed and healthy. Non-irrigated trees were moisture stressed for short periods in October and November with some relief obtained by storm events in October.

Crop There was a very light crop harvested over an extended period caused by poor flowering at the end of 2000. Harvest dates were 3rd July, 11th September, 9Th October and 13th November.

Flowering Early light blossoming on 8th October was triggered by rainfall on 22nd September on laterals not carrying crop. Good blossoming on tops of trees and moderate blossoming occurred through to ground level on 29th October that was triggered by rainfall on 17th October (many flowers still not triggered). Observations on 13th November revealed that some trees with good cherry set and buds were ready for next rainfall trigger, but most trees had the top metre of tree with cherry set while the flower buds on the smaller and lower laterals were still delayed. There was no observed difference between treatments in the flowering behaviour. A further blossoming was observed on 7th December triggered by rainfall on 26th and 27th November.

2002

Tree health Trees of all treatments were healthy throughout the year with full leaf cover despite excessive heat conditions in January. Heat stress symptoms of wavy leaf margins and leaf droop were evident on the non-irrigated trees which were moisture stressed from Mid December 2001 to the end of January 2002.

Crop A heavy crop was harvested over five harvests on 16th July, 13th August, 16th & 17th September, 23rd and 24th October and 14th November. The main crop was harvested **over two dates in September and October.**

Flowering Despite the hot dry spring period where the non-irrigated plots were moisture stressed from 28th September to 16th December, very little flower blossom was present after the three rainfall events of 15th and 30th November and 10th December. The flowering pattern seemed more linked to the amount of leaf retained after the mechanical harvester had stripped the block than the irrigation treatments. There was no difference in flowering behaviour of any of the irrigation treatments as most of the energy of the trees was probably being used to develop more leaf.

4.2.2 Mountain Top site

The initial planting was in March 2000. Many of these trees were damaged by their first winter and some replants were carried out in spring when the balance of the area was planted.

The first light blossoming was observed on 26th October 2000, but it was not until the following year that a substantial crop was set. In spring of 2001 there were two blossoming events. The first on 27th and 28th October, triggered by a rainfall event on 17th October, and the second on 18th November from rainfall on 10th, 11th and 12th November. These two blossomings were harvested on 9th August and 28th September 2002.

4.3 Root depth and distribution

4.3.1 Newrybar site

These trees were mature and developed mainly under natural rainfall conditions at a planting density of 2960/ha. Soil pits revealed the following:

Soil textures

A horizon sandy clay loam 0-160 mm
B horizon light clay 160-300 mm

Medium clay 300-700 mm
Bulk density of A horizon was 0.67 gms/cm^{3}.

Root Distribution Feeder roots predominantly in top 350-mm layers with a spread of 1350-mm radiating from the trunk. There was a dense mass of fibrous roots in the surface layer beneath the mulch.
Anchor roots were found between 600 and 700 mm angled from the centre taproot.

4.3.2 Mountain Top site

These trees were planted March 2000 into mounds that had been previously been ripped. Plant density 2960/ha

Soil textures

Western trial site

A horizon	Clay loam, dark brown to black 0-150 mm
B horizon	Medium clay with some mottles at 300 mm Fine sandy clay loam with weathered material at 300 - 700 mm Below 700mm weathered parent material.

Eastern trial site

A horizon	Clay loam, dark colour 0-300 mm
B horizon	Light to medium clay reddish colour 300 – 400 mm Gleying clay lighter colour than above layer medium clay 400 – 800 cms Below 800 mm red parent material.
Root Distribution	After 3 years under drip irrigation and natural rainfall the following was observed.
Tree height	1.9 metres
Fibrous roots	0 to 400-mm feeder roots in top 100 mm very fine. Roots around 200 mm were fine roots off thicker laterals. Fibrous roots radiated 800 mm from trunk, which corresponded to drip line. No roots outside drip line competing with Kikuyu inter-row cover.
Taproot	to 250 mm then split into at least 4 roots that continued vertically to about 750 mm. These roots were 3 mm diameter at 600 mm below ground. Secondary anchor roots from this system down to 600 mm growing diagonally. No J rooting or benching was evident.

4.4 Plant water relations

4.4.1 Stomatal behaviour of coffee

Stomata are only found on the abaxial surface of *C.arabica* leaves at densities variously quoted in the range 150 to 330 mm.$^{-2}$ Stomata are also present in green fruits at densities of 30-60 mm^{-2} that may represent 20-30% of the photosynthetic surface on heavily bearing trees (Cannell 1985).

Nutman (1937b) found that stomata opened early in the morning, but remained fully open throughout the day only when overcast, or when leaves were shaded from direct sunlight. On days when wilting of the youngest leaves was observed, stomata in the other leaves had closed by midday and stomatal conductance remained low for the rest of the day, even when leaves were shaded.

In Kenya, Wormer (1965) and later Browning and Fisher (1975) observed partial closure of the stomata during the day, even in irrigated trees. Wormer (1965) showed how increasing air temperatures (over 22 to 33 ^{0}C) and daily total solar radiation levels were each associated with linear reduction in the degree of stomatal opening during the afternoon. He derived an equation (IS = 18.5 – 0.365T) where IS represents the infiltration score (1-14), a large number indicating the stomata are wide open, and T the air temperature in the field (^{0}C).

Using this equation the following scores were achieved at the two sites in 2002.

Table 13 – Average monthly stomatal opening score (Wormer -1965)

Month	Ave daytime air temperatures ^{0}C– Newrybar site	Wormer score (1-14 range)	Ave daytime air temperatures ^{0}C– Mountain Top site	Wormer score (1-14 range)
January	24.7	9	29.2	8
February	24.4	10	28.9	8
March	23.2	10	27.6	8
April	21.2	11	24.6	10
May	18.4	12	21.6	11
June	16.9	12	16.8	12
July	16.2	13	16.1	13
August	16.5	12	16.5	12
September	19.4	11	19.8	11
October	20.7	11	22.6	10
November	22.3	10	24.4	10
December	23.5	10	25.0	9

In pot experiments Wormer showed that relative stomatal opening was closely related to the soil water content. He also observed that the application of nitrogen fertiliser (100kg N ha^{-1}) increased stomatal opening, particularly in irrigated trees.

Fanjul *et al.* (1985) in field experiments at two site in Veracruz state Mexico (lat 19^{0}27-31', alt. 1225-1340 m asl) reported that at dawn, stomatal conductance values in sun-grown plants were large (12 mm s^{-1}), but they normally decreased during the day (to about 4mm s^{-1}) as total irradiance (0-800 Wm^{-2}), air temperatures (14-26^{0}C) and saturated deficits (0-1.6 kPa) increased. At higher values of each of these variables though (eg 1000 Wm^{-2}, 26-30^{0}C, and 1.6-2.8 kPa respectively) the stomata remained closed all day.

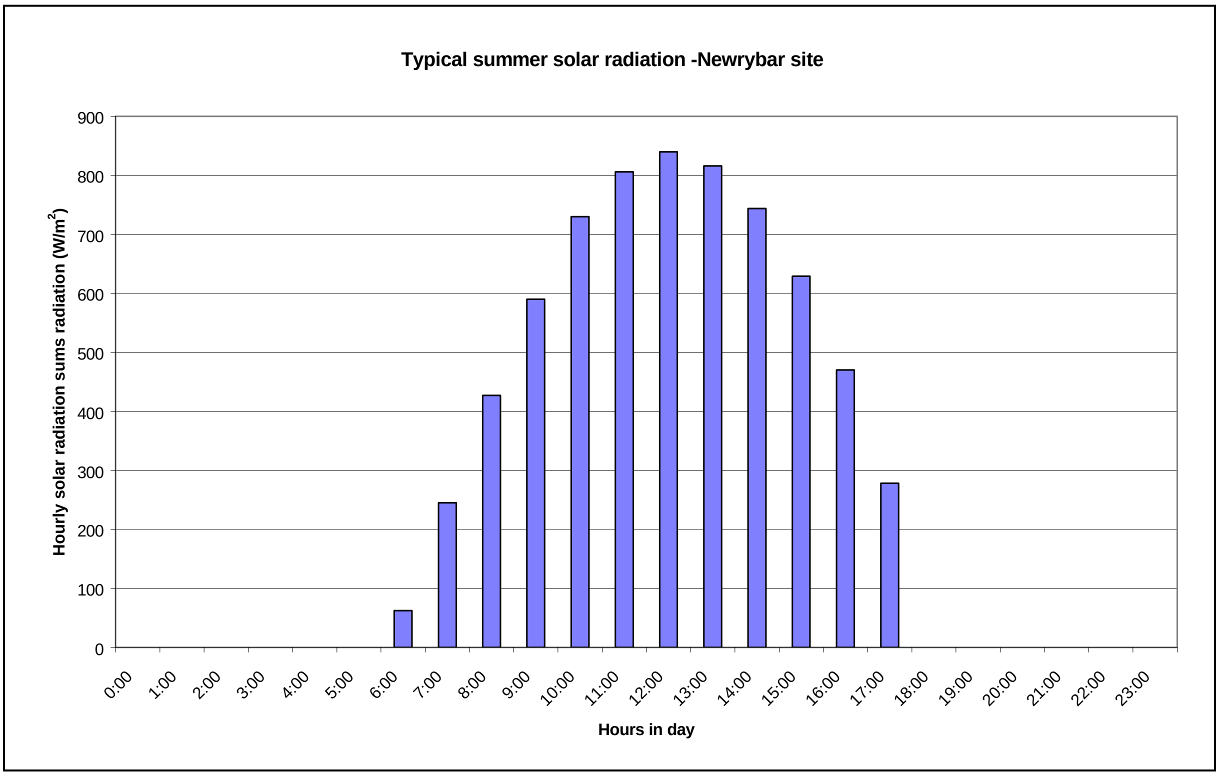


Figure 1 – Typical summer hourly solar radiation sums for Newrybar site

Partial stomata closure is likely to occur between 9 am and 4 pm in summer at this site.

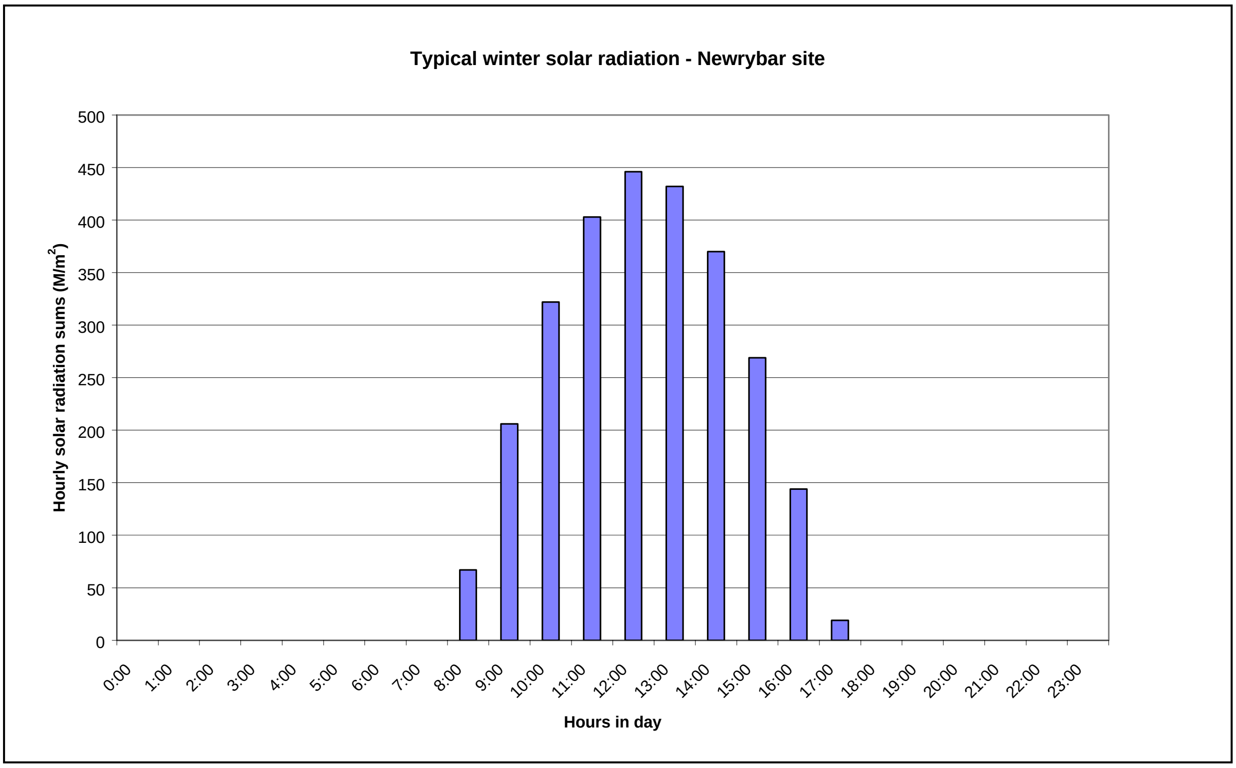


Figure 2 - Typical winter hourly solar radiation sums for Newrybar site

Stomata are likely to remain open for all but two hours in the middle of the day at this site.

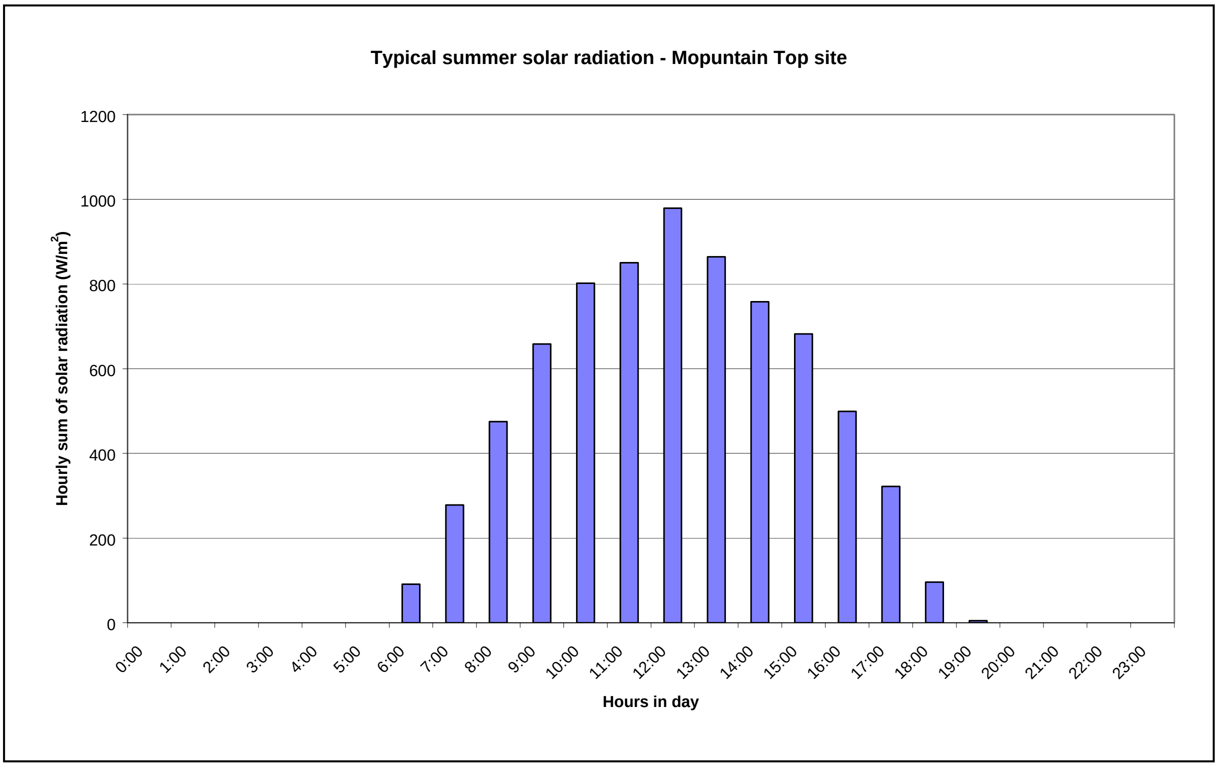


Figure 3 - Typical summer hourly solar radiation sums for Mountain Top site

Partial stomata closure would be likely between 8.30 am and 4.30 pm during summer at this site.

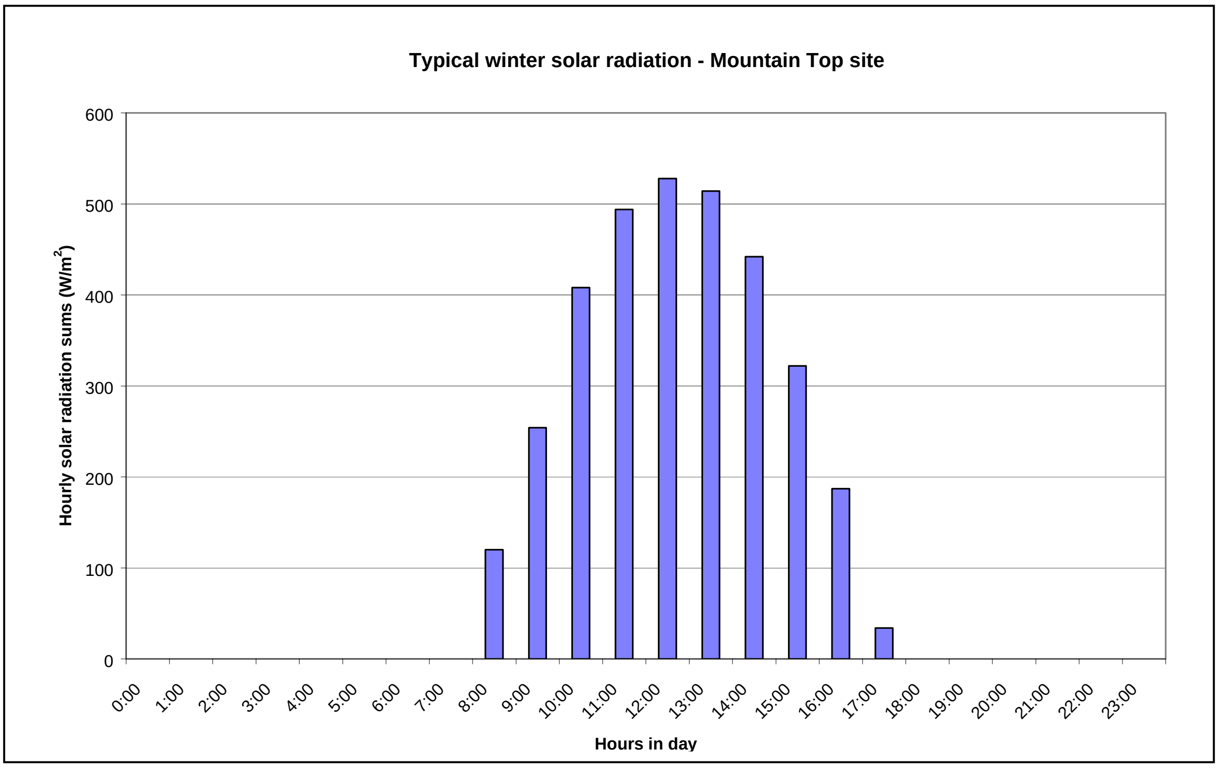


Figure 4 - Typical winter hourly solar radiation sums for Mountain Top site

Partial stomata closure would be likely between 10.30 am and 3 pm during the winter at this site.

The relationship of crop factor (Kc) to solar radiation was examined from data for the 2002 season.

The crop factor is meaningless when the soil moisture profile is increasing. Thus, daily mean soil moisture deficit was used to extract the days of 2002 when the soil profile was drying (ie. a positive deficit). A total of 831 observations from the 1095 made on the three treatments remained after this step.

The observations of soil moisture were used to create four classes of days ranging from low (14%-24% soil moisture) to high (43% to 52% soil moisture) water availability. The relationship between crop factor and solar radiation was then examined within each soil moisture class.

The results are described in the following graph at Figure 5. It is clear that as soil moisture became less limiting, crop factors tended to be lower on days with a high component of solar radiation. While these correlations were weak due to a high level of natural variation in the crop factor, they were found to be statistically important.

This seems to confirm the results obtained by Wormer (1965) and Browning and Fisher (1975). It is interesting that during periods of low soil moisture when trees are under mild stress and stomata are already partially closed that increase in solar radiation also increased the transpiration rate. As the soil moisture increases above the refill point this trend ceases and further rises in soil moisture right up to field capacity reverses the trend so that high solar radiation levels become the limiting factor controlling stomatal closure.

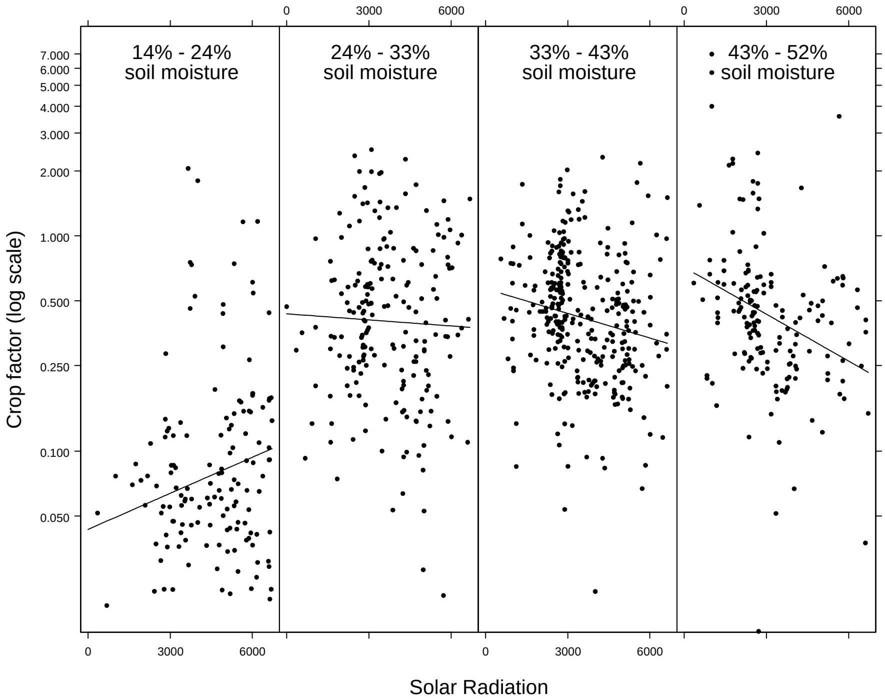


Figure 5 – Relationship of crop factors and solar radiation over varying soil moisture regimes

In a detailed study in Hawaii (lat. 21^{0}54' N; alt. 98 m asl). Gutierrez *et al.* (1994) concluded that stomatal control of water fluxes from the canopy of a well-watered coffee crop was strongly influenced by the interaction of wind and atmospheric humidity.

Analysis of the data on the effect of temperature, humidity and wind on crop water use was inconclusive. Some days of similar climate (ie temperature, cloud cover wind etc) produced different water uptake rates even when water was freely available in the soil profile. It is suspected that the dynamic combinations of weather features at certain times of the day may trigger subtle differences.

From a practical point of view growers need to monitor soil moisture levels and not rely on weather based scheduling systems.

4.4.2 Photosynthesis in coffee

According to Cannell (1985), the photosynthetic rate of leaves of *C.arabica* seems to reflect its evolutionary history as a shade-adapted C3 species. The maximum net photosynthetic rates of *sun* leaves are low (around 7 µmol CO_2 $m^{-2}s^{-1}$ at 20^oC) but higher (up to 14 µmol CO_2m^{-2} s^{-1}) for *shade* leaves that contain more chlorophyll per unit area than do sun leaves.

Stomatal closure can be triggered by low soil water, high temperatures and high solar radiation. All these factors will decrease the photosynthetic rates. Maintaining the soil water status above the refill point at all times will help improve these rates. In the low stress treatment water was even more freely available and this treatment consistently out yielded the medium stress treatment that maintained soil moisture levels above the refill point. This suggests that low water stress may enhance photosynthetic rates, as the crop factors of the low stress treatment were higher than the medium stress treatment with corresponding higher transpiration rates and water use.

The sub-tropics with its normal cloud cover during mid summer to late autumn during the rainy season could also reduce the effects of high temperatures and high solar radiation effects on the photosynthetic rates.

4.4.3 Transpiration

In northern Tanzania, Nutman (1941) found that at low radiation levels ($630Wm^{-2}$) transpiration increased with radiation, but at higher levels ($840W\ m^{-2}$) the relationship was less clear due to stomatal closure. Gutierrez and Meinzer (1994b) recorded similar findings in Hawaii.

In Japan, Kanechi *et al.* (1995) found that transpiration was always greater on cloudy days compared to sunny days for both well-watered (especially) and droughted plants. These differences, which reached a factor of three, were attributed to the sensitivity of the stomata to the leaf-to-air saturation deficit, and not simply to radiation levels. Stomatal conductance declined logarithmically with increasing leaf temperatures and saturated deficits. When the values of these two variables exceeded about 30^0C and 2.0 kPa respectively, the stomata were virtually closed, even in well-watered plants.

Transpiration rates for well-watered plants may not be appreciably higher than plants under mild water stress.

4.4.4 Drought resistance

The K7 cultivar used in this project at both sites appears to be able to withstand hot dry conditions. (Clowes and Logan 1985). The water stress of the unirrigated treatments seems to have had little permanent effect on the plants as they fully recovered after rainfall.

4.5 Crop water requirements

4.5.1 Evapotranspiration

In the most recent FAO manual on crop evaporation (FAO 56-1998) the tabulated Kc values presented for coffee are in the range 0.9-0.95 for clean weeded crop, and 1.05-1.10 for a crop with weeds, when using the FAO versions of the Penman-Montheith equation to estimate Eto. These values are for well-managed crops, 2-3 metres tall, grown in a sub-humid climate (minimum relative humidity *c*.45%).

The Kc factors derived in this project were calculated from soil moisture deficits measured by capacitance sensors and an automatic weather station at each site that derived the Eto using the Penman-Monteith equation.

Over the years 1999 to 2002 Kc factors were derived for each of the EnviroSCAN sites (ie two/ treatment). These have been averaged for each treatment and are shown at Figure 6.

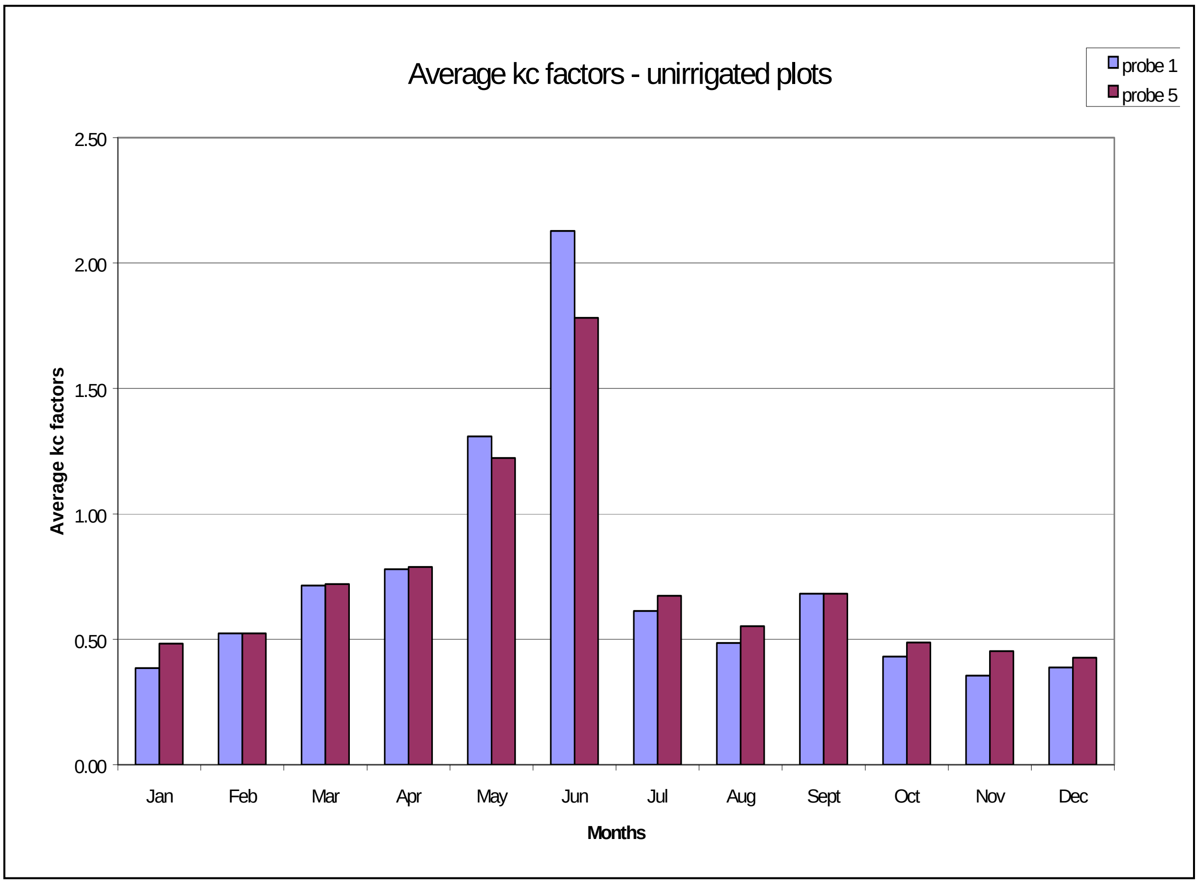


Figure 6 – Average kc factors for unirrigated plots 1999 – 2002 Newrybar site

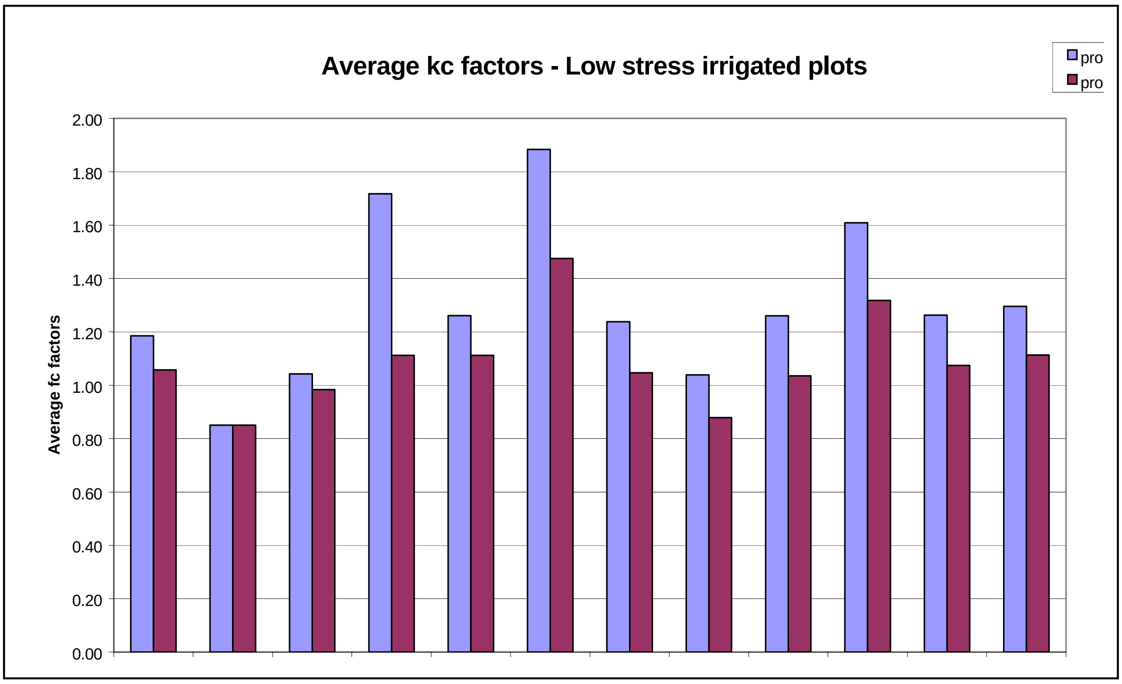


Figure 7 - Average kc factors for low stress irrigated plots 1999 – 2002 Newrybar site

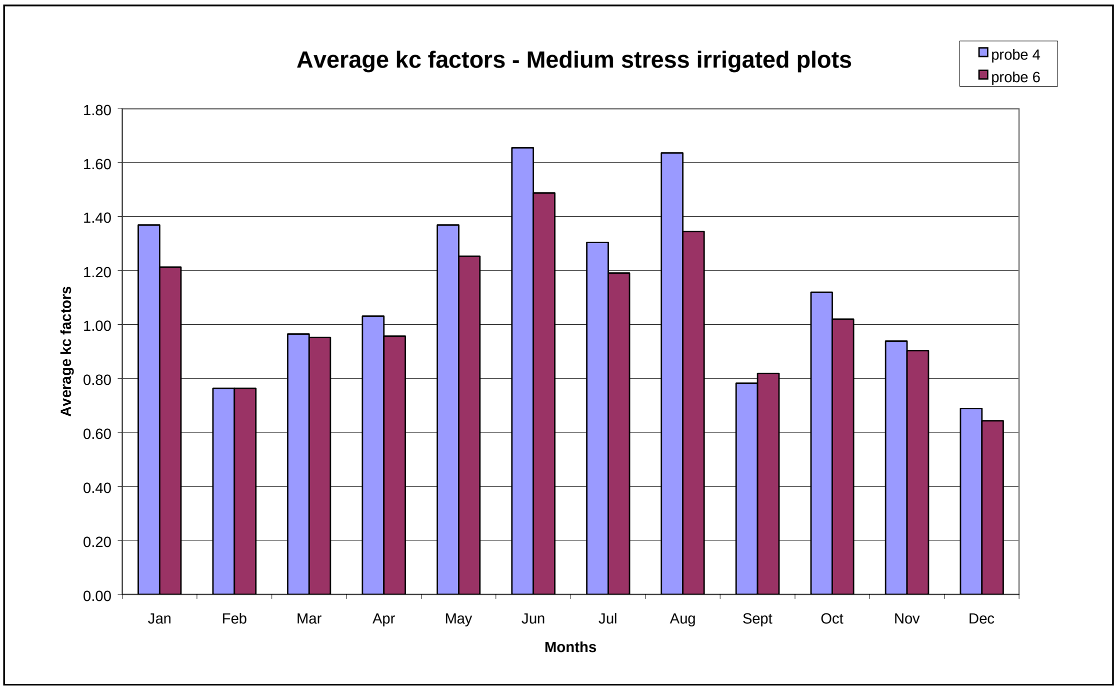


Figure 8 - Average kc factors for medium stress irrigated plots 1999 – 2002 Newrybar site

This data confirms the results of research discussed earlier particularly in the unirrigated treatment where the high crop factors (Kc) are evident in winter when the air temperature and solar radiation are lower. Some of the low reading in months July – January will also be due to insufficient soil moisture being available in the top 300-400 mm where the fibrous root system is located.

The irrigated treatments are similar and although the monthly variations are smaller there is still the trend that the lowest Kc factors are generally in the hottest months.

4.6 Irrigation

4.6.1 Newrybar site

Irrigation was applied to each of the irrigation treatments when required to replenish the top 300 mm soil profile. This normally represented an 11 – 15 mm irrigation application.

1999 rainfall and irrigation summaries

This year was a wet year at Newrybar with a total of 2994 millimetres falling over 195 days distributed as shown in Figure 9. No irrigation for either treatment was required over the full year.

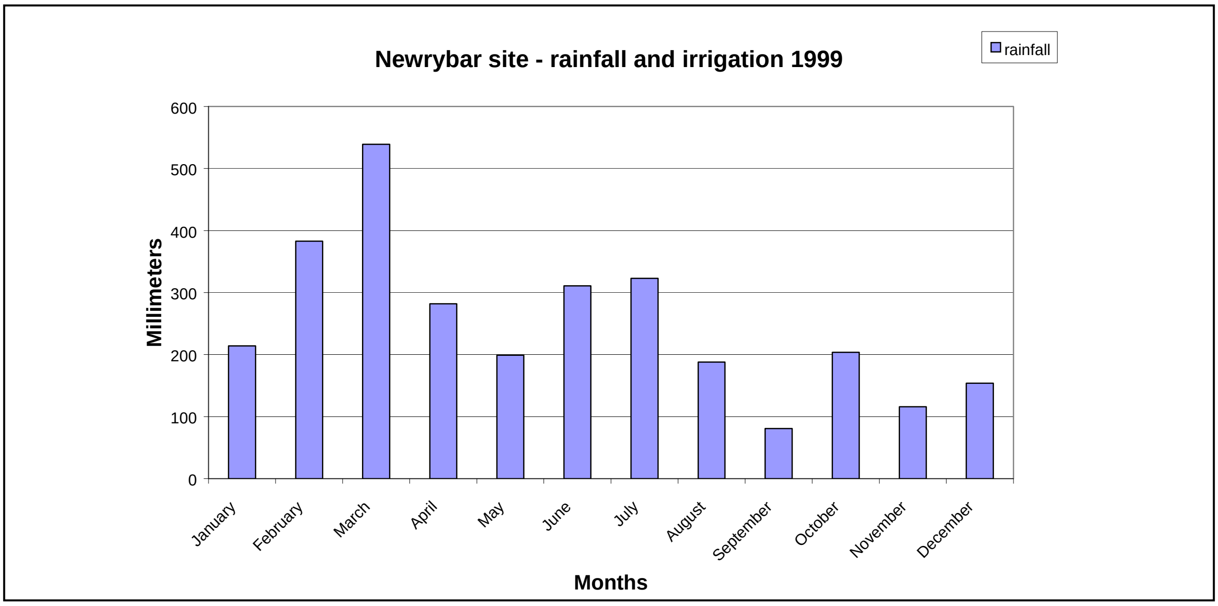


Figure 9– 1999 Rainfall and irrigation summaries Newrybar site

2000 rainfall and irrigation summaries
High rainfall levels continued until June. Irrigation was then required for both treatments from July – October and in December. The total annual rainfall was 1449 mm as shown in Figure 10.

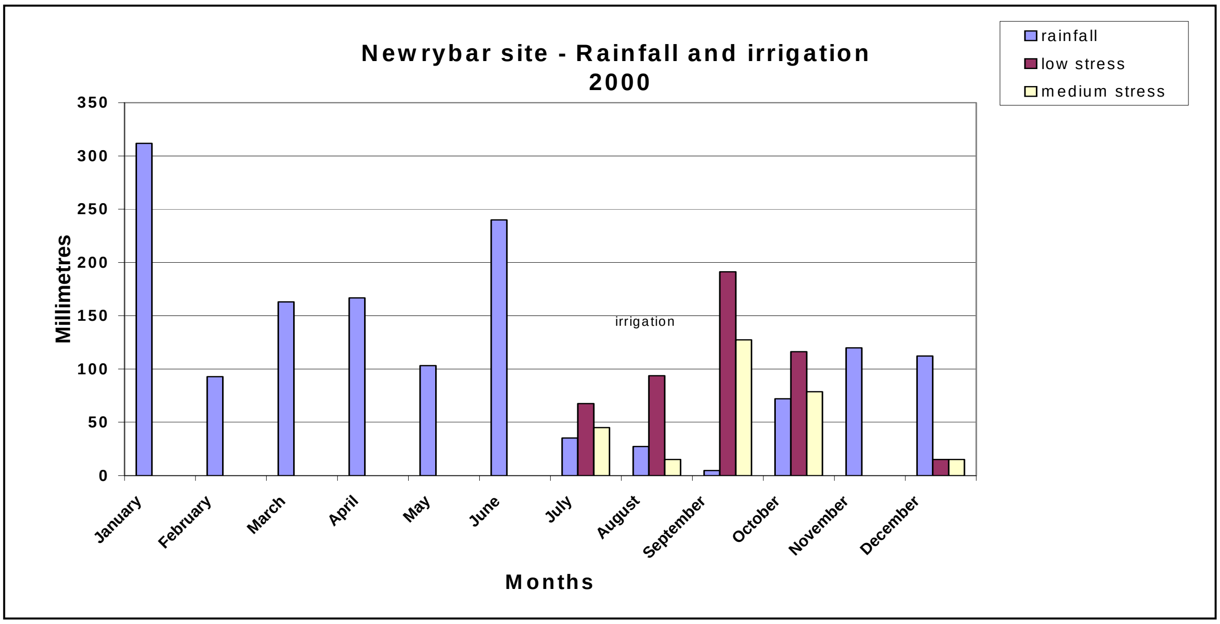


Figure 10 - 2000 Rainfall and irrigation summaries Newrybar site

Treatment 2 had a total irrigation application of 484 mm which represents 0.92 ML/ha of plantation. Treatment 3 had a total irrigation application of 281 mm which represents 0.53 Ml/ha.

2001 rainfall and irrigation summaries
Some high rainfall events occurred in February and March, the rest of the year was lighter. The annual rainfall was 1760 mm distributed as shown on Figure 11.

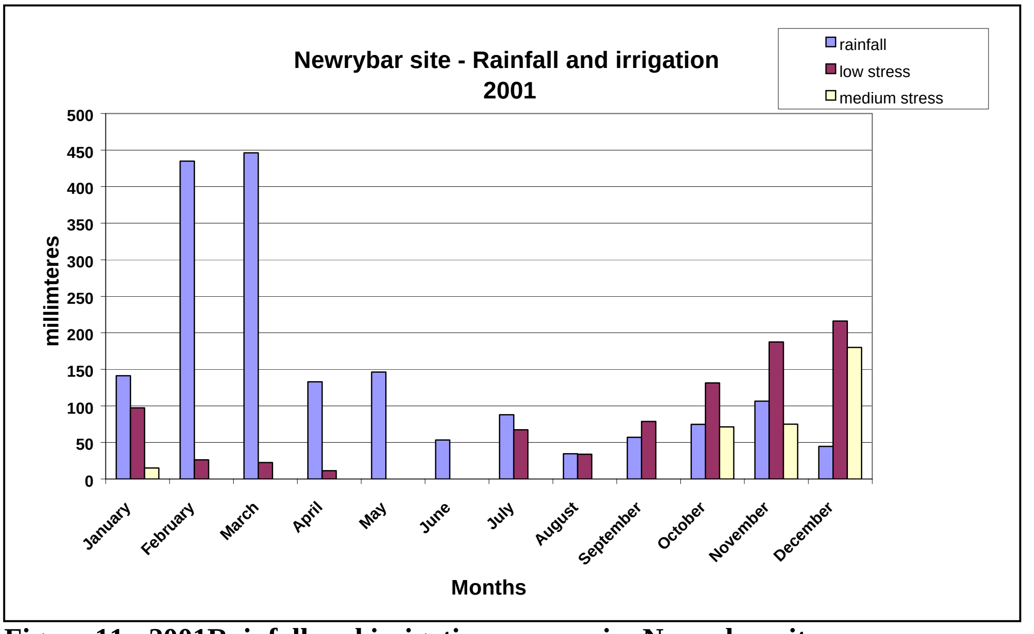


Figure 11 - 2001Rainfall and irrigation summaries Newrybar site

Treatment 2 required irrigation from January to April and July to December. Treatment 3 only required irrigation from October to December. Treatment 2 had a total irrigation application of 938 mm which represents 1.78 ML/ha of plantation. Treatment 3 had a total irrigation application of 326 mm which represents 0.62 Ml/ha.

2002 rainfall and irrigation summaries

Good rainfall occurred from March to June, much of the rainfall in the other months came by way of storms and the coffee trees shed most of the rain into the inter-row spaces producing runoff away from the trees. The annual rainfall was 1634 mm distributed as shown on Figure 12. The summer months also produced higher temperatures and higher evaporation rates.

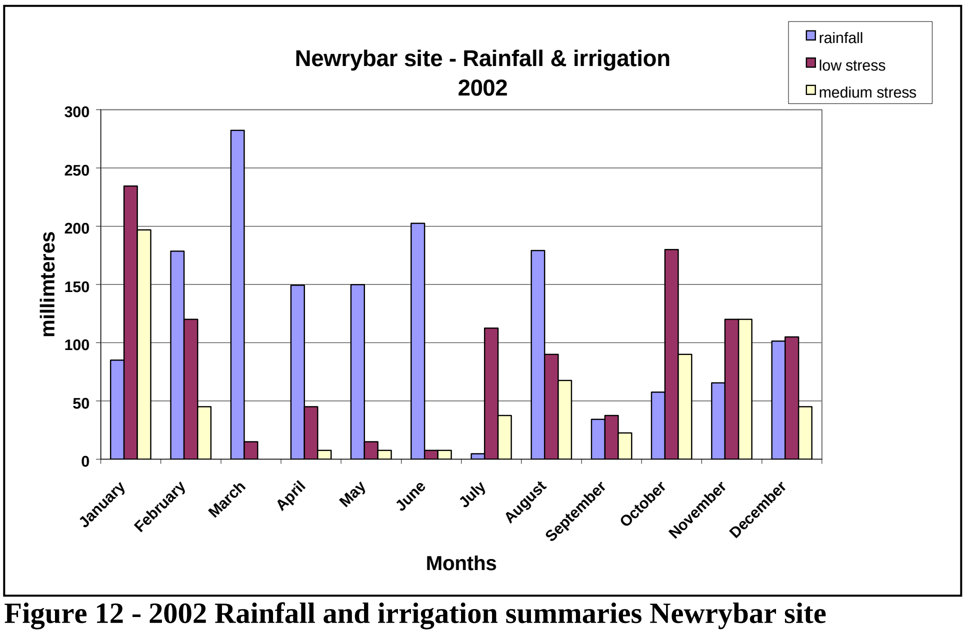


Figure 12 - 2002 Rainfall and irrigation summaries Newrybar site

Treatment 2 required irrigation in every month and treatment 3 in all but March. Treatment 2 had a total irrigation application of 2164 mm which represents 4.11 ML/ha of plantation. Treatment 3 had a total irrigation application of 647 mm which represents 1.23 Ml/ha. This year was considered a dry year and it recorded the highest monthly irrigation applications of 234 and 197 mm for treatments 2 and 3 respectively. These figures represent 31 and 26 hours of monthly irrigation/block.

4.6.2 Mountain Top site

2001/2002 rainfall and irrigation summaries.

There were no treatment differences used as the young trees are still developing. Irrigation was applied to keep soil moisture levels above the refill point. Between 1st September 2001 and 30th August 2002 there were a total of 140, 30-minute irrigations applied. The highest month was December 2001 with 24 irrigations. The total applications for this period was 504 mm which represents 1.06 ML/ha. The rainfall for the period was 1241 mm distributed as shown on Figure 13.

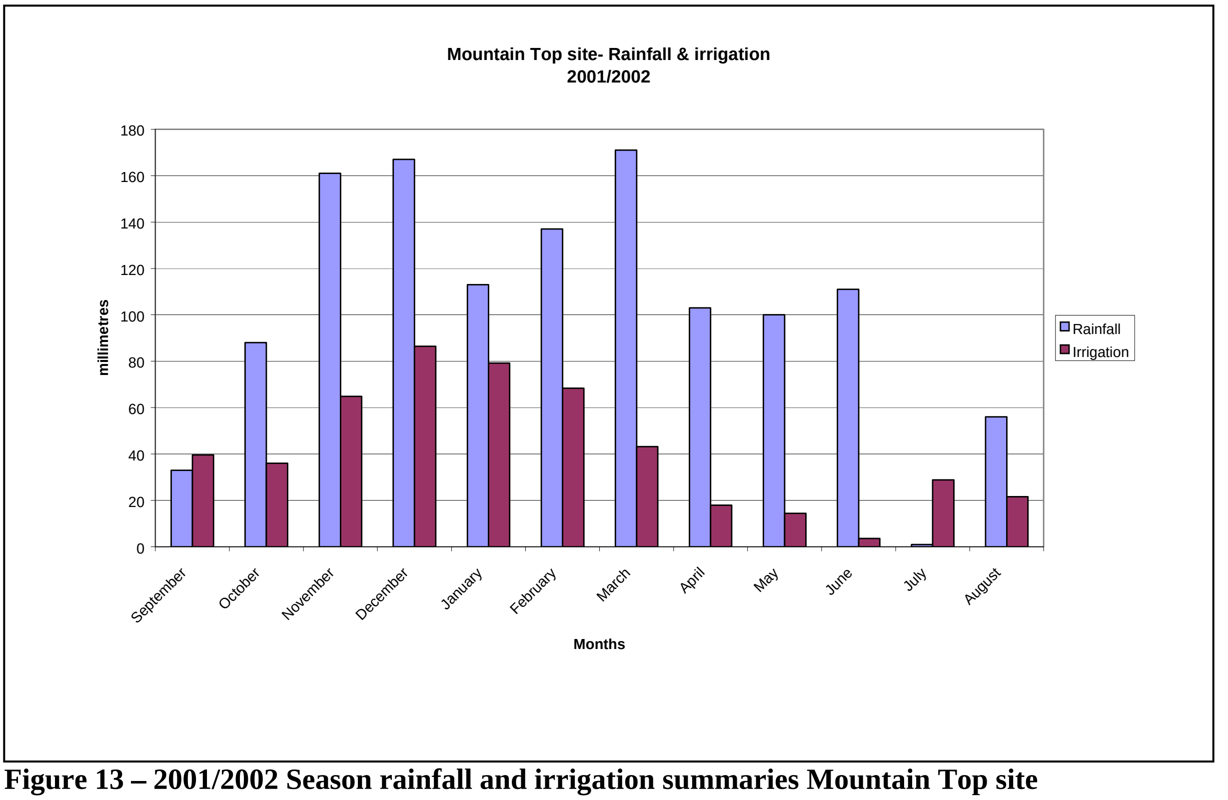


Figure 13 – 2001/2002 Season rainfall and irrigation summaries Mountain Top site

4.6.3 Plant water use

From the data generated by the hourly readings of the EnviroSCAN capacitance sensor some analysis of water extraction can be undertaken. Looking at a probe in the non irrigated treatment at the Newrybar site with mature trees carrying a full crop, typical data shown in Figure 14.

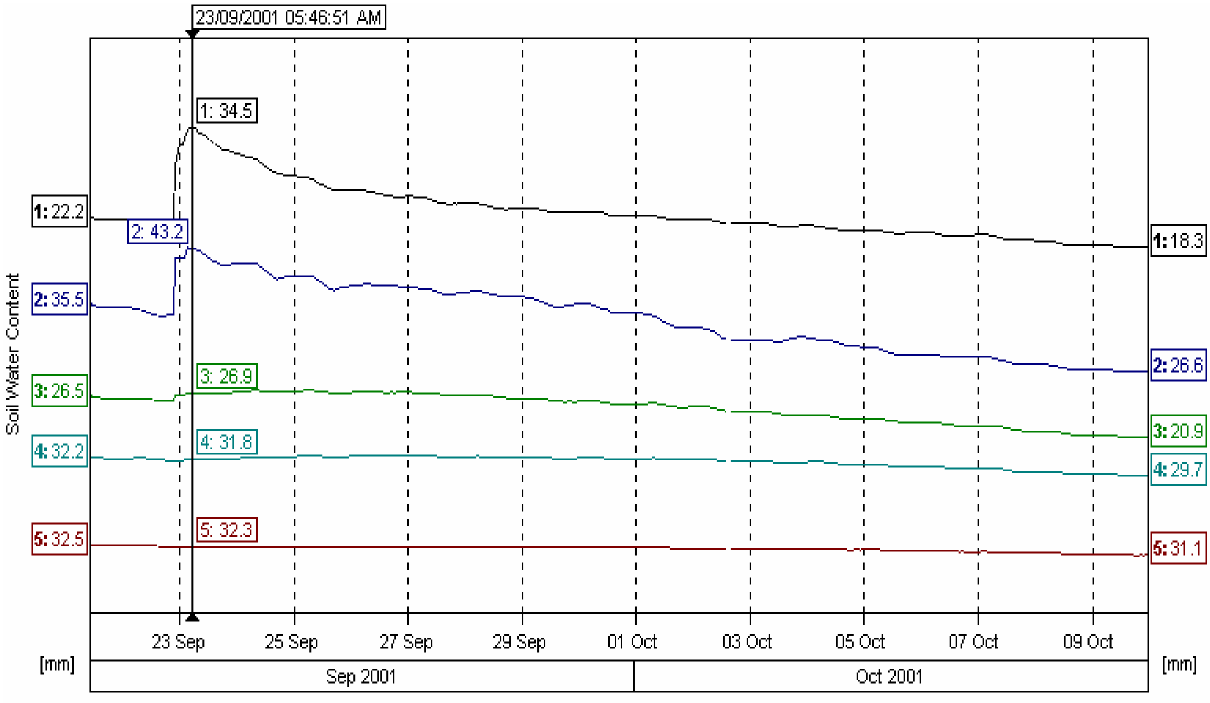


Figure 14 – EnviroSCAN probe 5 Newrybar 5 sensor graph 23rd September to 8th October 2001

Water extraction between 23rd September and 9th October 2001 was distributed as follows: -

Table 14 – Distribution of water extraction probe 5

Soil depth	% Extraction
100 mm	38%
200 mm	40%
300 mm	14%
500 mm	5%
800 mm	3%

The rise in moisture shown on the 23rd September was due to 19 mm of rainfall. This rainfall penetrated to less than 300 mm which showed that some of this precipitation was either absorbed by the mulch or produced runoff from the canopy or both. This illustrates the importance of measuring the actual soil moisture to fully gauge the effectiveness of rainfall.

The rainfall collected by the top layers of the soil profile were quickly used by the plant, the top 100 mm sensor returning to stress levels in six days and the 200 mm sensor in ten days. Only at this point did some extraction recommence at the 300 mm sensor. Moisture extraction at the deeper sensors was not effected by this rainfall event

In January 2002 when the moisture status top 300 mm of soil depth was well below the refill point, as shown in Figure 15. The water extraction between 1st and 14th January was distributed as follows:

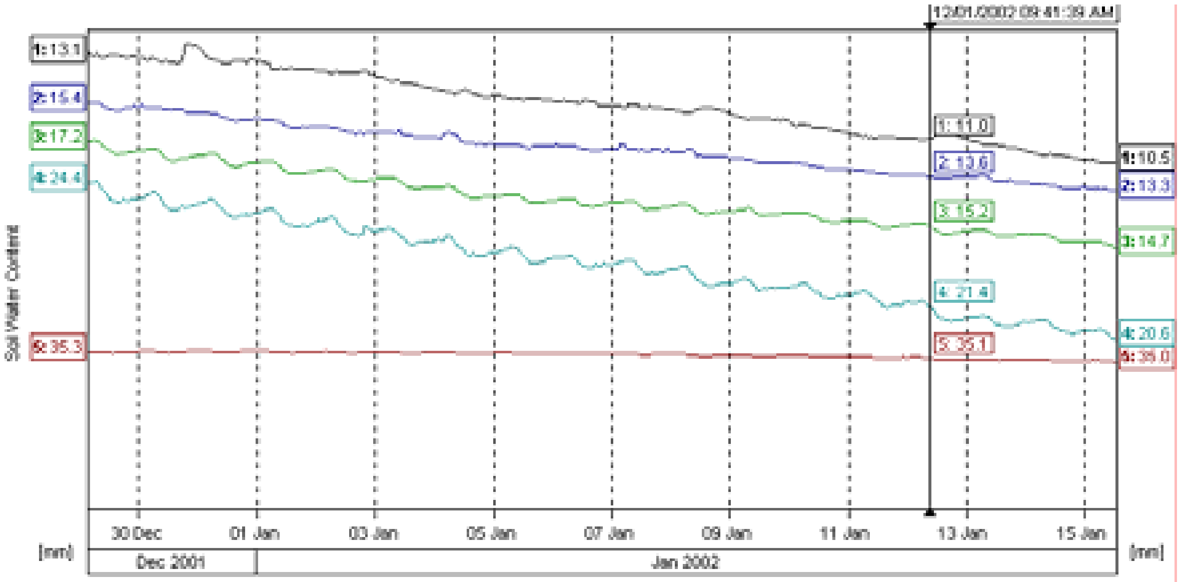


Figure 15 – EnviroSCAN probe 5 Newrybar 5 sensor graph 30th December 2001 to 15th January 2002

Table 15 – Depth of soil moisture extraction from figure 15

Soil depth	% Extraction
100 mm	30%
200 mm	27%
300 mm	13%
500 mm	13%
800 mm	18%

There was only a slight shift to deeper water extraction and the trees could not extract sufficient from depth to meet full potential transpiration rates.

Looking at an irrigated treatment at the same site there were eight irrigations between 1st January and 14th January 2002 applying a total of 95 mm of water.

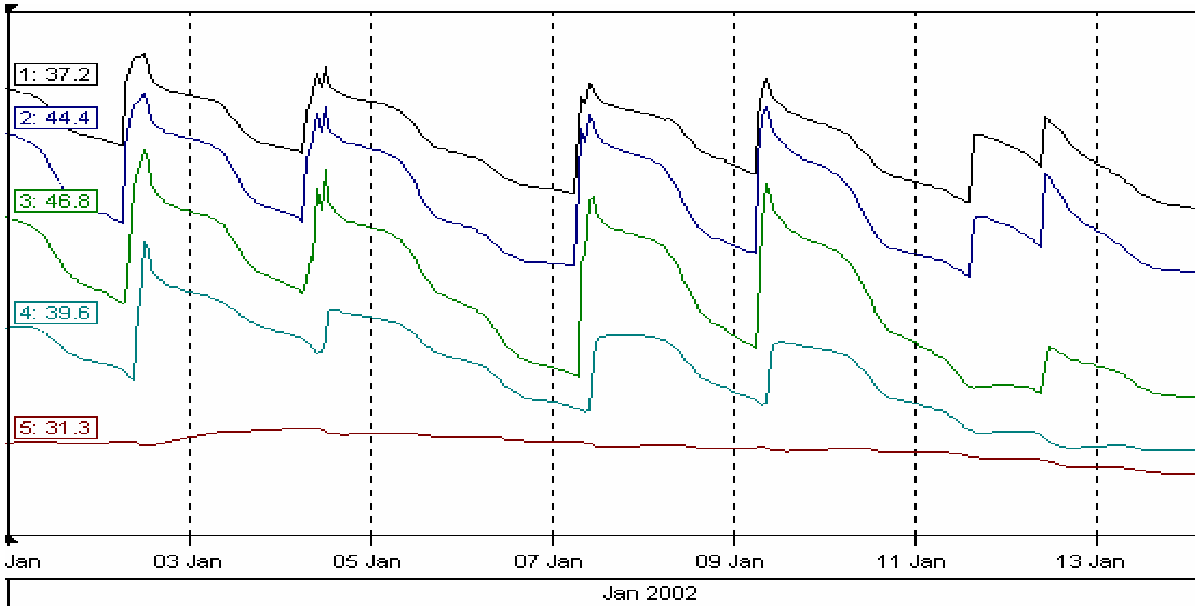


Figure 16 - EnviroSCAN probe 3 Newrybar 5 sensor graph 1st – 14th January 2002

From the chart above, the applications of over 20mm placed water down to the fourth sensor 500 mm below ground level. The two lighter applications on the 11th and 12th January applied 7.5 and 9.5 mm respectively and these only supplied water to the third sensor at 300mm depth. Of the total application of 95 mm the following percentages were extracted from each depth.

Table 16 – depth of soil moisture extraction from figure 16

Soil depth	% Extraction
100 mm	20%
200 mm	30%
300 mm	32%
500 mm	16%
800 mm	2%

At Mountain Top site the two-year-old trees between 25th September and 5th October 2001 were irrigated four times for 30 minutes each time with a total application of 14.4 mm. The extraction pattern as shown in Figure 17 shows the following percentages extracted from each depth.

Table 17 – Depth of soil moisture extraction from figure 17

Soil depth	% Extraction
100 mm	34%
200 mm	35%
300 mm	24%
500 mm	7%

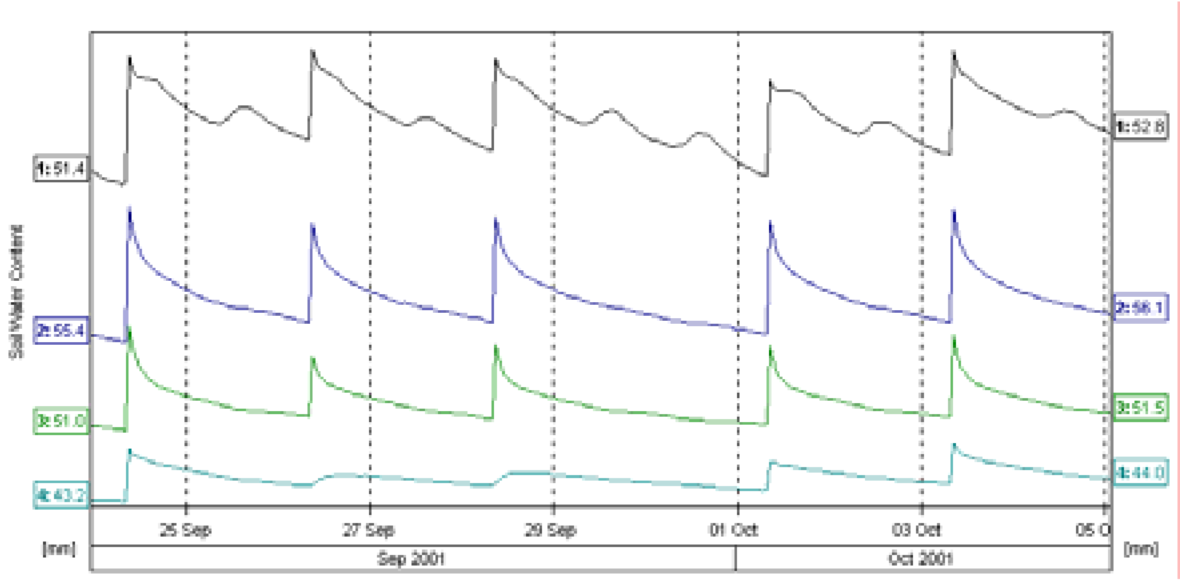


Figure 17 – Mountain Top EnviroSCAN 4 sensor graph 25th September to 5th October 2001

This data would suggest that coffee trees are well suited to our climate with its unreliable rainfall. The trees will survive dry periods and can respond quickly to moisture application with a highly developed fine root system that are located in the top 300 mm provided these roots are protected with an effective layer of mulch.

The relationship between moisture and yield is discussed in the next chapter.

4.7 Yield responses

4.7.1 Newrybar site

Yields were harvested from the trial site in 1998 to establish a benchmark with the trees in their current health and again in 1999 although no separate treatments were employed because of the high rainfall (2994 mm over 195 days). In 1998 the average tree yield was 9.0 kg of cherry and in 1999 it was 6.33 kg of cherry.

Data exploration

The change in cherry yield over time for each plot under each water management strategy is displayed in figure 18. The pattern of yield change over time indicates a biennial bearing tendency for coffee; a trait shared with many other fruit crops. This provides strong evidence for the need to carry out research into coffee production over a number of seasons.

Four "rogue" plots are indicated, two in the control group and one in each of the managed groups. However these proved to have a minimal impact on the statistical analysis and so, in the absence of any evidence for exclusion, were retained in the analysis.

Figure 19 presents the average production under each management strategy over time and indicates that while both irrigation strategies consistently yielded more cherry than the control, there were only marginal yield increases for mildly stressed plants compared to medium stress.

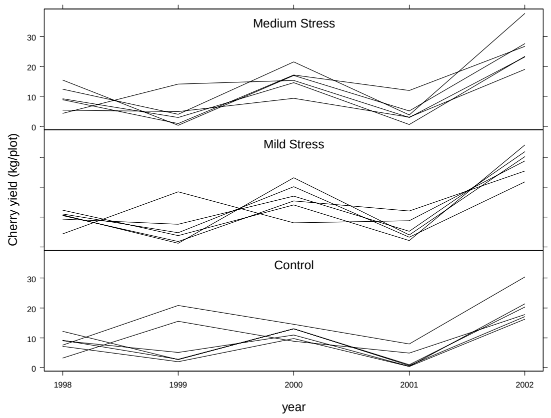


Figure 18 –Cherry yields over time for each plot (2 trees)

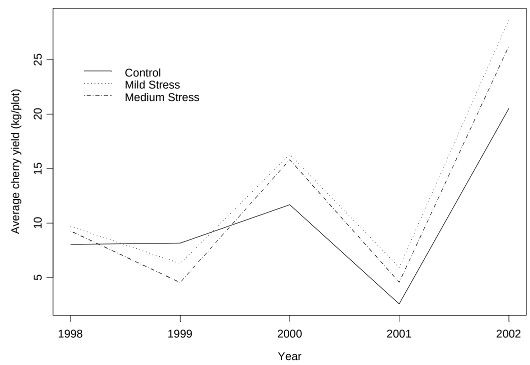


Figure 19– Average yield over time for each strategy

Data analysis

For the reasons outlined above yields observed in 1998 and 1999 were excluded from the analysis and focus was placed on the 2000-2002 observations. Variation in yields due to treatment and time was compared to that due to field variation via the analysis of variance. The analysis indicated statistically important differences in yield due to treatments and seasons and that treatment differences were consistent across seasons

Results are best summarised by tabulation of the average yields for each strategy within and across years together with a measure of the precision of each average. In this case, the "least significant difference" was chosen to indicate precision. This gives the amount by which a pair of averages must differ in order to be regarded as a statistically important difference.

	Yield in kg cherry /plot (2 trees)			
	2000	**2001**	**2002**	**Average**
Control	11.69	2.57	20.53	11.60
Low Stress	16.31	5.92	28.68	16.97
Medium Stress	15.81	4.57	26.26	15.55
Average	14.61	4.35	25.16	

Lsd for comparing: **Individual means = 4.95**
Seasonal means = 2.68
Treatment means = 3.52

Yield data from the years 2000 – 2002 have been further displayed in Figure 20 below for the three treatments.

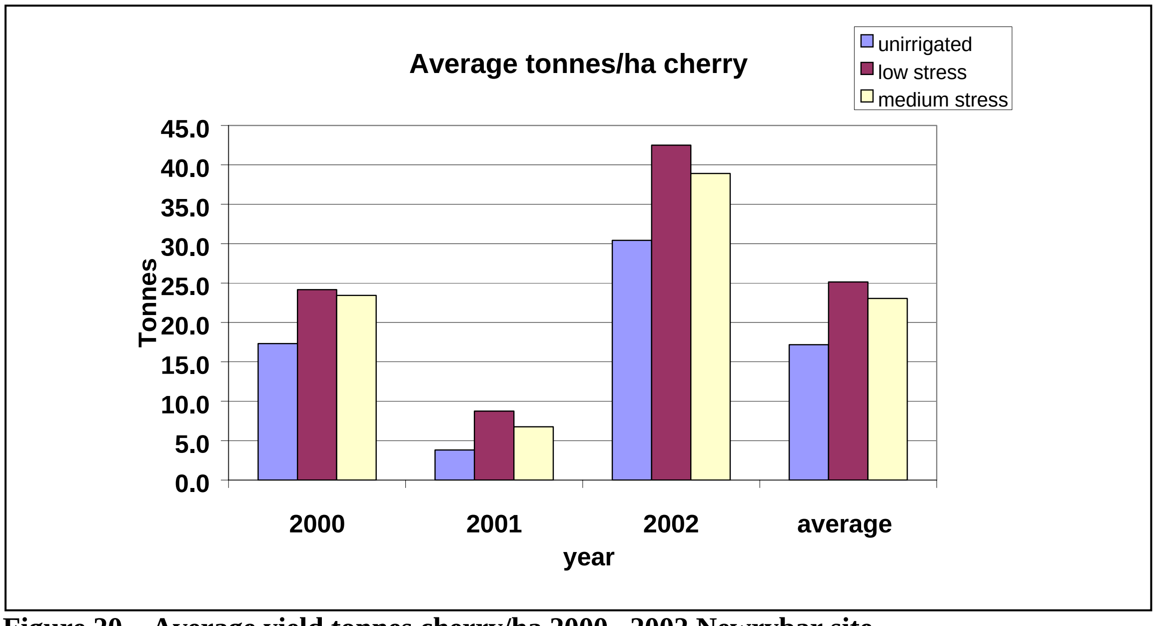


Figure 20 – Average yield tonnes cherry/ha 2000 –2002 Newrybar site

Within these three years, there was a significant variation in the yields of cherry, but consistently treatment 2 was higher than treatment 3, which was always higher than treatment 1. The additional yield from the two irrigated treatments over the non irrigated treatment is shown on Figure 21.

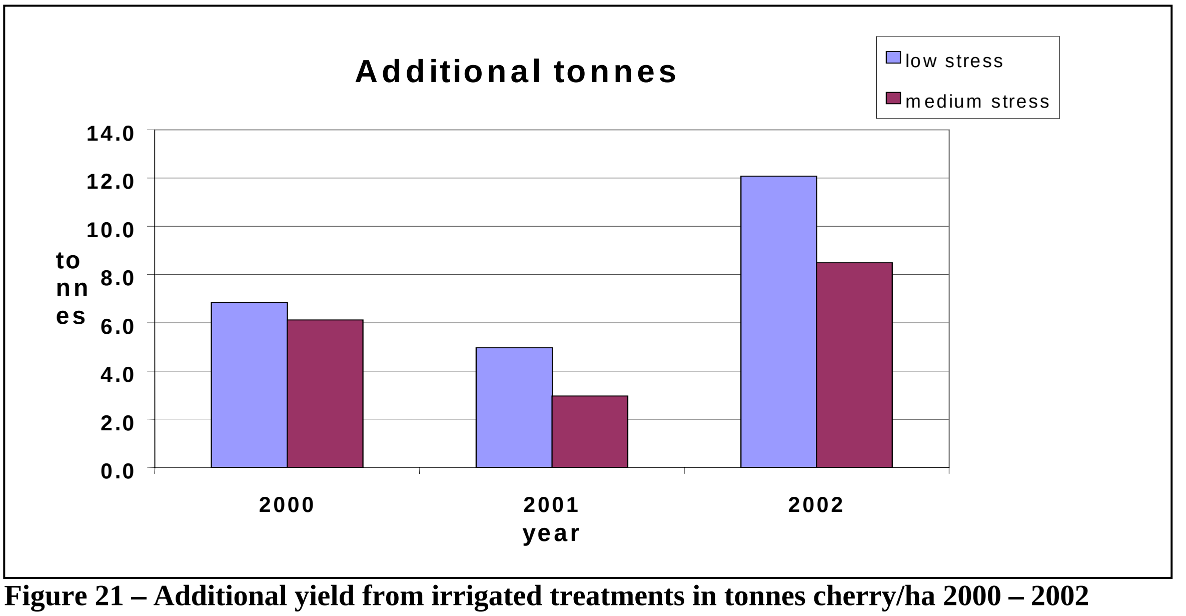


Figure 21 – Additional yield from irrigated treatments in tonnes cherry/ha 2000 – 2002

The value of the additional return/treatment is shown at Figure 22. The average cherry to dry green bean (DGB) ratio in the trial was 6.5:1.

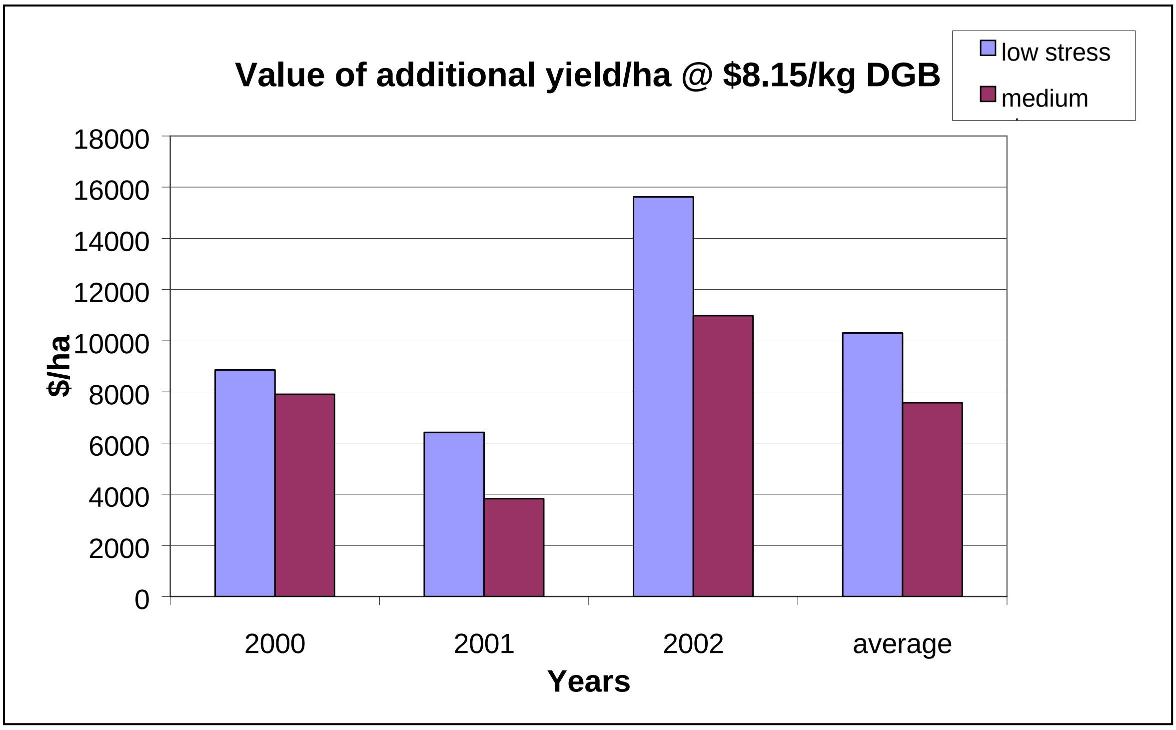


Figure 22 – Value in $/ha of additional yield from irrigated treatments

If water is the limiting factor then the additional tonnes/Ml might be more applicable. This reverses the treatments so that although treatment 3 has a reduced yield when compared to treatment 2 it uses much less irrigation water, so the yield per megalitre is greater.

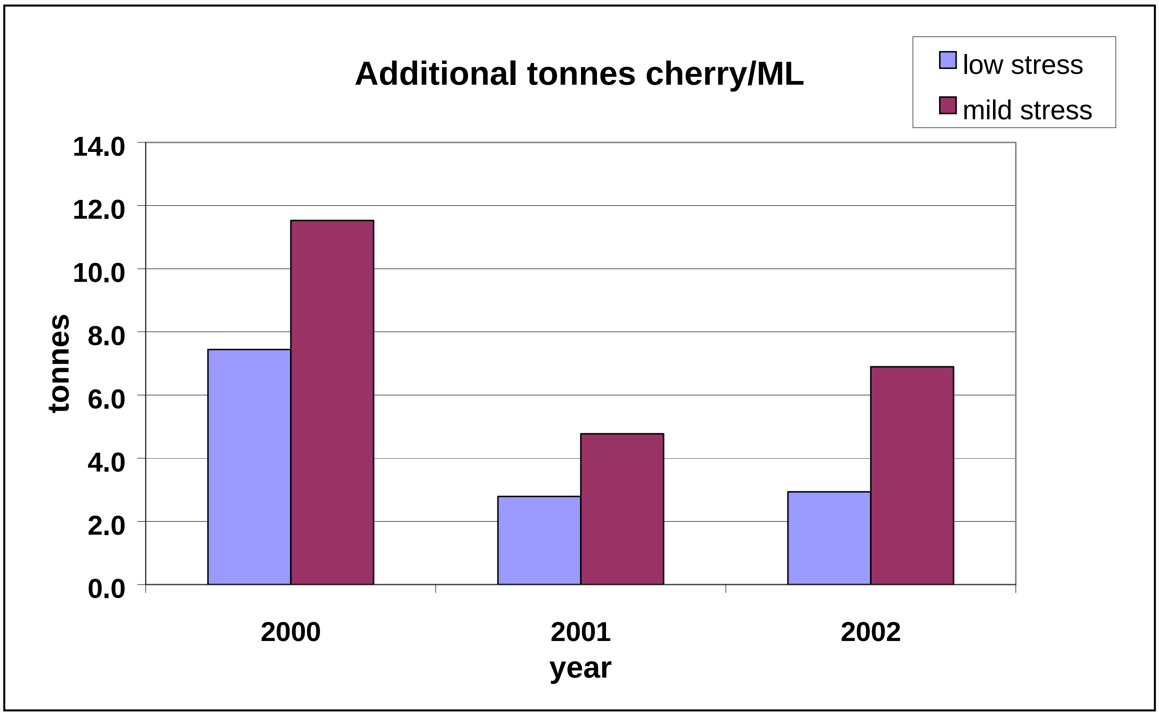


Figure 23 – Additional cherry yield/Ml for irrigated treatments

To fully evaluate the cost of providing additional on farm storage or constructing a bore to add groundwater supplies to improve the water security, the additional returns/ML are shown in Figure 24.

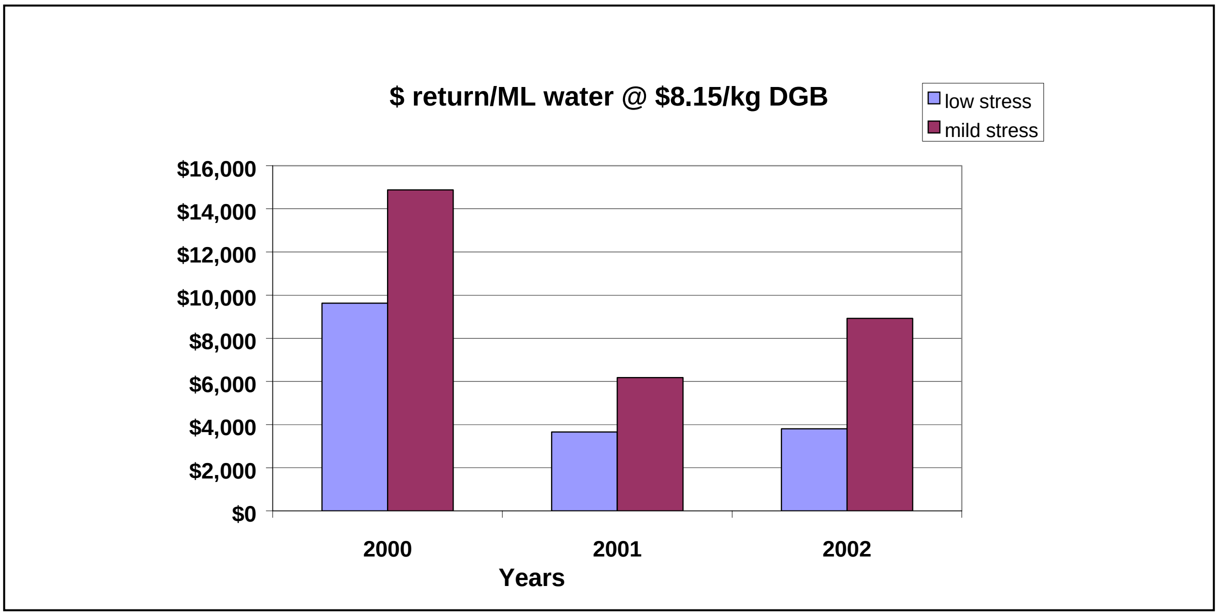


Figure 24 – Returns $/Ml for irrigation treatments

4.7.2 Mountain Top site

The average yield of the first harvest was 0.83 kg per tree.

Though this result is preliminary only, the yield/ hectare of **available** cherry is estimated at 0.8 kg average x 2963 trees/ha or 2.37 tonnes per ha of cherry. Some reduction of yield from the available cherry can be expected with mechanical harvesting.

4.8 Bean quality

Bean size and cupping quality were compared for each year that irrigation was carried out.

4.8.1 Bean sizing

Coffee is sold as dry green bean (DGB) with quality and price assessed on the basis of bean colour, size and shape (Wormer and Njuguna, 1966) as well as defects and cupping quality. Larger beans attract higher prices.

Winston and Thomson (1993) evaluated bean size over a large number of cultivars from two North Queensland locations (Kamerunga and Southedge) over a three year period. From previous research they concluded that coffee bean size is determined by a number of factors. Cultivars differ in their ability to produce well formed beans (Wormer, 1966; Cannell, 1974) while both rainfall and irrigation have been found to improve bean size and shape (Wormer, 1964, 1966; Cannell, 1974,1985) and cooler temperatures may increase potential bean size (M.J.St. Clowes, pers. comm.) The time of flowering is important in relation to the conditions prevailing during the period of fruit expansion as expansion inhibited by lack of water which can occur during dry weather (Cannell, 1974). Large seasonal differences in bean size have been related to rainfall during expansion period (Wormer, 1966)

The results from the K7 cultivar, which is the same as used in this project, were as follows from both sites over 3 years:

Table 18 - Bean size grading from North Queensland evaluation trial (1993)

Bean size	percentage
18	17
16	42
15	18
<15	23

Some of these cultivars were also planted in Northern NSW under unirrigated conditions and many produced larger beans in 1990 (65% - 88% retained on a size 16 screen). Furthermore, most lines in NSW had 25-46% size 18 whereas most of the selections at Kamerunga and Southedge (Qld.) had less than 10% size 18.

Differences in bean size between north Queensland and the sub-tropics may be due to the shorter flowering to maturity period in north Queensland (7 – 8 months) compared to 9 – 11 months in the sub-topics or higher temperatures in the tropics or a combination of both.

Observations in North Queensland (*Coffee growing in Australia*, 1997) suggest that rapid cherry growth phase determines the bean size and begins four to eight weeks after flowering and continues for a further 12 weeks. In Zimbabwe, they suggest that a most sensitive stage is the period from 10 to 17 weeks after flowering and a drought at this time is particularly likely to affect final bean size and weight (Coffee handbook, 1987). The extent to which the final bean size is realised is influenced by soil moisture levels throughout the whole fruit growing period.

The Dry green beans from the Newrybar site from the 2000 crop were graded as shown in Figure 25

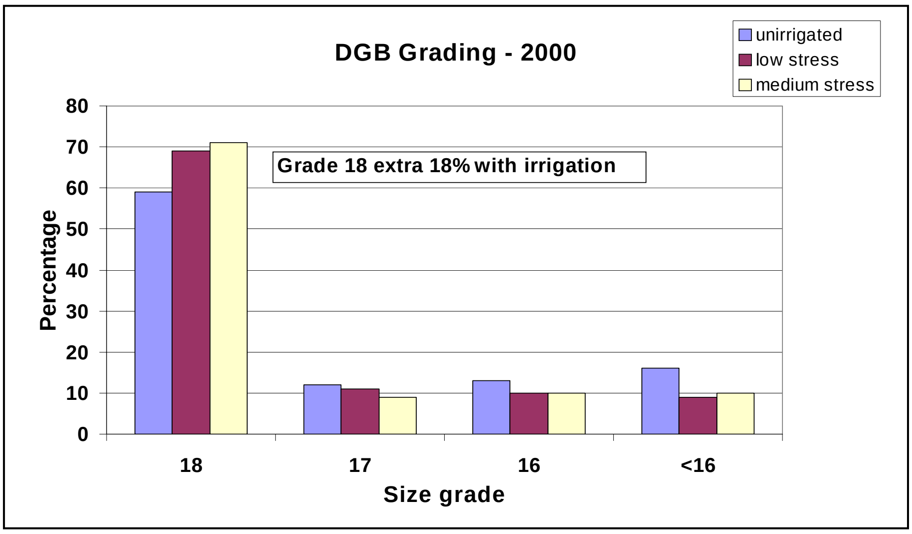


Figure 25 – Dry Green Bean gradings for harvests from treatments at Newrybar site 2000

This showed an 18% increase in size 18 bean for both the irrigated crops when compared to the non-irrigated crop. This was despite the fact that the irrigated trees were first watered on 18th July some 25 weeks after the last blossoming event (21st January). This would suggest that not only does irrigation late in fruit development increase the yield (by 40% in 2000) but it also can potentially increase the bean size developing the beans to their full potential as set in earlier fruit development.

In 2001 a similar trend was evident in the non irrigated and irrigated with the non irrigated treatment having a smaller percentage of size 18 and larger percentage of less than size 16 beans seen in Figure 26.

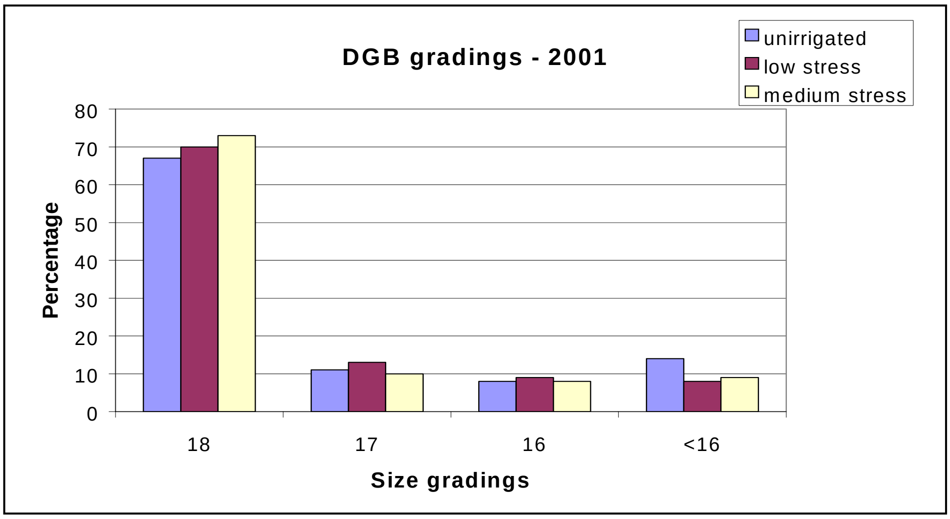


Figure 26 – Dry Green Bean gradings for harvests from treatments at Newrybar site 2001

In 2002 the difference in bean size for each treatment was insignificant as shown in Figure 27.

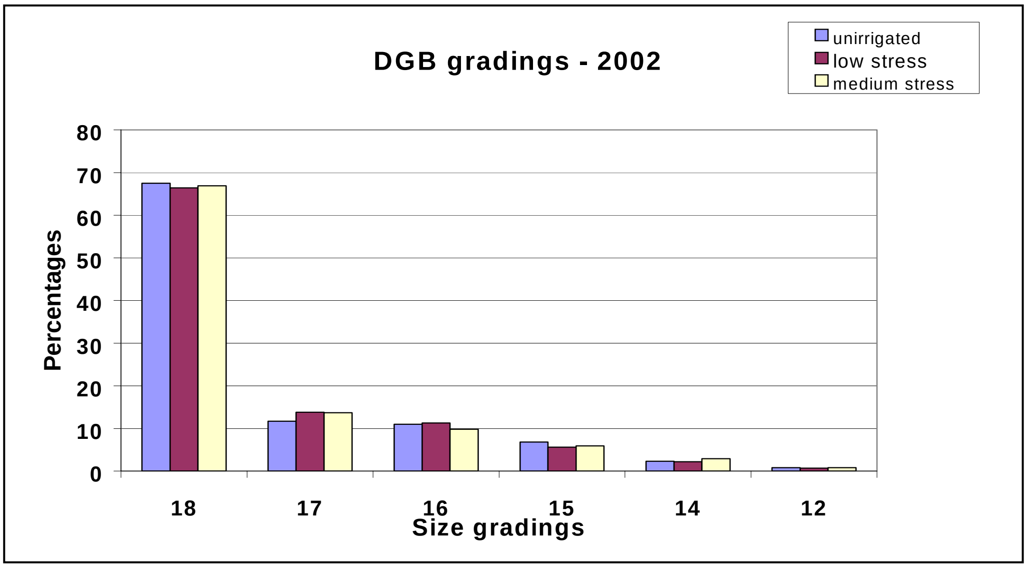


Figure 27 – Dry Green Bean gradings for harvests from treatments at Newrybar site 2002

In this year the irrigated crops were watered in most months throughout the fruit development phases.

4.8.2 Cupping quality

Newrybar site

In 1999 samples from the 1998 season were roasted, ground and evaluated for taste by the NSW Coffee Growers Association taste panel and independent taste experts. The analysis showed no significance between the treatment plots. This established a valid benchmark for the rest of the trial from this site.

As 1999 was a wet year with no irrigation, there was no difference in the cupping quality of the treatments.

The liquoring quality of the 2000 harvest was evaluated by blind taste tests in May by an independent professional panel. Results indicated that samples from each treatment were not significantly different and “all had evident sweetness, good acidity/brightness and medium body one would expect from quality local coffee"

For the 2001 harvest, the Austral Asian Specialty Coffee Association (AASCA) and another independent professional taste panel were used to assess appearance, aroma and cupping (tasting) quality of each irrigation treatment in duplicate split samples and blind taste tests. Results from both tasting trials showed no significant differences in quality between irrigation treatments or between harvest dates with the exception of the final pick in November when quality scores decreased slightly.

The 2002 harvest was assessed under SCAA cupping form by AASCA.

- The non irrigated scored 69 –“*low acidity and mild smoky flavour and thin body”*
- The low stress irrigated treatment scored 73 –“ *dull bakey aroma, nice acidity, sour, green apple flavour”*
- The medium stress irrigated treatment scored 75.5 – “ *faint but sweet aroma, juicy, citrus flavour. Ok body”*

From this evidence it would appear that there are no detrimental effects on cupping quality from irrigation, nor does it provide any significant benefit in taste.

Mountain Top site
A 5 kg sample of cherry was harvested on 24th September from a range of trees in the sample row and ‘wet’ processed to parchment, then to DGB, before forwarding a sample to AASCA for taste testing using the internationally accepted SCAA cupping form.

The Mountain Top sample scored 81.75 out of 100. The Roastmaster provided the following comments: -
“sweet candy aroma, delicate acidity, slightly fermented. Bolder body, slight astringency, overall good balance” Ranking – very good.

Further taste testing is required to confirm this taste profile as trees mature, however it is encouraging that such a high quality score was achieved from young trees in their first production year.

4.9 Irrigation management

Unlike the climate of North Queensland coffee producing area that has a defined dry season, rainfall events at both sites during the trial period showed conclusively that a defined dry season with little or no rainfall couldn’t be relied upon in the sub-tropics. This point is illustrated in Figure 28 where the rainfalls for the supposed dry season are shown for the Newrybar site for the years 1999 – 2002

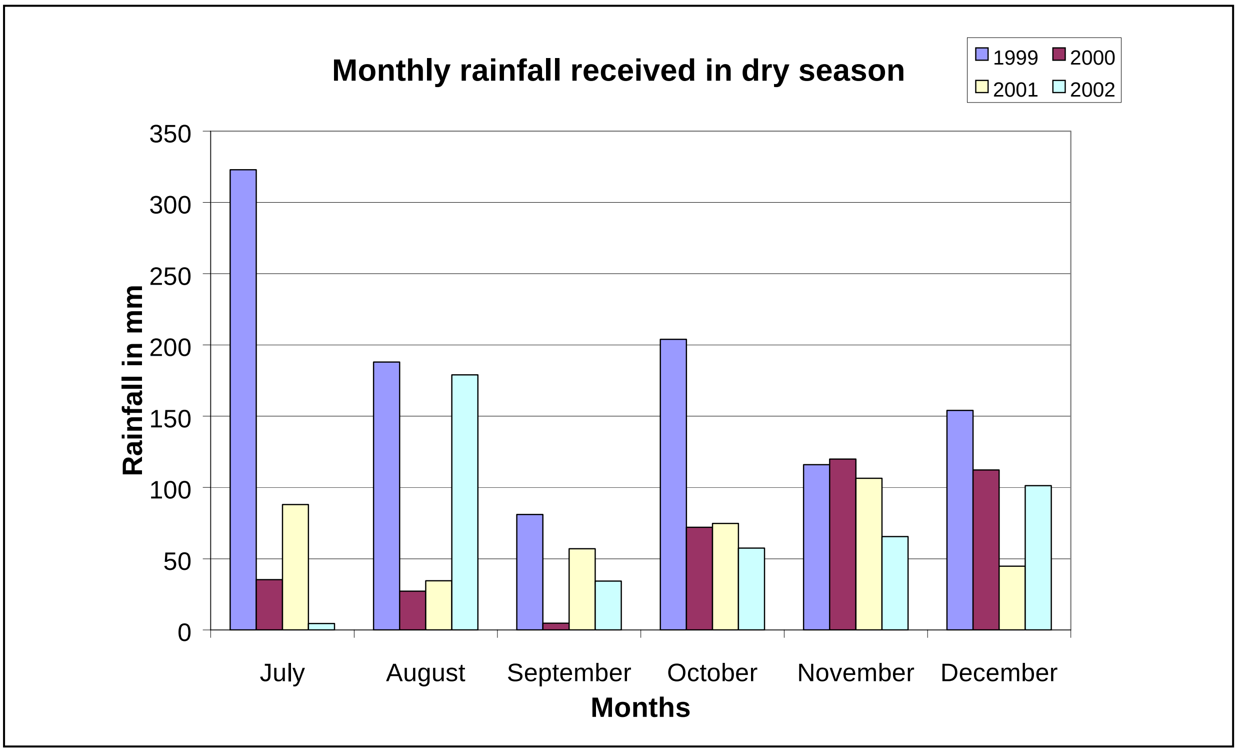


Figure 28 – Monthly rainfall recordings for Newrybar site in dry season 1999 - 2002

Drip irrigation of the trees at each site only provided water to between 19% and 21% of the total root area of the trees. The bulk of the roots are under water stress in a similar way to the non-irrigated treatments and flower blossoming was only triggered by rainfall, regardless of the water status of a small proportion of the root area. This means that irrigation to keep the trees healthy during crop development and ripening will have little effect on the blossoming pattern for next year's crop.

For this soil type and climate the following management options are available:

- To achieve maximum yield irrigation should be available throughout the year and water provided when soil moisture in the top 300 – 400 mm profile reaches 50% of the readily available water supply for this section of the profile.

- If water supply is limited then trees can be dried out to 100% of the readily available water supply in the top 300 – 400 mm of the soil profile with some reduction in yield but no change in quality or bean size.

To achieve this level of management it is important that growers use a reliable soil moisture-measuring device. It is strongly recommended that continuous capacitance probes or their equivalent become the industry standard. User groups should be established to exchange information and improve the scheduling skills of the industry.

Single row driplines with dripper spacings that provide a continuous wetted strip along the row with either 1.6 or 2.3 litre/hour dripper discharge will allow the trees to extract sufficient water to meet their requirements.

As coffee trees in full sun are gross feeders, fertigation is strongly recommended to provide adequate nutrition throughout the growing season, preventing carbohydrate depletion and dieback. Even during 'the wet season' fertiliser can still be applied at higher concentrations in short irrigations to meet nutritional needs and minimise any nutrient leaching caused by excessive rainfall events.

5. Implications for Industry

5.1.1 Community and environmental

The expansion of the coffee industry in the sub-tropics is limited by a shortage of frost-free, protected land with adequate secure water supplies and low to moderate slope to suit machine harvesting. High land prices and competing land uses including increasing urbanisation are eroding the area available for commercial production of a high quality product with minimal pest and disease pressure.

Community pressure will make sure that the development of this industry will have minimal impact on the environment. A high level of management is therefore necessary in water and nutrition application to minimise any impacts on the catchment while maintaining high production levels of quality bean.

Under the current development of the water reform process, producers will need to secure their water supplies with either an on farm storage or a reliable groundwater supply. The returns/megalitre achieved in this trial would suggest that the payback period for this additional infrastructure would be well within normal business timeframes.

It is important that the industry establish the best managing practices for growing and processing coffee to maintain consistent quality that will sustain markets for this speciality product at a return that will provide stability to the industry. This has been done successfully by the Australian wine industry and many of the standards set by this industry could be adopted by the coffee industry.

5.1.2 On farm

- Unlike the climate of North Queensland coffee producing area, with its defined dry season which is favourable for managing flowering, rainfall events at both sites during the trial period showed conclusively that a defined dry season with little or no rainfall couldn't be relied upon in the sub-tropics. As a consequence flowering cannot be manipulated with irrigation in this region.

- The average benefits/annum/ha of drip irrigation is between $10,300 for the low stress treatment and $7,600 for the medium stress treatment (based on $8.15/kg DGB return). The cost of an irrigation system depends on the distance of the plantation from the water source, the topography, soil type and complexity of the system. A fully automated installed system complete with flushlines, fertigation and automatic backwash filtration will cost about $3.00/tree (2003). At the current spacing of 2963 tree/ha this translates to $8,890/ha.

- Well designed drip irrigation and fertigation can generate up to $10,000 per megalitre of water per annum used (for DGB) which compares well with many irrigated crops in Australia. The cost of an on farm storage will depend on the site and soil type, cost of earthworks/M^3 and the volume of water required. This could range between $1300 and $2700/megalitre.

- On farm soil moisture monitoring is strongly recommended rather than relying on weather based scheduling systems.

- The sub-tropics with its normal cloud cover during mid summer and late autumn during the rainy season could be reducing the effects of high temperatures and high solar radiation effects on the photosynthetic rates. This could account for the larger bean sizes recorded here compared to North Queensland.

- The data collected in this project would suggest that coffee trees are well suited to our climate with its unreliable and variable rainfall. The trees will survive dry periods and can respond quickly to moisture application with a highly developed fine root system that is located in the top 300 mm provided these roots are protected with an effective layer of mulch.

6. Recommendations

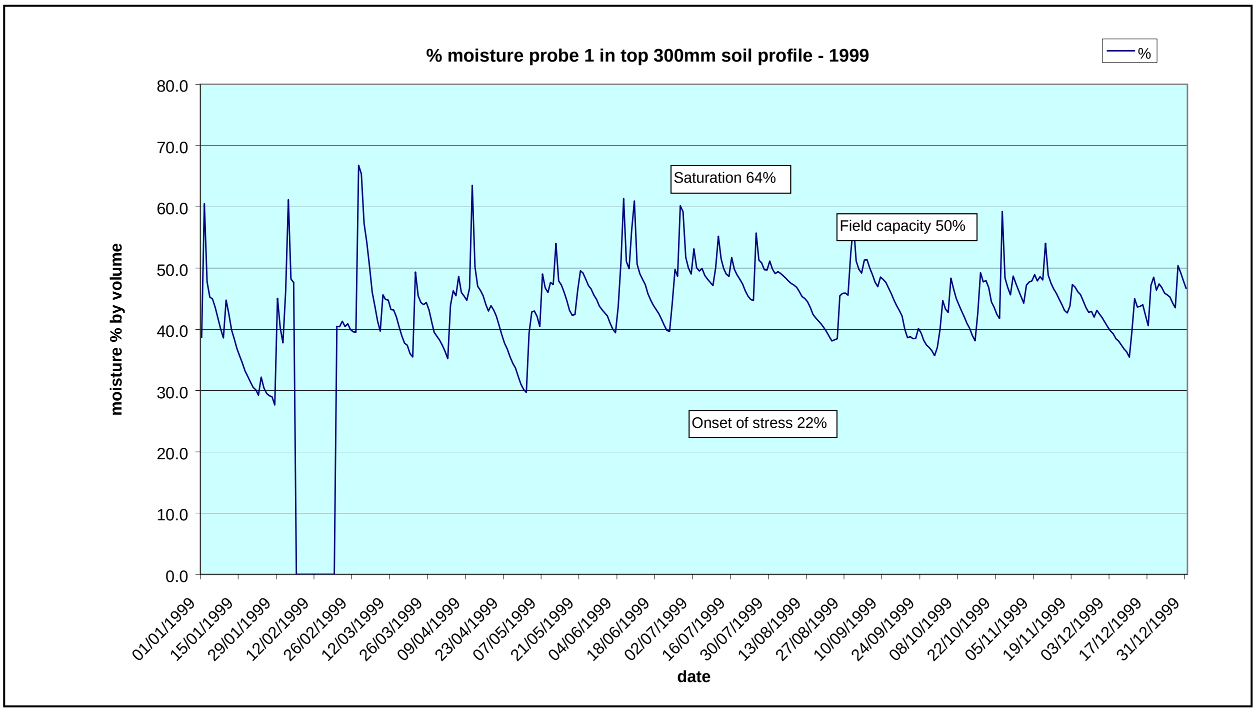
As part of this project an extension booklet is being prepared by NSW Agriculture for "***The best management guidelines for irrigation of coffee in the sub-tropics"*** setting out:

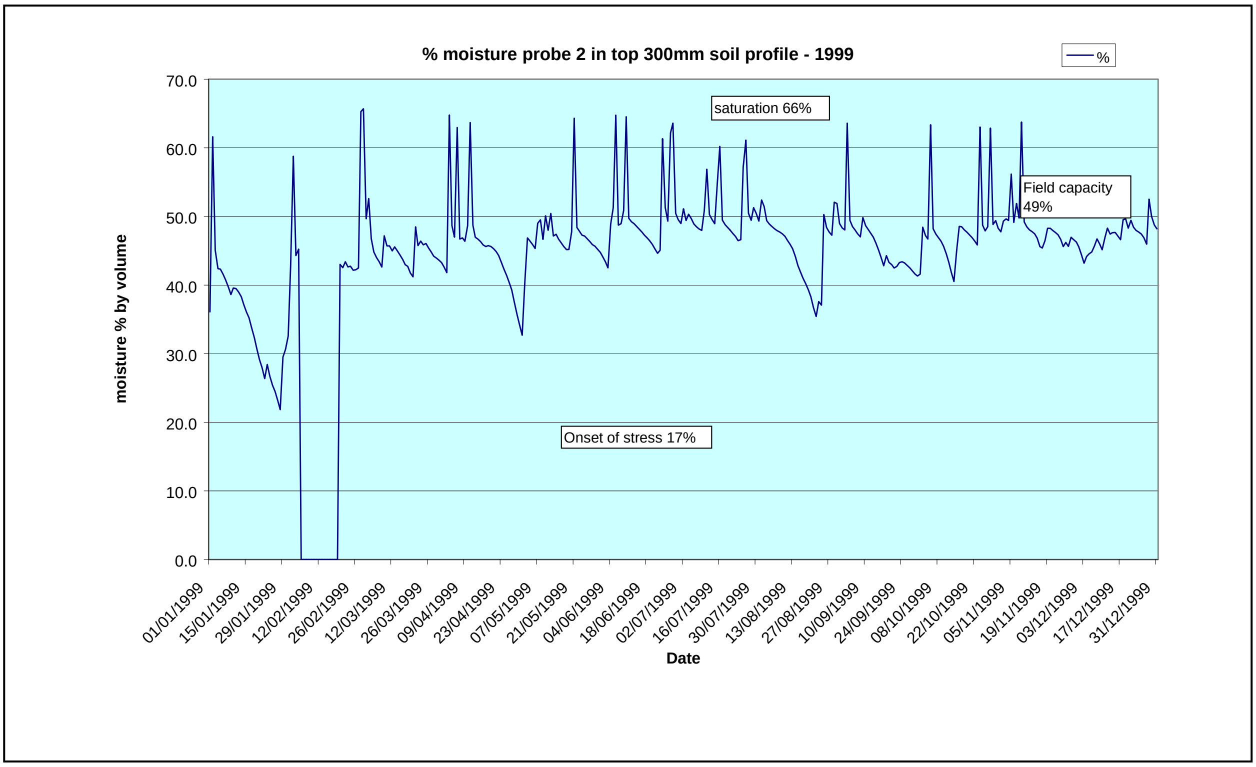
- the benefits of drip irrigation for coffee
- water requirements of coffee
- Costs and benefits of irrigation
- Irrigation scheduling for coffee plantation
- Design, monitoring and maintaining a of drip irrigation system
- Fertigation of coffee trees.

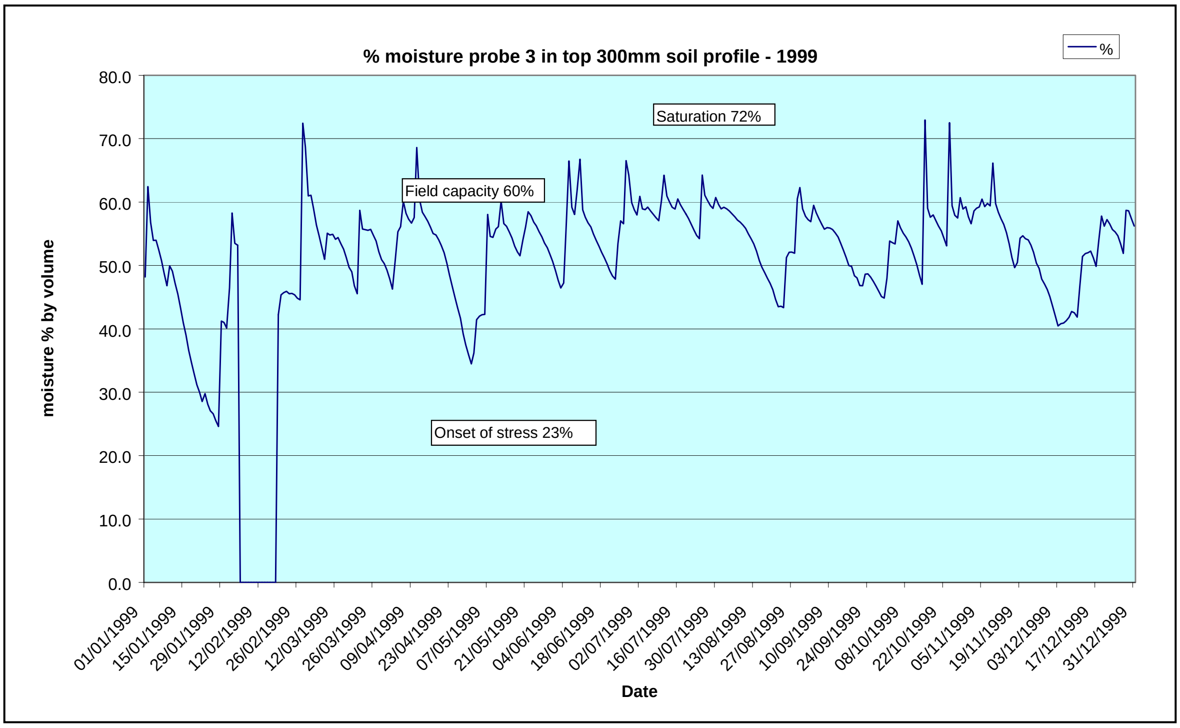
It will be important that the industry runs workshops and conducts practical demonstrations to upskill new entrants into the industry with the level of management and knowledge that will help them to establish and expand the industry. To achieve the goal of a sustainable quality coffee industry it will be important that growers share information and support R & D on all facets of production.

7. Appendices

The midnight soil moisture readings for each of the EnviroSCAN probes have been tabulated on the following charts.



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%
Saturation 72%
Field capacity 60%
Onset of stress 23%
moisture % by volume
80.0
70.0
60.0
50.0
40.0
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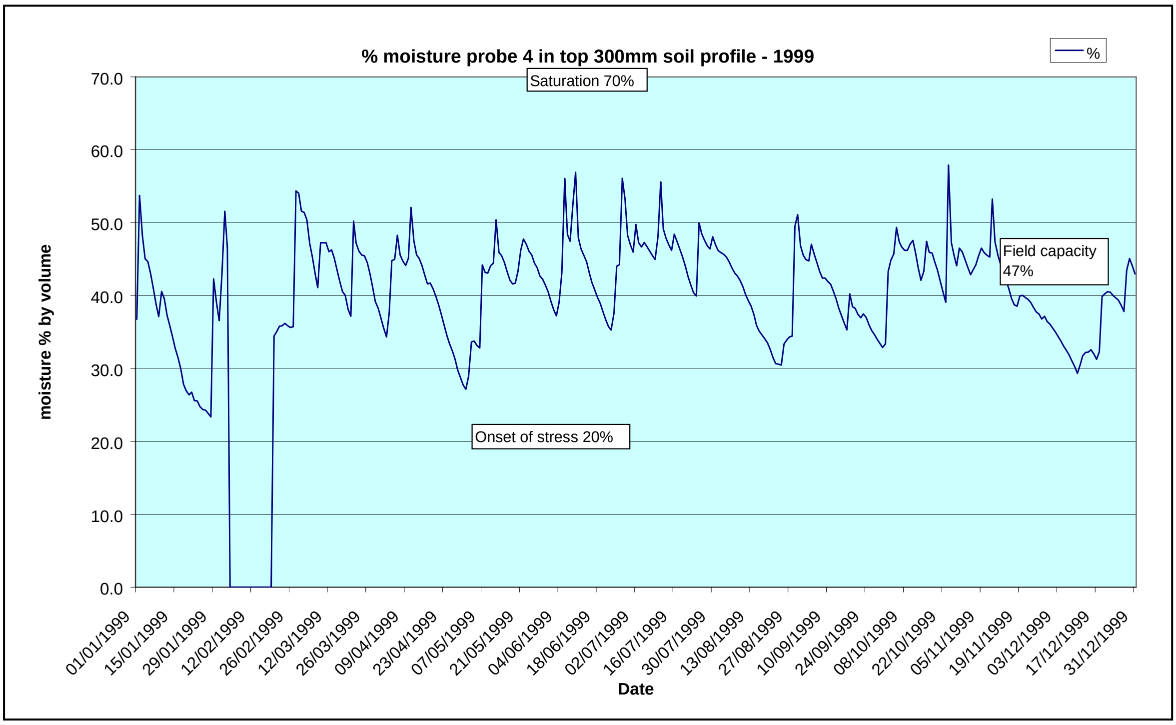
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%
Saturation 70%
Field capacity 47%
Onset of stress 20%
moisture % by volume
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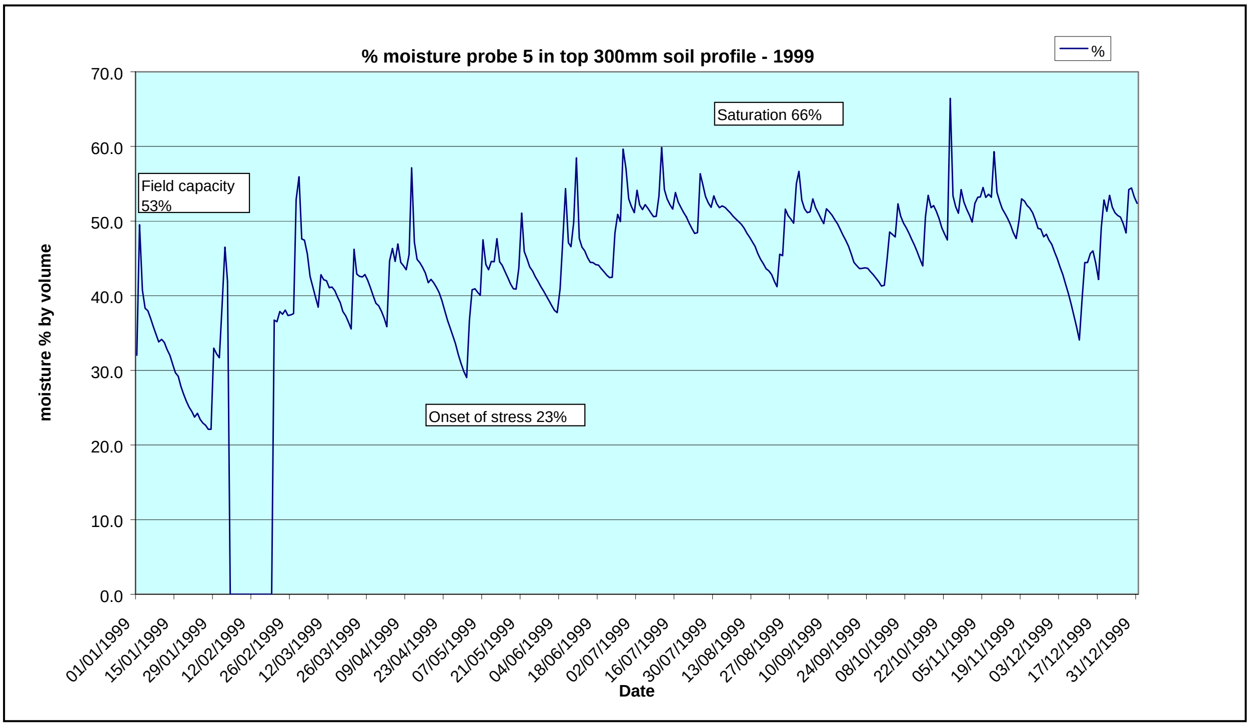
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Saturation 66%
Field capacity
53%
Onset of stress 23%
moisture % by volume
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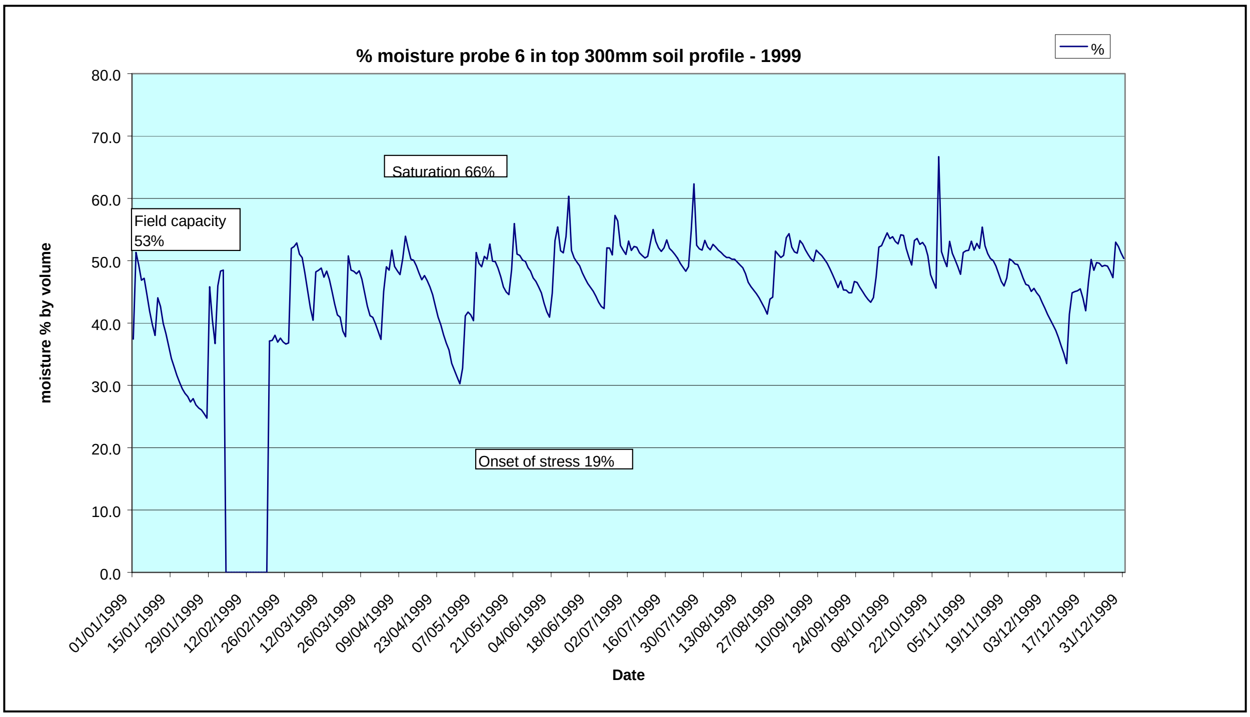
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Saturation 66%
Field capacity
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Onset of stress 19%
moisture % by volume
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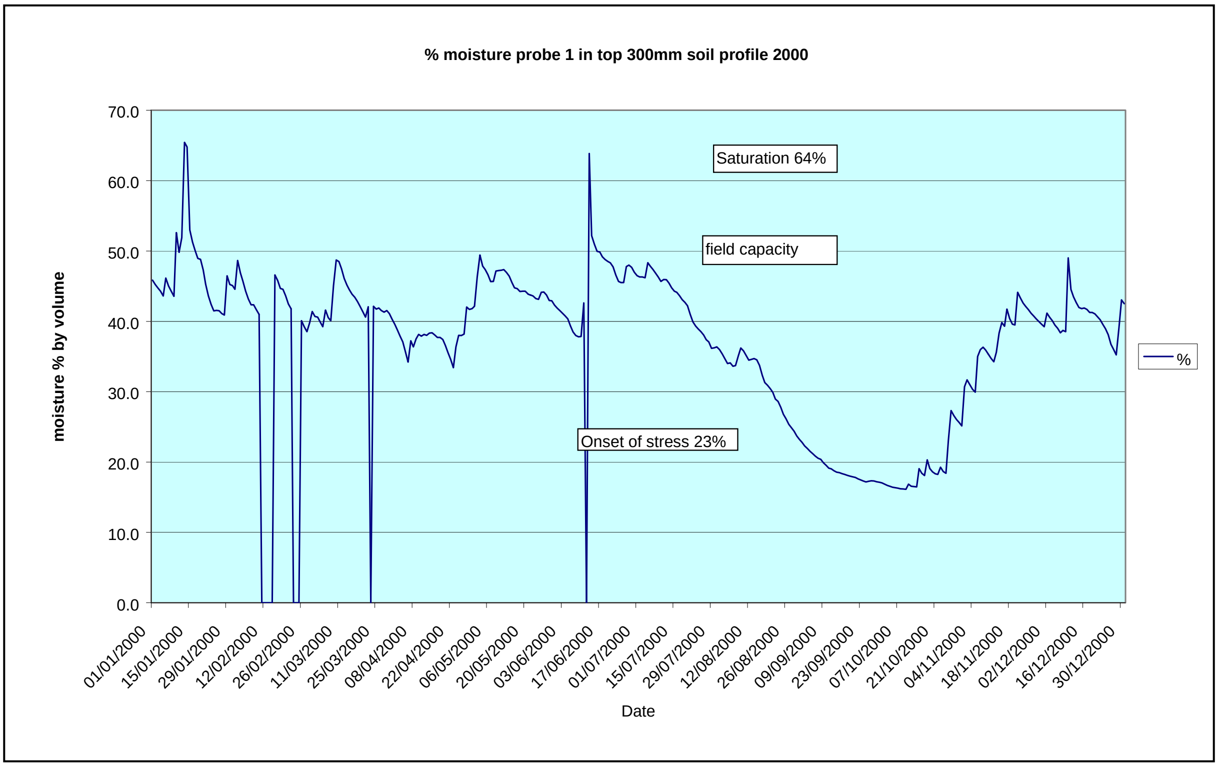
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Date
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field capacity
Onset of stress 23%
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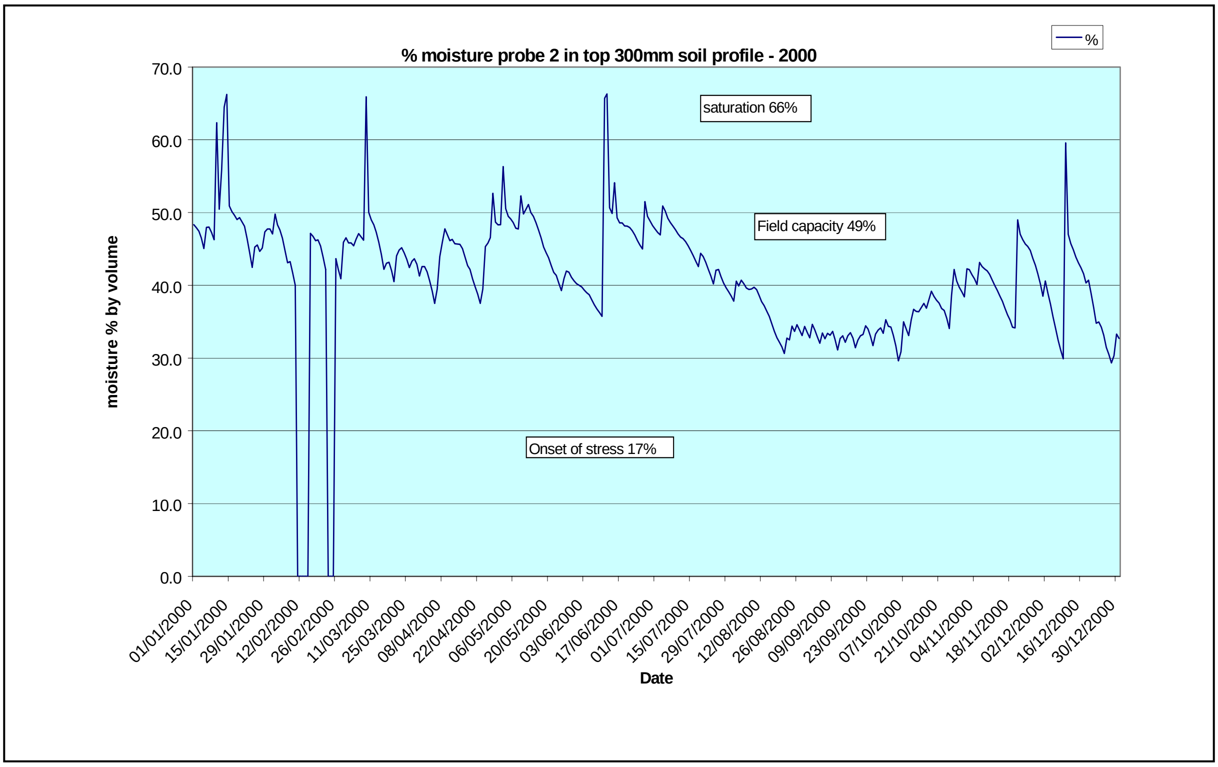
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Field capacity 49%
Onset of stress 17%
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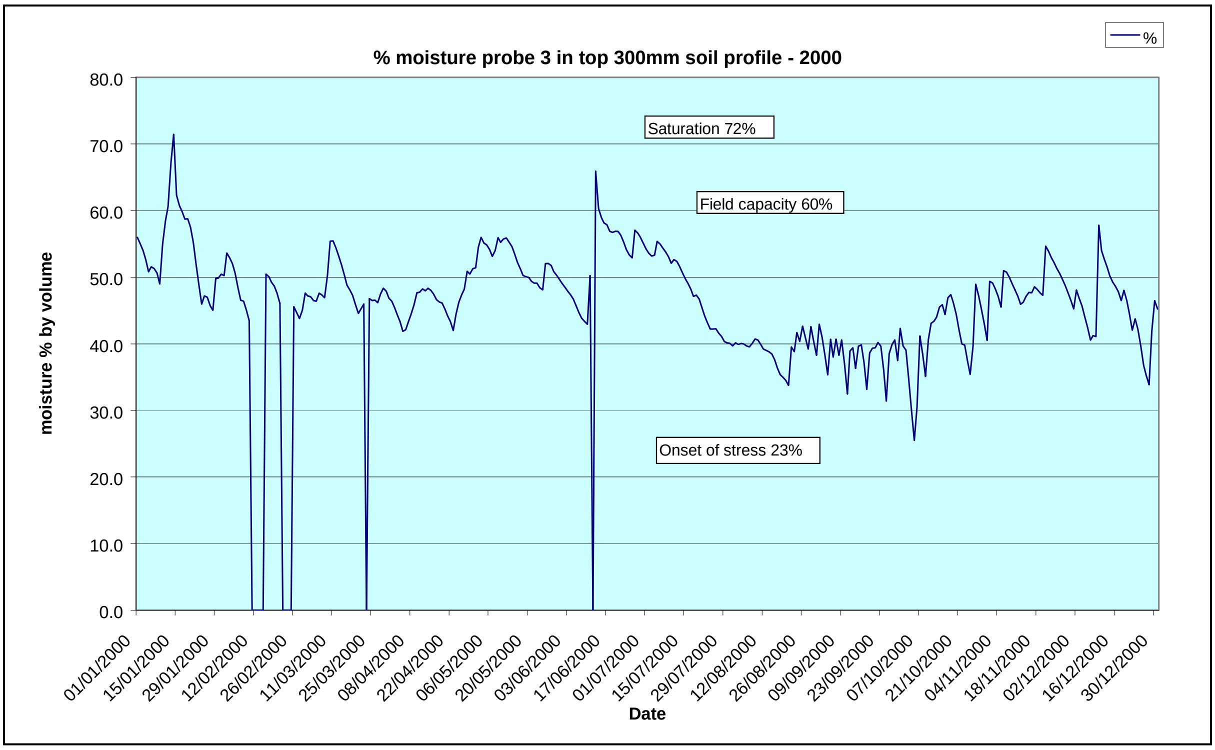
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Saturation 72%
Field capacity 60%
Onset of stress 23%
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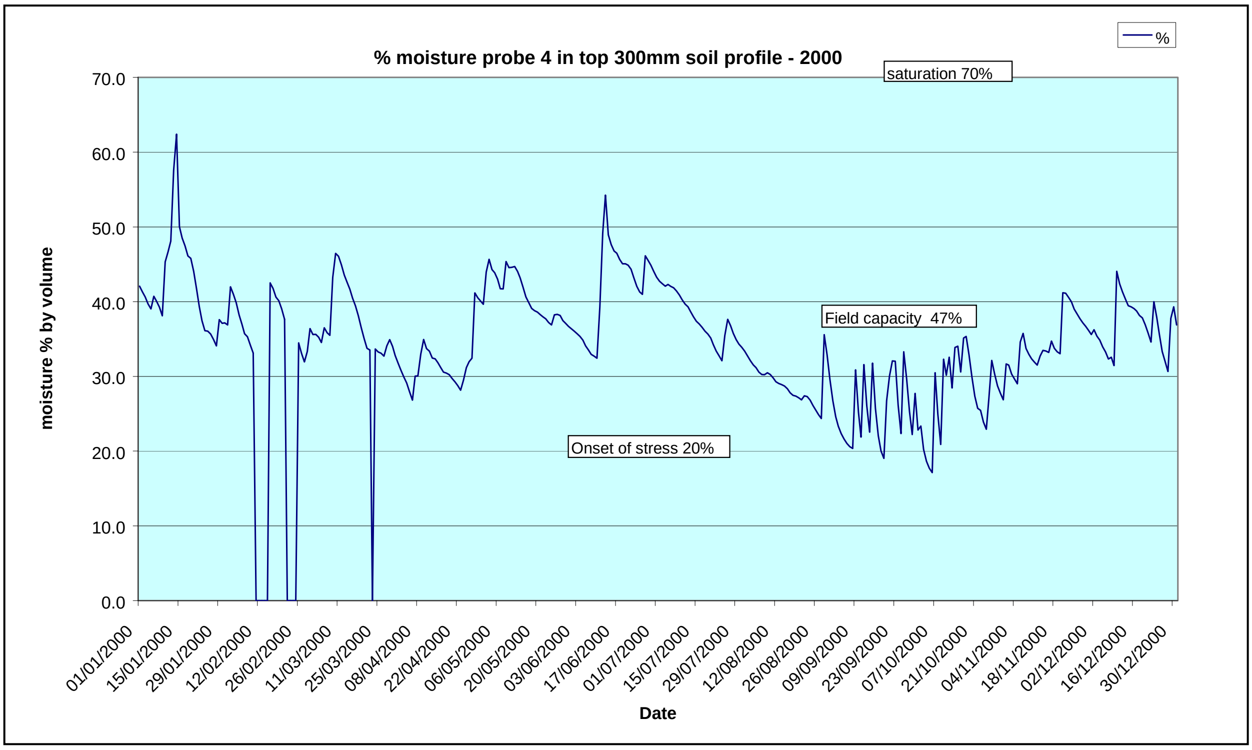
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Field capacity 47%
Onset of stress 20%
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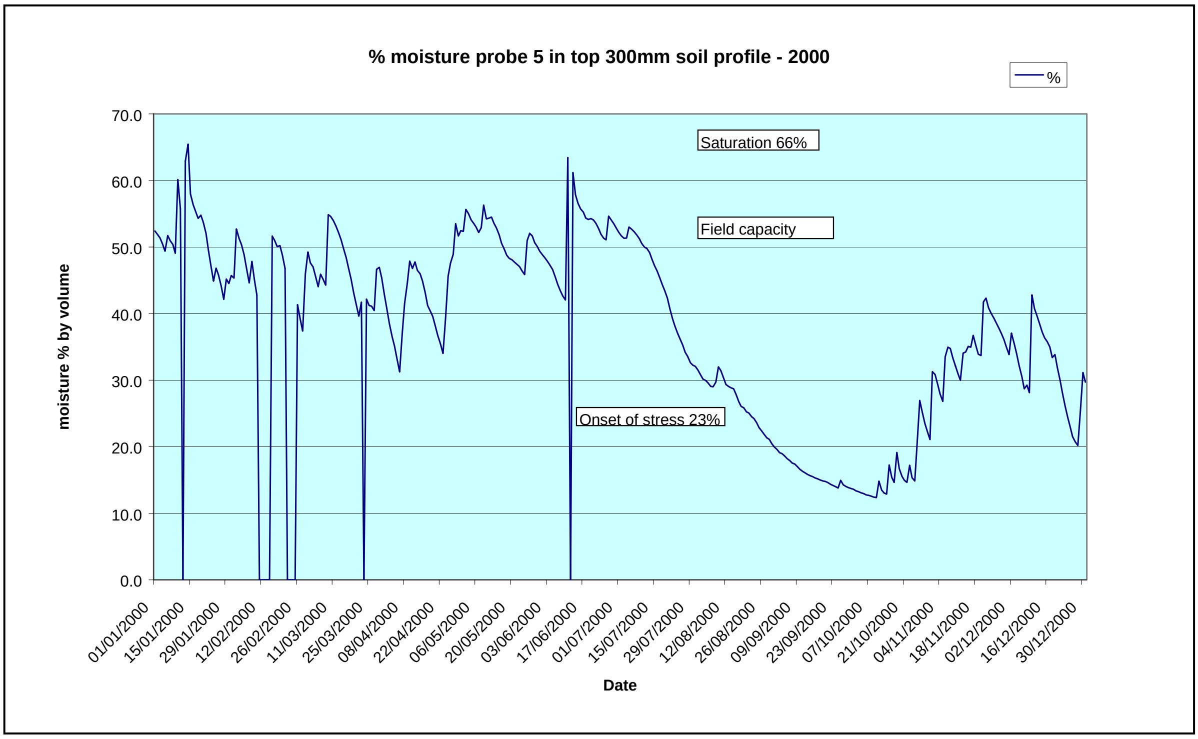
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Field capacity
Onset of stress 23%
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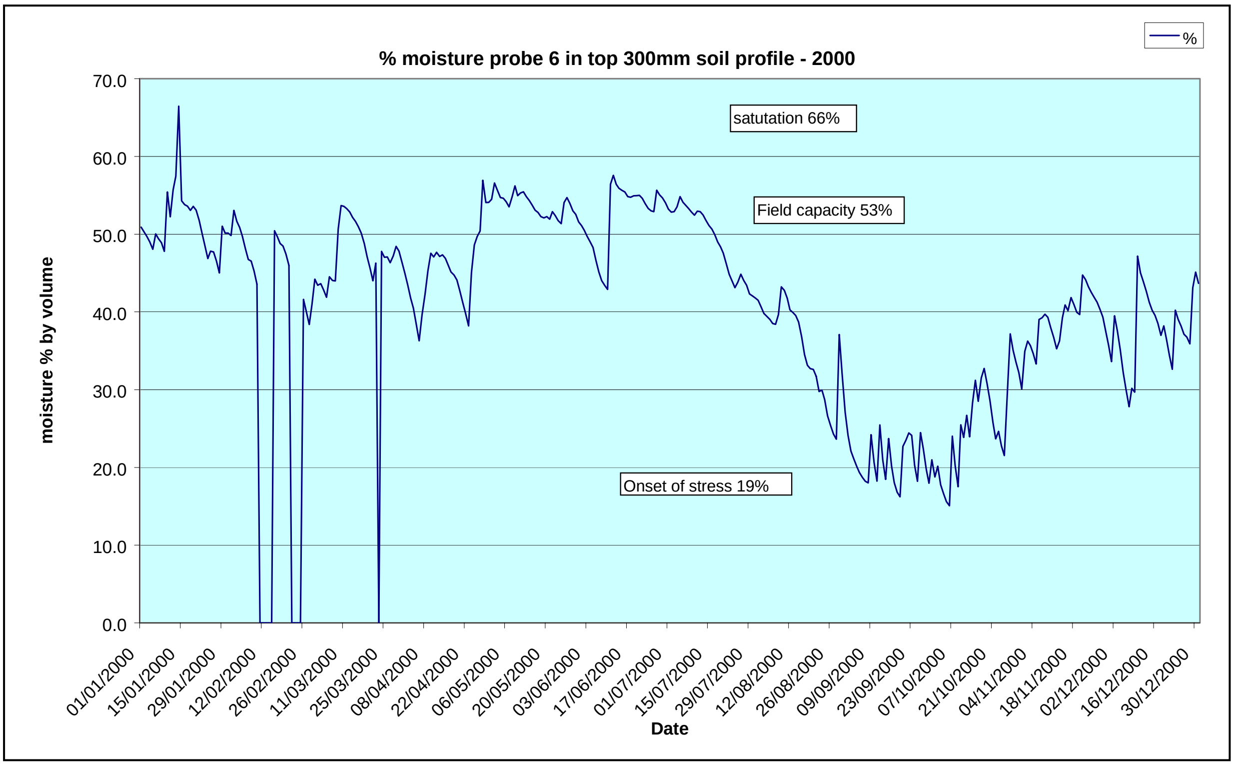
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Field capacity 53%
Onset of stress 19%
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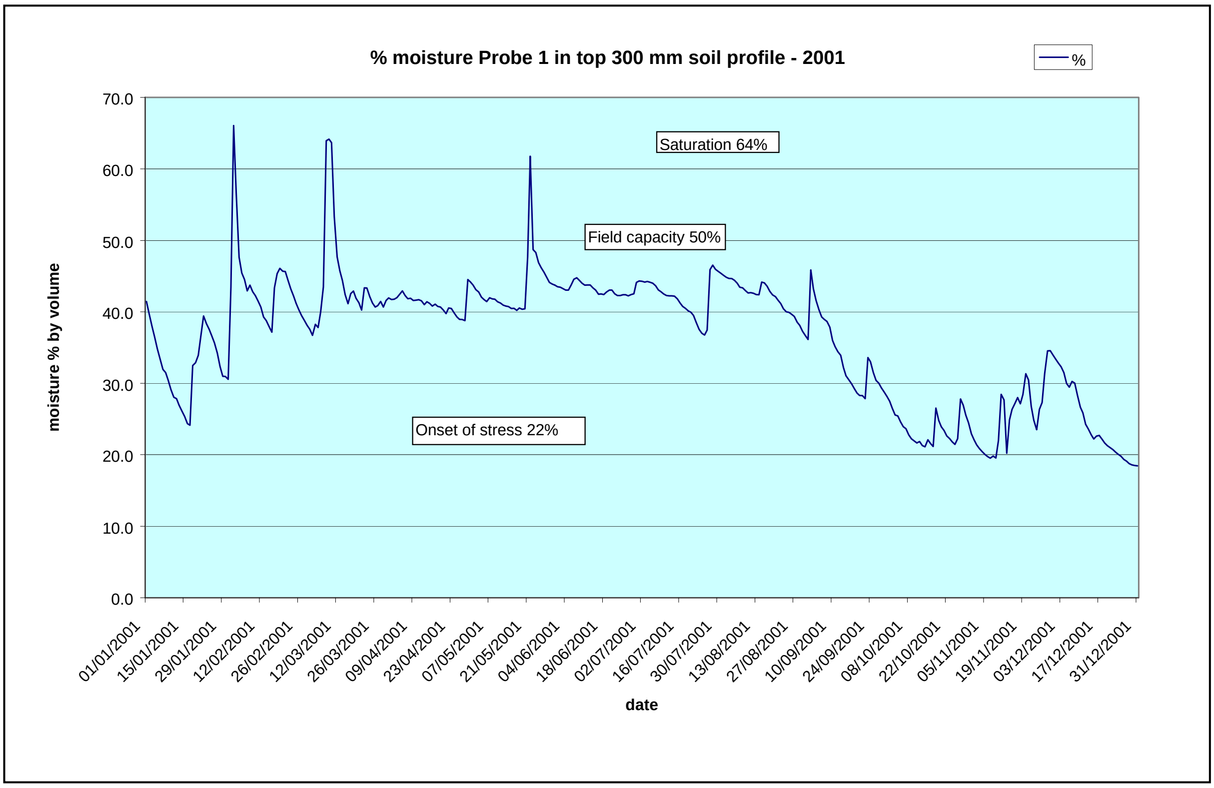
Date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%
Saturation 64%
Field capacity 50%
Onset of stress 22%
moisture % by volume
date
70.0
60.0
50.0
40.0
30.0
20.0
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01/01/2001
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29/01/2001
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19/11/2001
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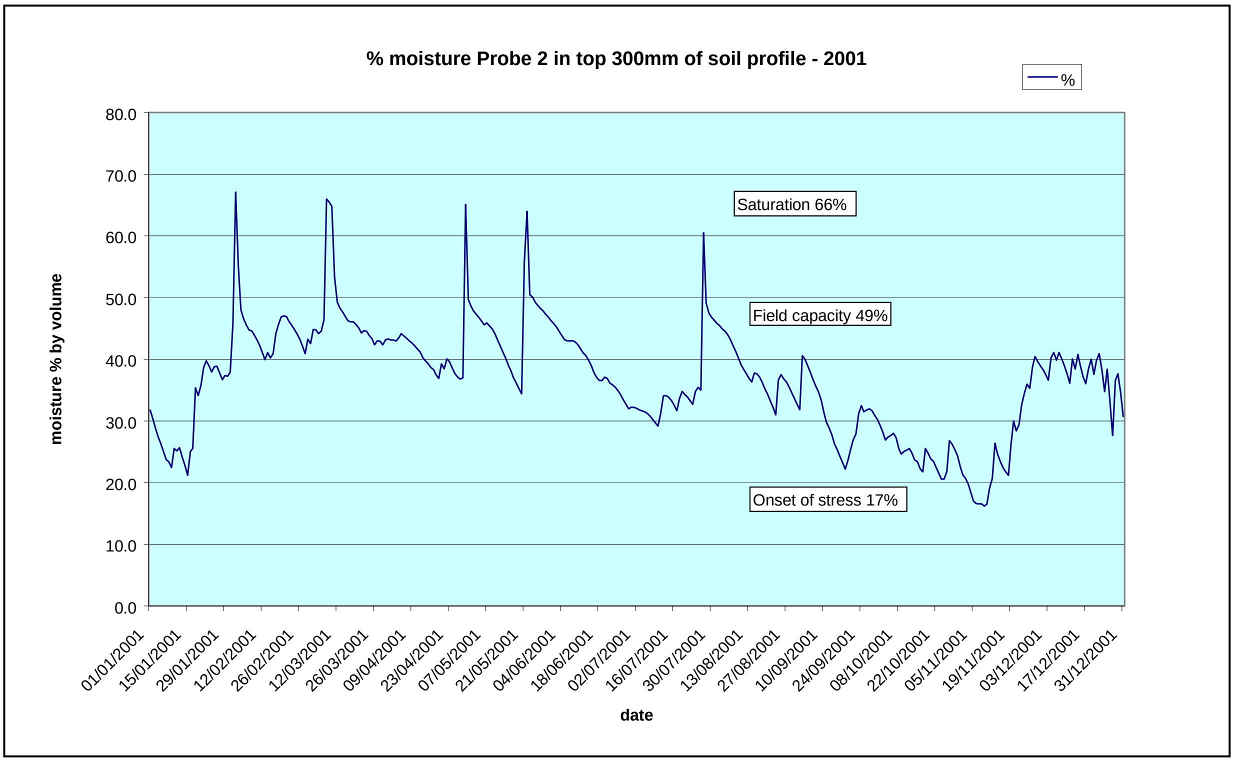
17/12/2001
31/12/2001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%
Saturation 66%
Field capacity 49%
Onset of stress 17%
moisture % by volume
date
80.0
70.0
60.0
50.0
40.0
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01/01/2001
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26/02/2001
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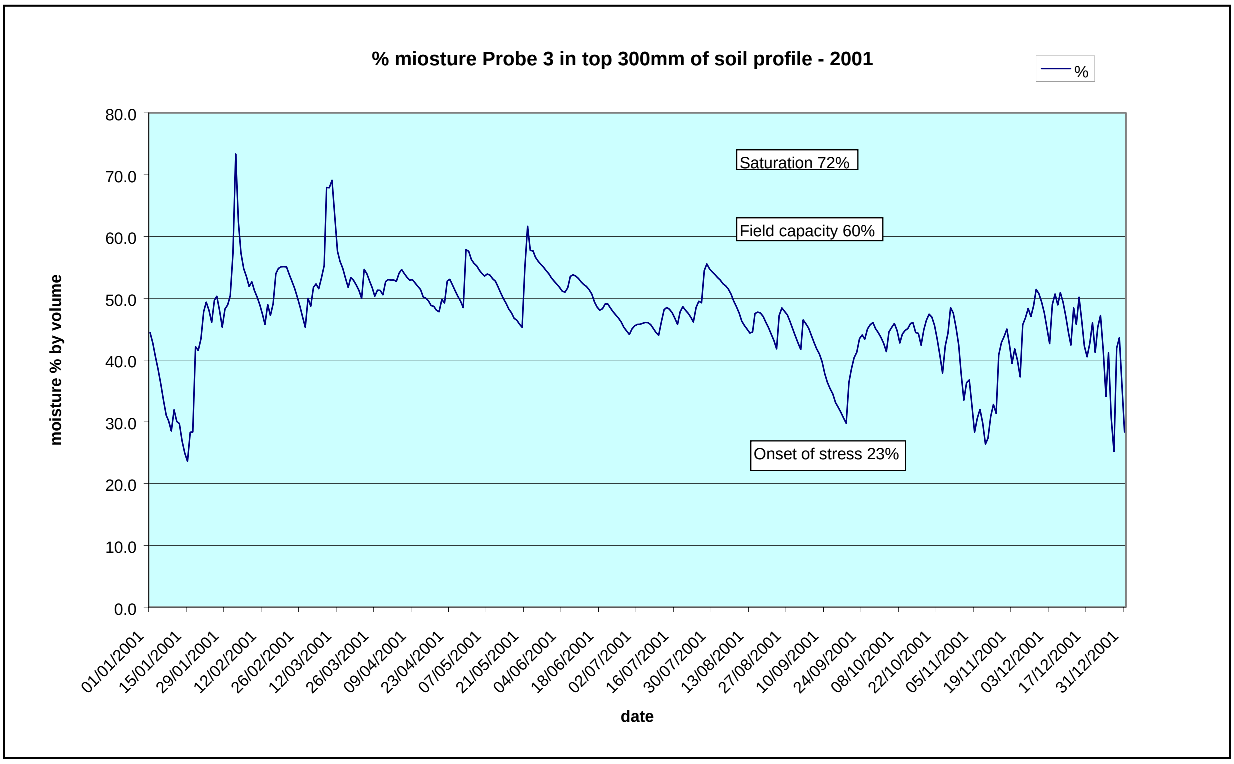

% miosture Probe 3 in top 300mm of soil profile - 2001
%
Saturation 72%
Field capacity 60%
Onset of stress 23%
moisture % by volume
80.0
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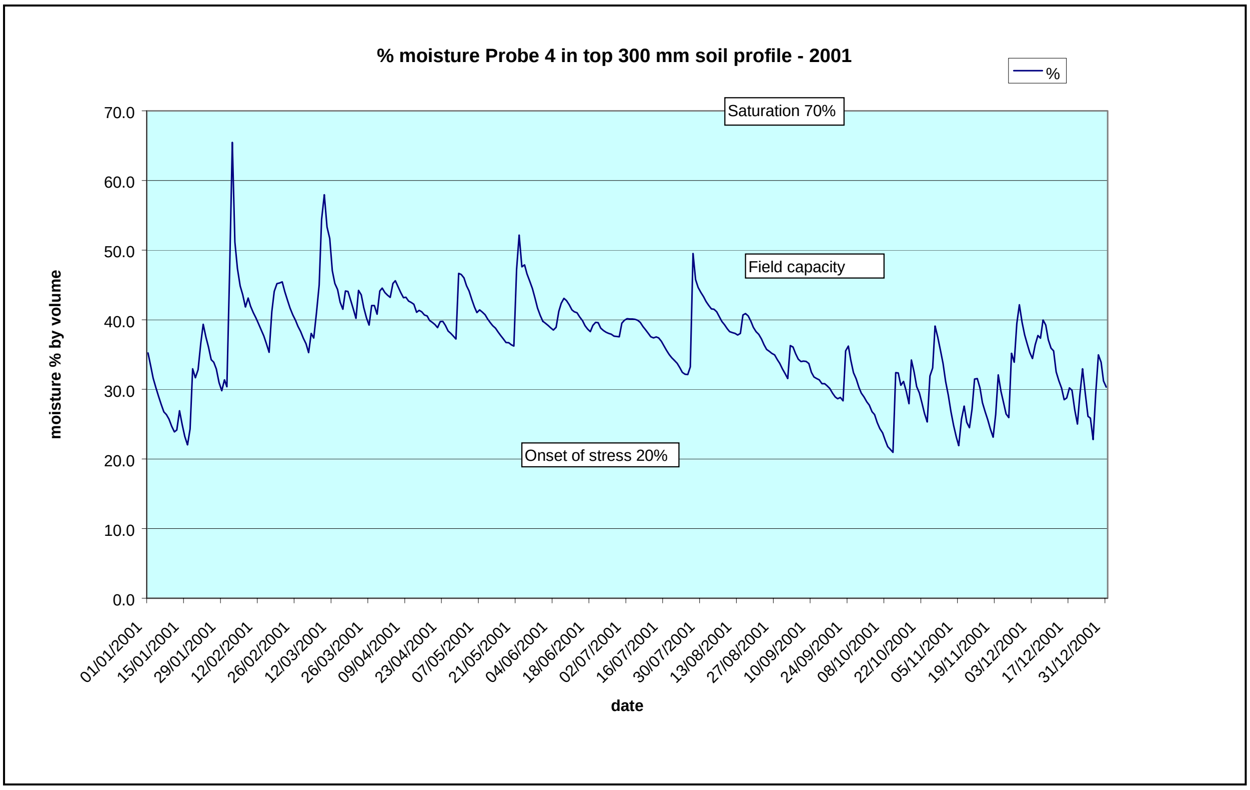

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%
Saturation 70%
Field capacity
Onset of stress 20%
moisture % by volume
70.0
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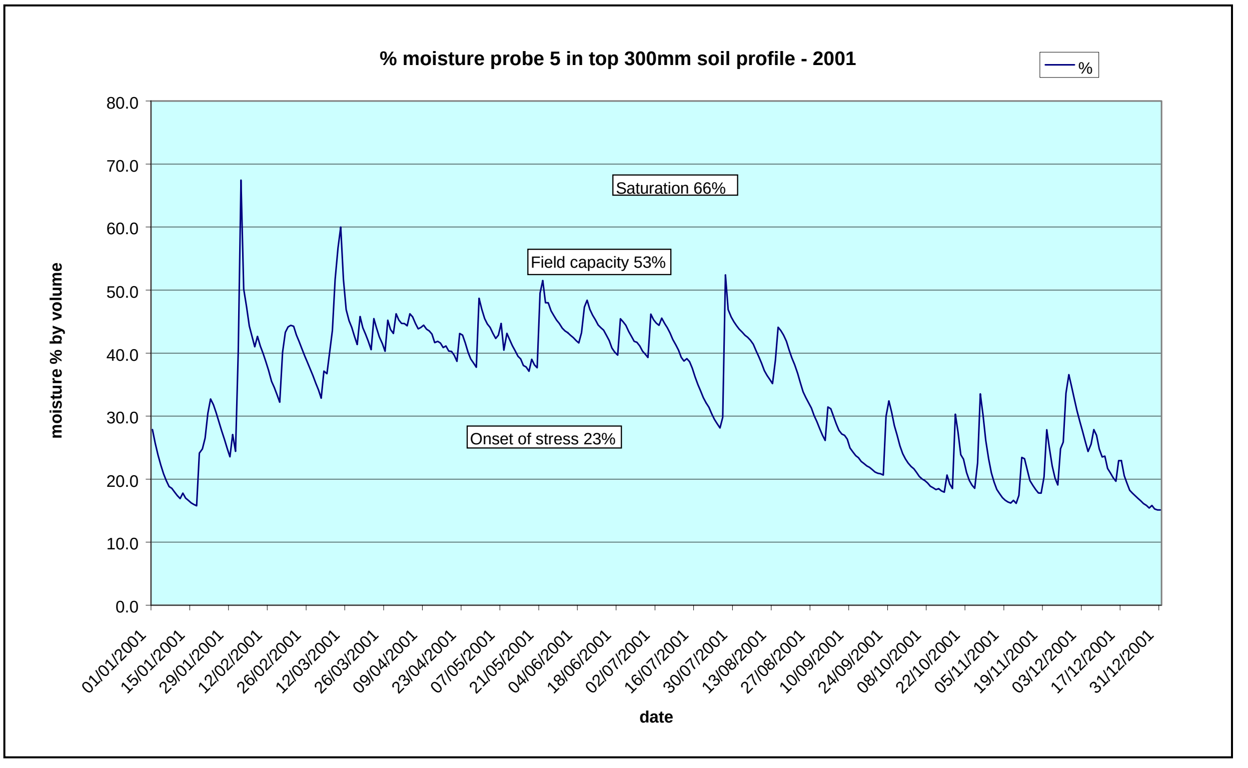
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moisture % by volume
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Saturation 66%
Field capacity 53%
Onset of stress 23%
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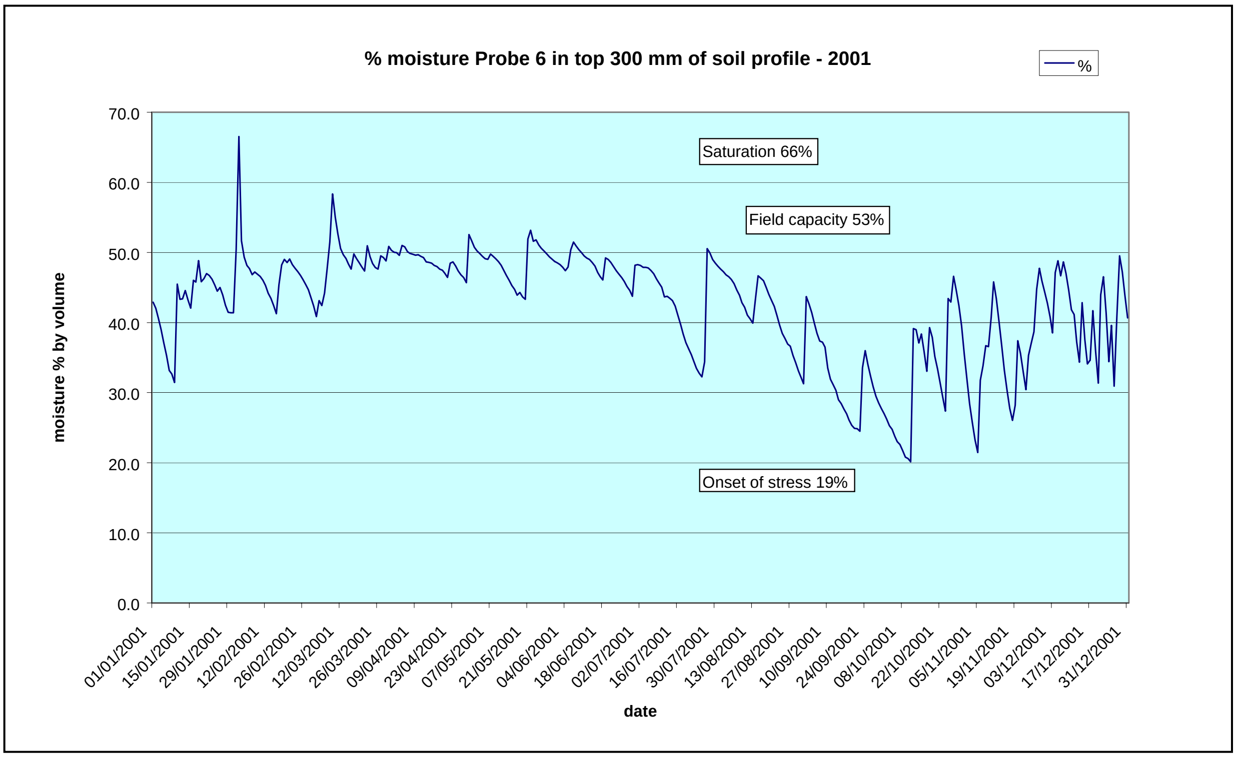
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%
moisture % by volume
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Saturation 66%
Field capacity 53%
Onset of stress 19%
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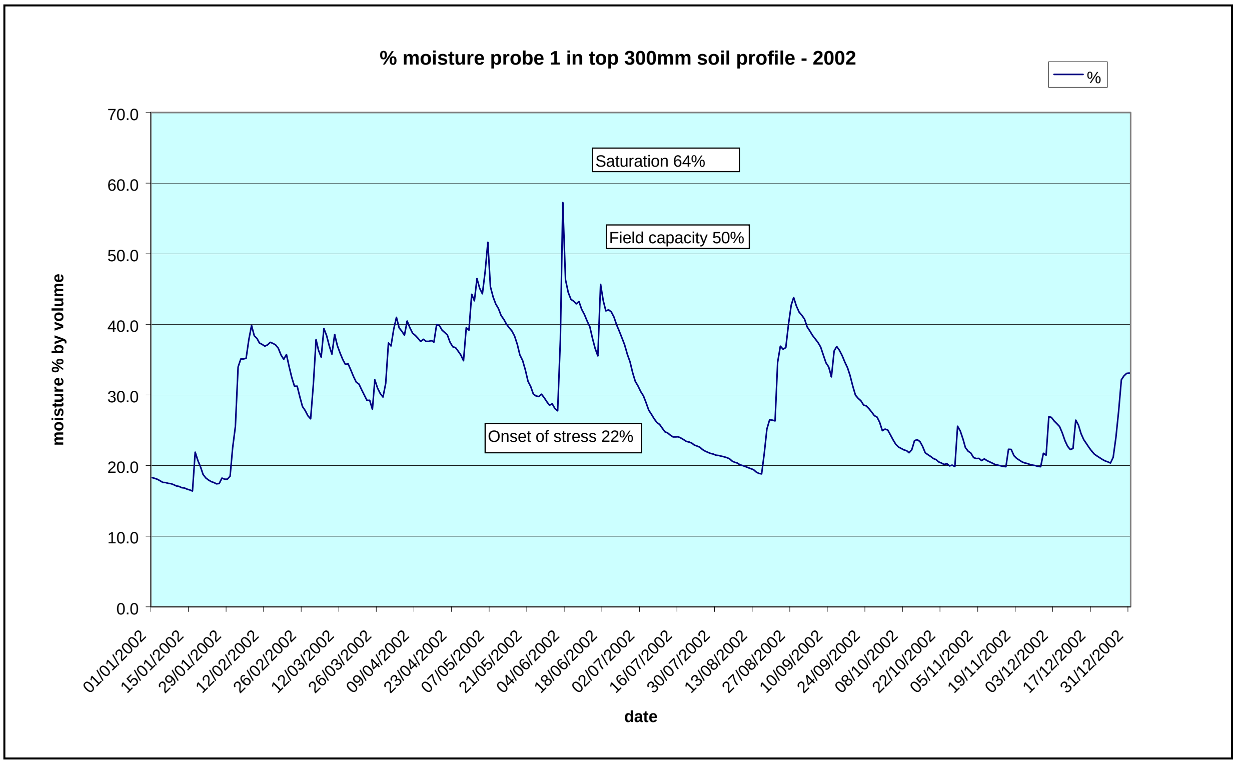

% moisture probe 1 in top 300mm soil profile - 2002
%
Saturation 64%
Field capacity 50%
Onset of stress 22%
moisture % by volume
70.0
60.0
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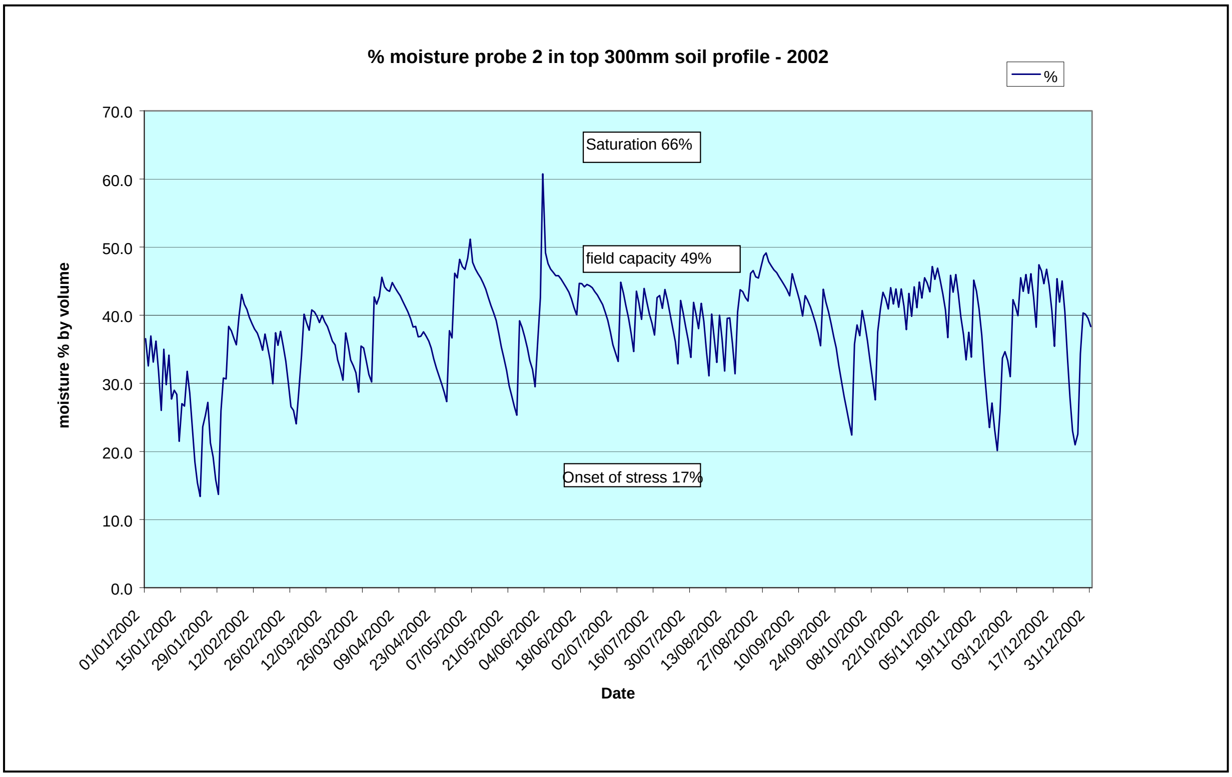

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%
Saturation 66%
field capacity 49%
Onset of stress 17%
moisture % by volume
70.0
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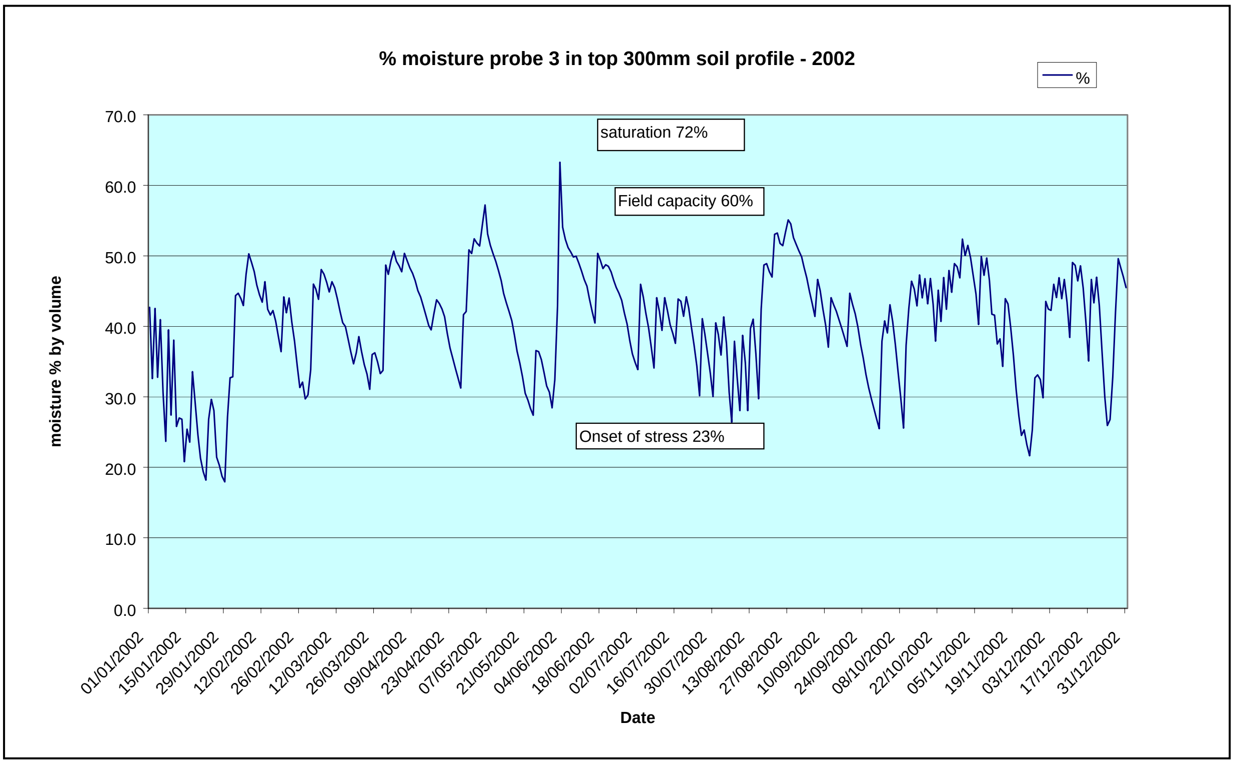

% moisture probe 3 in top 300mm soil profile - 2002
%
saturation 72%
Field capacity 60%
Onset of stress 23%
moisture % by volume
70.0
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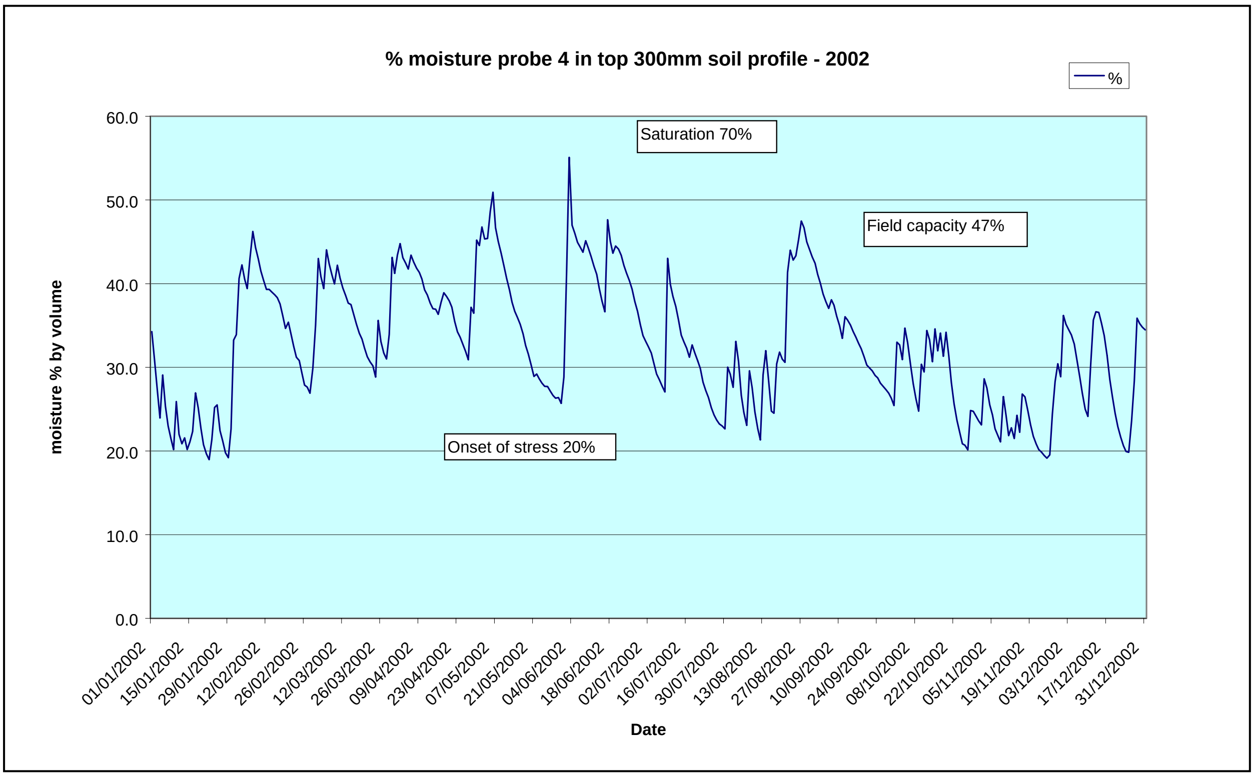

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%
Saturation 70%
Field capacity 47%
Onset of stress 20%
moisture % by volume
60.0
50.0
40.0
30.0
20.0
10.0
0.0
01/01/2002
15/01/2002
29/01/2002
12/02/2002
26/02/2002
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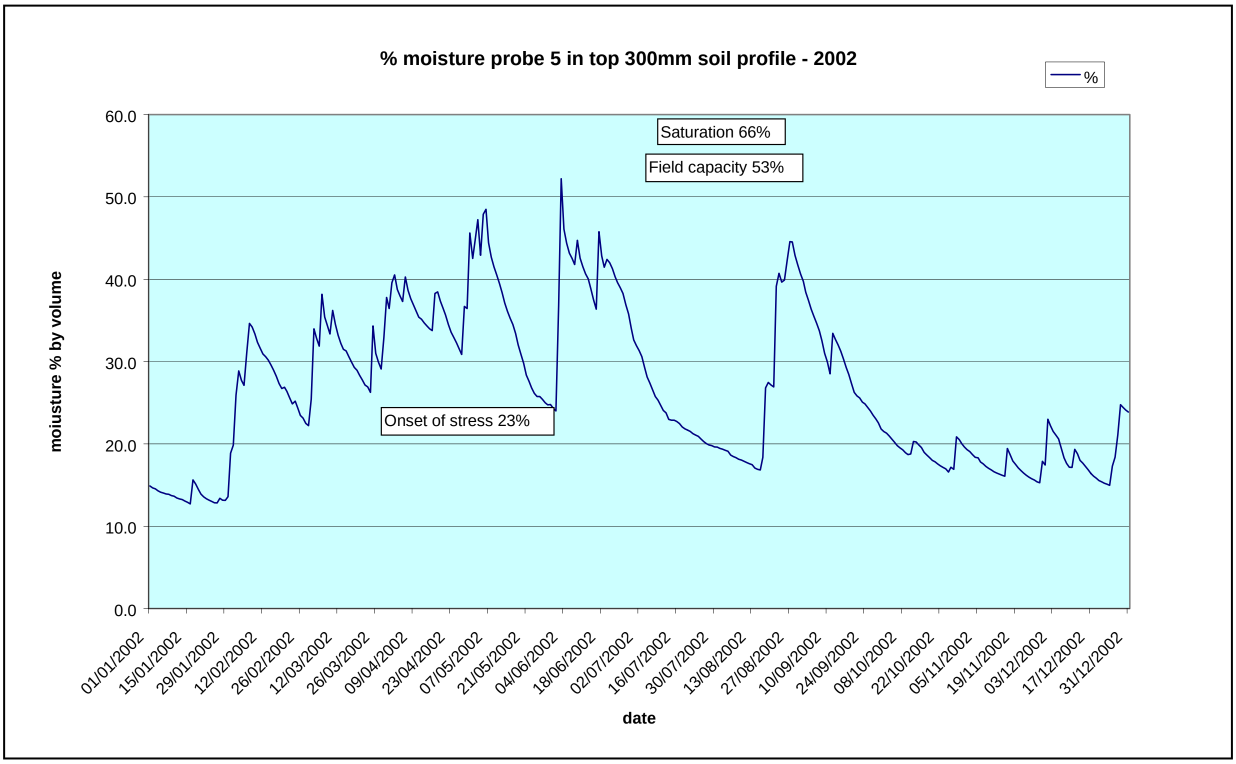

% moisture probe 5 in top 300mm soil profile - 2002
%
Saturation 66%
Field capacity 53%
Onset of stress 23%
moiusture % by volume
60.0
50.0
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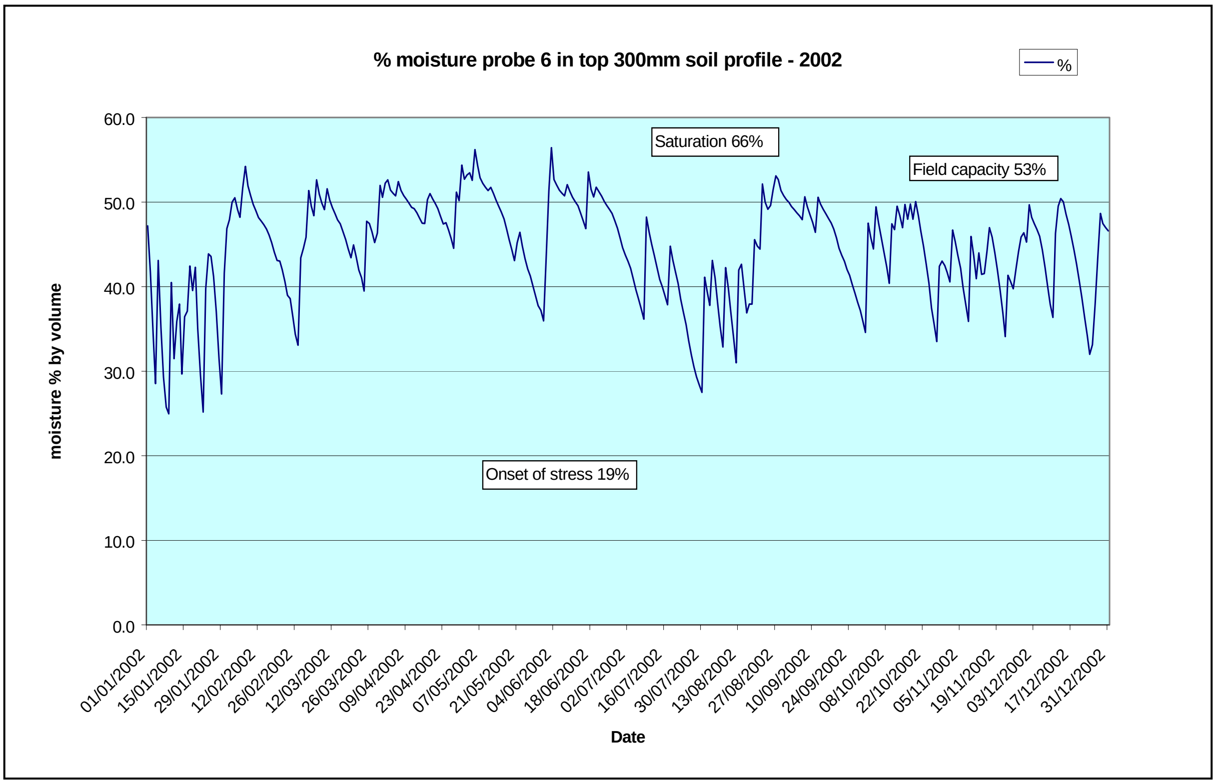

% moisture probe 6 in top 300mm soil profile - 2002
%
Saturation 66%
Field capacity 53%
Onset of stress 19%
moisture % by volume
60.0
50.0
40.0
30.0
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01/01/2002
15/01/2002
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12/02/2002
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24/09/2002
08/10/2002
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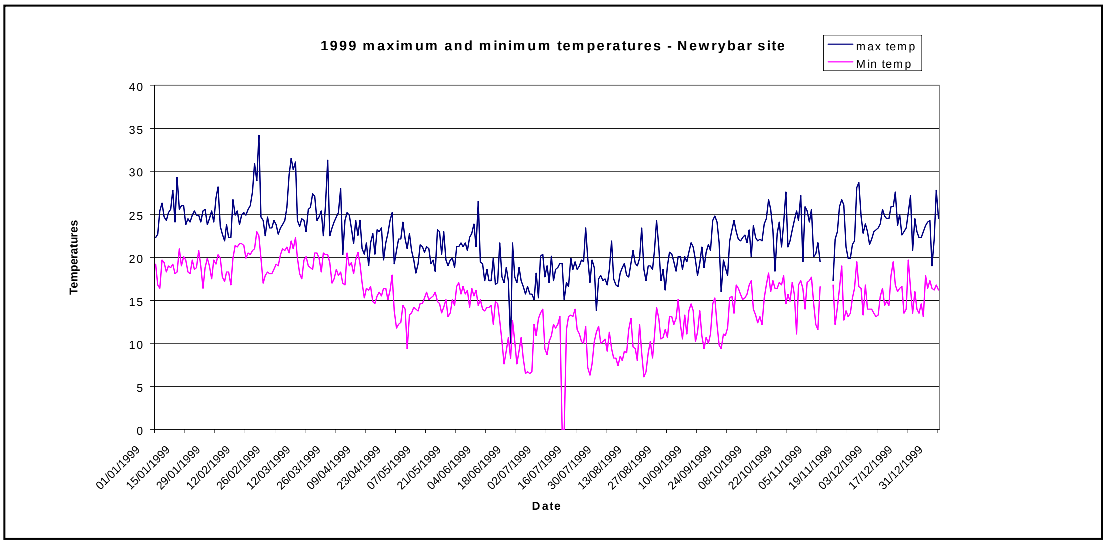
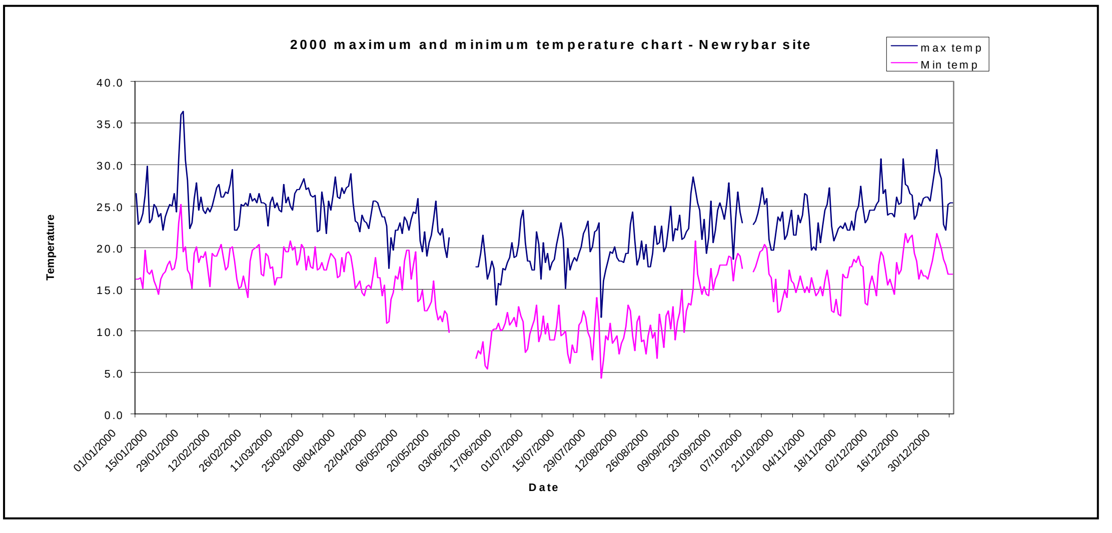
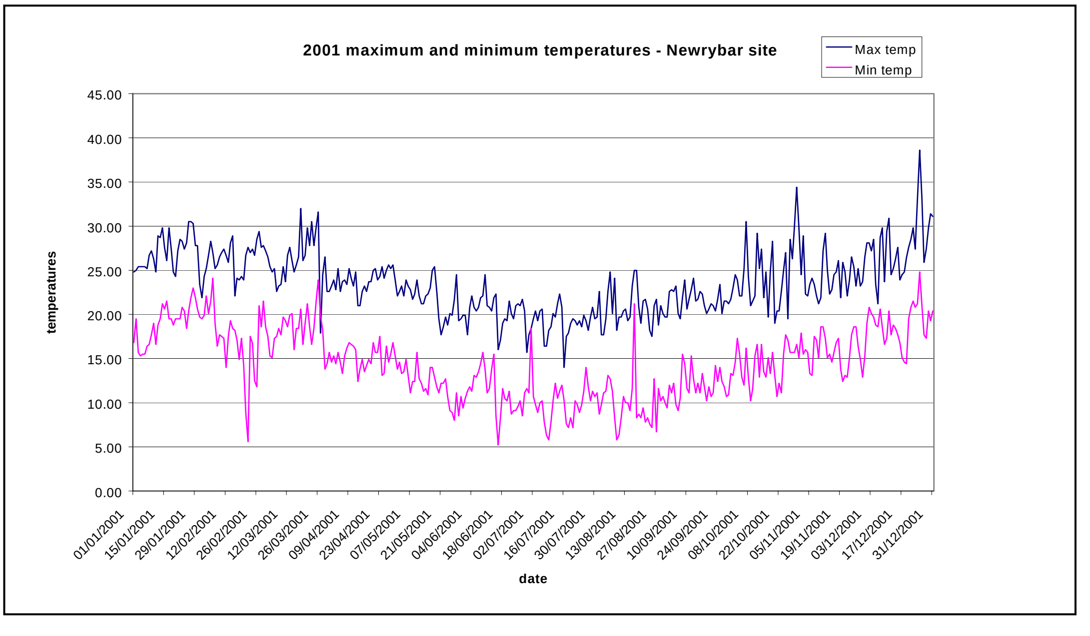
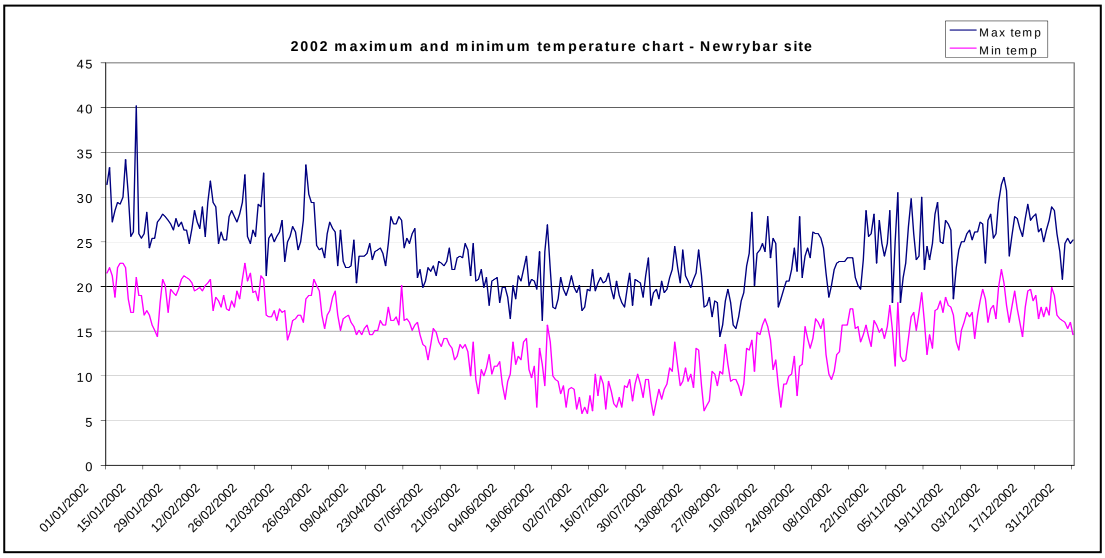
17/12/2002
31/12/2002
Date

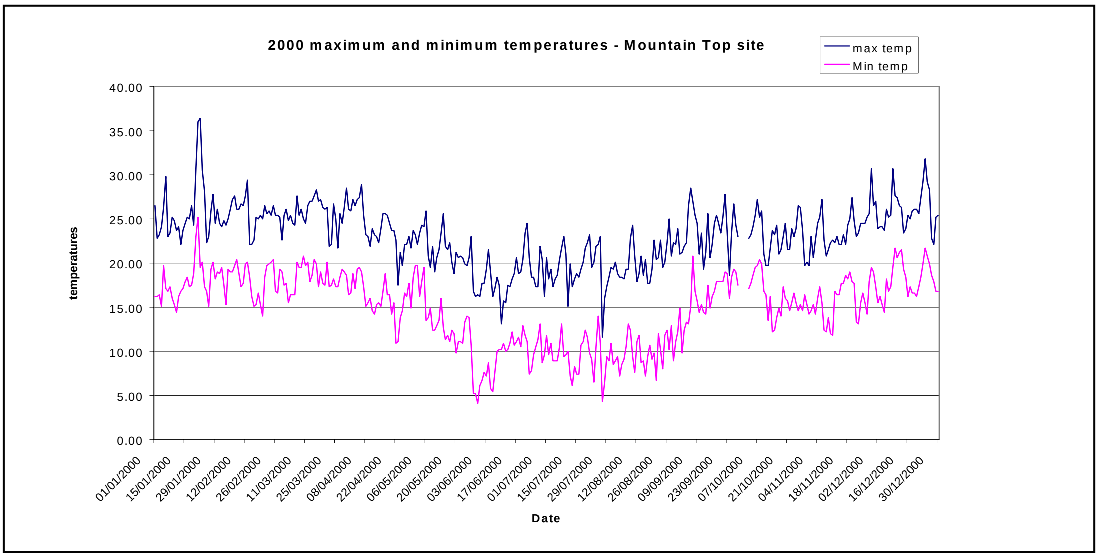
The charts showing the maximum and minium temperatures from both sites are detailed below.

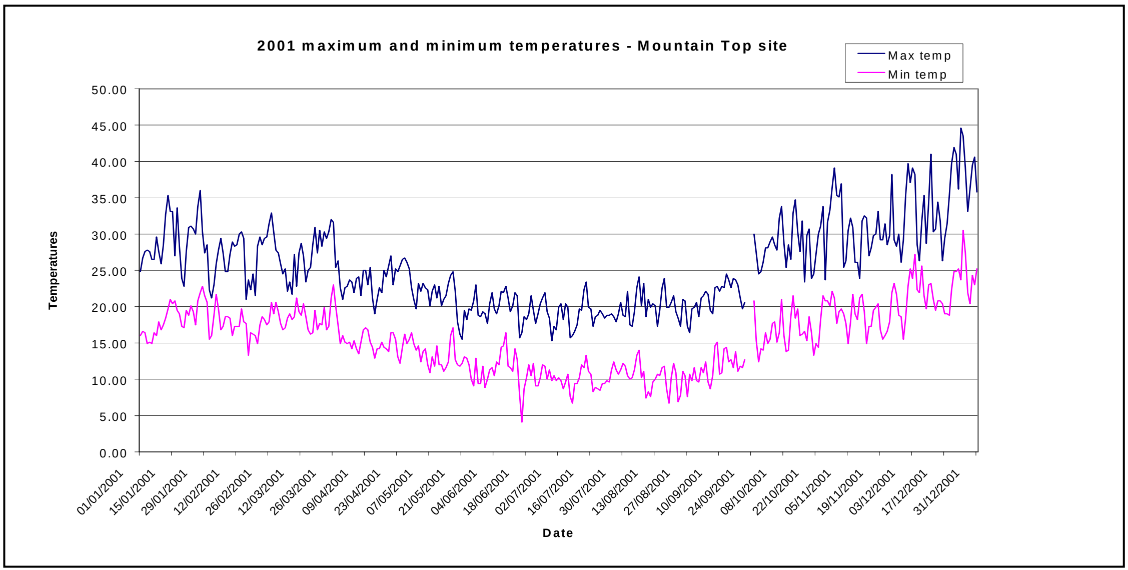


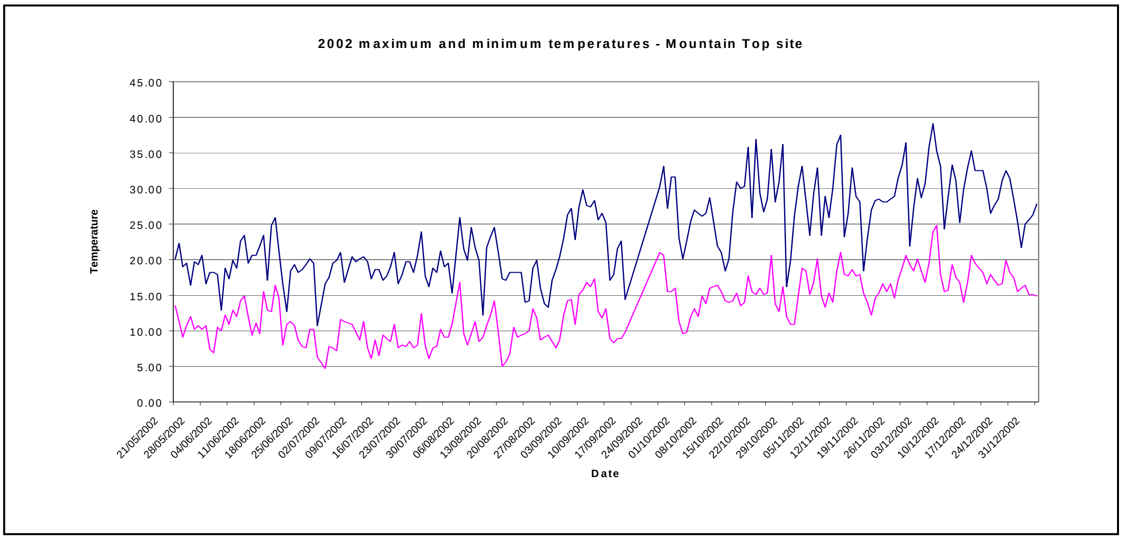





2002 maximum and minimum temperature chart - Newrybar site
Max temp
Min temp


2000 maximum and minimum temperatures - Mountain Top site
max temp
Min temp
temperatures
Date


2001 maximum and minimum temperatures - Mountain Top site
Max temp
Min temp
Temperatures
Date



2002 maximum and minimum temperatures - Mountain Top site
Temperature
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
21/05/2002
28/05/2002
04/06/2002
11/06/2002
18/06/2002
25/06/2002
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31/12/2002
Date

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Wormer, T.M. (1966). Shape of bean in *coffee arabica* L. in Kenya. *Turrialba* **16**: 221-236.