CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 January/February Lucerne Growth Cycle

Overview

This cycle was the first to be harvested for statistical analysis and evaluation of the six treatments. The very first cycle was not included as the lucerne was allowed to establish itself prior to testing of the different treatments. The results obtained with FS1, FS2, SWB and the control treatment (NP) will be discussed here. The results for the CF and MACH treatments will not be discussed because during this cycle the wires between the controller and the solenoid valves that supplied water to the CF and MACH treatments were accidentally swapped. In the light of this, these two treatments were excluded for this cycle.

The results obtained show that FS1, FS2 and SWB used less water than the control (NP) to produce statistically similar dry matter yields (Table 5.1 and Fig. 5.1). The FS1 and FS2 treatments received similar amounts of water, both less than the SWB treatment. Before the first cycle, the plots received 45 mm of sprinkler irrigation in an attempt to start the treatments at the same soil water content. However, this irrigation did not rewet the subsoil in the FS1 and FS2 treatments, so they started-off drier and remained so throughout the cycle (Fig. 5.2). The NP treatment served as a control treatment. Irrigation was applied according to the average soil water deficit measured across all NP treatment plots. The deficit was determined from the difference between the measured soil water content before irrigation application and the original field capacity values determined before the experiment began (described under 4.2.5), and then averaged over five plots.

Table 5.1 *Dry matter yields obtained, cumulative irrigation applied to, and calculated ET + D_r, as well as change in soil water storage* (ΔS) for the entire soil profile (0 to 120 cm) *for the FS1, FS2, SWB and CF treatments throughout the January/February growth cycle.*

Treatment	Dry matter ($t\ ha^{-1}$)	Cumulative irrigation (mm)	ΔS (mm) (0 to 120 cm)	Estimated ET + D_r (mm)
FS1	4.2	137	-22	159
FS2	3.7	140	2	138
SWB	4.2	154	-21	175
NP	4.0	196	-19	215
$LSD_{p = 0.05}$	Not Significantly Different			

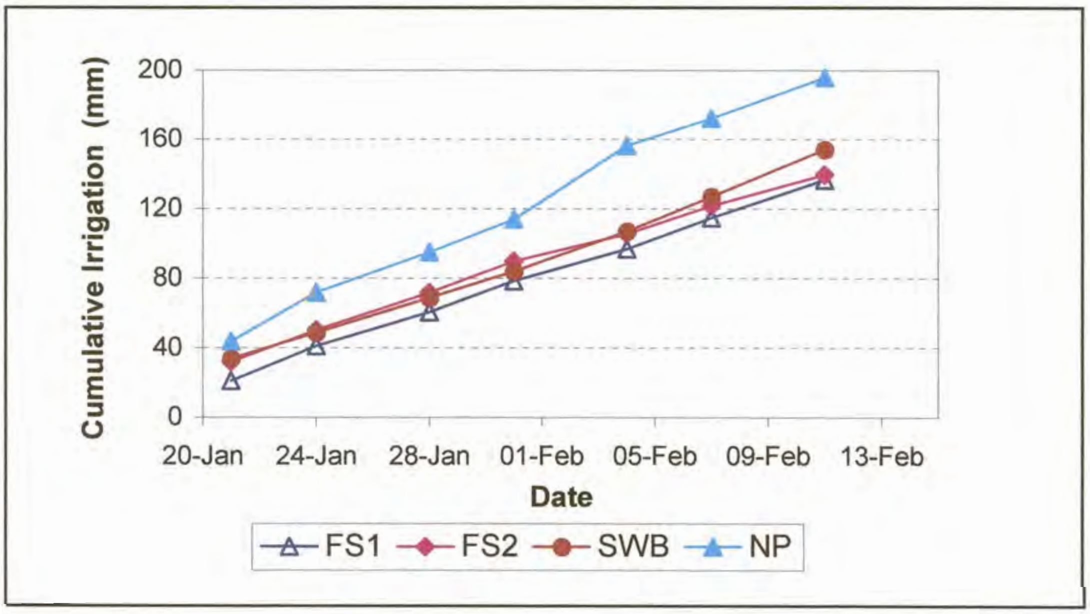

Figure 5.1 *Cumulative irrigation applied to the FS1, FS2, SWB and NP treatments throughout the January/February growth cycle.*

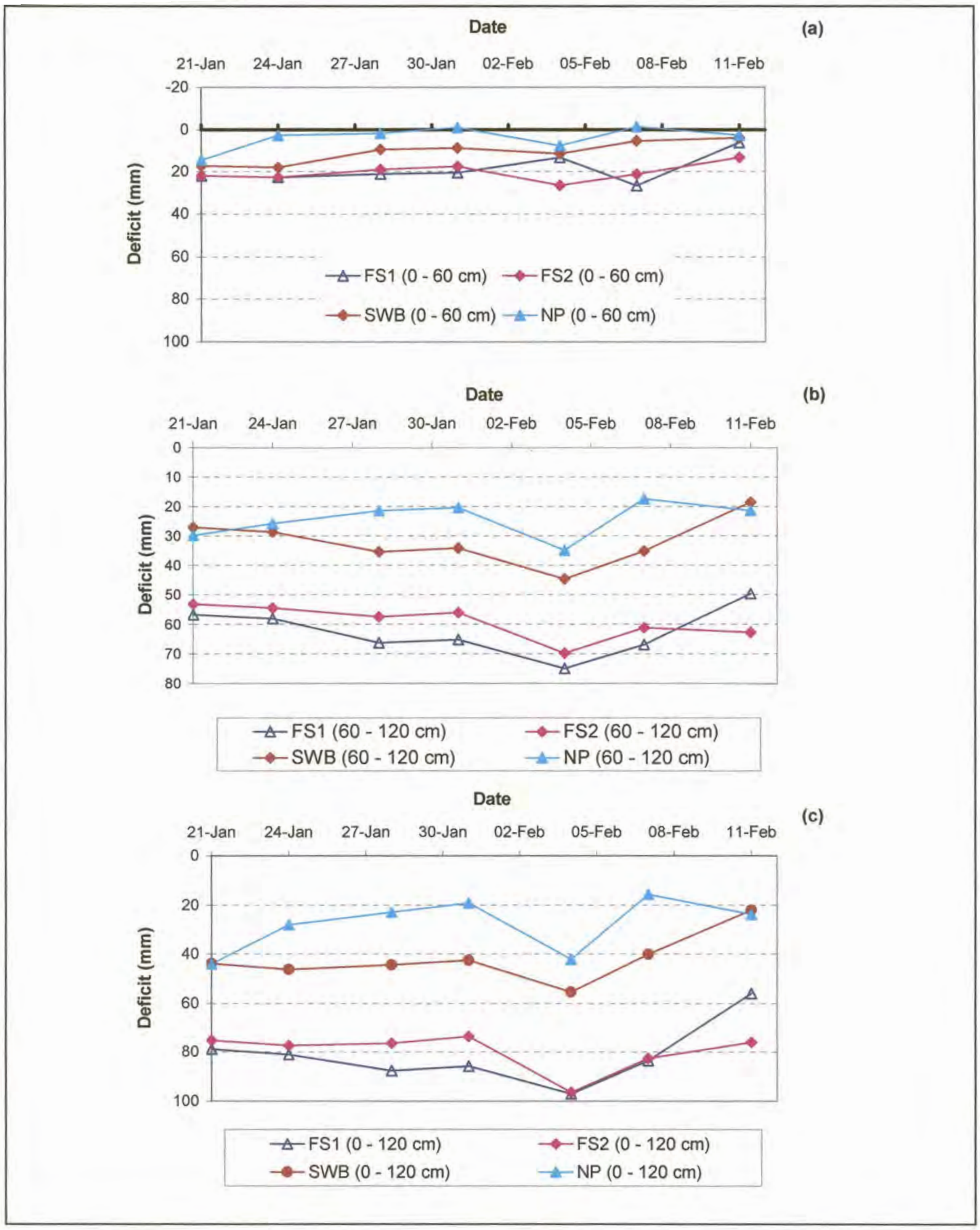

Figure 5.2 *Soil water deficit measured (a) within the "managed effective root zone" (0 - 60 cm), (b) below the root zone (60 – 120 cm) and (c) for the entire soil profile (0 – 120 cm) for the FS1, FS2, SWB and NP treatments during the January/February growth cycle.*

In the NP treatment, the measured water deficit shows that the topsoil root zone was kept at or near FC throughout the cycle (Fig. 5.3a). The aim was to refill the whole profile to field capacity. So, before irrigation, when the neutron probe measurement was taken, the soil water content should have been three days of water use below field capacity. The amount of water applied per irrigation indicates that it was in accordance with the averaged measured deficit. However, the cumulative irrigation received by the NP treatment was higher than that of the other treatments, this indicates that the FC value was over estimated. Thus, the topsoil in the NP treatment remained constantly around FC throughout the cycle (Fig. 5.3a).

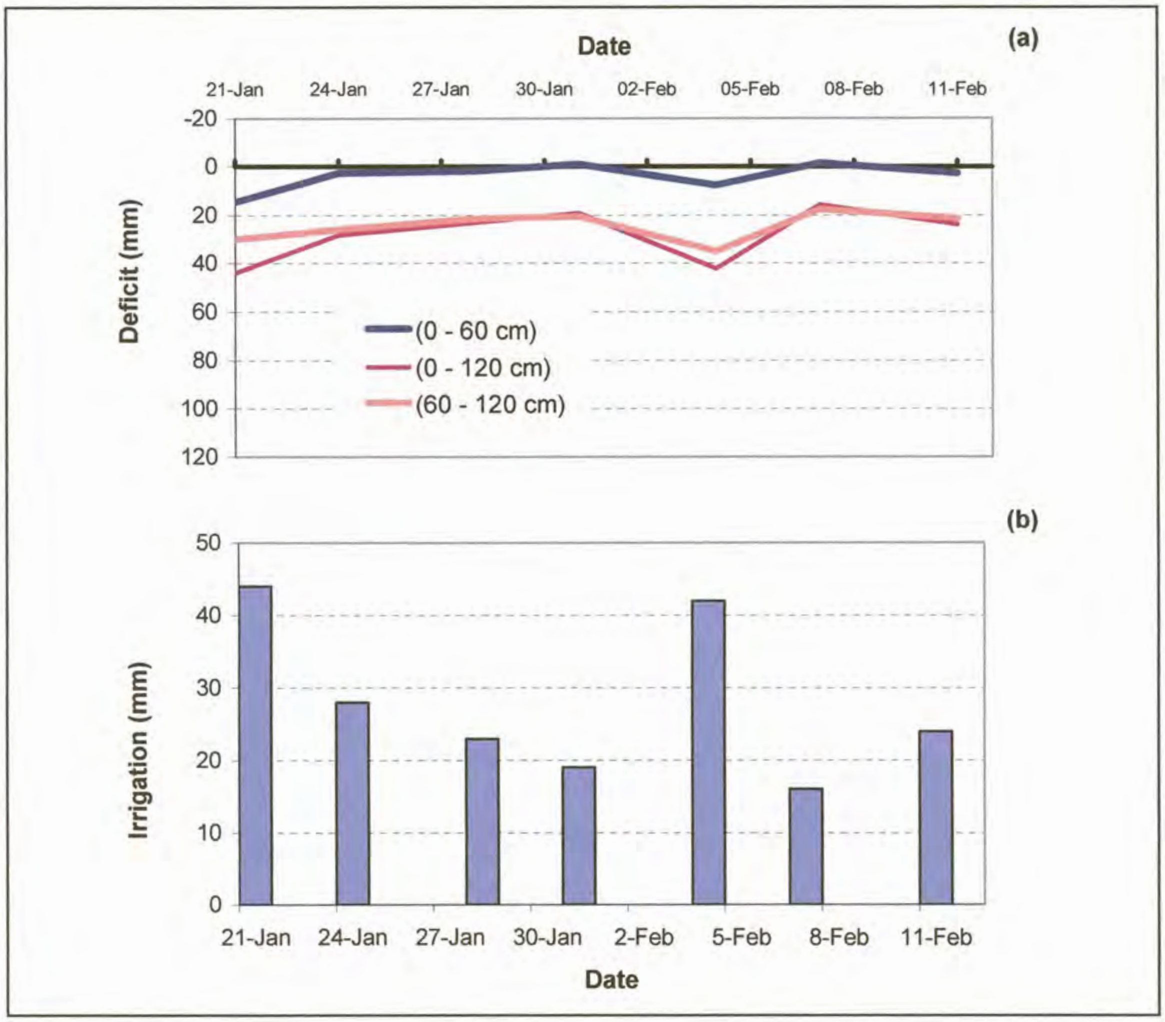

Figure 5.3 *(a) Measured soil water deficit and (b) amount of water applied per irrigation event to the NP treatment during the January/February growth cycle.*

5.1.1 FS1 Treatment

The individual plots of this treatment received different amounts of water, depending on the time when the control FullStop at 30 cm stopped irrigation.

This treatment's total irrigation is an average over five replicates. The dry matter yields from each replicate were therefore, added together as a treatment mean for statistical comparison to other treatments, and so was the water use.

Although Table 5.1 shows that the total amount of water applied was 137 mm, the control FullStop *'wanted'* 120 mm, 76 mm less than the control treatment (Table. 5.2). The 137 mm total resulted because of reactivation of the control detector after the first activation. This means that shortly after irrigation was stopped, the FullStop was emptied through capillary action, causing the float switch in the detector to drop, and in that way completing the circuit between the solenoid valve, the irrigation controller and the detector thereby allowing for continual irrigation. The reactivation was recorded with the dataloggers, and it was a result of a long irrigation run time of 180 minutes, set on the irrigation controller. However, the extended irrigation was fortunately not long enough to have caused over irrigation. As such, this treatment received less water than the control treatment. This is further confirmed by the measured soil water deficit for FS1 as compared to NP (Fig. 5.2a).

At first, there was no increase in soil water deficit, but towards the end of the cycle there was a decrease in soil water deficit. Measured soil water deficit within the effective root zone, 0 to 60 cm, never exceeded 28 mm from field capacity (Fig. 5.4a). The deficit in the whole profile, 0 to 120 cm, neither drastically increased nor decreased. Moreover, there was a dry layer of soil below the effective root zone (60 to 120 cm), and this confirms that irrigation application was good enough not to result in drainage below the root zone.

Table 5.2 *Amount of water that the treatment 'wanted' and that the control detector 'gave', and observed detector response for the FS1 treatment during the January/February growth cycle.*

Date	**Irrigation *'wanted'* (mm)**	**Irrigation *'given'* (mm)**	**Number of shallow detectors responding**
21-Jan	20	21	5
24-Jan	17	20	5
28-Jan	17	19	5
31-Jan	15	18	5
04-Feb	16	19	5
07-Feb	16	18	5
11-Feb	19	22	5

All detectors (shallow) responded to irrigation throughout the cycle (Table 5.2 and Fig. 5.4b), and although there was no *'feedback detector'*, the amount of water redistributing below the control detector could not have been large because the water content of deeper soil layers did not increase. That is why the layers of soil below the root zone was constantly dry throughout, except towards the end of the cycle when the deficit decreased due to a decreased atmospheric demand, whilst the irrigation quantities were increasing (Fig. 5.4b).

FS1 produced a dry matter yield of 4.2 t ha^{-1}, which is not significantly different from the other treatments at a 5 % confidence level (Table 5.1). The

FS1 treatment, however, used less water (137 mm) than the control treatment, NP.

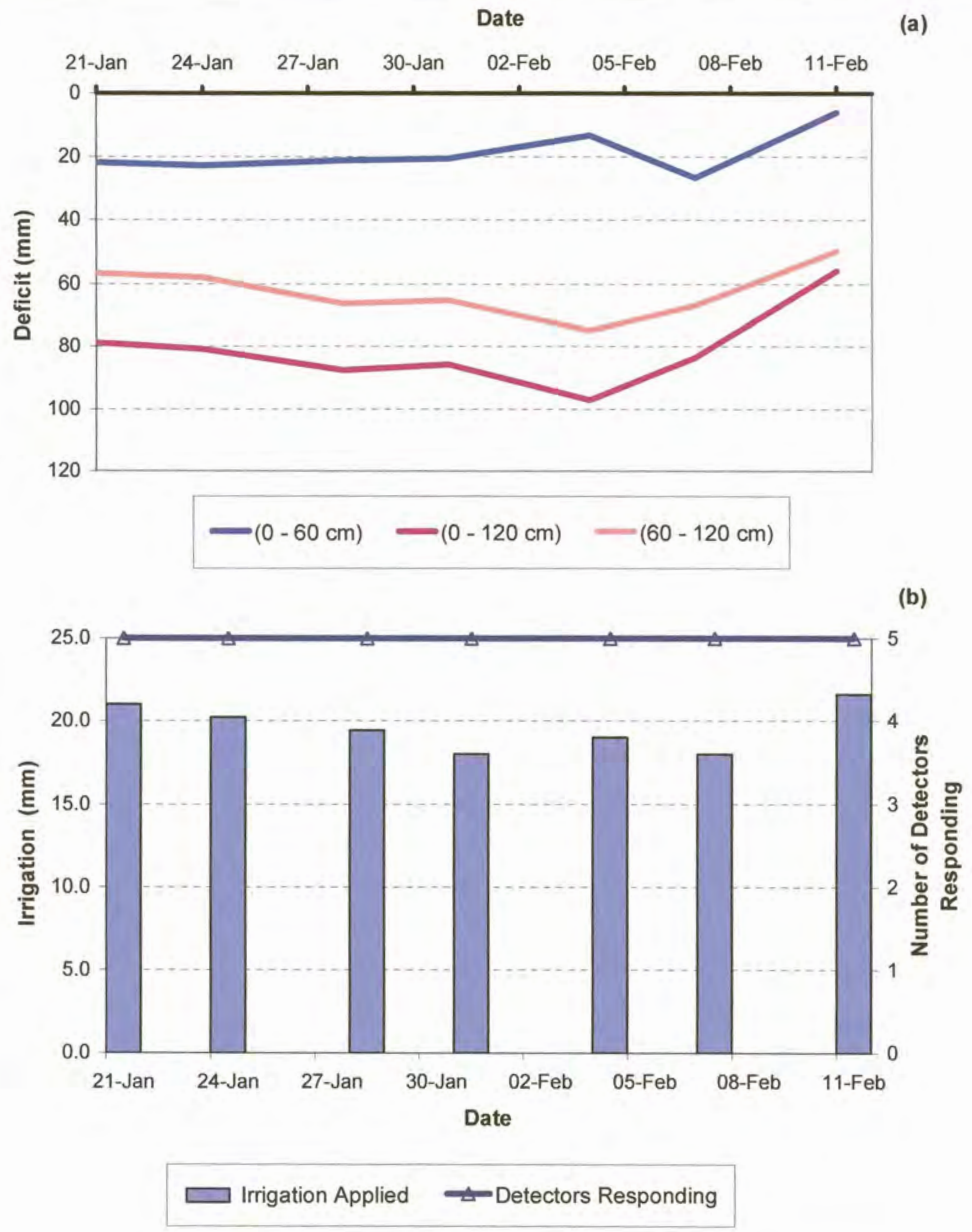

Figure 5.4 *(a) Measured soil water deficit, and (b) detector response, as well as the amount of water applied per irrigation to the FS1 treatment during the January/February growth cycle.*

5.1.2 FS2 Treatment

The total amount of water applied and yield obtained with this treatment has been averaged over four replicates out of five because the wires between the solenoid valve and the detector in the 5th replicate were accidentally cut-off, and as a result received no irrigation.

Table 5.1 shows that FS2 irrigated a total of 140 mm, whereas the control FullStop *'wanted'* 132 mm (Table 5.3), 64 mm less than the control treatment. The 140 mm resulted from *"reactivation"* of the control detector due to a prolonged run time set on the irrigation controller. However, in this case it was a minor problem. As with FS1, irrigation was controlled at a 30 cm depth. However, FS2 had feedback, which required that if a deep detector was tripped, that treatment plot missed the next irrigation. However, no deep detectors responded to irrigation during this cycle of seven irrigation events (Figs. 5.5a and b). This treatment can therefore be taken as a replicate of FS1. Hence, both treatments used similar amounts of irrigation water to produce similar dry matter yields.

The measured soil water deficit within the effective root zone (0 to 60 cm) indicates that the water deficit never exceeded 27 mm throughout the cycle (Fig. 5.5a). In this case, just like with FS1, there was a dry layer of soil below a wet effective root zone, and this implies that there was little water redistributing below the control detector. There was no response from the feedback detectors at 60 cm. This is an indication that there was not much water redistributing to deeper soil layers, which is in agreement with the neutron probe data (Fig. 5.5b). FS2 produced a dry matter yield that was not statistically different from the other treatments (Table 5.1). However, FS2 used less water to produce a similar yield to the NP treatment.

Table 5.3 *Amount of water that the treatment 'wanted' and that the control detector 'gave', and observed detector response for the FS2 during the January/February growth cycle.*

Date	Irrigation *'wanted'* (mm)	Irrigation *'given'* (mm)	Number of shallow detectors responding	Number of deep detectors responding	Replicate skipped
21-Jan	32	32	4	0	None
24-Jan	17	19	4	0	None
28-Jan	19	21	4	0	None
31-Jan	18	18	4	0	None
04-Feb	15	16	4	0	None
07-Feb	14	16	4	0	None
11-Feb	17	18	4	0	None

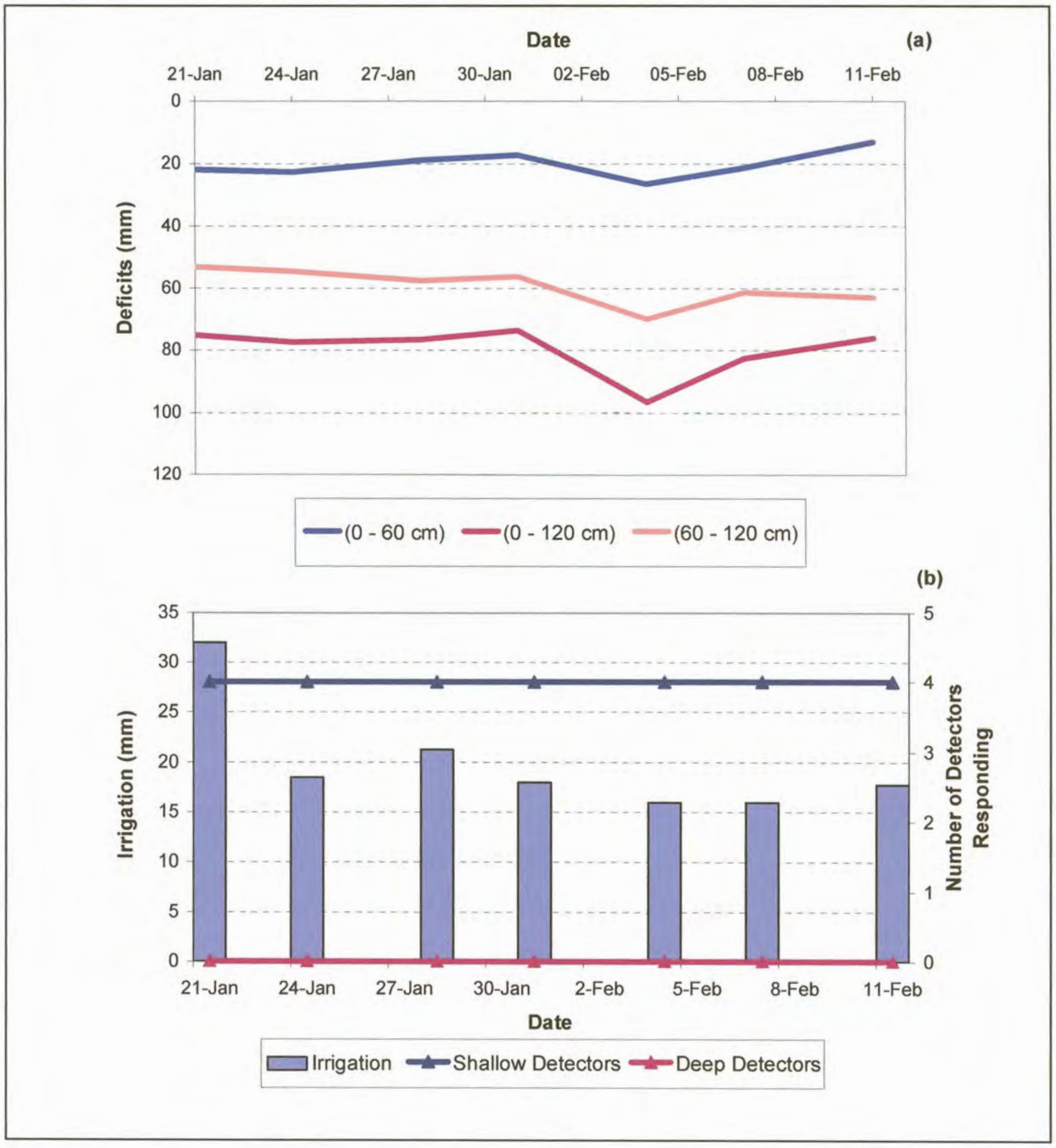

Figure 5.5 *(a) Measured soil water deficit, and (b) observed detector response as well as water applied per irrigation event to FS2 during the January/February growth cycle.*

5.1.3 SWB Model Treatment

This treatment was irrigated according to the irrigation depth (mm) recommended by the SWB model, and water deficits were also monitored with the neutron probe for comparison purposes.

Out of the seven irrigation events, the highest amount was 34 mm and the lowest 5mm (Fig. 5.6b). The 154 mm cumulative irrigation predicted by the model was 42 mm less than that of the control treatment - NP (Fig. 5.1).

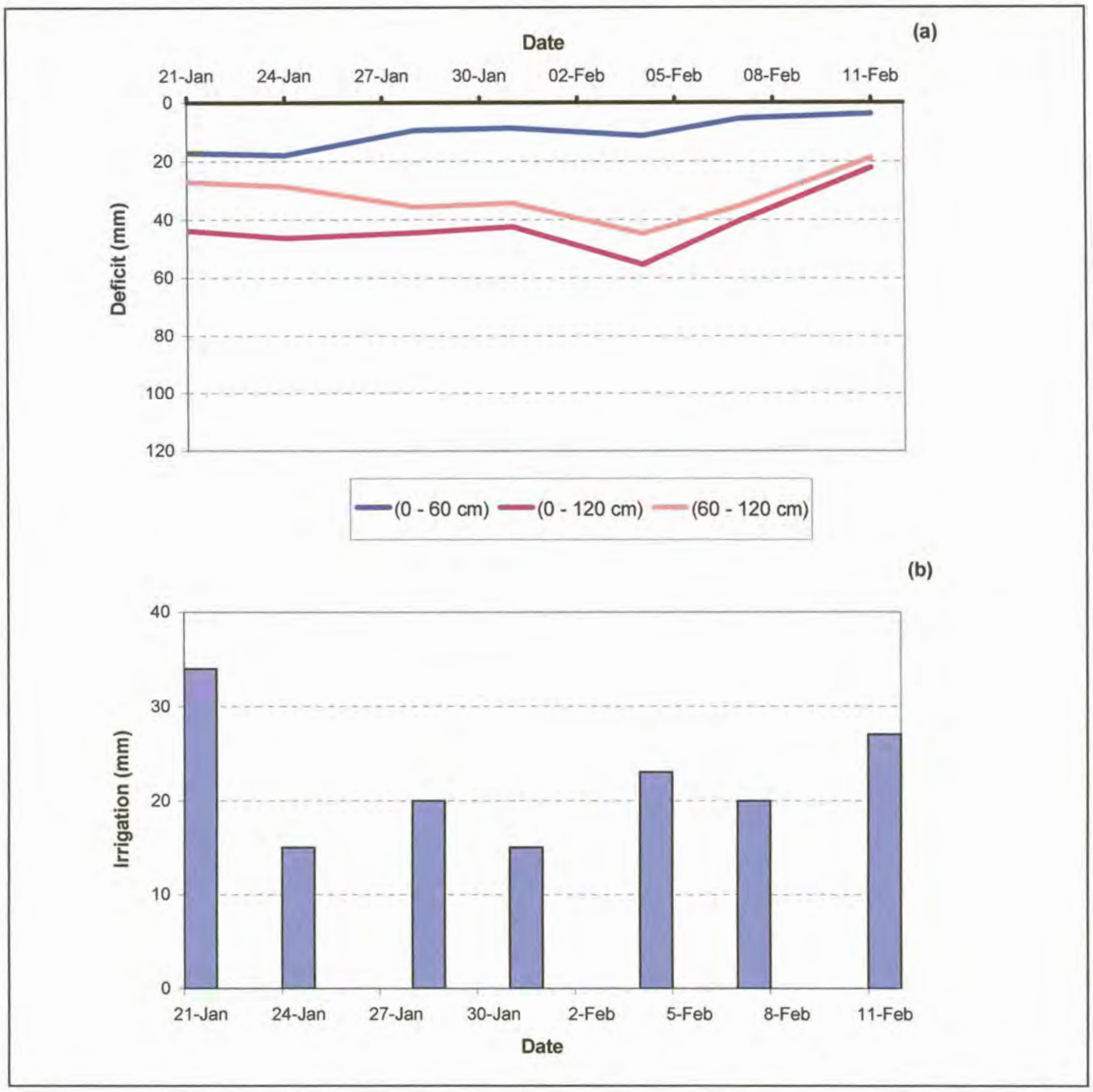

Figure 5.6 *(a) Measured soil water deficit and (b) irrigation amount applied per irrigation event to the SWB treatment during the January/February growth cycle.*

The treatment started off with a 17 mm deficit in the effective root zone and ended with water content near FC (Fig. 5.6a). The topsoil deficit decreased over time, like the FS1 and FS2 treatments. The yields were also not statistically different at a 5% confidence level, but this was achieved with 21% less water than the NP treatment.

5.1.4 CONCLUSIONS

The amount of water applied to the FS1, FS2 and SWB treatments was 137, 140 and 154 mm respectively. The FS1 and SWB treatments ended the cycle 22 and 21 mm wetter than they started. The FS2 was 2 mm wet. Using equation 4.2 we can see that ET + D_r was 159, 138 and 175 for FS1, FS2 and SWB respectively. Since the water content below 60 cm did not increase substantially (Fig. 5.2a), and was well below FC, we conclude that drainage was low. Therefore, the calculated ET + D_r was largely ET. The fact that ET + D_r for the NP treatment was 215 mm suggests that this treatment was over-irrigated, although the graph of deficit does not show that (Fig. 5.3a). Maybe the calibration or FC determination for the NP profile was incorrect (too high FC). Thus, the soil water status measurements said there was a deficit, but maybe there was not or the deficit was lower, thus over irrigation (and drainage) occurred.

5.2 March/April Lucerne Growth Cycle

Overview

This cycle proceeded after replacing the 13.6 mm h^{-1} drip system (2 ℓ h^{-1}) with 18.4 mm h^{-1} pressure compensated drip system (2.7 ℓ h^{-1}). This was to ensure a uniform water application rate when irrigation switched-off between the solenoid valves of the different treatments. Before the start of treatment application, the crop was given a sprinkler irrigation of 64 mm. This was an attempt to bring the soil profile back to FC in all treatments, so that all the plots started at a uniform soil water content. All treatments were well executed except SWB. The SWB model was not updated for each irrigation, so with time the computer programme assumed that the crop was drier, and therefore recommended a higher irrigation amount than it actually required. As a result, the SWB treatment was excluded from the analysis for his growth cycle.

The MACH, FS1 and FS2 treatments received more water than the control (NP), whilst the CF treatment received less than the control (Table 5.4 and Fig. 5.7). The measured soil water deficit shows that CF, NP and FS2 dried out their soil profiles, whereas there was no increase in deficit for the FS1 treatment (Fig. 5.8). There was a large variation in cumulative irrigation applied among the treatments (143 mm applied to the CF, 149 to NP, 172 to FS2, 183 to FS1, and 255 mm to the MACH).

Table 5.4 *Dry matter yields, cumulative irrigation to, calculated ET + Dr, as well as change in soil water storage for the FS1, FS2, MACH, NP and CF treatments for the March/April growth cycle.*

Treatment	Dry matter ($t\ ha^{-1}$)	Cumulative irrigation (mm)	ΔS (mm) (0 to 120 cm)	Estimated $ET + D_r$ (mm)
FS1	2.8	183	-15	198
FS2	2.8	172	17	155
MACH	2.8	255	-20	275
NP	2.8	149	-4	153
CF	3.4	143	10	133
$LSD_{p=0.05}$	Not Significantly Different			

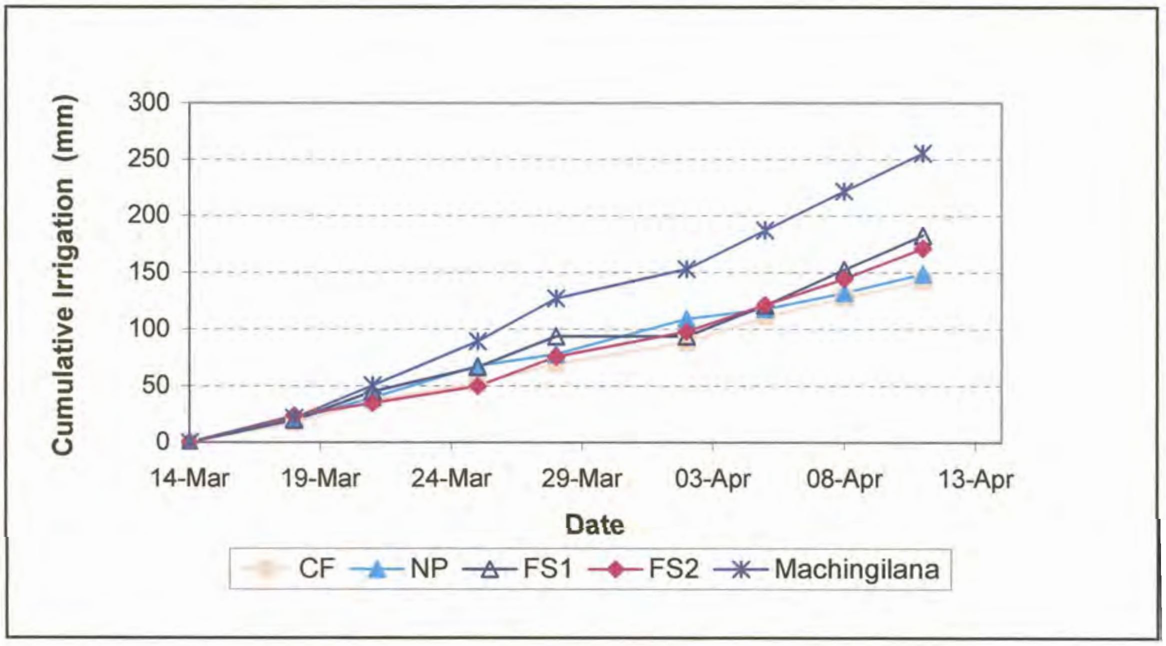

Figure 5.7 *Cumulative Irrigation applied to the MACH, CF, NP, FS1 and FS2 treatments throughout the March/April growth cycle.*

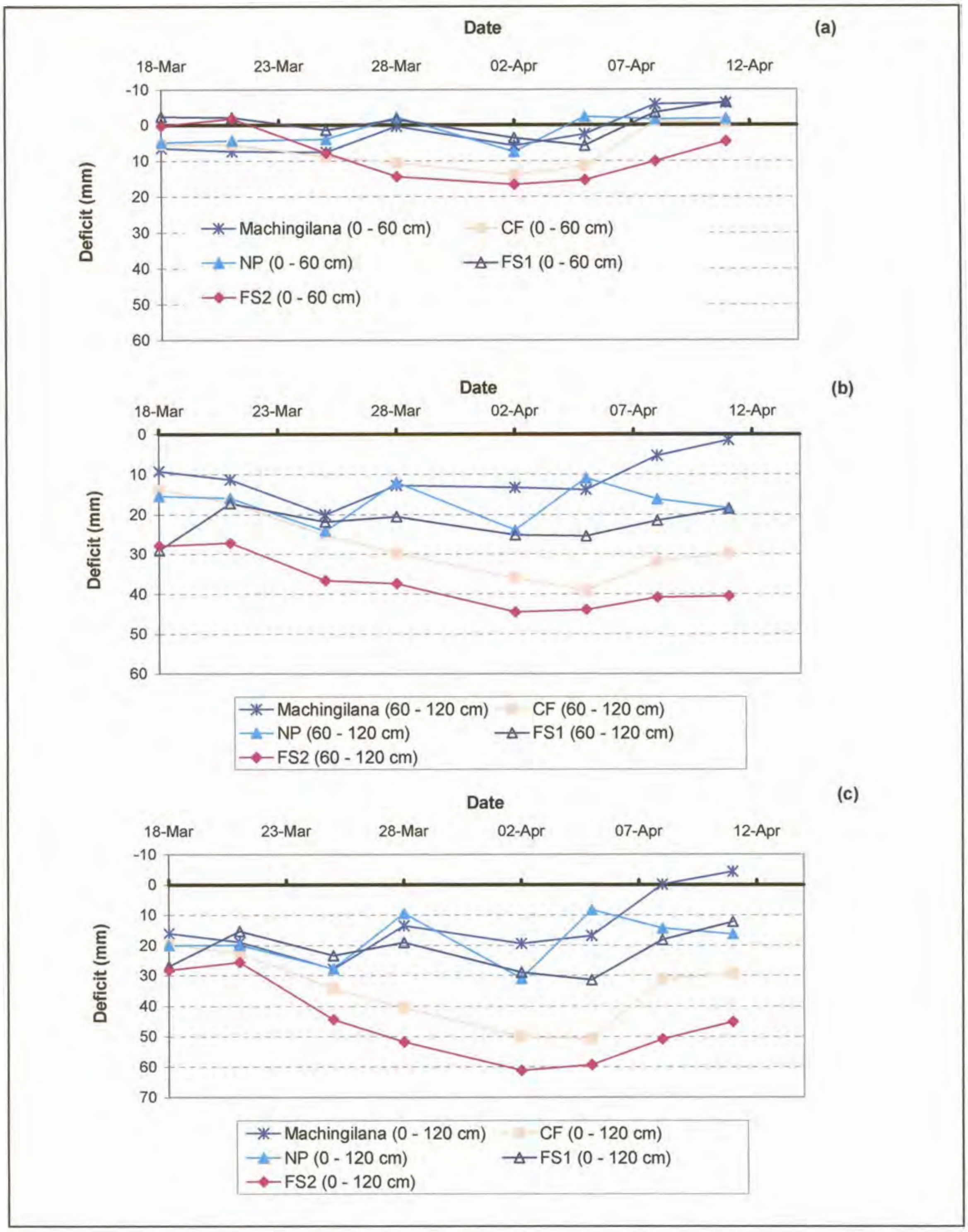

Figure 5.8 *Soil water deficit measured for the MACH, CF, NP, FS1 and FS2 treatments (a) within the effective root zone (0 - 60 cm), (b) below the root zone (60 – 120 cm), and (c) for the entire soil profile during the March/April growth cycle.*

The soil water deficit measurements for NP show that there was a substantially drier layer of soil below a wet managed root zone (Fig. 5.9a).

Bearing in mind that the control treatment was irrigated to refill the entire profile to field capacity, irrigation was applied based on the averaged deficit over the replicates (Fig. 5.9b). According to Fig. 5.9a the deficit at the beginning and at the end were not substantially drier, there should have been no drainage. The dry matter obtained with NP was also not different from the other treatments, which indicates that this treatment used water efficiently, the profile was not overfilled or under filled during this cycle (Table. 5.4).

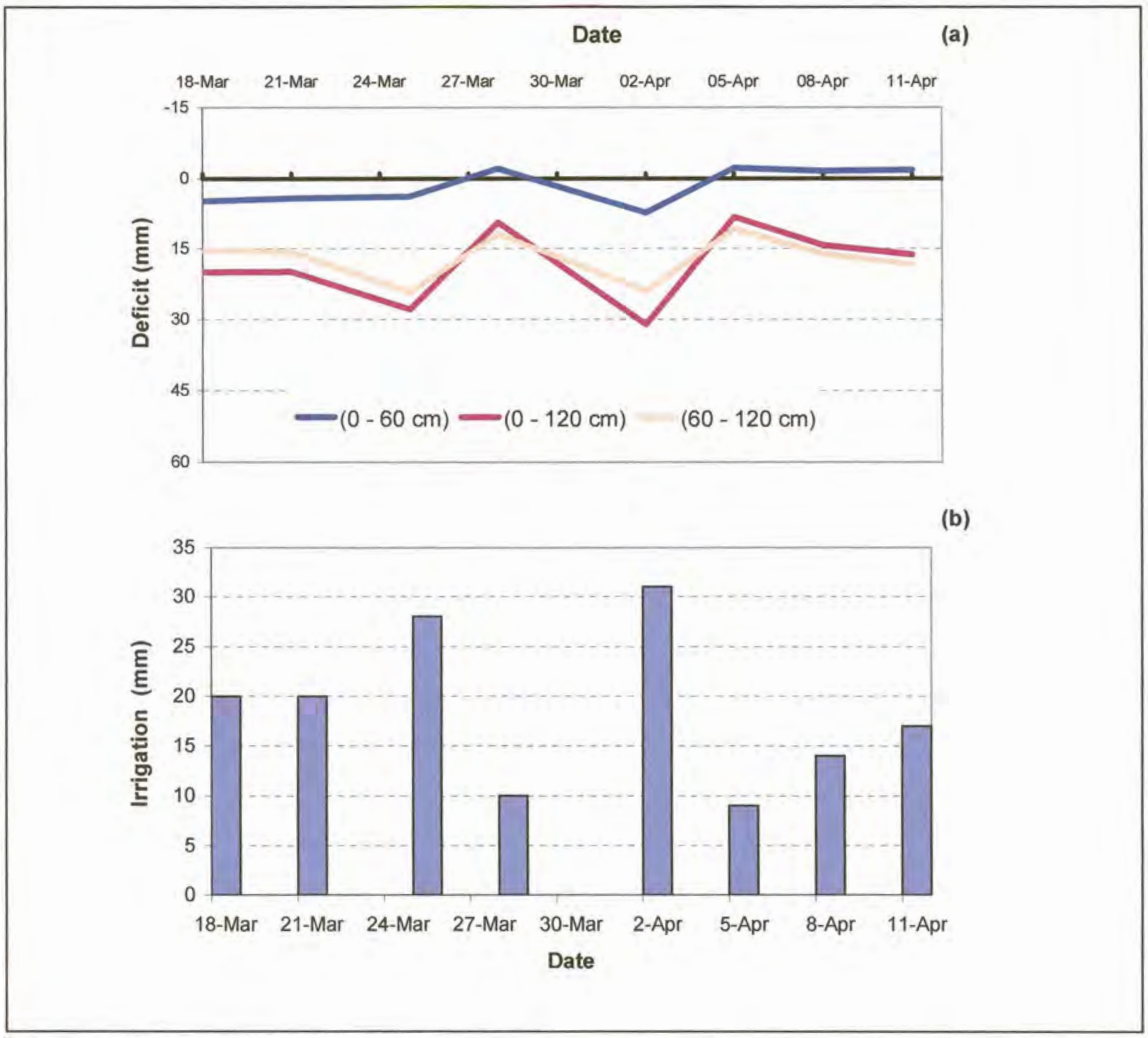

Figure 5.9 *(a) Measured soil water deficit and (b) water applied per irrigation event to the NP treatment during the March/April growth cycle.*

5.2.1 MACH Treatment

This treatment received 255 mm of irrigation, 106 mm more than the control. However, the yields obtained with this treatment were similar to other treatments, indicating that the treatment was over irrigated (Table 5.4).

Irrigation amounts were controlled from deep detector response. There were 8 irrigation events with the highest being 38 mm and the lowest 22 mm (Table 5.5 and Fig. 5.10b).

Table 5.5 *Amount of water applied, observed detector response as well as algorithm followed for the MACH treatment throughout the March/April growth cycle.*

Date	Irrigation applied (mm)	Number of shallow detectors responding	Number of deep detectors responding	Irrigation adjustment
18-Mar	22	0	0	30% Up
21-Mar	29	5	1	30% Up
25-Mar	38	5	1	30% Up
28-Mar	38	5	3	Same
02-Apr	26	5	5	30% Down
05-Apr	34	5	1	30% Up
08-Apr	34	5	3	Same
11-Apr	34	5	3	Same

The first three irrigations did not go deep enough to activate the required number of deep detectors (Table 5.5), and thus the chosen algorithm required an increase in irrigation amount. However, all shallow detectors were activated at all times, except from 22 mm irrigation on the 18th March (Fig. 5.10b). After the 38 mm irrigation on the 28th March the algorithm required that the next irrigation on the 2nd April be reduced, and then only 1 deep detector responded which required that the next irrigation amount be increased again. From there onwards, the algorithm required that irrigation be kept constant at 34 mm throughout, because 3 deep detectors were responding. As a result, the MACH treatment was over irrigated, with a large contribution being from the last three irrigations (with a total of 102 mm).

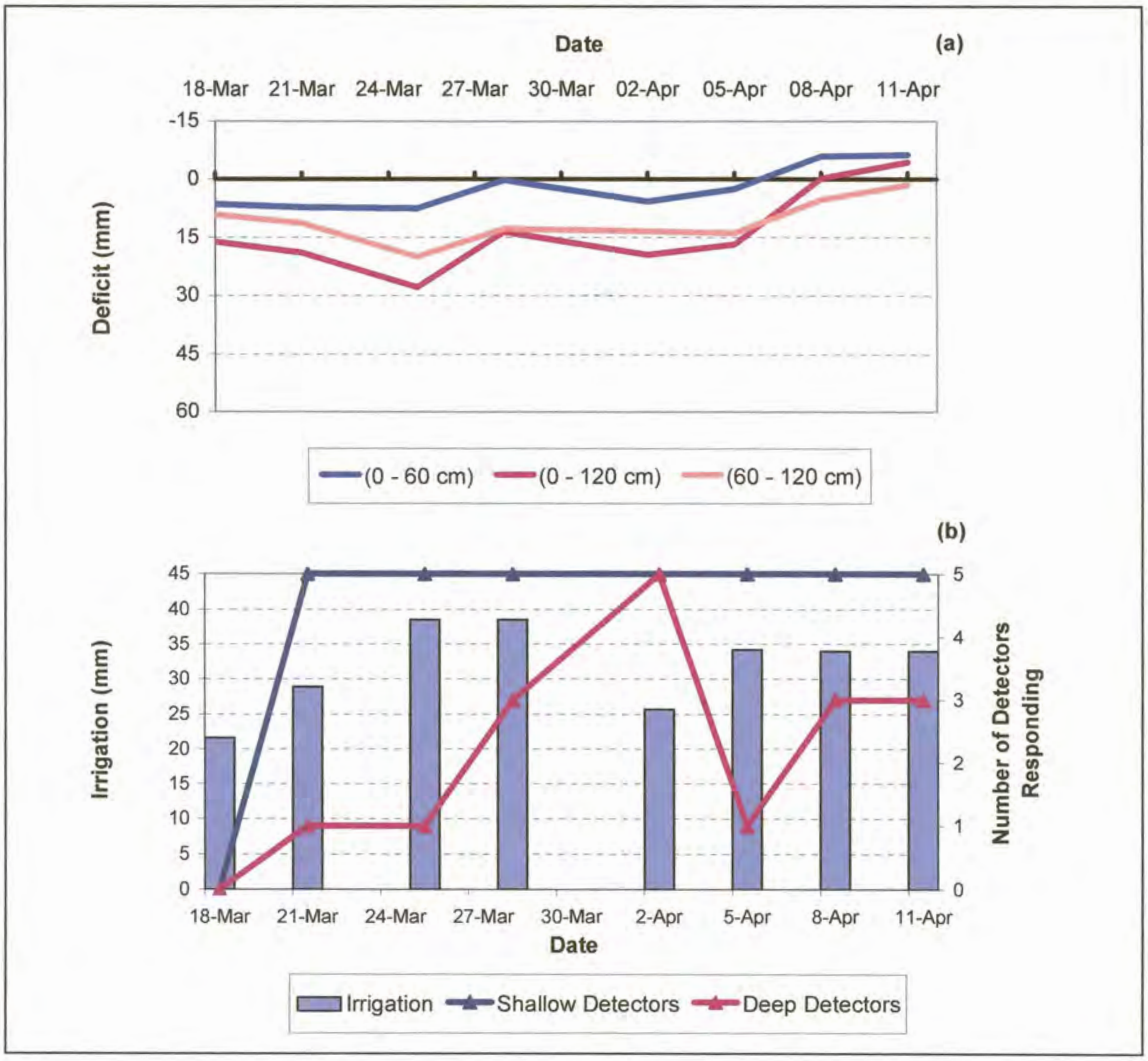

Figure 5.10 *(a) Measured soil water deficits, and (b) amount of water applied per irrigation as well as the observed detectors responding for the MACH treatment during the March/April growth cycle.*

The reason for over irrigation is that irrigation was controlled from the 60 cm detector. So, the soil had to be filled with water up to 60 cm to cut down the irrigation. However, deep detector response was not enough to cut down irrigation as required by the chosen algorithm. Theoretically, the WFD will trip if it experiences a wetting front having a water potential of -2 kPa. The measured soil water deficit graph shows that there was water redistribution to deeper soil layers (Fig. 5.10a); however, it was not detected by all the WFDs.

As a result, soil water deficit for deeper soil layers decreased with time. This is due to *'weaker'* wetting fronts resulting from frequent irrigation applications under conditions of decreasing atmospheric demand. This aspect of *'weaker'* wetting fronts still needs to be investigated more fully.

5.2.2 CF Treatment

This treatment received 6 mm less water than the control, to produce a dry matter yield not significantly different to the control or other treatments at a 5% confidence level (Table 5.4). There was an increasing deficit from the beginning of the cycle (Fig. 5.11a). This is because the initial crop factor was underestimated (Fig. 5.11c), and this led to continual under irrigation of the crop throughout the cycle. The chosen algorithm required an increase in irrigation amounts, but the crop factor increment was not high enough to even activate a single detector during the first four irrigations (Table 5.6 and Fig. 5.11b).

***Table 5.6** The calculated ET_O, adjustment in crop factors based on deep detector response and irrigation amounts applied to the CF treatment during the March/April growth cycle.*

Date	$\sum ET_o$ Between irrigations (mm)	Crop factor	Irrigation Required (mm)	Amount according to water meter(mm)	Number of shallow detectors responding	Number of deep detectors responding	Adjust crop factor
18-Mar	22.42	0.60	13	17	0	0	Up
21-Mar	22.05	0.70	15	20	0	0	Up
25-Mar	14.67	0.80	12	15	0	0	Up
28-Mar	14.59	0.90	13	17	2	0	Up
02-Apr	14.59	1.00	15	19	0	0	Up
05-Apr	20.7	1.10	23	23	5	2	Same
08-Apr	15.14	1.10	17	17	4	0	Up
11-Apr	12.63	1.20	15	15	3	0	Up

There were eight irrigations in total, and irrigation was adjustment took into account deep detectors response. However, it took till the sixth irrigation (Fig. 5.11b), before any deep detector could respond. This was after the crop factor had increased to 1.1 (Table 5.6), indicating full canopy cover. The soil water deficit then started decreasing due to four large irrigations towards the end of the cycle, when the daily ET_o was decreasing (Table 5.6 and Fig. 5.11c). The soil water content therefore, increased because crop uptake was low when the crop had already reached maturity. This is clearly visible with the soil water deficit trend (Fig. 5.11a), which shows that there was a sudden decrease in soil water deficit towards the end of the cycle.

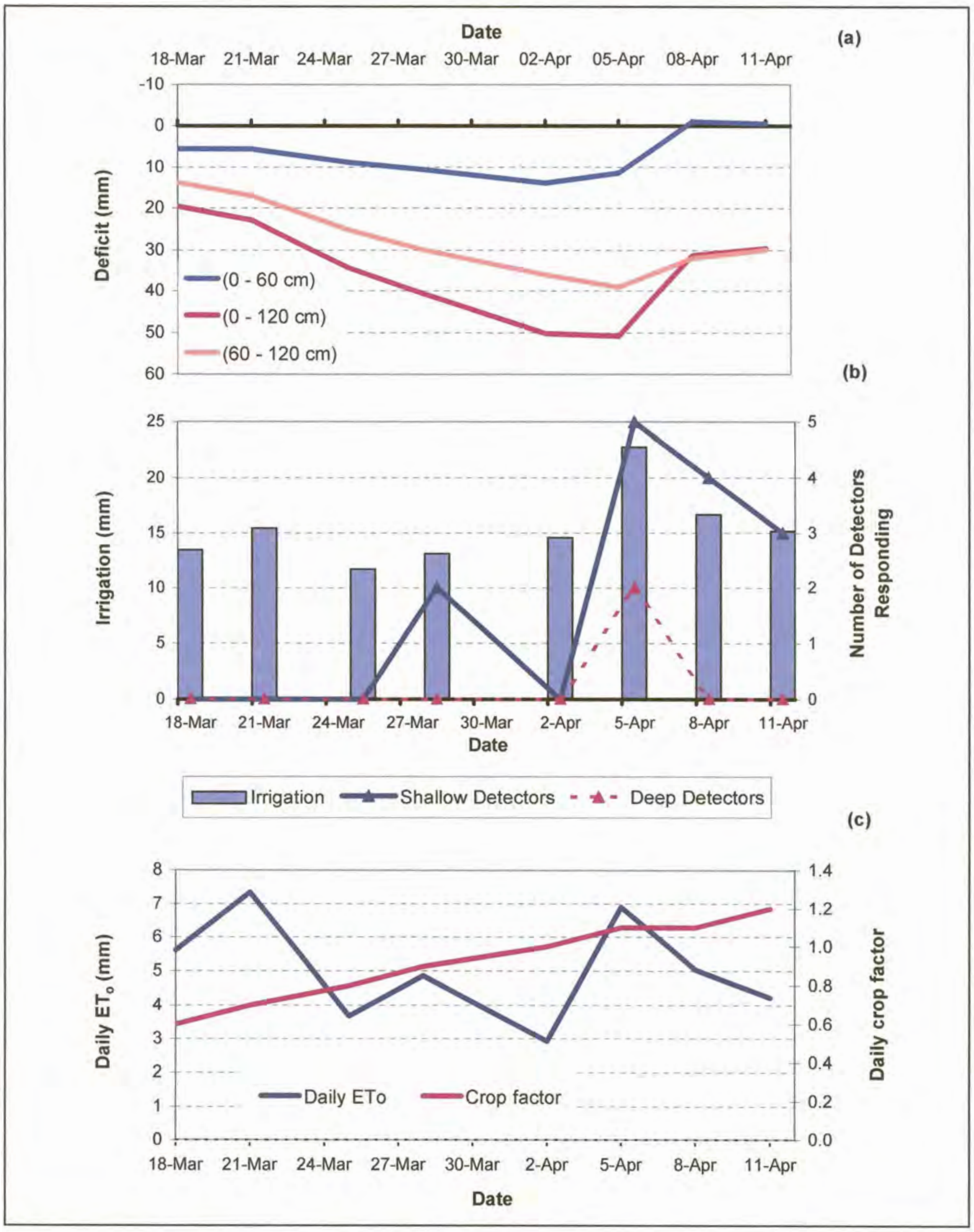

Figure 5.11 *(a) Measured soil water deficit, (b) observed shallow and deep detectors responding as well as the amount of water applied per irrigation and (c) crop factor and ET$_o$ plotted against time for the CF treatment during the March/April growth cycle.*

5.2.3 FS1 Treatment

Due to *'reactivation'* of the control detector a total of 183 mm was applied to this treatment. However, the control FullStop at 30 cm *'wanted'* 173 mm (Table 5.7). This treatment received the second highest amount of irrigation water (after MACH, Fig. 5.7) to produce similar yields to the other treatments.

Table 5.7 *Amount of water that the treatment 'wanted' and that 'given', as well as observed detector response for the FS1 treatment during the March/April growth cycle.*

Date	**Irrigation *'wanted'* (mm)**	**Irrigation *'given'* (mm)**	**Number of shallow detectors Responding**
18-Mar	19	20	[a]4
21-Mar	22	25	5
25-Mar	20	22	5
28-Mar	25	27	5
02-Apr	[b]0	[b]0	[b]0
05-Apr	26	28	5
08-Apr	31	31	5
11-Apr	30	30	5

[a] *One of the five replicates was not turned on due to broken wires.*
[b] *There was no irrigation on this day because the irrigation controller was not turned on.*

The measured soil water deficit suggests that the treatment was slightly over irrigated (Fig. 5.12a). The deficit fluctuated around field capacity in the effective root zone (0 to 60 cm), and the water content in this zone ended up wetter than at the beginning of the cycle. The measured deficit (Fig. 5.12a) for the 60 to 120 cm layer started at 29 mm and ended at 19 mm, so there was substantial decrease in water deficit below the root zone. There might have been drainage to the deeper soil layers. Up to the third last irrigation on the 5th April (Fig. 5.12b), the soil water deficit over the entire profile seemed to be consistently decreasing, which suggests the crop was not over irrigated.

However, the treatment did use 34 mm more water than the control, so we expect that over irrigation occurred right at the end of the cycle. These results show that irrigation interval is of great importance when using FullStops to control irrigation, because water can redistribute below the control depth after irrigation was stopped. Thus, the interval should be long when using FullStop to control irrigation without any means of monitoring redistribution.

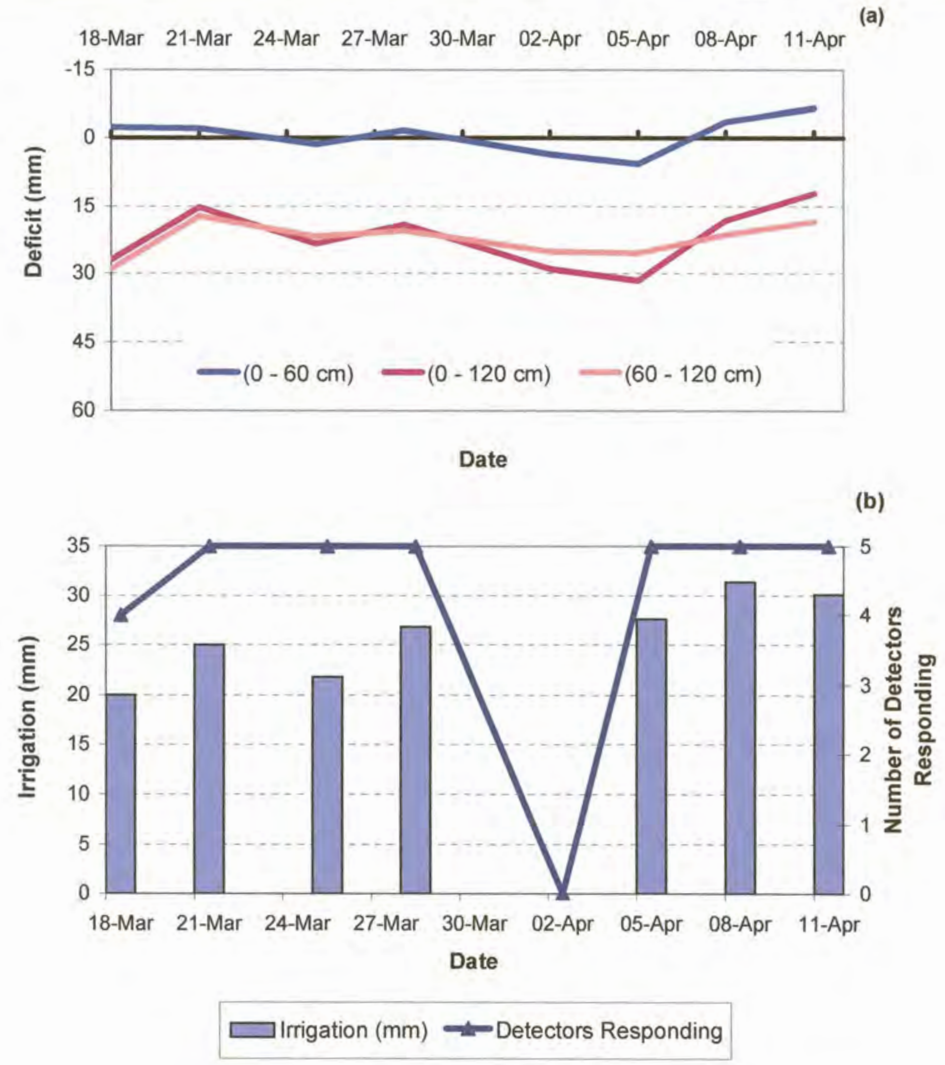

Figure 5.12 *(a) Measured soil water deficit, and (b) observed detector response as well as amount of water applied per irrigation to the FS1 through the March/April growth cycle.*

5.2.4 FS2 Treatment

This treatment received 172 mm of irrigation (Table 5.4), 23 mm more than the NP treatment (Table 5.8 and Fig. 5.7). Irrigation was controlled at 30 cm, like for FS1, however, a feedback detector placed at 60 cm was used to monitor water redistributing below the managed root zone.

Table 5.8 *Amount of water that the treatment 'wanted' and that 'given', as well as observed detector response and the replicate that skipped irrigation for the FS2 treatment during the March/April growth cycle.*

Date	**Irrigation *'wanted'* (mm)**	**Irrigation *'given'* (mm)**	**Number of shallow detectors responding**	**Number of deep detectors responding**	**Replicate skipped**
18-Mar	24	24	5	3	1, 2 & 3
21-Mar	11	11	2	0	None
25-Mar	[1]15	[1]15	0	[2]2	[2]1 & 2
28-Mar	26	26	0	[2]2	[2]1 & 2
02-Apr	22	22	3	3	3, 4 & 5
05-Apr	24	24	2	1	3
08-Apr	23	23	[3]No Data		
11-Apr	27	27	[3]No Data		

[1]On this day the shallow detectors did not respond to irrigation, however, the irrigation was turned on and water meters recorded the given amount of water.
[2]Although replicates 1 and 2 were not turned on, on this date; the deep WFDs malfunctioned and were not irrigated.
[3]Logger files lost due to power failure of the notebook used to download data.

Whenever the wetting front was detected at 60 cm, that particular plot skipped the next irrigation allowing it to dry out before applying water (Table 5.8), and this prolonged the irrigation interval to 7 days. This treatment was not over irrigated (Fig. 5.7), as was the case with the MACH treatment.

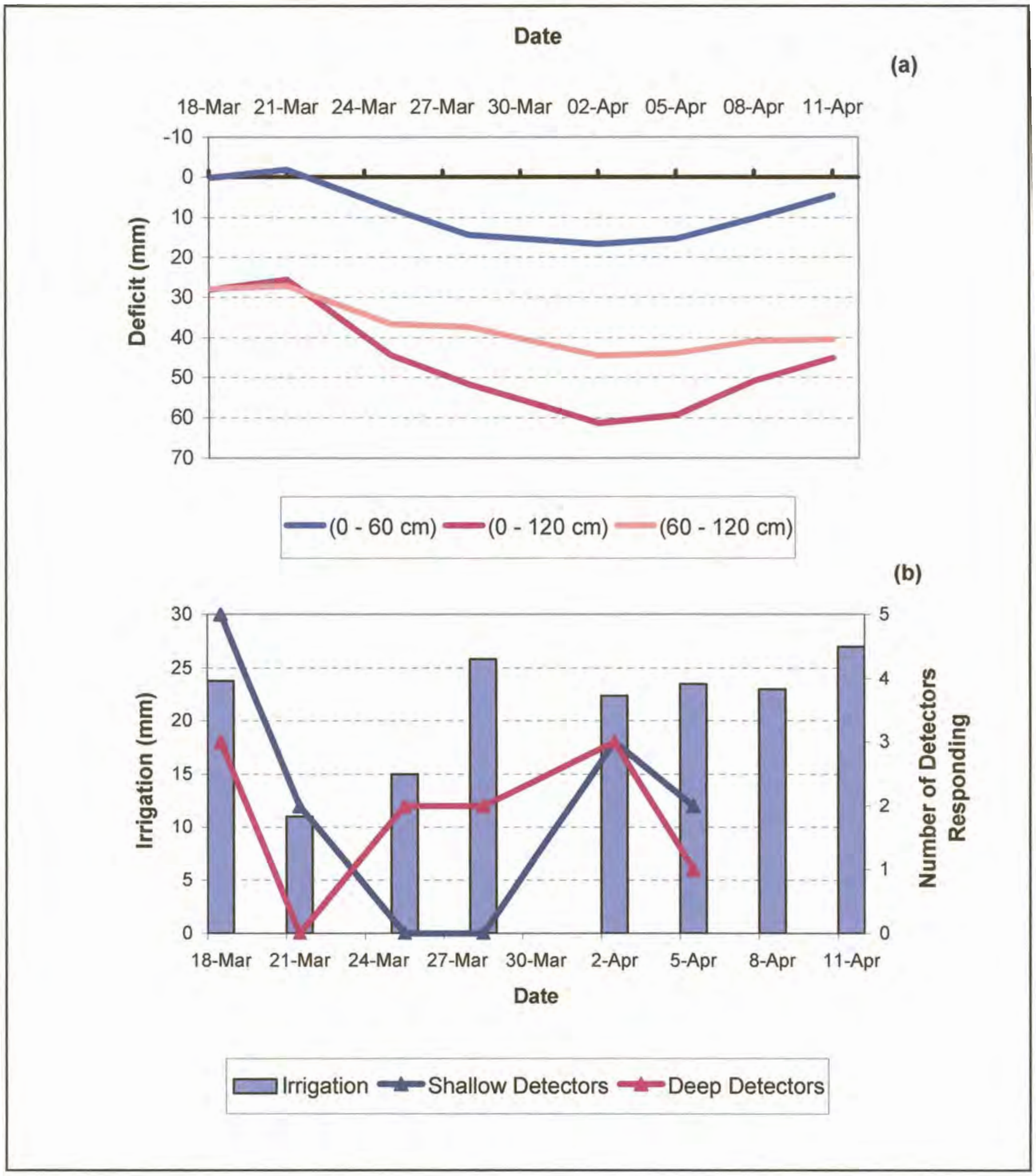

Figure 5.13 *(a) Measured soil water deficit, and (b) irrigation amount applied per irrigation event as well as, observed detector response for the FS2 treatment through the March/April growth cycle.*

The first 24 mm irrigation on the 18th March activated 5 shallow and 3 deep detectors (Table 5.8 and Fig. 5.13b). The algorithm required that the three plots skip the next irrigation, and this then led to a decreased averaged irrigation amount for FS2 on the 21st March, because only two of the five plots were irrigated.

From the measured soil water deficit, it is evident that water drainage from the management root zone (0 to 60 cm) was minimal, as there was a continuous increase in deficit below the root zone (60 to 120 cm) (Fig. 5.13a). However, the last two irrigations commencing from the 8^{th} of April increased the profile water content significantly, as noted by the decrease in profile water deficit towards the end of the cycle (Fig. 5.13a and b).

5.2.5 CONCLUSIONS

The trend in soil water deficit measurements was that the soil profiles became generally drier as the cycle progressed, which suggests that the D_r component was relatively low and the calculated ET + D_r was mostly ET. FS2 treatment did dry out the profile by 20 mm. However, there was a slight decrease in soil water deficits towards the end of the cycle. The NP treatment on the other was better irrigated than FS2. The FS2 treatment had a dry subsoil throughout the cycle (Fig. 5.13a), which implies that the crop had to use water from the subsoil due to insufficient water supply from within the topsoil or managed root zone. FS1 was probably managed close to correct, as it did receive a little bit more water and did not experience an increase in deficit. So, it seems that an ET of around 180 mm is probably right. In the MACH treatment, an inappropriate choice of irrigation interval and controlling depth and also the algorithm for increasing irrigation, led to over irrigation of this treatment.

5.3 April/May Lucerne Growth Cycle

Overview

All treatments were executed according to plan. However, the solenoid valve in one replicate of FS2 (replicate 5) and the detector in one replicate of FS1 (replicate 4) malfunctioned and therefore, they were omitted from the analysis of water use and lucerne growth for this cycle.

The MACH and FS1 treatments put on more water than the control, and FS2, CF and SWB treatments put on less water than the control (Table 5.9 and Fig. 5.14). The measured soil water deficit shows the all treatments except for the MACH had an increase in soil water deficit throughout the cycle, and it was even more conspicuous with the CF and SWB treatments (Fig. 5.15). Treatment application started on the 29th April and ended on the 30th May, however, there were NP measurements taken on the 26th April following 47 mm sprinkler irrigation the previous day.

Table 5.9 *Dry matter yields, cumulative irrigation applied, change in soil water storage, and estimated ET + D_r for the NP, FS1, FS2, MACH, CF and SWB treatments for the April/May growth cycle.*

Treatment	Dry matter ($t\ ha^{-1}$)	Cumulative irrigation (mm)	ΔS (mm) (0 to 120 cm)	Estimated ET + D_r (mm)
NP	2.5	211	3	208
FS1	2.5	254	8	246
FS2	2.4	193	5	188
MACH	2.7	285	0	285
CF	2.6	92	37	55
SWB	2.5	123	21	102
$LSD_{p=0.05}$	Not Significantly Different			

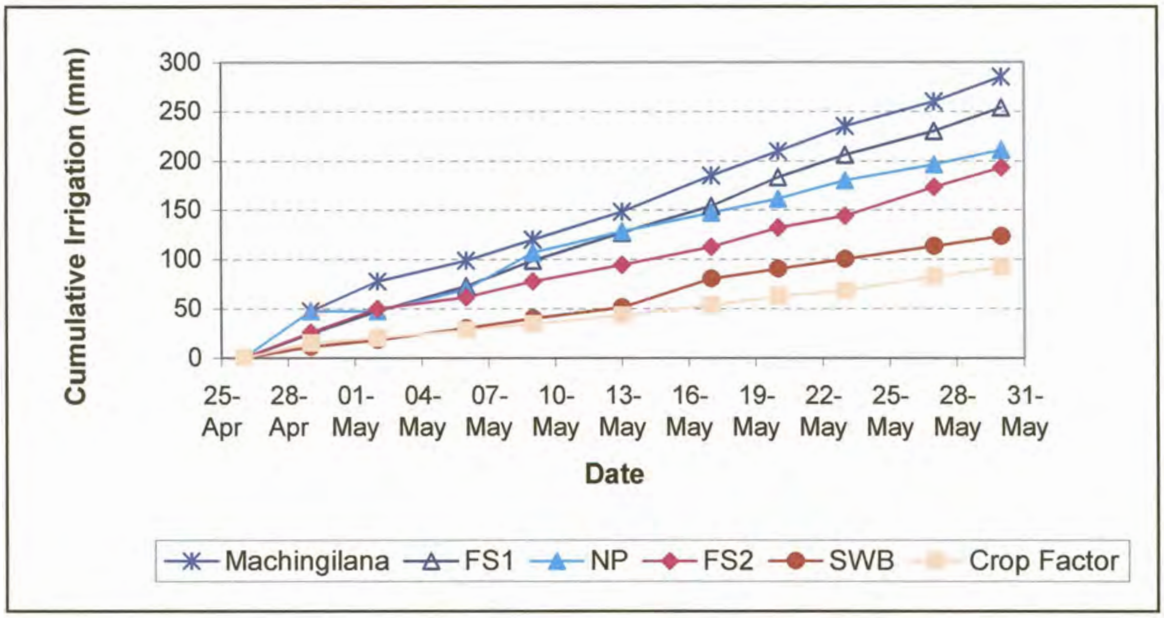

Figure 5.14 *Cumulative Irrigation applied to the MACH, CF, NP, SWB, FS1 and FS2 treatments throughout the April/May growth cycle.*

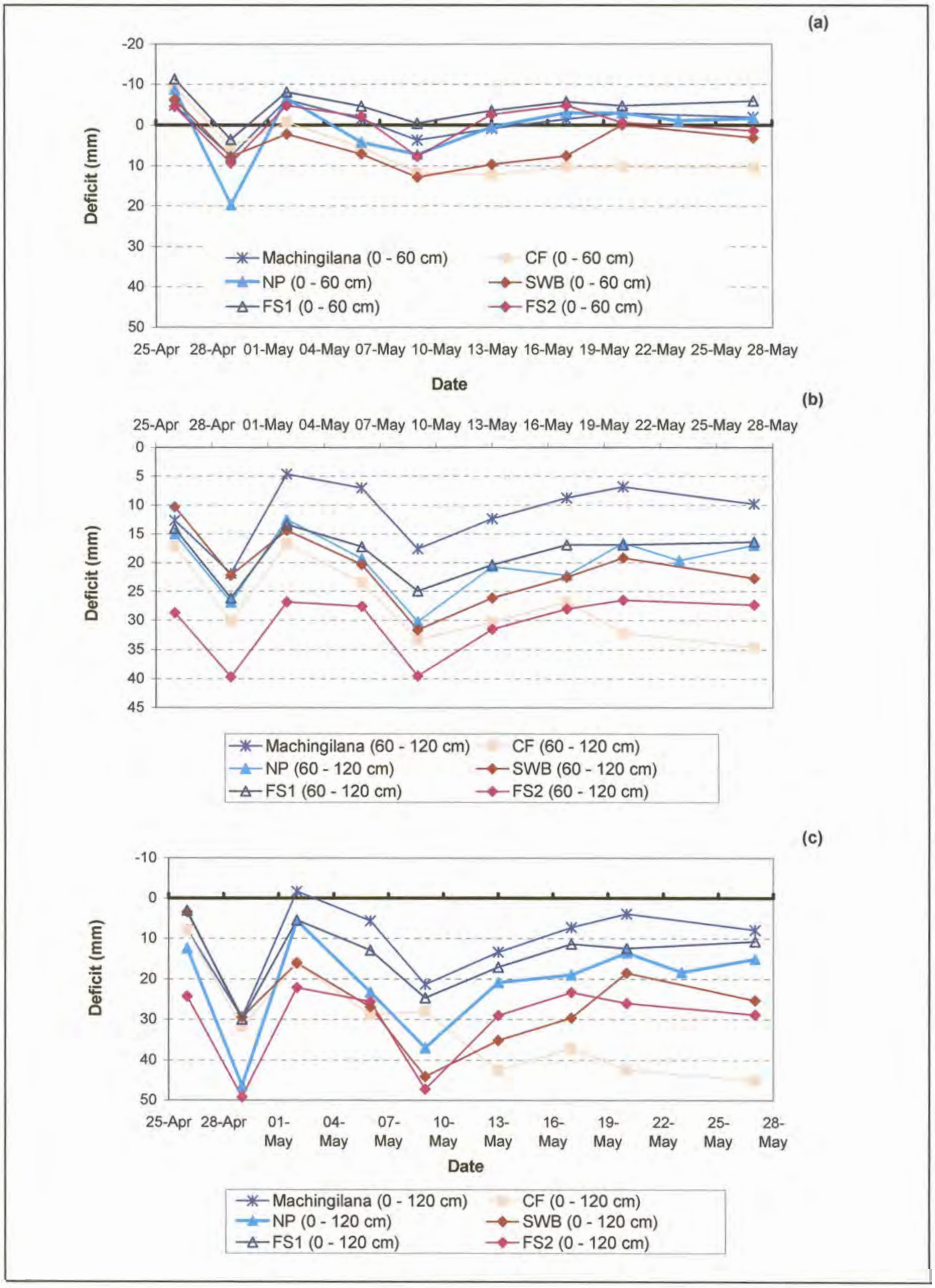

Figure 5.15 *Soil water deficit measured for the MACH, CF, NP, SWB, FS1 and FS2 treatments (a) within the effective root zone (0 - 60 cm), (b) below the managed root zone (60 – 120 cm), and (c) for the entire soil profile (0 – 120 cm) during the April/May growth cycle.*

The control (NP) treatment received 211 mm of irrigation. Since the soil water storage increased by 3 mm between the beginning and end of the cycle we calculate ET plus drainage to be 214 mm (Table 5.9). The soil water deficit measurements (Fig. 5.16a) show that although water content within the effective root zone started 9 mm above FC, it was later maintained within the range of FC for most of the cycle. However, the aim was to refill the whole profile to field capacity. So, before irrigation soil water content should be 3 days of water use below field capacity, because water application was based on averaged deficit of the NP replicate plots (Fig. 5.16b).

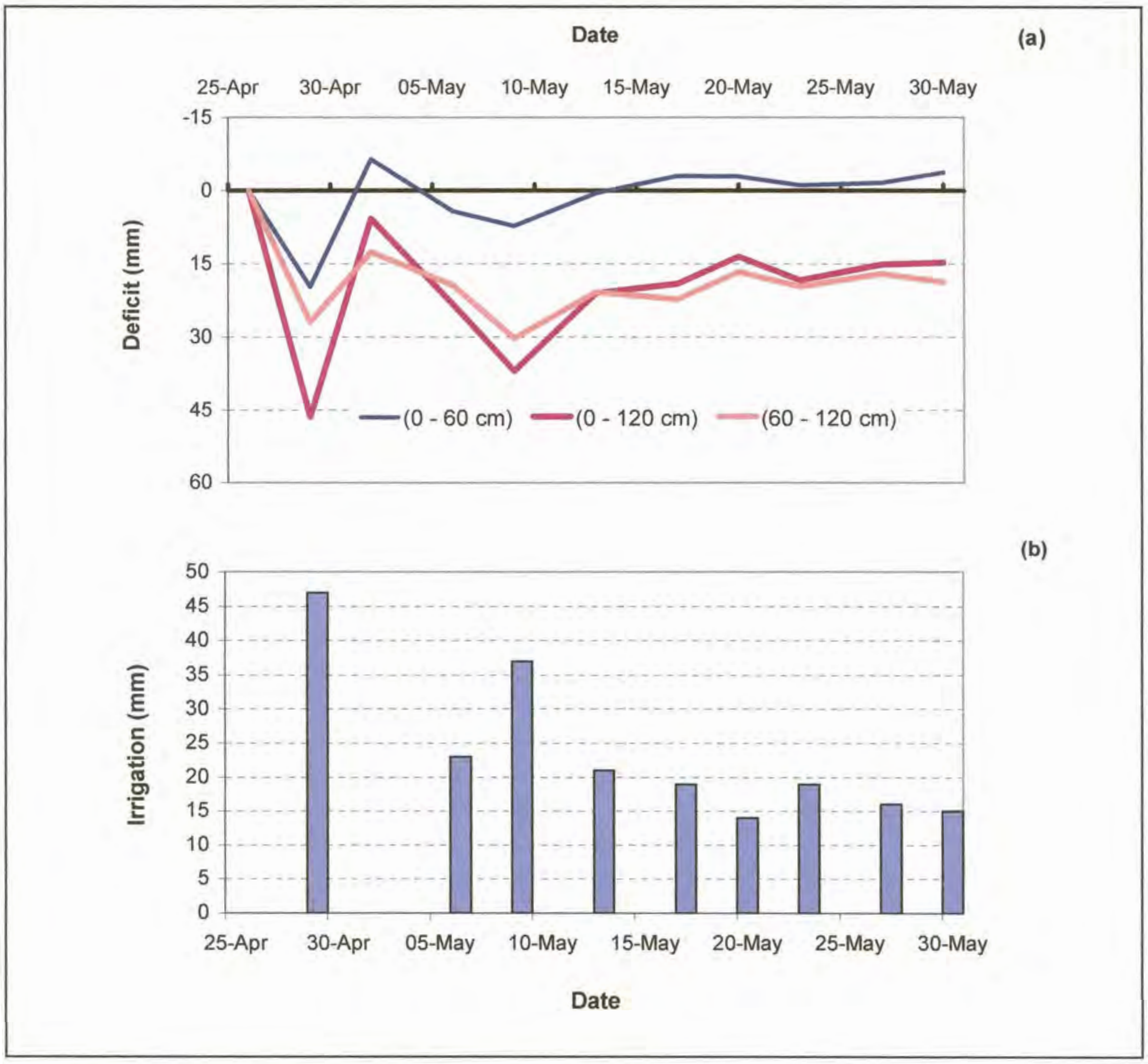

Figure 5.16 *(a) Measured soil water deficit and (b) amount of water applied per irrigation to the NP treatment during the April/May growth cycle.*

Theoretically, there should have been no drainage in this treatment, assuming the FC values are correct and the probe accurately measured the deficit. Since the soil remained fairly wet throughout the cycle we can say that this treatment was not under irrigated. However, if similar soil water deficit graphs are obtained for treatments that had less irrigation we could deduce that this treatment (NP) was over-irrigated.

5.3.1 MACH Treatment

This treatment received 285 mm, 74 mm above the "control", NP treatment (Fig. 5.14). There were 10 irrigation events with the highest being 47 mm and the lowest being 21 mm (Table 5.10 and Fig. 5.17a). The first irrigation on the 29th April (Fig. 5.17a) was made on freshly cut lucerne. All treatments received 47 mm four days earlier on the 25th April in an initial attempt to start the experiment on a full profile (FC). The first irrigation on the 29th April was clearly too much for freshly cut lucerne on a nearly full profile in late autumn. This large initial irrigation resulted from the fact that 47 mm was the last irrigation entered into the spreadsheet on the 25th April and the algorithm *"used it"*. Thus, the first reason for over irrigation is that wrong data was fed into the algorithm. If the first irrigation had been 20 mm and three deep detectors were activated, then about 40 mm would have been used before the 6th May.

The first two irrigation events activated four deep detectors (Fig. 5.17c) and the algorithm reduced the irrigation from 47 to 21 mm by the 6th May. However, 21 mm was not sufficient to get many deep detectors responding. The algorithm increased the irrigation from 21 to 37 mm over the next seven days (Fig.5.17a and Table 5.10). This caused five deep detectors to respond on the 17th May and so, the irrigation was again reduced by 30%. The last four irrigations were all 25 mm with only two deep detectors responding – not reaching the threshold of four detectors needed to bring the irrigation down by 30%. It is most likely that over irrigation occurred from the 17th May onwards. The measured soil water deficit shows that soil water content increased with time even for deeper soil layers (Fig. 5.17b). The measured deficit clearly shows that there was an increase in profile water content, but the algorithm was not sensitive enough to ensure a reduction in irrigation amount to minimize drainage (Fig. 5.17b).

Thus the algorithm had three mistakes. Firstly, it would have been better to base the algorithm on the shallow detectors. Secondly, an irrigation interval of 3 to 4 days was too short for this time of year when evapotranspiration rates are low. Thirdly, the first irrigation of 47 mm was made on an already near full or full profile and it definitely contributed to this over irrigation.

Table 5.10 *Amount of water applied, observed detector response as well as algorithm followed for the MACH treatment throughout the April/May growth cycle.*

Date	Irrigation applied (mm)	Number of shallow detectors responding	Number of deep detectors responding	Irrigation adjustment
29-Apr	47	5	4	30% Down
2-May	31	5	4	30% Down
6-May	21	5	2	Same
9-May	21	5	1	30% Up
13-May	28	5	1	30% Up
17-May	37	5	5	30% Down
20-May	25	4	2	Same
23-May	25	5	2	Same
27-May	25	5	2	Same
30-May	25	5	2	Same

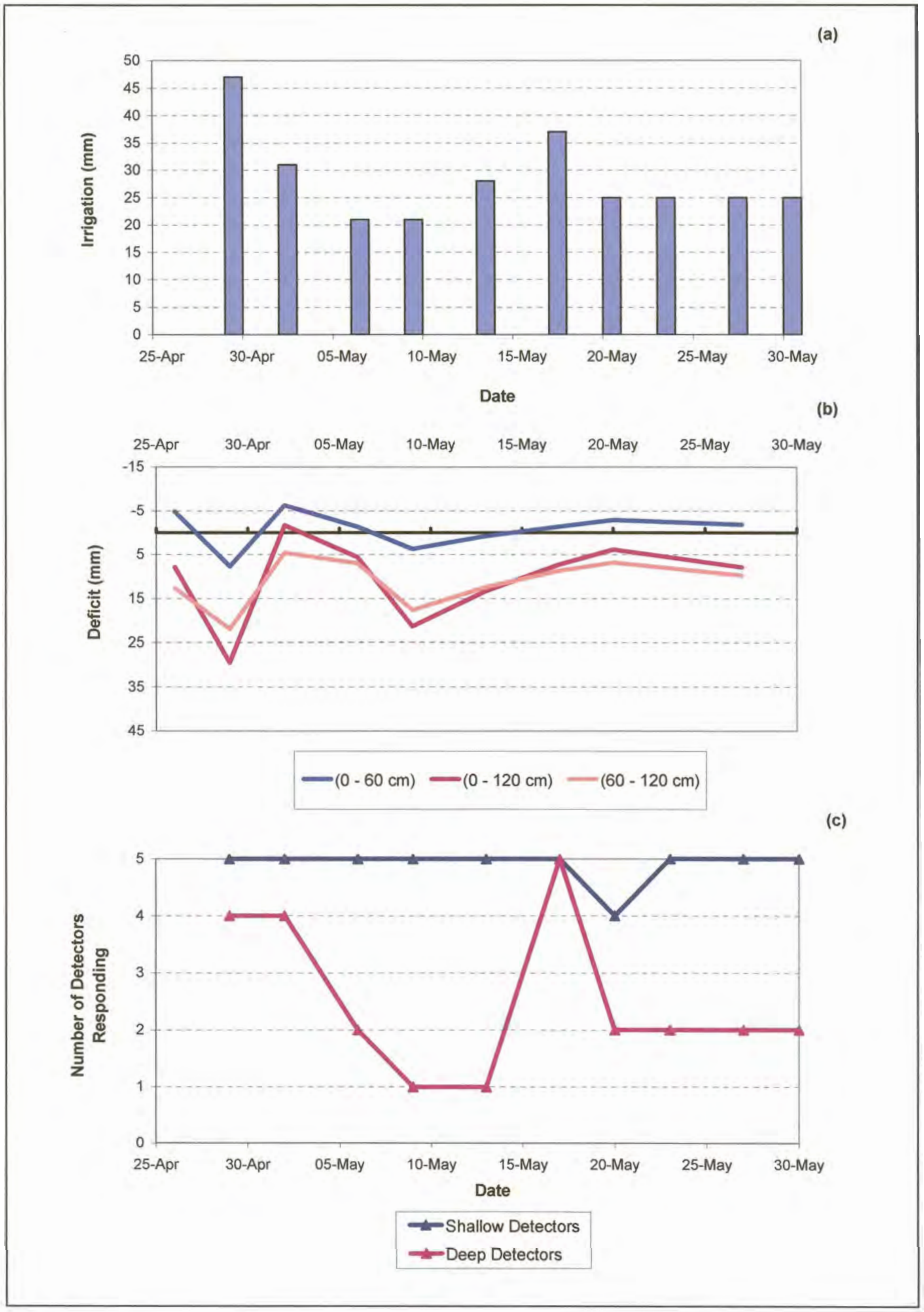

Figure 5.17 *(a) Amount of water applied per irrigation event, (b) measured soil water deficit and (c) observed detector response for the MACH treatment through the April/May growth cycle.*

5.3.2 CF Treatment

This treatment *'wanted'* 92 mm of irrigation, 119 mm less than the control treatment (Fig. 5.14 and Table 5.9). There were 10 irrigation events with the highest being 15 mm (Fig. 5.18a). The reason this treatment was under irrigated relative to the control is clearly because the algorithm could not increase the crop factor fast enough (Fig. 5.18c). The algorithm increased the crop factor with every irrigation event, but it was never able to get the application high enough to set off a single detector (Table 5.11 and Fig. 5.18a). The crop factors were increased by 0.05 and not by 0.1 as stipulated in the treatment methodology (spreadsheets not updated). The increasing soil water deficit confirms that the detector response was correct (Fig. 5.18b).

Table 5.11 *Measured ET_o and methodological action taken for the CF treatment as well as irrigation applied and observed detector responding throughout the April/May growth cycle.*

Date	$\sum ET_o$ (mm)	Crop factor	Irrigation Applied (mm)	Number of shallow detectors responding	Number of deep detectors responding	Crop factor adjustment
29-Apr	32.6	0.45	15	0	0	Up (0.05)
2-May	10.1	0.50	5	0	0	Up (0.05)
6-May	13.9	0.55	8	0	0	Up (0.05)
9-May	10.2	0.60	6	0	0	Up (0.05)
13-May	12.1	0.75	9	0	0	Up (0.05)
17-May	11.9	0.85	10	0	0	Up (0.05)
20-May	9.7	0.95	9	0	0	Up (0.05)
23-May	5.9	1.05	6	0	0	Up (0.05)
27-May	12.3	1.15	14	0	0	Up (0.05)
30-May	8.3	1.25	10	0	0	

A second problem may have been that the calculated ET_o (108 mm) was too low, and this is also observed with the SWB treatment. However, CF produced yields similar to other treatments and was not significantly different at a 5% confidence level. This implies that the crop was able to *'tap'* into deeper soil layers for water, hence the profile got drier (Fig. 5.18b). More importantly, the treatment may have used water from below the depth of the neutron probe measurements, which would lead to an underestimate of ET.

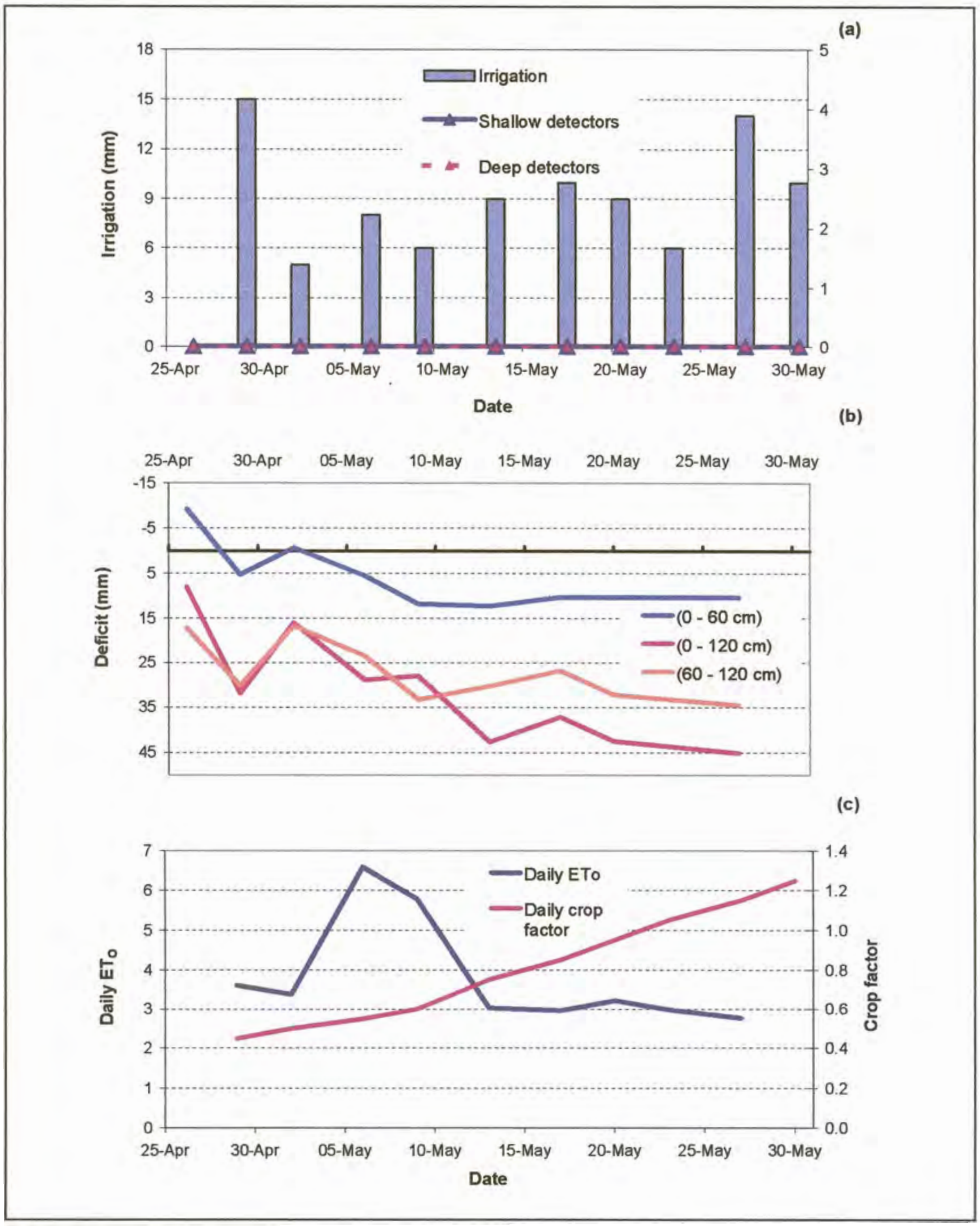

__Figure 5.18__ (a) Observed detectors responding as well as amount of water applied per irrigation event, (b) measured soil water deficit and (c) daily crop factor and measured average daily ET_o for the CF treatment during the April/May growth cycle.

5.3.3 FS1 Treatment

The control detector *"wanted"* 216 mm, 5 mm above the control treatment (Fig. 5.14 and Table 5.9). However, the cumulative water *"given"* was 254 mm. This is because of *'reactivation'* of the control detector as a result of too long an initial irrigation run time (180 minutes) set on the irrigation controller.

Table 5.12 *Amount of water that the treatment 'wanted' and that the control detector 'gave', as well as observed detectors response for FS1 during the April/May growth cycle.*

Date	**Irrigation *'wanted'* (mm)**	**Irrigation *'given'* (mm)**	**Number of shallow detectors responding***
29-Apr	21	24	4
2-May	19	23	4
6-May	23	26	4
9-May	23	26	4
13-May	24	28	4
17-May	23	27	4
20-May	21	29	4
23-May	20	23	4
27-May	21	24	4
30-May	21	24	4

**Note that only 4 replicates were operating.*

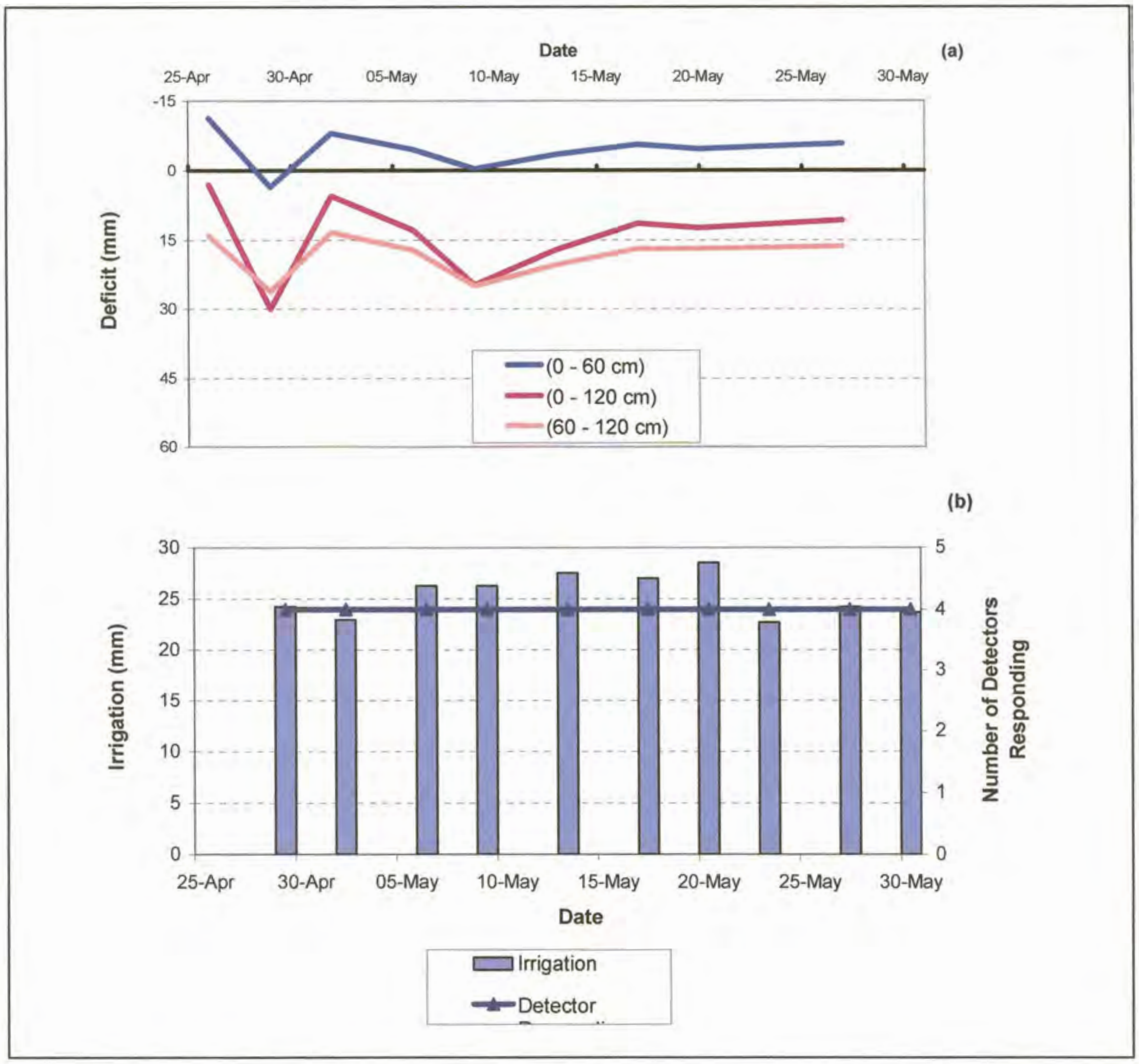

Figure 5.19 *(a) Measured soil water deficit and (b) observed detector response, as well as the amount of water applied per irrigation event to FS1 treatment during the April/May growth cycle.*

The measured soil water deficit shows that soil water content was above FC within the effective root zone, and as a result, the deeper soil layers also got wet due to drainage from the root zone (Fig. 5.19a). This treatment did not get drier, so it was probably over irrigated. Since the NP treatment was given less water and also did not get drier we can say the treatment was over irrigated relative to the NP. The reason for over irrigation is that the run time on the controller was too long so more irrigation occurred after the reset. The treatment actually *'wanted'* 216 mm, which is close to the 208 that the NP *'wanted'*. The detectors were responding to irrigation all the time, however, the depth of redistribution was not monitored (Fig. 5.19b).

5.3.4 FS2 Treatment

This treatment received 193 mm (Table 5.13), 18 mm less than the NP treatment (Fig. 5.14 and Table 5.9). However, FS2 produced statistically similar dry matter yields to the other treatments.

***Table 5.13** Amount of water that the treatment 'wanted' and that the control detector 'gave', as well as observed detector response and replicates that 'missed' irrigation after responding to irrigation for FS2 treatment during the April/May growth cycle.*

Date	Irrigation *'wanted'* (mm)	Irrigation *'given'* (mm)	Number of shallow detectors responding	Number of deep detectors responding	Replicate(s) skipped
29-Apr	25	25	4	0	None
2-May	21	24	4	2	1 & 2
6-May	11	12	2	0	None
9-May	10	16	4	1	2
13-May	17	17	3	2	1 & 2
17-May	18	18	Lost data file, all replicates were irrigated		
20-May	16	19	4	2	1 & 3
23-May	11	12	2	0	None
27-May	29	30	4	1	3
30-May	19	20	3	1	1

In the FS2 treatment, irrigation was controlled at 30 cm like with FS1. The FS2 treatment, however, used the extra information provided by the feedback detector to lengthen the irrigation interval by skipping irrigation if the deep detector was tripped. This mechanism allowed the soil profile to dry out before applying irrigation. As a result, FS2 received less water than FS1 (Table 5.9). There were deep detectors responding during this growth cycle (Fig. 5.20b).

This method had the effect of lengthening the irrigation interval, the prime cause of over irrigation in the MACH treatment. The measured soil water deficit (Fig. 5.20a) indicates water content fluctuated around FC in the active root zone, and due to prolonged irrigation interval, less water was draining to the deeper soil layers.

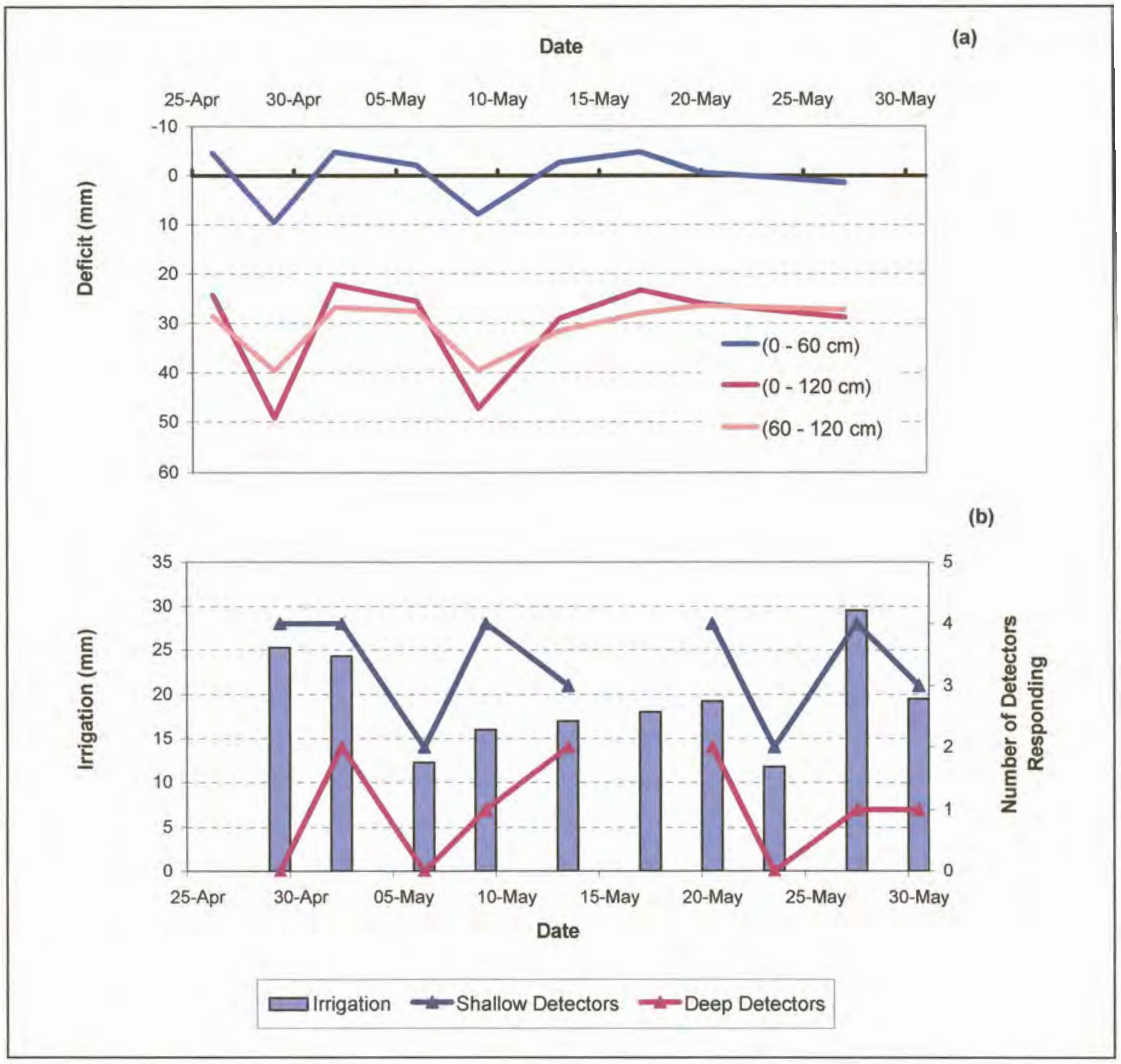

Figure 5.20 *(a) Measured soil water deficit, and (b) observed detector response as well as the amount of water applied per irrigation to the FS2 treatment during the April/May growth cycle.*

5.3.5 SWB model Treatment

This treatment received 123 mm of irrigation, 88 mm less than the control (Fig. 5.14 and Table 5.9). There was an under irrigation early in the season, which is confirmed by the soil water content measurements made in the SWB treatment (Fig. 5.21a).

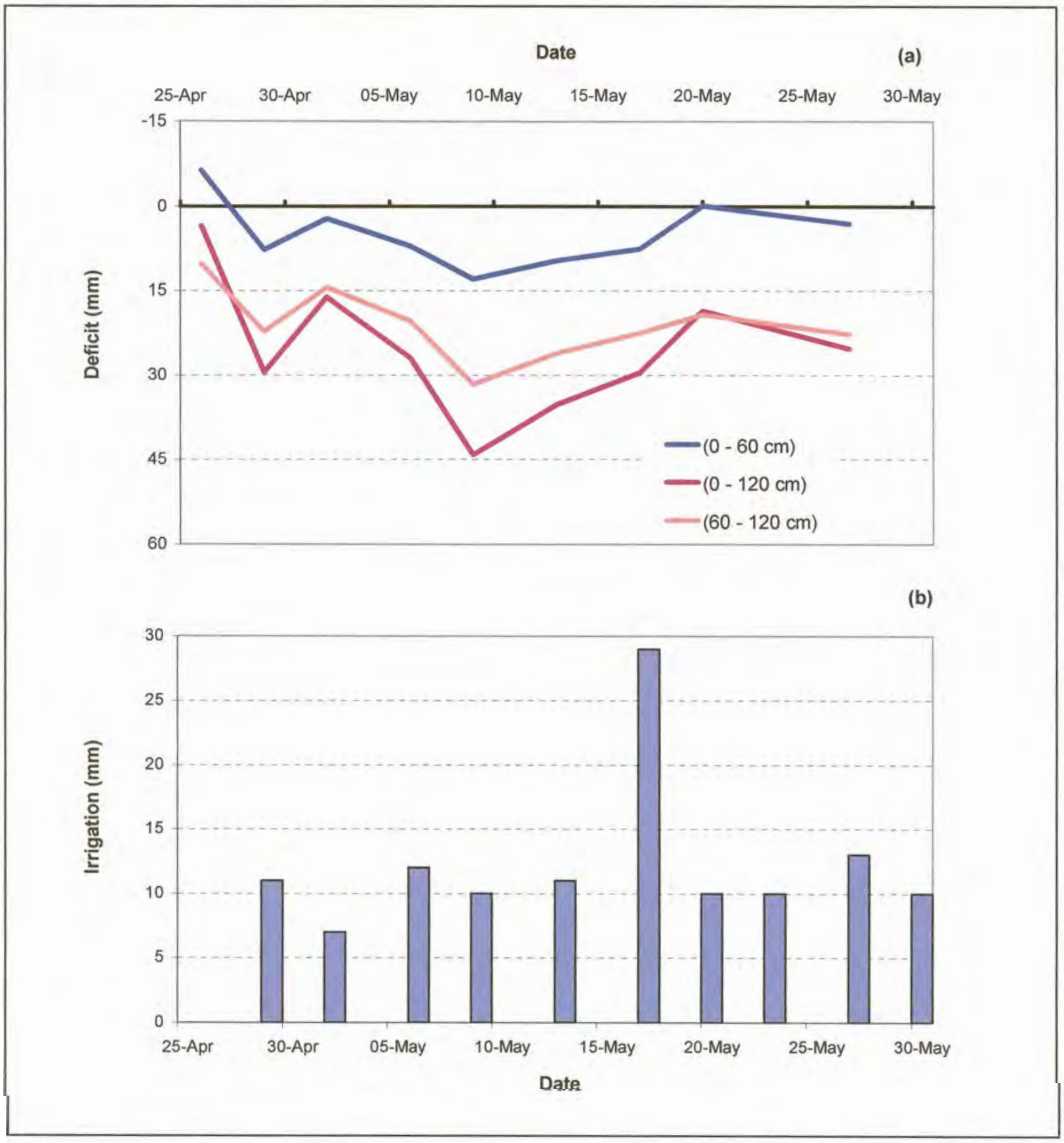

Figure 5.21 *(a) Measured soil water deficit and (b) irrigation amount applied per irrigation to the SWB treatment during the April/May growth cycle*

This is because the initial leaf area of the crop may have been underestimated and, as a result, the crop growth model 'grew' the leaf area too slowly. These mislead the model to estimate that the crop was adequately irrigated, however, the irrigation increments were too small for the ever-increasing canopy. Therefore, this led to underestimation of the crop water requirements, especially for the period between 4th April to 10th May as depicted by the measured soil water deficit within and below the managed root zone (Fig. 5.21a). This was due to inadequate irrigation applied per irrigation event (Fig. 5.21b). However, like in the CF treatment the crop was able to mine water from deeper soil layers.

5.3.6 CONCLUSIONS

The soil water content data shows that the SWB and CF treatments were under irrigated because the soil ended substantially drier than it started. There was little change in soil water content in the other four treatments. Since, FS2 received the least irrigation of these four treatments (193 mm) we conclude that the actual crop water requirement was between 55mm (CF) and 188 mm (FS2). However, it was closer to 188 mm (FS2) because water taken up from below 120 cm soil depth in SWB and CF would result in an underestimation of ET. The MACH treatment was over irrigated, as irrigation was controlled from deep detector response, like in the previous cycle. Depth of irrigation control and irrigation interval had an enormous impact on water applied to the MACH treatment. FS1 was also slightly over irrigated, as there was no feedback mechanism like in FS2. It is, therefore, highly recommended that there should be a feedback detector when using FullStops to control irrigation.

CHAPTER 6

GENERAL DISCUSSIONS AND CONCLUSIONS

6.1 General Discussions

The dry matter yields obtained with all treatments per growth cycle were similar, although with very different amounts of irrigation water (Tables 6.1 - 6.2). However, growth may have not been a good indicator of irrigation treatment success because treatments were wet up before each cycle, and towards the end of the experiment, lucerne probably grew roots below the depth of measurement. Thus, the lucerne was able to temporarily mine the soil storage and obtain good yields, but this strategy would eventually fail without the extra irrigation applied.

The soil at the experimental site is well drained, and there was no further fertilizer application after planting (leguminous crop), so leaching or water logging was unlikely to be a problem. The over irrigation also did not seem to affect yields. This is because the dry matter yield per cycle was not significantly different for different treatments whereas each treatment used varying amount s of water. As such, we use the water content trend measured by neutron probe in each treatment to make judgements about the most accurate treatment. Figure 6.1 is typical soil water content trends we will use to evaluate the experimental treatments. Each treatment will be evaluated for two soil layers, that being the topsoil (0 to 60 cm) and, the subsoil (60 to 120 cm). This is to serve as an indicator of whether the treatment was well irrigated or not.

The results obtained during the January/February cycle when the atmospheric demand was high, with ET averaging 6 to 8 mm day^{-1} indicate that, the FS1, FS2 and SWB treatments were better irrigated than the control. The control (NP) treatment was irrigated 196 mm, and since the profile was refilled to FC per irrigation, it is apparent that the crop was not under irrigated because the subsoil was uniformly wet throughout the cycle (Fig. 5.3a). Water content within the topsoil fluctuated around FC. This is an indication that the FC points determined at the start of the experiment may have been overestimated, so when the soil should be 10 or 20 mm below FC, our calculations indicated that ~~it~~ the soil was at FC because the full point was set too high. Also, the FC of the 60 to 120 cm layer might have been overestimated.

Table 6.1 *Dry matter yield (t ha^{-1}) obtained with each treatment per growth cycle.*

Cycle ID/ Treatment	January/February (cycle #1)	March/April (cycle #2)	April/May (cycle #3)
NP	4.0	2.8	2.5
MACH	-	2.8	2.7
FS1	4.2	2.8	2.5
FS2	3.7	2.8	2.4
CF	-	3.4	2.6
SWB	4.2	-	2.5
$LSD_{p=0.05}$	Not Significantly Different	Not Significantly Different	Not Significantly Different

So, for the first irrigation on the 24th January (Fig. 5.3b) was applied more water than the actual profile deficit, and therefore, the irrigations that followed was just additions to a nearly full soil profile. Hence, NP treatment received too much water during the January/February cycle.

The pattern in soil water deficit depicted by the topsoil or managed root zone in the NP treatment is similar to scenario 1 in Fig. 6.1 for the January/February cycle, which in this case can be argued to be a reflection of an over irrigation because the amount of water used by the treatment did not have a significant positive effect on dry matter production, and other treatments with similar neutron probe reading trends and yield required less water.

Table 6.2 *Cumulative irrigation (mm) applied to each treatment over the three growth cycles.*

Cycle ID/ Treatment	January/February (cycle #1)	March/April (cycle #2)	April/May (cycle #3)
NP	196	149	211
MACH	-	255	285
FS1 ***"Gave"***	137	183	254
"Wanted"	120	173	216
FS2 ***"Gave"***	140	172	193
"Wanted"	132	172	177
CF	-	143	92
SWB	154	-	123

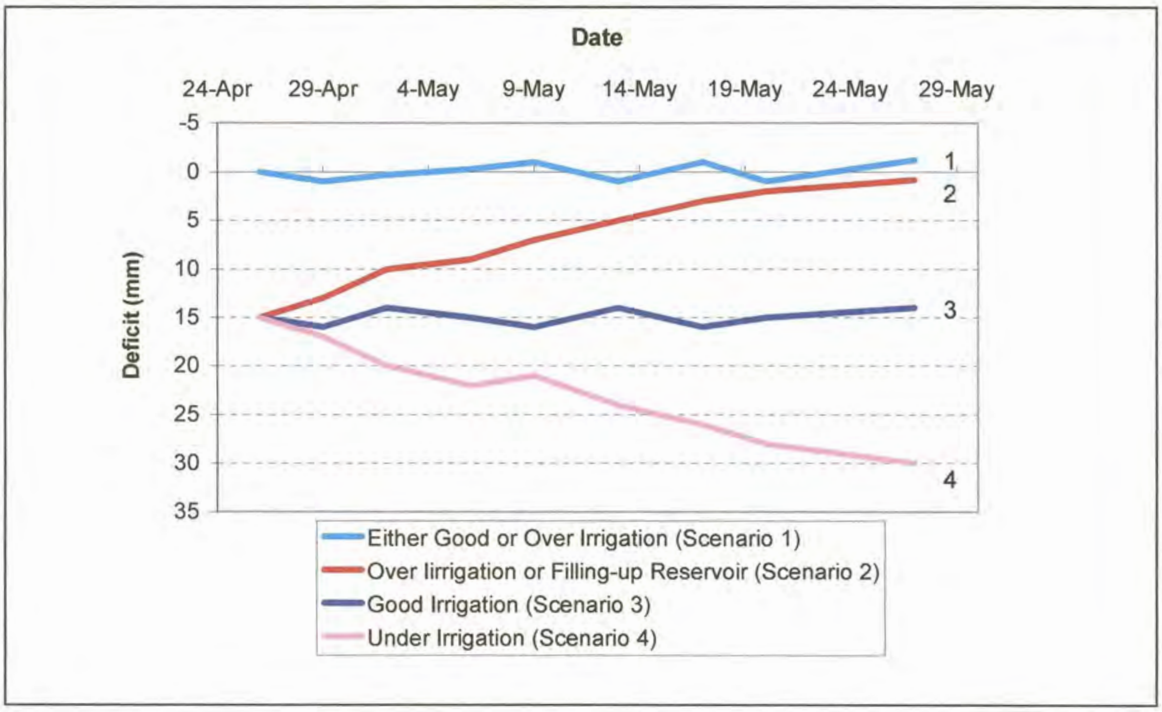

Figure 6.1 *Trends that depicts possible scenarios that can be obtained with the measurements of soil water deficit.*

During the March/April cycle, the soil water content in the topsoil stayed around FC for NP, and total water applied was 149 mm, as compared to 183

During the March/April cycle, the soil water content in the topsoil stayed around FC for NP, and total water applied was 149 mm, as compared to 183 mm for FS1 (Table 6.2) with the same yield of 2.8 t h^{-1} (Table 6.1). The trend in soil water content for FS1 treatment shows that the water content within the active root zone fluctuated around FC and the soil layers below the root zone remained dry. However, FS1 might have been over irrigated towards the end of the cycle with water content exceeding FC (Fig. 5.12a). The NP treatment during the March/April cycle received less water than during the January/February cycle. Before the start of treatment application during the March/April cycle, all the plots received 64 mm sprinkler irrigation in an attempt to start the profile at uniform water content. During the January/February cycle, all treatments started off drier, unlike during the March/April cycle, and therefore, in an attempt to bring the soil water content to FC more water was applied during the January/February to an already full or near full profile. This happened because of over estimation of the determined FC points.

The first irrigation applied to the NP treatment on the 18th March was applied to a fairly wet soil, unlike during the January/February cycle, which started drier. This may have been an over irrigation dictated by an overestimated FC, as happened in the previous cycle. The pattern of soil water deficit for the NP during the March/April (Fig. 5.9a) is similar to scenario 1 for the active root zone (0 to 60 cm) (Fig. 6.1). The NP treatment produced similar yields as the other treatments, so it can be concluded that growth and/or yield was not a good indicator of irrigation accuracy because different treatments used different amounts of water produce statistically similar dry yields.

The cumulative irrigation received by the NP treatment during the April/May cycle (211 mm), was reasonably close to the presumably correct ET of 198 mm for FS2 (Table 6.3). Soil water deficit was decreasing with time, the excess irrigation can also be attributed to faulty FC points. The difference in cumulative irrigation applied for the NP during the January/February cycle (over irrigation), March/April cycle (good irrigation) and April/May (good irrigation) can be attributed to errors in calibration of the neutron probe. The differed for each cycle. For instance, cycle 1 started drier (no sprinkler irrigation), cycle 2 received 64 mm and cycle 3 received 47 mm of sprinkler irrigation.

Table 6.3 *Estimated crop water requirements plus drainage (ET +D_r) (mm) for all treatments per growth cycle calculated from equation 4.2.*

Cycle ID/ Treatment	January/February (cycle #1)	March/April (cycle #2)	April/May (cycle #3)
NP	215	153	208
MACH	-	275	285
FS1	159	198	246
FS2	138	155	188
CF	-	133	55
SWB	175		102

Thus, if according to the determined FC points, the deficit for the top 0 to 60 cm was 100 mm but the real number should be 110 mm. If the NP measurement before irrigation was 90 mm, 10 mm will be irrigated to refill the profile to 100 mm, but the plants actually used 20 mm. This would cause an under irrigation. If according to the determined FC points, the deficit for the 60 to 120 cm is 110 mm but the real number should be 100 mm, the deficit will be overestimated. Thus, if the NP measurement before irrigation is 100 mm, 10 mm will be irrigated on an already full profile because the plants did not use any water. This would cause an over irrigation. Fortunately, the errors in the top and subsoil layers appear to have largely cancelled each other out.

For both cycles that good data was collected for the MACH treatment, this treatment was irrigated more water than all the other treatments and, as a

For both cycles that good data was collected for the MACH treatment, this treatment was irrigated more water than all the other treatments and, as a result it can be deduced that the MACH treatment was over irrigated. Data was collected for the last two cycles under conditions of decreasing ET.

From knowledge of the possible overhead when controlling irrigation from 60 cm at a transpiration rate of 3 to 4 mm per day, about 15 mm could drain past the detector after a front was detected (Equation 3.2). Thus, **O** = 600 mm (0.21 – 0.18) – 3 mm, and therefore **O** equals to 15 mm. This means we would have to use at least 15 mm below the deep detector before the next irrigation if we wanted no drainage. However, plants use water from the topsoil first – the ET was too low and the interval too short for this growth cycle (March/April cycle). So, because the crop was not allowed enough time before the next irrigation, the MACH treatment was over irrigated mainly because the crop could not use all the water at deeper soil layers. This is because irrigation was controlled from deep detectors – at the bottom of the managed root zone.

The chosen algorithm required four or five deep detectors to respond before it would reduce irrigation, and this was far too strict. The measured soil water deficit during the March/April cycle indicates that for the entire profile (0 to 120 cm), soil water deficit never exceeded 30 mm, and in fact, it was above FC towards the end of the cycle (Fig. 5.10a). The flat NP trace near FC means we either over-irrigated or were exactly right, and other treatments have flat traces with less irrigation – so we can confidently assert that this treatment was over irrigated. This implies that there was drainage from the topsoil to the deeper soil layers. This is exactly a depiction of scenario 1 in Fig. 6.1, and in this case, it can be ascertained that there was over irrigation.

For the April/May cycle, the over irrigation that occurred with the MACH treatment was partly due to an error in updating data to be used in the chosen algorithm. It is observed that large irrigation amounts were applied at the beginning of the cycle on freshly cut lucerne, and it is expected that the crop water requirement was not high at this point. The first irrigation on April the

29^{th} took into account the previous irrigation amount applied with sprinklers because only 3 deep detectors were activated from the sprinkler irrigation (Table 5.10) The algorithm required that the first irrigation be kept the same as the previous one if 3 deep detectors responded to the previous irrigation in (that being the 47 mm sprinkler irrigation applied four days earlier). As a result, this treatment was over irrigated, and so did drainage occur.

Another contributing factor for over irrigation with the MACH treatment during the April/May cycle, just like during the March/April cycle, is that irrigation was controlled from deep detector response and we know for a fact that the wetting front will continue to move after the detector has detected it. The soil behind the wetting front will be near saturation because θ_{wf} occurs at suctions wetter than -2 kPa (Hillel, 1998). With redistribution, the excess water would definitely be pushed to deeper soil layers (Stirzaker *et al.*, 2000, and Zur *et al.*, 1998). The chosen algorithm permitted this to happen because until the wetting front had activated at least 2, 3, 4 or 5 detectors it would receive the same or an increase in irrigation. This over irrigation scenario is further outlined by the measured soil water deficit that fluctuated around FC with a wet layer of soil below the managed root zone indicating that there was water drainage to deeper soil layers (Fig. 5.17b). A typical scenario 2 (Fig. 6.1), would best suit the soil water deficit pattern depicted by the top 60 cm soil layer of the MACH treatment.

As it happened during the March/April cycle it appears that there were weaker redistributing wetting fronts that all deep detectors could not detect, such that the number of responses from deep detectors was not enough as required by the chosen algorithm to cut down irrigation quantities. The MACH treatment was not scheduled accurately because more water was applied to produce statistically similar dry matter yield to other treatments at a 5% confidence level (Table 5.4).

In the FS1 and FS2 treatments irrigation was controlled from a 30 cm depth, thus the top 30 cm was at wetting front water content, (θ_{wf}), immediately after irrigation. However, FS2 had a feedback detector at 60 cm to monitor redistribution. During the January/February cycle, FS1 and FS2 treatments became replicates because there were no deep detectors responding. These treatments received similar amounts of water during this cycle (137 and 140 mm respectively), although the soil storage in FS1 increased by 22 mm. So, the soil water deficit in the FS1 treatment was decreasing with time, unlike FS2 that had a constant deficit over time. The soil water deficit pattern for the FS1 and FS2 treatments is a close approximation of scenarios 2 and 3 (Fig. 6.1), for FS1 and FS2 respectively. So, there might have been drainage with FS1 but very unlikely with the FS2 treatment. In fact, both ended with relatively dry subsoil, so there was little likelihood of drainage.

As the season progressed into the cooler times during the March/April cycle, there were deep detectors responding to irrigation in the FS2 treatment, so the feedback detector prolonged irrigation by at least 7 days for the particular plot whenever it had responded to previous irrigation. In this way, the crop had to mine water from the deeper soil layers, hence, the soil profile dried out with time in FS2. On the other hand, in the FS1 treatment, the soil water deficit for the topsoil and subsoil neither drastically increased nor decreased, except towards the end of the cycle due to three large irrigations (Fig. 5.12b). The most notable feature about the FS1 and FS2 treatments is that the feedback detector in the FS2 treatment provided additional information by monitoring the depth of redistribution, whereas FS1 treatment did not. The benefit of the feedback mechanism was more pronounced during cooler times when ET was low.

Theoretically, the cooler time of the year means that less water would be used below the 30 cm detector between irrigations and less ET on the day of irrigation means that there is more water to redistribute, so we would expect fronts to travel deeper. Thus, the feedback provided a mechanism of allowing the profile to dry out before irrigating. This was observed during the April/May cycle, when the FS2 treatment received substantially less water than FS1. The measured soil water deficit shows that, in the FS2 treatment, water content within the topsoil fluctuated about FC whilst the subsoil was dry. In FS1, the subsoil was getting wetter whilst the topsoil was often above FC. The soil water deficit pattern depicted by the two treatments is similar to scenario 1 (Fig. 6.1). However, there was definitely drainage in FS1 whereas in FS2 drainage, if any, was minimal

The SWB model made a reasonably good prediction of the crop water requirement compared to NP during the January/February cycle. The estimated crop water requirement plus drainage was 175 mm according to equation 4.4, and the model predicted 154 mm for the same period. It can be assumed that the greater proportion of the 154 mm irrigation was used for dry matter production with little water lost due to drainage. However, the possibility of drainage to subsoil cannot be completely dismissed because the topsoil got wetter with time (Fig. 5.6a). The estimation of crop water requirements, according to equation 4.2, indicates that SWB was over irrigated by 21 mm. Perhaps the model's prediction of crop water requirements was not that accurate but because we started off dry it was fortunate that we slightly over irrigated as opposed to under irrigate. According to scenario 2 Figure 6.1, this is an indication that we were filling up the resevoir. During the April/May cycle, SWB treatment was under irrigated relative to the control, as confirmed by the soil water deficit measurements. The SWB treatment was under irrigated by at least 21 mm according to the soil water balance equation (equation 4.2). This under irrigation can be attributed to the fact that the initial updated leaf area of the crop may have been underestimated and this led the crop growth model in the SWB model to under estimate the leaf area. Therefore, the model under estimated the actual crop water requirements. During cycle 1, the initial leaf area may have been over estimated, and therefore the treatment was slightly over irrigated.

When using the SWB model to run crop water requirement simulations, it is important to make a proper update of the input variables, like initial leaf area of the crop grown.

The patterns depicted by soil water deficit measurements for the CF treatment (Fig. 5.11a and Fig. 5.18b), show that the soil profile was increasingly drier throughout the cycles, except towards the end of the cycle during the

March/April cycle. Scenario 4 (Fig. 6.1) best describes this situation (under irrigation). This is an indication that the crop had to tap water stored below the root zone because of its extensive root system. Hence, this resulted in 10 mm and 37 mm depletion of soil water storage by the crop during the March/April and April/May cycles respectively.

Although the crop factors were increased with each irrigation episode, the increment was not enough to cause a large enough increase in irrigation amount. Moreover, during the April/May cycle the increment used was by 0.05 instead of 0.1. In addition, the calculated ET_0 may have been too low. The pattern depicted by WFD response during the April/May cycle, shows that the irrigation quantities were too low to initiate detector response (Fig. 5.18a). There were detectors responding towards the end of the second cycle when the weather was getting cooler and water uptake was definitely decreasing. For the April/May cycle, it can be seen that the increment in irrigation quantities was not enough to initiate any detector response (Table 5.11 and Fig. 5.18a).

The CF and SWB treatments were under irrigated relative to the control (NP). Both treatments used the ET_0 determined with the ET_0 calculator of the SWB model. The cumulative ET_0 for the April/May cycle was 108 mm (Table 5.12), which averages 3 mm day^{-1}. The ET_0 may have been too low for autumn because the average ET_0 value for a 5-year weather data set for Hatfield experimental station averaged 4.5 mm day^{-1} in autumn (Jovanovic, 2003). As a result, CF and SWB had to use water stored in the deeper soil layers (most notable with CF treatment), and that is the reason the two treatments produced statistically similar dry matter yields to the other treatments. Water content within the topsoil was steadily decreasing for CF, and declined even more pronounced for the subsoil, which is a typical resemblance of scenario 5, whereas scenario 3 would best suit SWB (Fig. 6.1).

6.2 CONCLUSIONS

The results obtained from this experiment revealed the great potential of using cheap and simple WFDs to manage irrigation, although we identified some important lessons to realise this potential. All treatments produced similar dry matter yields with varying amounts of irrigation water. However, each treatment used varying amounts of information to make that irrigation decision whereas the WFD (MACH in particular) used a *'Yes or No'* to make that decision. The MACH treatment received more irrigation than all treatments for all the cycles that it was evaluated, showing that there are several issues that need to be addressed for successful use of WFDs. Firstly, it is important that, when using the WFD, the user should choose an algorithm that increases irrigation amount when few shallow detectors respond to irrigation, and decrease irrigation amount or increase irrigation interval when more deep detectors are activated. The idea is to maintain adequate soil water content within the root zone or topsoil, and at the same time ensure minimum or no drainage to subsoil. This is helpful in the sense that WFDs can help the farmer not to consistently under or over-irrigate. The experience with FullStops shows that the MACH could be used more accurately when used in feedback mode, thus using the shallow detectors to control irrigation (increase or decrease amount or interval based on chosen algorithm) and deep detectors to decrease irrigation amount or lengthen interval. However, in this case, irrigation was controlled from deep detector response and most likely, due to weaker redistributing wetting fronts the deep detectors could not detect enough wetting fronts required by the algorithm to cut down irrigation quantities.

Hillel (1998) describes the existence of the wetting front as being due to lower hydraulic conductivity of the unwetted soil below and therefore water can only penetrate it when the gradient of the decrease in wetness is steep. So, it follows that the drier the soil is initially, the sharper must be the wetting front, and therefore in an initially wet soil the opposite can occur leading to weaker wetting fronts. This aspect of weaker wetting fronts is being further investigated.

It has also been found that it is important to keep a proper record on irrigation history because if irrigation is to be applied based on detector response it is important to have knowledge of the last irrigation amount. This is noticeable with the April/May cycle, wherein wrong data about the irrigation and detector response was fed into the algorithm and ultimately contributed to over irrigation of the treatment. Potential errors were also made with other treatments e.g the full point was not determined accurately enough for the NP treatment and ET_o may have not been correctly estimated for the CF and SWB treatments.

The lesson learned with the FullStops is that it is good to control irrigation at 30 cm for the irrigation interval we choose. However, FullStops perform even better if there is a mechanism to check the depth of redistribution. This is because water continues to move downwards long after the control detector has stopped irrigation. Therefore, detector installed at the bottom of the root zone can effectively serve this feedback purpose. Thus, FS2 performed better than FS1 as the season progressed into the cooler times of the year because FS2 operated in a feedback mode.

A point here is not to say WFD technology is an ultimate solution to problems pertaining to irrigation management. However, given the nature of already available tools and technologies for scheduling irrigation, it can be envisaged that WFDs have potential for changing the way many farmers perceive irrigation management as being difficult and costly. Examples of our experience in this regard are briefly mentioned below.

In three case studies undertaken on farm level in the Western Cape, Mpumalanga and Limpopo provinces of South Africa, wetting front detectors were used. In the first case study, table grapes were grown under drip irrigation with the aim of reaching the early export market season. The farmer was introduced to WFD technology to evaluate his current practices. Three electronic detectors were logged at a depth of 60 cm. This farmer over irrigated his crop, and he used to employ a consultant with a neutron probe, but felt the service was no longer required on a regular basis. They were surprised at the potential water saving they could make based on the wetting front detector record and decided to re-evaluate their current practice during times of low crop water use (Stirzaker et al., 2003).

In the second case study, grapes were grown under an open hydroponics system, in which drip irrigation was pulsed throughout the day. Detectors were buried at 30 and 50 cm. The aim was to ensure that the soil was regularly rewetted to 30 cm, but to minimize the drainage past 50 cm. Water was the central issue to this farmer. He used weather data and logged tensiometers to schedule irrigation and by changing irrigation infrastructure and management, he consistently cut back water applications. His feeling was that the detectors complemented his other scheduling methods, but that they could not be used on their own because his system was very fine-tuned and he needed, and had the skill to implement, detailed information. However, the detectors did show him that there were two reasonably long periods where he was under irrigating, and shorter periods when slight over irrigation occurred.

The third case study involved a small-scale farmer growing 2.5 ha of wheat under sprinkler irrigation. The major problem with this farmer was the risk of purchasing and applying fertilizer, both because of the financial risk and he was aware that leaching was a major problem on his very light soils. The farmer requested a pair of wetting front detectors, having seen them used on nearby food plots. He decided to apply nitrogen fertilizer and then followed the advice that "the shallow detector should respond regularly to irrigation and the deeper detector occasionally". At the end of the season, he harvested 5.4 t ha^{-1}, when the average yield for the scheme was 2.4 t ha^{-1}, and made a considerable profit. The farmer in this case did not have access to any scheduling method other than the WFDs. The most likely reason for this farmer's success is that he reduced N leaching by reducing drainage to deeper soil layers.

The above case studies show that irrigation-scheduling decisions for the farmer are different from the type of questions posed in this study. The study described here was about fine-tuning irrigation with different amounts of available information. For the farmers described in the case studies the detectors allowed them to evaluate the strengths and weaknesses of their irrigation strategy and reduced their risk with respect to giving "insurance" irrigations and applying fertiliser.

After all it is important to consider the fact that WFDs require a *'Yes or No'* to make irrigation adjustment whereas other well-known and widely accepted methods, like the neutron method require more detailed information to make an accurate irrigation decision. Moreover, the problems associated with adoption and use of irrigation scheduling aids is widespread (Leib *et al.*, 2002 and Tollefson, 1995), but it is mainly a function of a balance between costs, complexity and simplicity (Stirzaker *et al.*, 2003). These effects are even more pronounced in developing countries. Tollefson (1996) further contends that researchers need to develop economically viable technology that is readily adaptable to rural society, and that agricultural research must be directed to producer needs and results be made available to producers. Van der Westhuizen *et al* (1996) conclude that in South Africa the reason farmers do not schedule irrigation is that they do not perceive the net benefit to be positive.

The issues pertaining to irrigation scheduling still need to be addressed at *'grass roots level'* in some farming communities. An irrigation-scheduling tool like the WFD is simply meant to start an evaluation process wherein the farmer himself can use the tool to evaluate his current irrigation practices. It follows suite that in the case studies outlined, all the farmers were left with visible results as to what was happening with their irrigation practices. However, it is up to the farmers to make that decision of saving water and thereby cutting down the cost of irrigation. According to Walker (1995), a good preparation before on-farm trials when implementing a new technology is vital to successful adoption, and this lead to establishment of a good relationship of trust between researchers, extensions staff, and farmers. These linkages created must be of mutual benefit to all parties, thus helping in capacity building and skills training in general agronomic practices that are important for sustainable irrigated agriculture.

This experiment revealed that WFDs could be used as an irrigation management tool, for monitoring current on-farm irrigation practices. For instance, when crop factors are used to schedule irrigation, WFDs can be used an indicator of over- or under-estimation of crop factors. This helps the farmer to avoid continual under or over-irrigation. In this way, WFDs serve as a learning tool that builds up information that can be used to rectify the mistakes made previously. When using the WFDs as an irrigation-scheduling tool, the farmer must choose an algorithm that controls irrigation from shallow detectors and use deep detectors for feedback. This helps to keep water content within the effective root zone at optimal levels, whilst minimizing drainage to subsoil.

Future work with WFDs should be done with a water sensitive crop that grows over one growing season, in this way, water use efficiency can be used to evaluate the efficiency of WFDs in irrigation scheduling.