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Plant Water Relations, Crop Yield and Quality of Arabica Coffee (*Coffea arabica*) as Affected by Supplemental Deficit Irrigation

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Abstract

Low amount and erratic distribution of the seasonal precipitation and recurrent droughts are major threats to coffee production in Ethiopia. This necessitates application of supplemental deficit irrigation for coffee production. This study evaluated the impact of two supplemental irrigations, viz. supplemental full (SFI) and deficit irrigation (SDI) in comparison to rain-fed (RF) control on plant water relations, yield and quality of *Coffea arabica* L. during the dry season using three cultivars (cv. F-59, 74110 and 75227). Supplemental full irrigation consistently improved soil and plant water status and stomatal conductance (g_s) during the dry season and resulted in significantly higher yield. However, the difference between SFI and SDI was not significant for crop yield, but had higher yield than RF control. Overall quality in terms of raw appearance and total quality of coffee beans was substantially improved and the amount of irrigation water applied was considerably reduced by SDI compared to SFI practice. Therefore, SDI appears to be more effective than SFI for coffee production in areas of frequent water scarcity and recurrent drought as for eastern and northern parts of Ethiopia. © 2013 Friends Science Publishers

Keywords: *Coffea arabica*; Supplemental full irrigation; Supplemental deficit irrigation; Rain-fed culture; Crop yield

Introduction

Irrigation is becoming increasingly important in areas where frequent drought incidence and seasonal rainfall is inadequate for crop production. On the other hand, water resources are becoming increasingly limited and can no longer satisfy the continuously increasing demand of water for irrigation. This necessitates effective use of available water for conventional irrigation practices supplementing the seasonal precipitation to ensure optimum crop production. Supplemental irrigation is referred to improve growth and productivity of crop plants, particularly in drier areas (Qadir *et al.*, 2003; Wakrim *et al*., 2005). Although, less frequent watering or deficit irrigation has been reported to reduce shoot growth of coffee (Tesfaye, 2005), grapevines (dos Santos *et al*., 2003), tomatoes (Kirda *et al*., 2004; Zegbe *et al*., 2004) and hot pepper plants (Dorji *et al*., 2005), it has increased fruit quality of grapevines without a significant yield reduction (dos Santos *et al*., 2003) and enhanced fruit quality of tomatoes by way of increasing water soluble dry matter in fruits compared to those harvested from fully irrigated treatments (Kirda *et al*., 2004). Besides, Tesfaye (2005) has also reported that deficit irrigation can improve coffee quality, increase water use efficiency and reduce the amount of water required for full irrigation. Therefore, an effective use of supplemental deficit irrigation may be required to maximize returns from the practice by optimizing growth, yield and water use efficiency of crop plants.

Coffee is one of the most important commodities next to petroleum in the world market and plays a significant role in the national economy of some developing countries like Ethiopia. Thus, supplemental deficit irrigation could be advantageous and more feasible than full irrigation for coffee production in areas of frequent water scarcity and recurrent droughts.

Conventional deficit irrigation has been widely used in different crops, but its effect on coffee yield and quality is not extensively studied under field condition especially in countries like Ethiopia with drought as one of the major threats to crop production. Although the crop is a leading commodity in the world market, it is suffering from seasonal water stress and recurrent droughts in these areas. As reviewed by Carr (2001), despite the international importance of irrigation in coffee production, the benefits to be derived from irrigation have not been adequately studied and quantified in terms of yield, quality and water use efficiency. The objectives of present study were, therefore, to determine the effect of supplemental deficit irrigation on plant water relations, yield and quality of Arabica coffee cultivars under field condition in Ethiopia.

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Materials and Methods

Plant Materials

Two sets of field experiments were conducted at Jimma Agricultural Research Centre (JARC) of the Ethiopian Institute of Agricultural Research (ElAR), Ethiopia. The first set of experiment was laid down on a well established six years old coffee stand of cultivar F-59, while a three years old younger stand of two coffee berry disease (CBD) resistant cultivars (cv. 74110 and 75227) was used for the second set of experiment. Both stands were planted on the same hill side terrain receiving the same management level.

Plot Arrangement

One meter deep, 30 cm wide and 18 m long ditch was dug at all sides of each plot (36 m^2 size) consisting of nine trees. A plastic sheet with two meter width and 20 m length was buried in the ditch along its length and depth, and the ditch was filled with soil with a meter wide plastic sheet lying above ground to prevent the seepage of water from adjacent plots during the dry period. In the first set of experiment, two supplemental irrigation treatments viz. supplemental full irrigation, SFI and supplemental deficit irrigation, SDI were compared along with a rain-fed (RF) control in a randomized complete block design with four replications. On the other hand, SDI and RF treatments were compared in the second set, superimposed on a uniformly growing three years old coffee stand of two cultivars. The stand was planted at 2 m × 2 m spacing in split plot design. Therefore, SDI and RF treatments were laid down as sub plot and cultivars as main plot factors in four replications on the existing plots.

Irrigation Treatments

Supplemental irrigation treatments were applied twice (on December 30, 2003 and March 8, 2004) during the dry spell. Water was applied in the conventional way when the soil moisture content at 30 cm depth declined to less than 35% of the FC. The first set of experiment involved supplemental full irrigation (SFI) to raise the soil moisture level at 30 cm depth to FC, and half of the irrigation water in SFI applied as supplemental deficit irrigation (SDI) during each application. A rain-fed (RF) plot was also maintained for comparison. On the other hand, SDI and RF treatments were tested in the second set of field conventional irrigation experiment. In both cases, water was applied evenly to the root zone of coffee trees during irrigation supply.

Measurement of Water Relations

Leaf relative water content (RWC), stomatal conductance (g_s) and soil moisture content (SMC) was determined on weekly basis. Soil moisture content (SMC) was measured at a depth of 30 cm from the surface using both volumetric (soil moisture probe TRIME-FM, Field Measurement Device P3, IMKO GMBH Micromodule technik, Germany) and gravimetric methods. Soil moisture content on dry weight basis was determined by the gravimetric method by oven drying soil samples at 110°C to constant weight.

Measurements were taken at 50 cm distance from the main stem of each sampled tree. The SMC was measured for both sides of the root system of two randomly selected plants from each treatment before irrigation. Leaf relative water content (RWC) was measured using fully expanded leaves sampled from the third or fourth node from the apex of younger plageotropic branches. After measuring the fresh weight (FW) of leaves right after abscission, the petiole of each leaf was immersed in distilled water in a glass box and immediately sealed, and leaves were allowed to float in dark at 4°C for 24 h to determine their turgid weights (TW). Then, the leaves were oven-dried at 80^0C to a constant weight (DW). After measuring dry weights, RWC (%) was calculated based on the relationship:

RWC = 100 (FW-DW/TW-DW)

Like RWC, stomatal conductance (g_s) was also measured at noon between 11:00 and 13:00 on the same leaves right before abscising for RWC determination. Stomatal conductance was determined with a diffusive porometer (AP-4, Delta T Devices Ltd., Cambridge UK).

Crop Yield and Quality Analysis

Yield and yield components, as well crop quality attributes, were determined following standard procedure. Crop yield was estimated based on fruit count per tree and actual yield harvested from each tree in a plot at the end of the cropping season. For quality determination, red fully ripe cherries were manually picked and processed in the wet processing method. The wet parchment coffee was dried under shade to 10-12% moisture content and stored in a well ventilated coffee store with about 60% relative humidity at 20°C. Then, it was hulled and three samples, each with 100 g clean coffee, were taken from each plot and the beans were sorted by size using flat screen graders, visually inspected and evaluated for raw quality based on shape and make, color and odor, accounting for 40% of the total coffee quality. A sample roaster (Probat welke, Von Gimborn Gmbhan Co. KG) was first heated to about 160°C and green coffee beans were put in the roasting cylinder and roasted for 10 min until the final temperature reached 240°C. 8 g of the medium roast was ground using roasted coffee sample grinder and put into a clean standard porcelain cup with 160 mL capacity. Fresh boiled water was poured over the ground coffee up to about half of the cup was filled. The contents of the cup were stirred to ensure a complete infusion of the ground coffee and the cup was filled to full capacity with boiled water. Then, the cup was left for about three min, allowing the coffee to brew and the grounds to settle either at the bottom or float to the top. The floating grounds were skimmed off and the cup was left to cool down to a palatable temperature. A spoon full of the brew was tasted for sensory evaluation and determination of its liquor characteristics (acidity, body and overall flavor), accounting for 60% of the total coffee quality. The cup taste was carried out by a panel of three liquorers, well-trained in the field and who have a long experience in the art and have acquired a memory of flavors.

Leaf RWC, stomatal conductance, SMC and both crop yield and quality were measured for the first set of experiment. But, in the second set of experiment only crop yield and yield components were recorded.

Statistical Analysis

Differences between the irrigation treatments for crop yield and quality were analyzed using the SAS statistical software.

Results

Experiment I

Soil moisture content: Soil moisture content (SMC) of SFI was always higher than SDI, except at end of the cropping season, where all the plots had similar SMC. Although these were consistently lower in RF plot compared with SDI treatment during the dry period, SMC in the former increased with the onset of rains after week 15 and reached a level almost similar to SDI since week 18 during the wet season. Furthermore, differences between the three treatments were narrowed down during the main rainy season after week 22 at end of June (Fig. 1).

Leaf Relative Water Content

Leaf RWC was consistently higher for SFI than for SDI and RF plots, but it was lower in RF than in the SDI treatment during the dry period. However, leaf RWC of plants in the RF plot increased with the commencement of rainfall in week 15 (Mid May) and all the treatments had almost similar values since week 22 (as of late June) in the main rainy season (Fig. 2). In general, leaf RWC varied depending on the corresponding change in SMC for each treatment.

Stomatal Conductance

Stomatal conductance (g_s) was consistently higher for SFI, followed by SDI, than for the RF control during the dry spell. However, RF plot exhibited increasing g_s with the onset of rains (after week 15) and had similar values to those of SFI and SDI treatments since week 22 in the peak wet season. In general, g_s of even irrigated plants were substantially lower in dry season than during rainy period (Fig. 3).

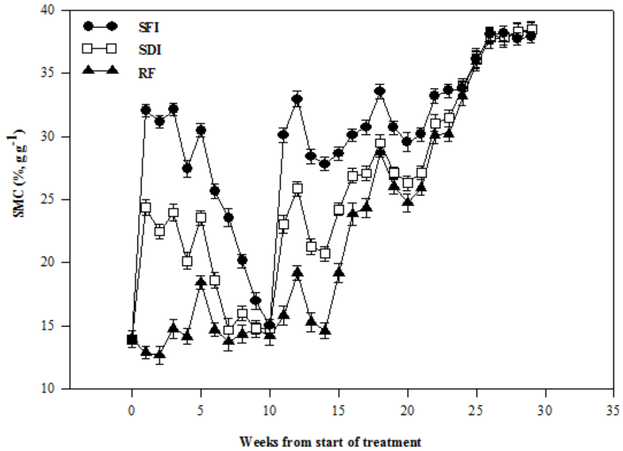

Fig. 1: Soil moisture content (SMC) as affected by supplemental irrigation in a coffee stand (cv. F-59) during the dry season (SFI = supplemental full irrigation when the soil moisture content declines to < 35% of FC, SDI = supplemental deficit irrigation with half of the amount applied to SFI; RF = rain fed control). Bars represent standard errors

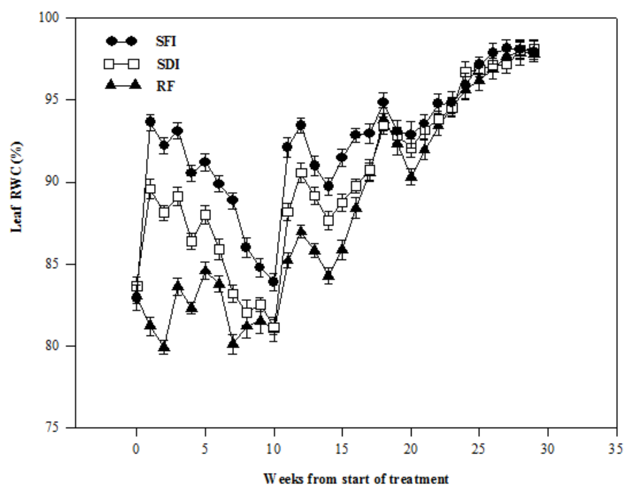

Fig. 2: Leaf relative water content (RWC) as affected by supplemental irrigation in a coffee stand (cv. F-59) during the dry season (SFI = supplemental full irrigation when the soil moisture content declines to < 35% of FC, SDI = supplemental deficit irrigation with half of the amount applied to SFI, RF = rain fed control). Bars represent standard errors

Yield Components

A comparative study of SDI in a conventional way and RF treatment on a young coffee stand of Cv. 74110 and 75227 indicated that number of fruits and fresh cherry weight per tree highly significantly (P < 0.01) affected by treatments and increased for SDI in both cultivars (Fig. 4).

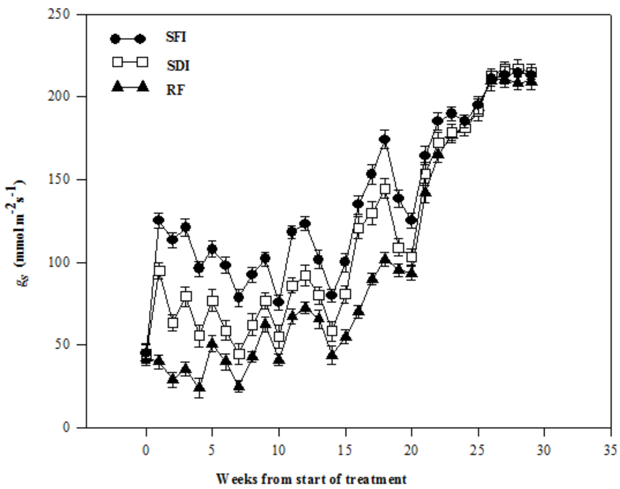

Fig. 3: Stomatal conductance (g_s) of coffee plants (cv. F-59) as affected by supplemental irrigation during the dry season (SFI = supplemental full irrigation when the soil moisture content declines to < 35% of FC, SDI = supplemental deficit irrigation with half of the amount applied to SFI, RF = rain fed control). Bars represent standard errors

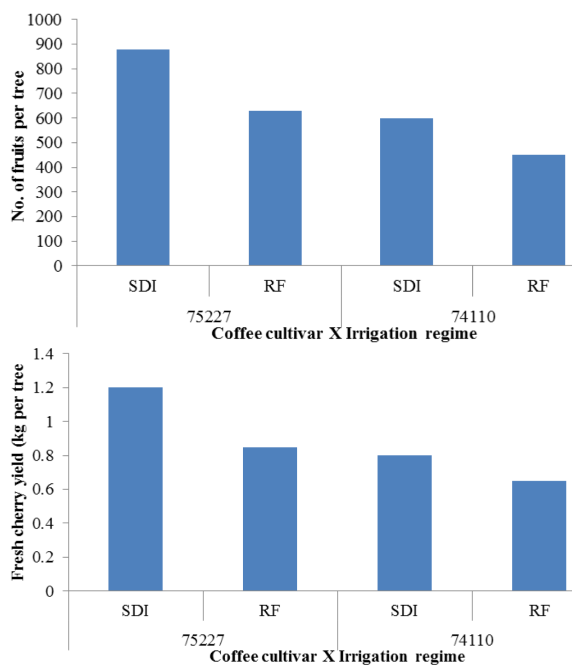

Fig. 4: Effect of conventional irrigation on number of fruits and fresh cherry yield per tree of two coffee cultivars (cv. 75227 and 74110). Irrigation treatments involved supplemental deficit irrigation (SDI) and rain fed (RF). Bars indicate standard errors

Crop Yield

Crop yield was also significantly (P < 0.05) affected by irrigation treatments. Supplemental full irrigation (SFI) resulted in significantly higher yield and was statistically similar to SDI but different from RF plot. Although SDI exhibited 21.34% more yield than RF treatments, the difference between the two was not significant. On the other hand, SDI and RF treatments had 16.75% and 34.52% less yield, respectively than SFI (Fig. 5).

Crop Quality

None of the quality parameters were significantly affected by the treatments in the conventional irrigation experiment, although bean shape and make, odor and cup acidity, body and flavor had slightly higher values under SDI and RF conditions than in SFI treatment (Table 1). Similarly, the overall liquor quality was unaffected (P > 0.05) by treatments, but it was higher for SDI and RF than in SFI treatment. However, as compared to SFI, SDI and RF treatments significantly increased (P < 0.05) both overall raw appearance and total quality of coffee beans (Fig. 6).

Bean size was highly significantly (P < 0.01) influenced by irrigation regime. The proportion of larger beans corresponding to screen size No. 20 and 19 was significantly reduced but that of smaller beans (≤ screen No. 15) increased by RF treatment. The difference between SFI and SDI was not significant for mean percentage of larger beans. However, SFI resulted in highly significant (P< 0.01) increase in the proportion of beans with medium size (No. 18, 17 and 16 sieves), which was also significantly higher for SDI than for RF treatment. Smaller beans graded by screens ≤ 15 were significantly higher in proportion for SDI than for SFI (Table 2). On the other hand, there were no significant variations among the treatments for mean weight of individual coffee beans in all grades, although beans from SDI and RF plots had slightly greater mean weight than those from SFI treatment (Table 2).

Experiment II

Yield components: A comparative study of SDI in a conventional way and RF treatment on a young coffee stand of cv. 74110 and 75227 indicated that number of fruits and fresh cherry weight per tree highly significantly (P < 0.01) affected by the treatments and increased for SDI in both cultivars (Fig. 4).

Crop Yield

In the second set of experiment, crop yield was highly significantly (P < 0.01) affected by the treatments. It was observed that SDI significantly increased fresh cherry yield of both cultivars, with an average of 24.59% advantage over the RF plot (Fig. 5). In general, coffee yield was relatively higher in the first than in the second set of experiment, because trees in the latter were younger than those in the former.

Discussion

Soil moisture content (SMC) remained higher in SFI than SDI treatment and RF during the dry period,

Table 1: Effect of supplemental irrigation [supplemental full irrigation (SFI), supplemental deficit irrigation (SDI) and rain-fed (RF)] on raw and cup quality of coffee beans (cv. F-59)

Treatment	Raw quality (40%)			Liquor value (60%)		
	Shape and make	Color	Odor	Acidity	Body	Flavor
SFI	8.50a	9.75a	8.50a	11.87a	11.87a	10.62a
SDI	9.00a	11.00a	9.50a	12.50a	13.12a	12.50a
RF	10.50a	9.75a	9.00a	12.50a	12.50a	11.25a

Figures followed by same letters within a column are not significantly different at P = 0.05 by LSD test

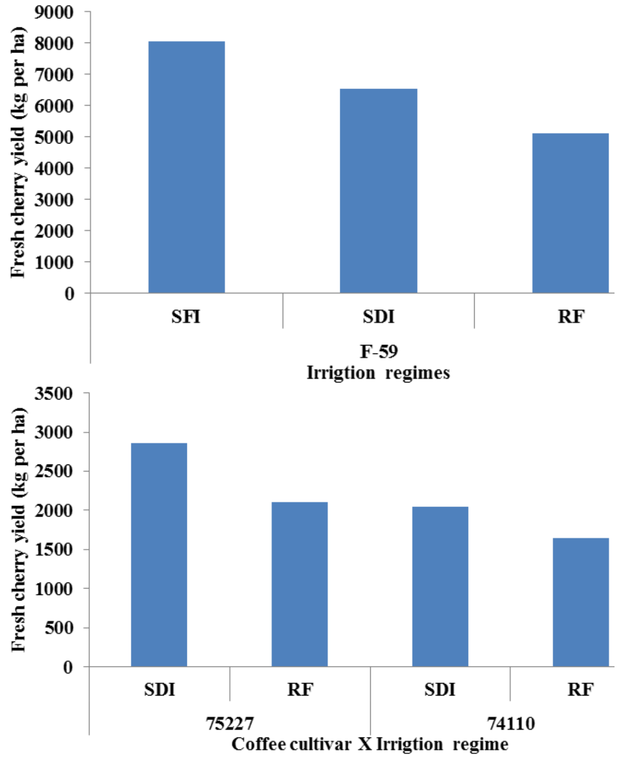

Fig. 5: Effect of conventional irrigation [supplemental full irrigation (SFI), supplemental deficit irrigation (SDI) and rain fed (RF)] on yield of three coffee cultivars (cv. F-59, 75227 and 74110). Bars represent standard errors

however only slight differences were observed in main rainy season after late June (Fig. 1). This decrease in SMC with soil drying or deficit irrigation is normally expected, because of higher evapotranspiration or evaporative demand of atmosphere and continuous depletion of soil moisture during the dry period (Wiersma and Christie, 1987; Hsiao, 1990). Similar results have been reported for pear (Kang *et al*., 2002), tomatoes (Zegbe-Dominguez *et al*., 2003; Kirda *et al*., 2004; Zegbe *et al*., 2004) and pepper (Dorji *et al*., 2005), where SMC considerably decreased with deficit irrigation compared to full irrigation.

Leaf relative water content (RWC) was consistently higher for SFI and followed the treatment order

Table 2: Size distribution (SD) and mean weight (MW) of coffee beans (cv. F-59) as affected by supplemental irrigation [supplemental full irrigation (SFI), supplemental deficit irrigation (SDI) and rain fed (RF)] treatments

Screen No.	Treatment	SD (%)	MW (g)
≤ 15	SFI	15.77 c	0.098 a
	SDI	23.83 b	0.102 a
	RF	32.98 a	0.102 a
16 – 18	SFI	68.35 a	0.146 a
	SDI	62.61 b	0.151 a
	RF	57.74 c	0.158 a
19 – 20	SFI	15.85 a	0.162 a
	SDI	13.56 a	0.168 a
	RF	9.27 b	0.173 a

Figures followed by same letters within a column for a given size range (screen No.) are .not significantly different at P = 0.05 by LSD test

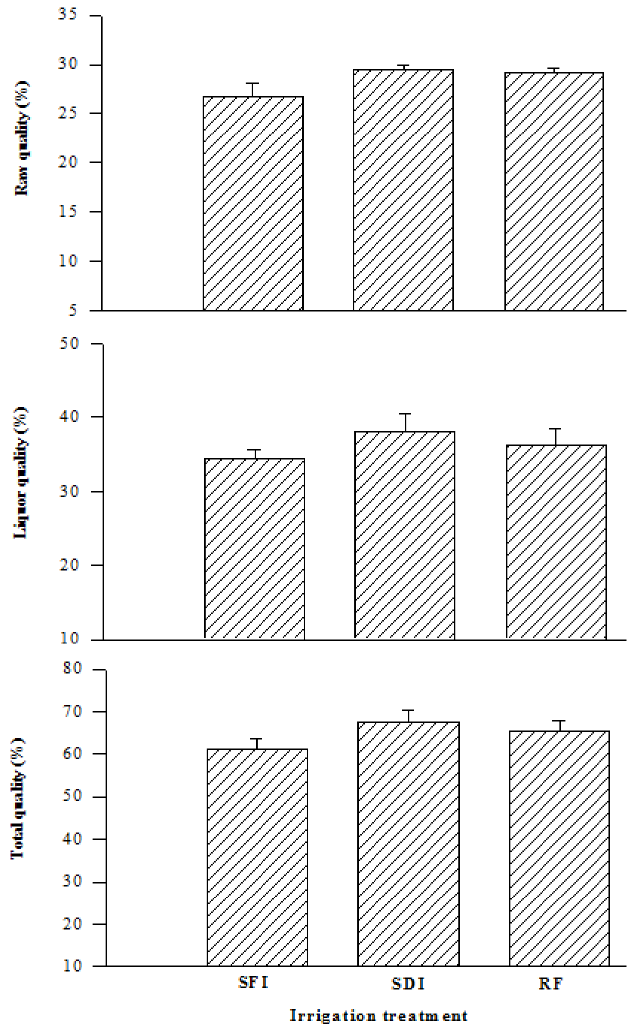

Fig. 6: Overall raw and liquor and total qualities of coffee beans (cv. F-59) as affected by conventional irrigation practices: supplemental full irrigation (SFI), supplemental deficit irrigation (SDI) and rain fed (RF) treatments. Bars indicate standard errors

SFI > SDI > RF. However, all the treatments had similar RWC during the wet season due to increase in SMC under SDI and RF treatments by heavy rains. Such substantial reductions in leaf water potential (LWP) due to soil drying and deficit irrigation has been reported for grapevines (de Souza *et al*., 2003; dos Santos *et al*., 2003), hot pepper (Dorji *et al*., 2005) and common bean (Wakrim *et al*., 2005). Significant decrease in LWP following the extent of decline in soil moisture availability has also been reported for water-stressed plants of Arabica coffee (Tausend *et al*., 2000a, b) and sweet pepper (Hawa, 2003). On the other hand, leaf RWC values fluctuated with measurement dates for all treatments during the dry spell. Such fluctuations in leaf RWC of coffee plants could be attributed to changes in some environmental factors affecting plant water status during the dry period. Zegbe-Dominguez *et al.* (2003) have suggested that LWP could be affected by evaporative demand of the atmosphere and radiation level regardless of SMC during the measurement period. Hsiao (1990), Rhizopoulou *et al.* (1991) and Gutierrez *et al.* (1994) have also emphasized the role of evaporative demand of the atmosphere in regulating stomatal aperture and LWP of plants.

Stomatal conductance (g_s) of plants in SFI was higher than that of SDI and RF plants during the dry spell. However, g_s of plants in RF plot was considerably lower than the values recorded for the SDI treatment during the dry period, and all the treatments had similar and higher values of g_s in the wet season, probably because of the increase in SMC by heavy rains. The decline in g_s of deficit irrigation treatment and under RF condition was quite in agreement with findings on apple (Gowing *et al*., 1990), three Arabica coffee cultivars (Tausend *et al*., 2000a; b) and grapevine (Stoll *et al*., 2000; de Souza *et al*., 2003). Several workers have reported that increases in concentration of root-sourced chemical signals such as ABA in the xylem sap, as a result of exposure of roots to a drying soil, may induce stomatal closure (Bano *et al*., 1993; Thompson *et al*., 1997; Naqvi, 1999; Davies *et al*., 2000; Stoll *et al*., 2000). Although changes in concentration of these chemical signals in plant system have not been measured in present study, it might have played a role in controlling stomatal aperture in SDI and RF plants during the dry season. In addition, it has been reported that changes in xylem sap pH (Thompson *et al*., 1997; Bacon *et al*., 1998; Kirda *et al*., 2004) and hydraulic signaling (Auge and Moore, 2002; de Souza *et al*., 2003; dos Santos *et al*., 2003) with soil moisture depletion could also induce stomatal closure in water-stressed plants. Nevertheless, hydraulic signal seems to play the major role in controlling g_s, because this followed the same trend as observed for both SMC and leaf RWC of coffee plants. In contrast, it has been observed that g_s was unaffected by soil drying in tomatoes (Zegbe *et al*., 2004). Besides g_s, photosynthetic rate of tomatoes (Zegbe *et al*., 2004) and hot pepper plants (Dorji *et al*., 2005) has not been significantly affected by deficit irrigation. This seem in agreement with results of present study, where SDI treatment exhibited g_s values closer to those of SFI than to RF coffee plants on some measurement occasions during the dry season. This could be attributed to SMC in SDI treatment, which might have induced only mild stress that was probably ineffective to bring about considerable reductions in g_s.

On the other hand, g_s of even irrigated plants was generally lower during the dry spell compared to its values recorded in the wet season. Such a decrease in g_s could also be associated with factors other than SMC and leaf RWC. It has been reported that seasonal changes in air temperature, radiation and evaporative demand of the atmosphere could bring about variations in plant water potential and stomatal aperture (Hsiao, 1990; Barros *et al*., 1997; Tausend *et al*., 2000a; Carr, 2001; Zegbe-Dominguez *et al*., 2003). Higher air temperature and lower relative humidity might have contributed to the decline in g_s of especially irrigated coffee plants during the dry spell. It has been reported that both irrigated and non-irrigated coffee plants experienced a similar low level of g_s during the dry period, and that stomatal behavior was more affected by cool night and morning temperatures than by irrigation or leaf water potential (LWP) in the dry spell (Barros *et al*., 1997). As observed in the present study, the decrease in g_s in dry period has also been associated with increased air temperature, longer daily time of elevated temperature and higher solar radiation and leaf-to-air vapor pressure deficit (VPD) (Gutierrez *et al*., 1994; Tausend *et al*., 2000a; Carr, 2001).

Coffee yield significantly increased with SFI, but considerably decreased for SDI and RF treatments in the present study. In agreement, it has been reported that fruit growth and yield of pear (Mitchell *et al*., 1984) and avocado (Adato and Levinson, 1988), pod biomass of common bean (Wakrim *et al*., 2005) and total fresh mass of pepper fruits (Dorji *et al*., 2005) were considerably reduced by soil drying or deficit irrigation compared to well irrigated treatments. Significant reductions in fruit dry mass yield under deficit irrigation and in fruit fresh and dry masses as a result of partial soil drying have also been reported for tomatoes (Kirda *et al*., 2004) and sweet pepper (Cantore *et al*., 2000), respectively. Similarly, it has been observed that deficit irrigation resulted in significantly lower crop yield in hot pepper plants (Dorji *et al*., 2005).

Previous reports also support the results of present study that RF treatment significantly reduced crop yield, but differences between SFI and SDI or among SDI and RF treatments were not significant. Lack of significant variation between SFI and SDI treatments for coffee yield is in agreement with previous studies on tomatoes, where fruit dry mass yield was not affected by deficit irrigation (Zegbe-Dominguez *et al*., 2003). On the other hand, RF treatment had significantly lower coffee yields, probably because of reduced rate of physiological activities associated with total dry matter production and its partitioning to fruits due to water deficit at critical berry development stages. It has been reported that withholding irrigation for the entire growth period resulted in 30% reduction in photosynthetic rate which caused considerable decline in fruit yield in field-grown sweet pepper (Delfine *et al*., 2000). Severe disturbance of physiological processes and reduction in growth and productivity of plants due to long-term water deficits has been well documented, and such a prolonged drought would be potentially most damaging to crop yields when it occurs at reproductive stages (Hawa, 2003; Kirda *et al*., 2004).

In general, reductions in total crop yield of deficit irrigation and RF plots in the present study could be attributed to decreases in number of fruits and fresh cherry weight per tree (Fig. 5), due to reduced flower to fruit set ratio and increased rate of fruit fall with reductions in soil and plant water status especially during the early months of berry development. It could also be associated with reduced rate of total biomass production and its partitioning to shoot organs especially to fruits in response to soil drying (Kang *et al*., 1998; 2001; Poorter and Nagel, 2000; Mingo *et al*., 2004), although coffee fruits are said to be powerful sinks of the total assimilate produced by the tree during cherry development phases.

Overall raw appearance and total quality of coffee beans were significantly higher for SDI and RF than SFI treatment. Significant improvement in crop quality due to SDI has been observed in tomato fruits because of redder color and higher concentration of total soluble solids (TSSC) compared to full irrigated plants (Davies *et al*., 2000; Zegbe-Dominguez *et al*., 2003; Zegbe *et al*., 2004) and similarly 21% higher TSSC and better color development in hot pepper fruits (Dorji *et al*., 2005). However, the quality of marketable coffee is normally determined by the raw appearance of its beans and liquor taste following a standard procedure without conducting a sophisticated laboratory biochemical analysis. It is also possible that soil drying or deficit irrigation might have brought about changes in the biochemical constituents of coffee beans and, thus, contributed to the observed differences among the treatments especially for liquor quality attributes in the present study.

On the other hand, RF plants had significantly lower percentage of both medium size (No. 18, 17 and 16 sieves) and larger coffee beans (No. 20 and 19 sieves) but higher ratio of smaller (≤ screen No. 15) beans compared to SFI and SDI treatments for the respective size grades. However, there was no significant variation among the treatments for mean weight of beans in each size group, but beans from SDI and RF plots had slightly greater mean weight. Increases in fruit weight with decreasing soil moisture status have been reported for tomatoes (Zegbe-Dominguez *et al*., 2003) and hot pepper plants (Dorji *et al*., 2005) grown under deficit irrigation. On the other hand, it has been observed that there was no significant difference between deficit and full irrigated tomato plants for mean fresh weight (Zegbe *et al*., 2004) and size of fruits (Kirda *et al*., 2004). The decrease in crop load probably, because of water stress-induced flower abortion and berry fall, might be the reason for increased mean weight of coffee beans from SDI and RF plants. As reductions in crop load in these treatments might have decreased the competition for assimilates and enhanced the accumulation of available carbohydrates in the remaining smaller number of fruits, maintaining the final bean weight and probably improving the crop quality, compared to SFI treatment (Tesfaye, 2005). Similar results have been reported for tomato (Zegbe-Dominguez *et al*., 2003) and hot pepper (Dorji *et al*., 2005). On the other hand, significantly higher proportion of coffee beans within the medium and large size range and lower percentage of smaller beans in the SFI treatment could be attributed to increased soil and plant water status during active fruit development stages. The findings of Carr (2001) have indicated that size of coffee beans is greatly affected by amount of rainfall or irrigation during the rapid fruit expansion stage and any failure in the development of the endosperm is reflected towards final yield and size grade of the crop. Conversely, the increase in bean size uniformity with greater proportion in the medium range is considered a good quality attribute and beans in this range are regarded best grades of washed Arabica coffee (Tesfaye, 2005).

In conclusion, difference between SFI and SDI was non-significant for crop yield, but SFI resulted in significantly higher coffee yield compared to RF treatment. On the other hand, SDI exhibited 21 to 25% more yield than RF treatment. Besides yield advantage, overall quality of the coffee beans was substantially improved and the amount of irrigation water applied was considerably reduced by SDI compared to SFI practice. Therefore, SDI appears to be more effective than SFI for coffee production in areas of frequent water scarcity and recurrent drought as in eastern and northern parts of Ethiopia.

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