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Systematic review: Effect of Irrigation Water Quality and Deficit Irrigation on Crop Yield and Water Use efficiency

Lelisa Endalu Tura[1,a], Tasisa Temesgen Tolossa[1,b,*]

[1]*Department of Plant Sciences, Samara University, Samara, Ethiopia*
[1]*School of Natural Resources Management and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia*
[*]*Corresponding author*

A R T I C L E I N F O

Review Article

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A B S T R A C T

The main purpose of this paper is to review on the effect of irrigation water quality and deficit irrigation on crop yield and water use efficiency. Low quality water for irrigation can impose a major environmental constraint to crop productivity. If salts become excessive, losses in yield will result. To prevent yield loss, salts in the soil must be controlled at a concentration below that which might affect yield. Irrigation application below the full evapotranspiration requirement is termed as deficit irrigation. Deficit irrigation consists of deliberately applying irrigation water in amounts below the plant's water requirements. Deficit irrigation can be applied at certain periods during the crop's growing season or throughout its growing season. Yield reductions also occur in a number of crops when subjected to water stress. Yield reductions depend on the crop's sensitivity to water stress at its various growth stages. In order for deficit irrigation to be an economically viable practice, the revenue lost due to yield reduction should be lower than savings in total cost of production. The goal of deficit irrigation is to increase crop water use efficiency by reducing the amount of water that is applied or by reducing the number of irrigation events. The interaction effects of water quality and DI illustrated that when the two types of stresses; saline and DI were coupled together, a serious reduction occurred on total dry biomass and total yield. The interaction effects of water quality and deficit irrigation illustrated that when the two types of stresses; saline and deficit irrigation were coupled together, a serious reduction occurred on total dry biomass and total yields.

[a] endalulelisa@yahoo.com https://orcid.org/0000-0003-1378-0723 | [b] tasisatemesgen@gmail.com https://orcid.org/0000-0001-8937-6364X

Introduction

Irrigated agriculture is the primary user of fresh water resources (FAO, 2002; Fereres and Soriano, 2007; Kenny et al., 2009). Irrigation uses take almost 60% of all the world's freshwater withdrawals. Irrigated agriculture, especially in arid and semi-arid or low land and highland areas, is facing pressures to reduce its water use in order to also cater for other water users like power and water needs for growing urban and industrial areas, and the ample water that is needed to provide in-stream flows to preserve native fish populations in various regions. In some countries like China and Chile, irrigated agriculture is already facing stress as water is already being transferred out of irrigation into urban and industrial uses (Rosegrant and Ringler, 2000). Irrigated agriculture is therefore forced to operate under conditions of water scarcity. Irrigation therefore needs to be managed more efficiently and sustainably, aiming at saving water, maximizing its productivity, and reducing non-point sources of pollution of the environment.

Deficit irrigation consists of deliberately applying irrigation water in amounts below the plant's water requirements. Deficit irrigation can be applied at certain periods during the crop's growing season or throughout its growing season. When irrigation is applied below the full crop ET requirement, the crop extracts water from the soil profile to compensate for the deficit. If there is sufficient water stored in the soil profile (normally from seasonal precipitation), transpiration of the crop is not affected and therefore growth and crop yield are not affected (Fereres and Soriano, 2007). Farmers' major aims are to keep a positive return from the irrigated crop and to ensure sustainability of irrigation (English and Raja, 1996; English, 2002; Fereres and Soriano, 2007; Rodrigues and Pereira, 2009). Deficit irrigation is profitable when the revenue lost due to yield reduction is less than the savings in costs of production due to applying less than the required water.

Most water used for irrigation is good to quality and is unlikely to present serious salinity constraints. Salinity control, however, becomes more difficult as water quality becomes poorer. As water salinity increases, greater care must be taken to leach salts out of the root zone before their accumulation reaches a concentration which might affect yields. Alternatively, steps must be taken to plant crops tolerant to the expected root zone salinity (Temesgen, 2018). The frequency of leaching depends on water quality and the crop sensitivity to salinity.

The impact of water stress on yields and economic returns depend upon the irrigation system, the performance of that system, production costs, and the type of crop. Therefore, the objective of this paper is to review the effect of irrigation water quality and deficit irrigation on crop yield and water use efficiency.

Approaches to Review and Literature Collection

The paper is based on review and use of secondary data published in journals, research centers, annual reports, technical and consultant reports available in the studies conducted by various researchers, institutions and organizations. The review focused primarily on literature search and restricted to articles and report papers published. Published articles were searched and identified from different electronic databases such as Web of Science, AGRIS, Research Gate, Science Direct, Springer, different African and Ethiopian Journals, and libraries of the Ethiopian research institutes. The secondary data available at the Food and Agriculture Organization (FAO) Corporate Statistical Database (FAOSTAT) and Central Statistical Agency of Ethiopia relevant to the review were also used. Based on the review objectives and content types, articles and published reports were retrieved from databases mainly focusing on empirical results reported on Irrigation and crop yield. Following a critical review, data and literatures were compiled on existing and detailed irrigation water quality, deficit level and yield, importance of water use efficiency and contribution in agricultural irrigation, their practicality in agricultural production and overall contribution to livelihoods. Research and technical gaps on the Irrigation Water Quality and Deficit Irrigation on Crop Yield and Water Use efficiency were identified and recommendations are forwarded for the future endeavor of enhancement in agricultural production system.

Effect of Water Quality and Deficit Irrigation on Crop Yield and WUE

Increased agricultural production has become an urgent requirement of the expanding world population (Howell, 2001 and Chen et al., 2011). Yet, there has been a continued decrease in available fresh water that can be used by agricultural production (Cai and Rosegrant, 2003). At the same time, the quality of irrigation water has also deteriorated. As a result, both deficit irrigation and saline irrigation have been prevalently used in agriculture.

The sustainable use of water in agriculture has become a major concern. The adoption of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topcu et al., 2007). In areas of water shortage and long summer droughts, maximizing water productivity may be more beneficial to the farmer than maximizing crop yield. A recent innovative approach to save agricultural water is conventional deficit irrigation (DI). It is a water-saving strategy under which crops are exposed to a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira et al., 2002).

The goal of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water that is applied or by reducing the number of irrigation events (Kirda, 2002). The DI process irrigates the root zone with less water than that required for evapotranspiration and makes use of suitable irrigation schedules, which are usually derived from field trials (Oweis and Hachum, 2001).

Irrigation Water Quality

Irrigation water quality can affect soil fertility and irrigation system performance as well as crop yield and soil physical conditions (Al-omran et al., 2010).

If the experiment treatments comprised no irrigation (T1), fresh water irrigation (T2), slightly saline water irrigation (T3: 2.8 dS m–1), and strongly saline water irrigation (T4: 8.2 dS m–1) at jointing stage. At harvest stage of average soil salinity over the entire 0–100 cm soil layer was 2.14, 1.95, 2.05 and 2.46 dS m–1 for the T1–T4 treatments in the 2009–2010 season, while at the 2010–2011 Wheat Winter harvest stage, the values significantly increased to 2.78, 2.74, 3.38 and 4.03 dS m–1 in the four treatments, respectively (Xiu-wei et al. 2016). At harvest stage of SM average soil salinity over the entire soil profile under the four treatments was 1.82, 1.80, 2.10, 2.23 dS m–1 and 2.10, 2.12, 2.87, 2.65 dS m–1 in the first and second season, respectively. Obviously soil salinity was in most cases significantly higher under saline irrigation (T3: FR+SJ1 & T4: FR+SJ2) compared to non-saline irrigation (T1: FO/FR & T2: FR+FJ), while strongly saline irrigation (T4) caused generally higher soil salinity compared to slightly saline irrigation (T3) over the entire soil profile and both crops. Increased soil salinity from saline irrigation occurred only in the top 40 cm (T3) and top 60 cm (T4) in the first Wheat Winter season, while increased soil salinity could be observed for the entire 100 cm soil profile in the second Wheat Winter season (Xiu-wei et al. 2016).

Effects of Irrigation with Saline Water on Crop Yield

The use of saline irrigation water has an adverse effect on soil–water–plant relations, occasionally severely restricting the normal physiological activity and productive capacity of the crops (De Pascale et al., 2013). Under high salinity level, the crop growth, leaf surface expansion, and primary carbon metabolism of many crops are negatively affected due to osmotic effect, water deficit, nutritional imbalance, and oxidative stress (Kim et al., 2008).

There have been several studies on the effects of saline irrigation water on plant systems in greenhouses (Andriolo et al., 2005). In the study by Reina-Sanchez et al. (2005) effects of salinity on tomato fruit yield have been quantified in experiments under greenhouse and soil-less cultivation with four salinity levels in Malaga, Spain. Lee et al. (2008) quantified the impact of saline irrigation water on chrysanthemums in a greenhouse in Athens, Georgia. Rameshwaran et al. (2015) investigated effects of different irrigation regimes with salinity treatments using a drip irrigation system for two pepper varieties in the greenhouse in Antalya, Turkey.

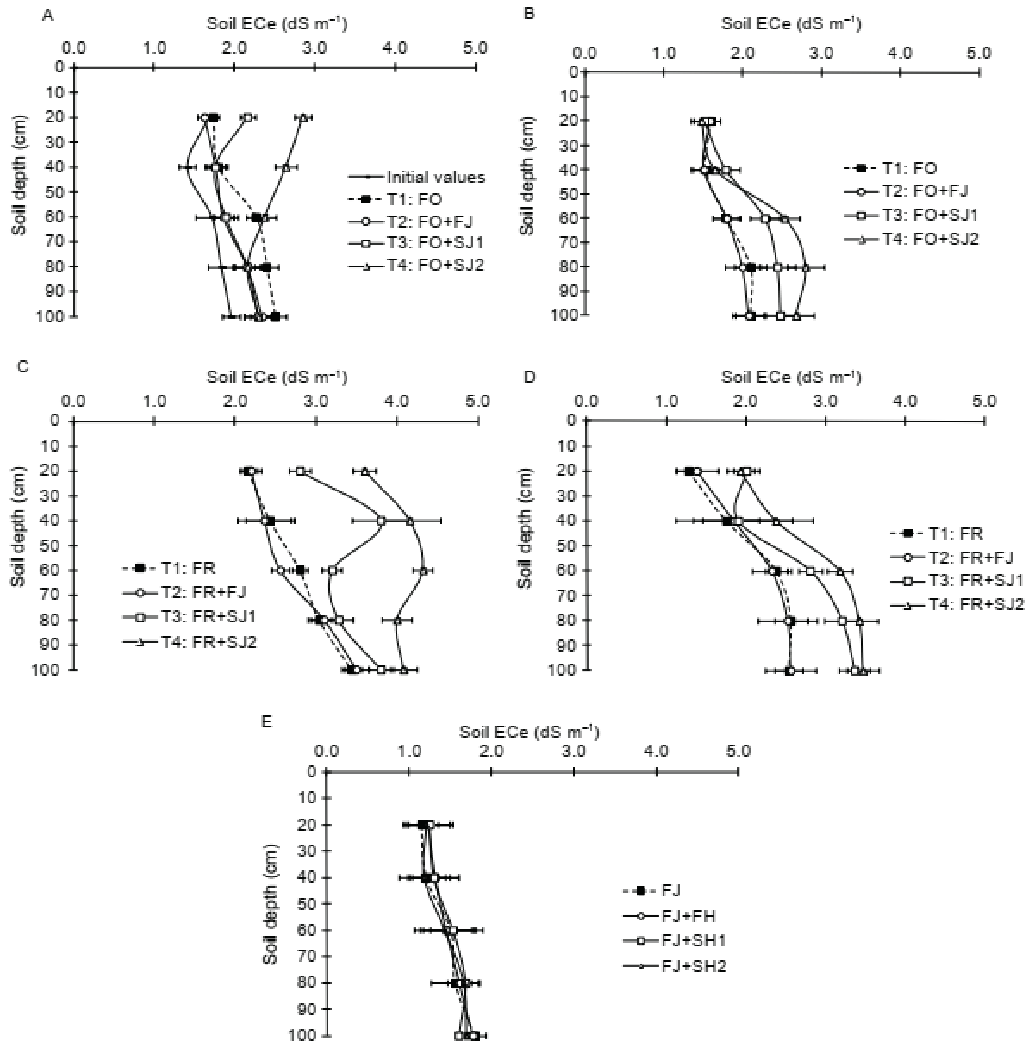


Figure 1. Electrical conductivity (ECe) of an extract of a saturated soil at harvest of winter wheat and summer maize of the 100 cm soil profile in the 2009–2012 seasons. No data is available for Wheat Winter in 2011–2012 season. A, 2009–2010 winter wheat season. B, 2010 summer maize season. C, 2010–2011 winter wheat seasons. D, 2011 summer maize season. E, 2012 summer maize season (Xiu-wei et al. 2016).

There is strong evidence that the difference in SM grain yields between the four experiment treatments is caused by the initial soil salt content. Therefore, leaf photosynthesis at seedling stage of SM was measured in 2010 and 2011 (Figure. 1). In both years, previous saline irrigation led to a significantly reduced photosynthesis rate, with the reduction in T4 (42% in 2010; 32% in 2011) being even significantly higher than that in T3 (17% in 2010; 20% in 2011). The reduced irrigation treatment (T1) featured a significantly lower photosynthesis rate compared to T2, and a significantly higher rate compared to T4. The measured photosynthesis data (Figure. 2) corresponds well with the yield data (Table 1 and 2) of the first two experiment years. For both parameters T2 ranks the first, T1 and T3 rank the second and T4 ranks the last. This highlights the effect of soil salinity stress during early growth of SM on its final yield (Pramod Jha et al, 2012).

Despite the number of studies on the subject, the sensitivity and tolerance of crops to salinity level may vary depending on meteorological and soil conditions in the region, as well as the irrigation method (Katerji *et al*., 2013). It is also recommended that a seawater or brackish water desalination system be used to solve the salinity problems of irrigation water and soil in greenhouses located in coastal areas (Xiu-wei *et al,* 2016). In designing the desalination system, the target salinity level for irrigation water substantially affects the cost of the product water. Thus, it is important to examine the salt tolerance of crops grown in greenhouse conditions and to determine the optimal salinity of irrigation water to minimize the negative impacts on crop production, and at the same time maximize the economic benefits.

Moreover, under extreme salinity conditions, plants cannot absorb water even when the surrounding soil is saturated. Similar results were reported by Alharbi *et al.* (2009). They mentioned that, irrigation with saline water having EC 4.7 dS m^{-1} significantly reduced the total fruits yield by 24.3%. Maggio *et al.* (2007) reported that there was an approximately 6% reduction in plant dry mass per one dS m^{-1} increase until approximately 9 dS m^{-1}, whereas, only 1.4% decrease in yield per dS m^{-1} after 9 dS m^{-1}. Al-Harbi *et al*. (2009) and Al-Omran *et al*. (2012) in line with Pramod Jha *et al,* 2012 they concluded that the adverse effect of irrigation with saline water on total dry biomass and total fresh tomato fruit yield were the reduction in WUE and TYWUE.

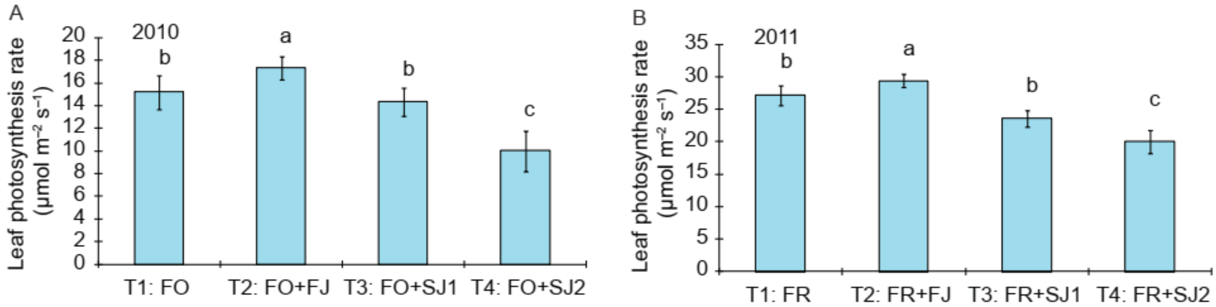


Figure 2. Average leaf photosynthetic rate of SM measured during a sunny day at four leaf stage for different irrigation treatments in 2010 (A) and 2011 (B). Different letters above the columns are significant at P=0.05. Bars are standard errors (Xiu-wei et al, 2016)

Table1. Quality of Irrigation water at different sites (Pramod Jha et al, 2012)

Site	pH (1:2)	EC (dS m $^{-1}$)	RSC	SAR	Na^+	Ca^{2+}	Mg^{2+}	CO_3^-	HCO_3^-	Mg/Ca ratio
			meq l^{-1}							
Site I	7.39	2.24	1.65	2.84	22.4	3.90	10.80	2.18	14.17	2.77
Site II	8.09	2.00	4.14	2.60	6.7	3.10	10.20	4.36	13.08	3.29
Site III	7.24	4.81	5.26	14.54	35.9	2.80	9.40	2.18	15.28	3.36

Table 2. Effect of treatemt imposition on yield and water use efficiency at different sites (Pramod Jha et al., 2012)

Wheat+ Treatment		Site I		Site II		Site- III	
		Yield (q ha $^{-1}$)	WUE (kg m $^{-3}$)	Yield (q ha $^{-1}$)	WUE (kg m $^{-3}$)	Yield (q ha $^{-1}$)	WUE (kg m $^{-3}$)
T_1	Green manure	33.75	2.87	27.06	2.55	22.5	2.41
T_2	T_1 + 25% more seed rate and fertilizer-line sowing	36.25	3.08	28.75	2.71	27.5	2.95
T_3	T_2 + Gypsum (As per RSC Value)	40.00	3.40	28.62	2.34	32.5	3.48
T_4	T_2 + FYM (10t ha $^{-1}$)	37.5	3.19	32.5	3.06	31.25	3.35
T_5	Farmer's practice	28.00	1.89	26.0	2.45	22	2.97
Mean		35.1	2.88	28.58	2.62	27.15	3.03

Table 3. Crop water productivity and amount of water saved (Temesgen et al., 2017)

Treatments	Irrigation (m^3/ha)	Total yield (kg/ha)	CWP (kg/m^3)	Water saved (m^3/ha)	Water saved (%)	Yield reduction (%)
T1	6039	46700	7.7	0.0	0.0	0.0
T2	4012	43200	10.8	2027	33.6	7.5
T3	3604	37500	10.4	2435	40.3	19.7
T4	2965	31300	10.6	3074	50.9	33.0
T5	2994	39100	13.1	3045	50.4	16.3
T6	2677	32800	12.3	3362	55.7	29.8
T7	2405	28200	11.7	3634	60.2	39.6
T8	1978	25500	12.9	4061	67.2	45.4
T9	2000	29700	14.9	4039	66.9	36.4

Deficit Irrigation and Water Use efficiency

Deficit irrigation implies the adoption of appropriate irrigation schedules, which are built upon validated irrigation scheduling simulation models (Sarwar and Bastiaanssen, 2001).

Water is becoming scarce, not only in arid and drought-prone areas, but also in regions where rainfall is abundant (Pereira et al., 2002). In areas where water is most limiting resource to production, maximizing water productivity may be more profitable to the farmer than maximizing crop yield. This is because the water saved when deficit irrigation is applied becomes available to irrigate more land since the latter is not limiting factor. Deficit irrigation is needed where essential resources such as water, capital, energy, and labour are limited. Under deficit irrigation, crops are deliberately allowed to sustain some water deficit and yield reduction. The irrigator aims to increase water use efficiency (WUE) by reducing the amount of water at irrigation or by reducing the amount the number of irrigation. The growth and yield of any crop is related to the amount of water used. The variable amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004).

As per the definition given, water productivity can be improved either by enhancing the yield or reducing the water application. From the stand point of resources conservation it is important to save as much water as the consequence on economic return is acceptable. It means producing more with less water. However, from the farmers' viewpoint, the target of irrigation is not water productivity per se, but improving net income, avoiding risk of crop failure, and ensuring sustainability of agricultural production (Fereres and Solano, 2007). As can be seen from Table 3, the water productivity ranged from 7.7 kg/m3 under full irrigation treatment and 14.9 kg/m3 under 50% stressed plot. WP varied from 10.4 to 13.1 kg/m under treatments which are not irrigated during one growth stage and irrigated with 75% ETc (25% stressed) during the rest of the growth stages (Temesgen et al., 2017). As summarized (Ali and Talukeder, 2008), attaining higher yields with increased WP is only economical when the increased gains in crop yield are not offset by increased costs of other inputs. Consequently, the intention of deficit irrigation is to improve yield and WP by efficiently managing agricultural water.

Features of Deficit Irrigation

Deficit irrigation, the deliberate under irrigation of crops, is a way to save water, maximize water use efficiency, reduce costs of irrigation, increase irrigation efficiency and also reduce non-point pollution sources of surface and ground water resources. In arid and semi-arid areas, irrigated agriculture is the primary user of water resources worldwide (Fereres and Soriano, 2007). Under scenarios of water scarcity, farmers are forced to either to concentrate irrigation application to a smaller land area or to deficit irrigate i.e. irrigate the total land area with irrigation levels lower than the maximum crop water requirement. Deficit irrigation is thus a practical strategy of irrigation water management in areas where water is scarce (Pereira et al., 2002).

When irrigation is applied at rates below the ET, the crop extracts water from the soil reservoir to compensate for the deficit. Two situations may then develop. In one case, if sufficient water is stored in the soil and transpiration is not limited by soil water, even though the volume of irrigation water is reduced, the consumptive use (ET) is unaffected. However, if the soil water supply is insufficient to meet the crop demand, growth and transpiration are reduced, and DI induces an ET reduction below its maximum potential. The difference between the two situations has important implications at the basin scale (Fereres et al., 2003). In the first case, DI does not induce net water savings and yields should not be affected. If the stored soil water that was extracted is replenished by seasonal rainfall, the DI practice is sustainable and has the advantage of reducing irrigation water use. In the second case, both water use and consumption (ET) are reduced by DI but yields may be negatively affected. The challenge of quantifying the ET reduction effected by DI remains, as direct measurements are complex and the models used to estimate the actual ET of stressed canopies are still quite empirical (Burba and Verma, 2006).

Deficit Irrigation Management

In order to measure successful deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils, plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. Therefore success with deficit irrigation is more profitable in finely textured soils. Under deficit irrigation practices, agronomic practices may require modification, e.g. decrease in plant population, apply less fertilizer, adopt flexible planting dates, and select shorter-season varieties (Kirda, 2002).

The treatments investigated were full irrigation (FIT), limited irrigation of 75%, 60%, and 50% of FIT, and rainfed conditions. The FIT treatment was irrigated to prevent crop water stress, and the limited irrigation treatments received a percentage of the FIT application depth at time of irrigation. Six-year treatment average grain yields were 221, 214, 203, 195, and 132 bu ac-1 for the FIT, 75% FIT, 60% FIT, 50% FIT, and rainfed, and the corresponding ET was 25.8, 25.1, 24.2, 23.8, and 20.3 inches, respectively. As a result, the average CWUE values were 9.5, 9.4, 9.3, 9.1, and 7.0 bu per ac-in for the FIT, 75% FIT, 60% FIT, 50% FIT, and rainfed, respectively. The author reported considerable variation in grain yield, ET, and CWUE from year to year and observed that rainfed production always obtained the lowest CWUE and the highest CWUE was usually obtained under FIT.

In most years, no significant differences in grain yield and CWUE between the FIT and 75% FIT treatments was observed. A similar study was conducted as SCAL from 2011 to 2014, to evaluate grain yield, CWUE, IWUE, and economic return of corn under irrigation (FIT, 75% FIT, and rainfed settings) and nitrogen (N) fertilizer rates (0, 75, 125, 175, and 225 lb N ac-1) (Rudnick et al., 2016). The authors assessed the relationship between economic return (i.e., net income) and CWUE to further evaluate differences among the FIT, 75% FIT, and rainfed settings. The relationships between CWUE and net income were linear for all years, and in all cases lower CWUE values were associated with lower net income values (Figure 2). The results showed that maximum net income was achieved under FIT, and therefore, under non-water limiting conditions full irrigation with N fertilizer rates not exceeding 175 lb ac-1 should be adopted for south central NE (Rudnick et al., 2016).

Figure 4. Relationship between relative net income (RNI) and crop water use efficiency (CWUE) for 0, 75, 125, 175, and 225 lb ac-1 nitrogen (N) rates under full irrigation (FIT), limited irrigation (75% of Full), and rainfed settings for the pooled. Relative net income of a treatment was calculated as a percentage of the FIT-225 lb N ac-1 treatment (i.e., non-limiting water and N) (Rudnick et al. (2016).

Yield Response to Water Deficit

Plant responses under moisture stress condition can be closely related to available water. The plant responds to drought/water deficit by attempting to both decreased transpiration and increased water uptake. The response of crops to water deficit depends on the extent and rate of water loss and its timing and duration. Stomata of the plant leaf close when the leaf potential declines below the threshold value. This is manifestation of the development of plant water deficit. Stomata closure can cause marked indirect effect on cell metabolism, changes in to CO_2 influx, water loss, leaf temperature and solute transport within the plant. Water stress results in stomatal closure and reduced transpiration rate, decrease in photosynthesis and growth inhibition, accumulation of abscisic acid, proline, sorbitol, formation of radical scavenging compounds and synthesis of new proteins (Zhang and Davis, 1990).

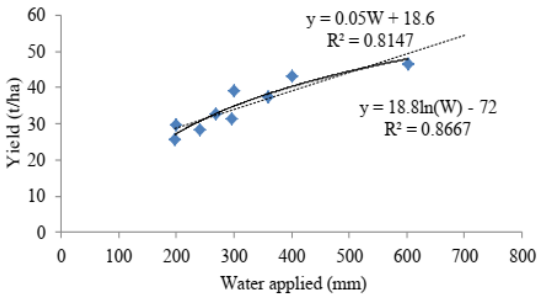
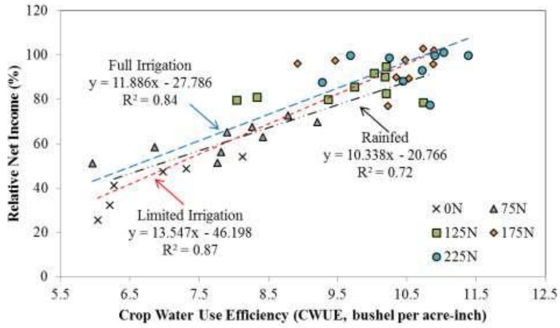


Figure 3. Yield versus total water applied (Temesgen et al., 2017)



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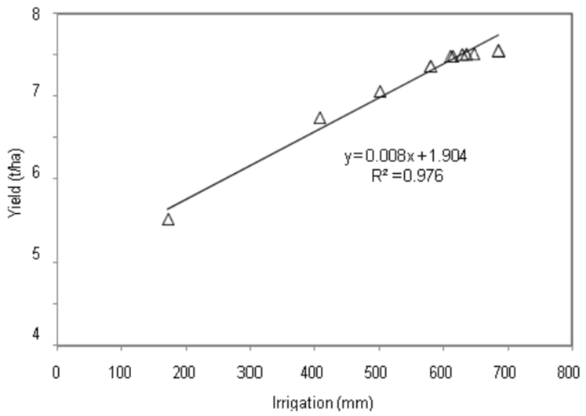

Figure 5. Yield-irrigation relationship (Yenesew and Tilahun, 2009)

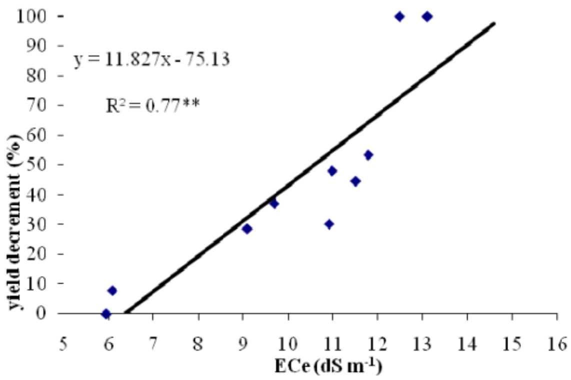

Figure 6. Safflower seed yield decrement due to soil salinity (Feizi et al. 2010).

The most common effect of water stress is decreased rate of growth and development of foliage. This has a cumulative effect through the season as plant stress early in crop development results in reduced leaf area. This means that light interception is reduced, carbon assimilation is reduced and therefore the rate of leaf growth is reduced. According to Stenitzer (1996), plant water stress varies with time during the day. It changes very quickly in response to wind, temperature, solar radiation, cloud cover and humidity. Plant stress also caused by other factors such as salinity, diseases and insect damage. Crop yield obtained under various levels of reduced evapotranspiration were fitted to the linear crop yield response functions of (Stewart et al., 1977).

Further statement made by Moutonnet (2002) is that the upper limit for yields is set by soil fertility, climatic conditions and management practices. Where all of these are optimal throughout the growing the growing season, yield reaches maximum value, as does evapotranspiration. Any significant decrease in soil water storage has an impact on water availability for a crop and, subsequently, on actual yield and actual evapotranspiration. The effect of water stress on yield is quantified by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield response factor (Ky) (FAO, 2002). Crop yield response data from deficit irrigation were fitted to the following linear equation used by (Stewart et al., 1977).

$$\left(1-\frac{ya}{ym}\right) = ky\left(1-\frac{ETa}{ETc}\right)$$

Where:

Ya : actual yield (kg/ha),

Ym : maximum yield (kg/ha),

Eta : actual evapotranspiration (mm),

ETm: Maximum evapotranspiration (mm) and Ky: yield response factor.

Deficit Irrigation in Annual Crops

Harvestable yield of annual crops is normally a fraction of the biomass produced (Evans, 1993). Water deficits, by affecting growth, development, and carbon assimilation, reduce the yield of most annual crops (Hsiao and Bradford, 1983).

Past research has shown that the response to water deficits very much depends on the pattern of stress imposed (Dorenboos and Kassam, 1979). In one pattern that has been frequently used, the water deficit increases progressively as the season advances due to a combination of the uniform application of a reduced amount and the depletion of the soil water reserve. This pattern, hereafter called sustained deficit irrigation (SDI), allows for water stress to develop slowly and for the plants to adapt to the water deficits, in soils with significant water storage capacity. Under an SDI regime, the differential sensitivity of expansive growth and photosynthesis to water deficits (Hsiao, 1973) leads to reduced biomass production under moderate water stress due to a reduction in canopy size and in radiation interception. However, dry matter partitioning is usually not affected and the HI is maintained. As the water stress increases in severity, though, there could be direct effects on the HI in many determinate crops, particularly when the post-anthesis fraction of total transpiration is too low (Fischer, 1979).

Table 4. Interaction effect of deficit irrigation levels and mulching materials on marketable yield of hot pepper at MARC in 2017 cropping season (Lelisa, 2018)

Treatment	Total Yield (kg ha^{-1})					
Mulching	Irrigation level					Mean
	100% ETc	80% ETc	70% ETc	60% ETc	50% ETc	
PM	2892[a]	2349[d]	2166[f]	1565[i]	1268[l]	2048.0
SM	2642[b]	2225[e]	2092[g]	1471[j]	1156[m]	1917.2
NM	2535[c]	2118[g]	1879[h]	1419[k]	1114[n]	1813.0
Mean	2689.7	2230.7	2045.7	1485.0	1179.3	

LSD (0.05) 34.27; F-test **; CV (%) 0.90

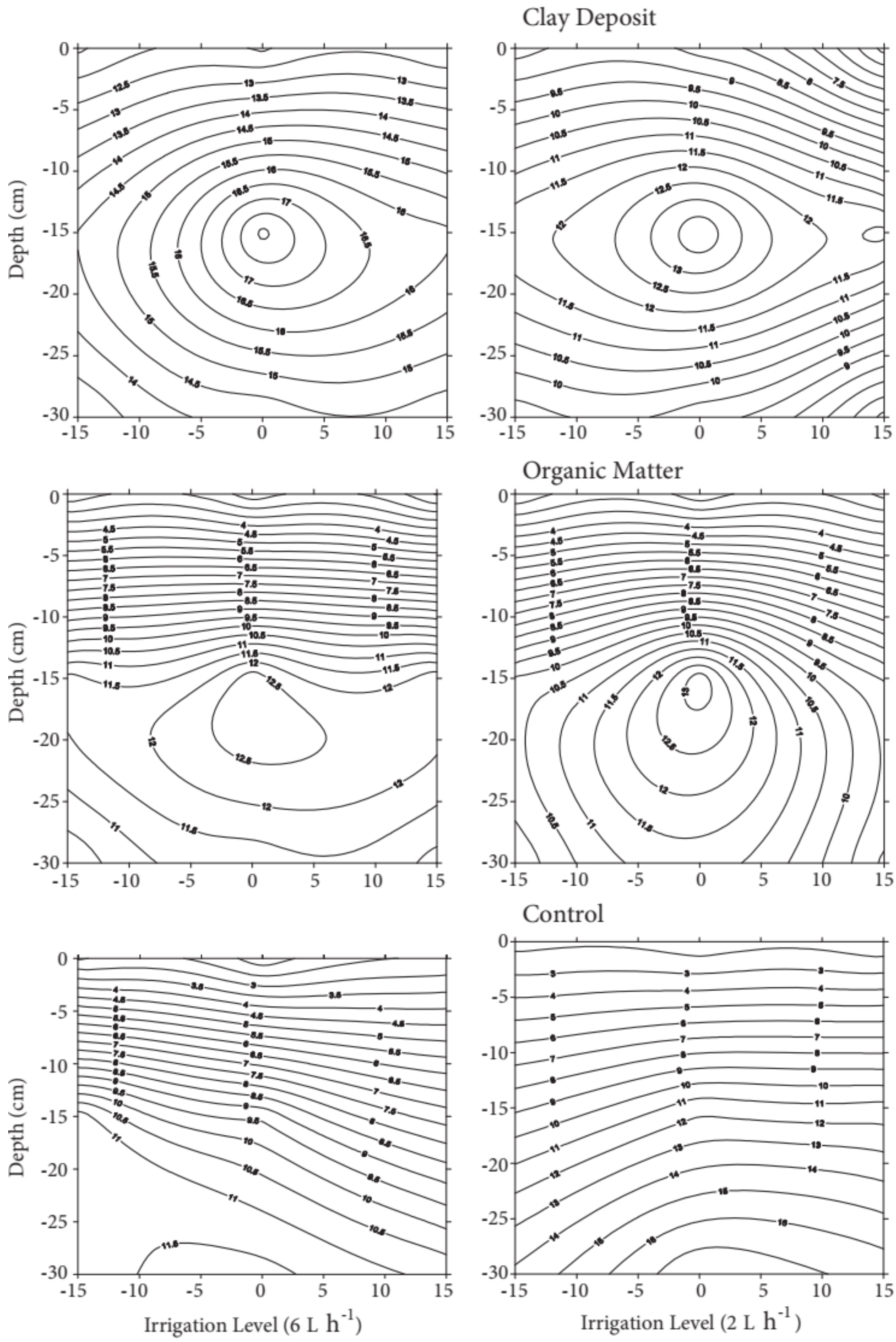

Figure 7. Water content distribution in root zone area for different types of amendments at high and low application irrigation rates for subsurface drip irrigation (Xiu-wei et al. 2016).

Yield Response to Water Quality

The first effect of salts is reducing the ability of plants to absorb water (osmotic effect), which leads to slower growth; second, salts may enter the transpiration stream and injure leaf cells, further reducing growth (Feizi et al. 2010). The high concentration of Na+ and Cl– in soil solution is generally the main cause of the saline stress (Hasegawa et al. 2000) and the consequent slower growth is an adaptive feature for plant survival because it allows plants to rely on multiple resources to combat stress.

In figure below safflower salt tolerance was determined based on average soil salinity during the growth periods. The highest yield was belonged to the lowest soil salinity. In Figure.6, the result of the linear regression analysis of the relationship between seed relative yield and ECe is presented according to the Maas and Hoffman (1977) equation.

Yield Response of Crops to Water Quality and Deficit Irrigation

Yield reductions also occur in a number of crops when subjected to water stress (English and Raja, 1996). Yield reductions depend on the crop’s sensitivity to water stress at its various growth stages. In order for deficit irrigation to be an economically viable practice, the revenue lost due to yield reduction should be lower than savings in total cost of production. Depending on the price per unit of yield, cost of water, cost of pumping the water and other production costs, the optimum level of water stress should be that where the overall net income is maximized. In areas where the cost of water is high, reduction in yields could result as a direct economic tradeoff against the higher costs of irrigation. In other areas like in Washington State, water costs may not reduce as the amounts in applied water reduce since a fixed fee is charged per acre of water. Direct tradeoff in this case may not be possible. However, reduction in applied water may imply reduction in water pumping costs and other production costs like harvesting costs. Whatever the scenario, deficit irrigation should be managed so that yield decline is minimized and /or the net income maximized.

Salinity is the other risk that is associated with deficit irrigation (Hargreaves and Samani, 1984; English, 2002). Deficit irrigation reduces water applied to volumes which do not meet the leaching requirements. Irrigation water contains varying amounts of salts and since crops utilize only pure water, salts may concentrate in the soil solution leading to increased salinity levels in the soil (Fereres and Soriano, 2007). Depending on the type of crop, soil salinity and irrigation water salinity, enough water may need to be applied so that excess salts will not accumulate in the crops root zone and affect growth and yields.

The Interaction Effects of Water Quality and Deficit Irrigation on Crop Yield and Water Use Efficiency

The interaction effects of water quality and DI illustrated that when the two types of stresses; saline and DI were coupled together, a serious reduction occurred on total dry biomass and total fruits yield. The productivity of water irrigation for both dry biomass (WUE) and total yield (TYWUE) were positively affected by DI, while being negatively affected by water salinity. Consequently, it is possible to improve the WUE and save water through a DI strategy for crop production; however, to attain sufficient yield, good-quality water should be applied to the crop throughout the whole growing season, even if at a low rate (50% ETc). Increasing water productivity in response to DI can be explained on the basis that DI can increase the ratio of yield over crop water consumption through the following strategies; reducing water loss by unproductive evaporation, increasing the proportion of marketable yield to the total biomass produced and applying adequate fertiliser and avoiding bad agronomic conditions during crop growth such as water logging in the root zone, pests and diseases, and other challenges (Steduto and Albrizio, 2005; Geerts and Raes, 2009).

The crop yield response factor (Ky) was determined for the different DI treatments. The Ky usually indicates a linear relationship of the relative reduction in water that was consumed with a relative reduction in yield (Lovelli et al., 2007). When crops have Ky values that are lower than one, they are considered to be tolerant of water deficiency. On the contrary, crops with Ky values greater than one are considered not to be tolerant for DI, as noted by Ayas and Demirtas (2009). The average crop response factor was 0.49 and 0.56 for non-saline and saline water, respectively.

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Conclusion

Irrigated agriculture is the primary user of fresh water resources. Irrigating saline water can result in salt accumulation in soil, leading to the decrease in yield and deterioration in soil resource. Irrigation water quality can affect soil fertility and irrigation system performance as well as crop yield and soil physical conditions. The continuous decrease in water resources in the world in general, and in arid regions in particular has forced farmers to use low quality water and to alter their irrigation practices. The decrease in crop yields with the increase in the salinity of irrigation water was caused by disturbances in physiological and biochemical activities under saline conditions. Yield reductions depend on the crop's sensitivity to water stress at its various growth stages. One of the irrigation management practices which could result in water saving is deficit irrigation. Deficit irrigation consists of deliberately applying irrigation water in amounts below the plant's water requirements.

The goal of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water that is applied or by reducing the number of irrigation events. Deficit irrigation can be applied at certain periods during the crop's growing season or throughout its growing season. In order for deficit irrigation to be an economically viable practice, the revenue lost due to yield reduction should be lower than savings in total cost of production. Yield reductions also occur in a number of crops when subjected to water stress.

The interaction effects of water quality and deficit irrigation illustrated that when the two types of stresses; saline and deficit irrigation were coupled together, a serious reduction occurred on total dry biomass and total yields.

Generally, in arid and semi- arid areas where water supply is scarce practicing deficit irrigation with different drought tolerant crops is more preferable than full irrigation and most susceptible crop. Therefore, further work should be done by applying good quality irrigation water and different amount of deficit irrigation at different growth stage of the crop so that sufficient information could be obtained in order to develop proper deficit irrigation scheduling. A deficit irrigation program should be designed to manage stress such that yield reduction is minimized.

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