Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.13, No.15, 2022

The Essentials of Deficit Irrigation for Crop and Water Productivity in Ethiopia: A Review

Abeba Hassen Selie
Ethiopian Institution of Agricultural Research, Pawe Agricultural Research Center P.O.Box 25, Pawe Ethiopia

Abstract
Improving irrigation water management and enhancing crop and water productivity (WP) are required to address future water scarcity in Ethiopia. Increasing WP through exposing the crop to a positive level of water stress the use of deficit irrigation (DI) is taken into consideration a promising strategy. To espouse deficit irrigation strategies, a shred of complete proof regarding DI for distinctive crops is required. The objective of this critical review is to collect adequate information about the indicators on the essential of DI to crop and water productivity. Just a study on the role of deficit irrigation indicates improve crop yield and water productivity. The end result confirmed that DI appreciably improved WP in comparison to complete irrigation. Despite better WP, the decreased yield became acquired in a number of the studied DI practices in comparison to complete irrigation. It was additionally observed that yield reduction can be low in comparison to the advantages won through diverting the saved water to irrigate extra arable land. The advantages of water-saving techniques which include alternate furrow and deficit irrigation want to be explored to make sure meals safety for the ever-growing populace in the context of declining availability of irrigation water. Consequently, reviewer concluded that deficit irrigation is doubtlessly important to enhance sustainable crop and water productiveness in Ethiopian agriculture.
Keywords:-Deficit Irrigation, Water Productivity and Crop Productivity
DOI: 10.7176/JNSR/13-15-02
Publication date: September 30th 2022

1. INTRODUCTION

The Ethiopian agriculture is the foundation of the country's economy. About 82% of the Ethiopian population are living in rural areas and involved in farming for their livelihood (Bank 2014). Agriculture also accounts for 40% of the gross domestic product (GDP) of Ethiopia (Awulachew et al. 2010). However, most Ethiopian farmers depend on low productivity rain-fed small-holder agricultures, even though rainfall is very inconsistent, drought occurs very frequently. Rain-fed agriculture produces almost all of the country's food crops. This shows that the country's water potential is underutilized, and that developing and effectively utilizing this natural resource will enable the country to become food self-sufficient in a short period of time.

During dry growing periods when there is not enough rainfall to compensate for soil moisture losses through evapotranspiration, application of irrigation water by artificial means is required to maintain proper crop growth and productivity. Improving irrigation water management and increasing water productivity (WP) is essential to address future water shortage with inside the sub-Saharan region. Through the growing water shortage in developing countries, improving agricultural water management approaches is of paramount significance to minimize food insecurity (Giordano et al 2016).

The adoption of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topçu et al. 2007). This long-term use of water in irrigated agricultural systems, with an emphasis on reducing water use, requires careful planning and management. In areas of water shortage and long summer droughts, maximizing water productivity may be more beneficial to the farmer than maximizing crop yield per given unit of land. One of the irrigation management practices which could result in water-saving is deficit irrigation (Eck et al. 1987). Deficit irrigation (DI) 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). DI could be considered as a way of maximizing water use efficiency (WUE) by applying a reduced amount of irrigation water, which has no significant impact on yield (Akele 2019a). Fereres and Soriano (2007) Recently reviewed the deficit irrigation, and concluded that the level of irrigation supply should be 60-100% of full crop evapotranspiration (ET_c) needs in most cases to improve water productivity. The DI could be considered as a way of maximizing WUE by applying a reduced amount of irrigation water, which has no significant impact on yield (Akele 2019b).

Even though irrigation is an old age exercise in Ethiopia, very low WP has been recognized (Erkossa et al. 2011; Hordofa 2006). Hence, to emphasis on efforts which can increase WP in irrigated agriculture, inclusive evidence and good enough knowledge regarding DI effect on WP and crop yield are desirable. Though there are numerous area trials on DI, there's a lack of complete assessment research approximately DI outcomes on WP and yield that may be used as a reference for students and practitioners in each Ethiopian and Sub-Saharan countries. This review paper, therefore, aims to bridge this knowledge gap and provide adequate information about the impact of DI strategies on different crop yield and water productivity, which is useful for growers, researchers, planners, and decision-makers

2. History of irrigation in Ethiopia

The Ethiopian agriculture is the dominant movement to tolerate the agricultural community's lifestyles and the essential for people's fundamental needs (Tesfaw 2018; Tilahun et al. 2011). Irrigation is currently considered as a means by which agricultural productivity can be improved to satisfy the growing food demand in Ethiopia (Awulachew et al. 2005). Moreover, to overcome the problem of inadequate rainfall irrigation development is the best approach and has been given significant attention in Ethiopia cited by Daniel G. Eshete (Ayele 2011; Hagos et al. 2009; Haile and Kasa 2015). Irrigation improvement has been recognized as an essential device to stimulate financial increase and rural improvement to enhance family food safety and poverty discount in Ethiopia (Garbero and Songsermsawas 2018; Hagos et al. 2009). Ethiopia has been began out traditional irrigation exercise during that historical time for the intention of subsistence food production (Awulachew et al. 2007). Bekele et al. (2012) reported that in Ethiopia, traditional irrigation changed into practiced earlier than centuries. Furthermore, with inside the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing survival food crops (Awulachew et al. 2007; Bacha et al. 2011). Different authors like; Awulachew et al. (2007); Makombe et al. (2007);Bacha et al. (2011) concerned that supplementary irrigation has been practiced through smallholder farmers of Ethiopia for centuries to solve their livelihood challenges.

Ethiopian agricultural practices traditionally used spat irrigation system particularly in Southern Tigray and in some semi-arid areas in Oromia region which has been used for water harvesting from flush floods flooded from larger catchments at upper streams (Mehari et al. 2011). These conventional irrigation structures have been advanced and controlled via forming a water user's association for capabilities of construction, water allocation, operation and upkeep and have been headed through individuals (Belay and Bewket 2013). However, modern irrigation was started in the early 1950's by the bilateral agreement between the government of Ethiopia and the Dutch company jointly known as HVA-Ethiopia sugar cane plantation (Bekele et al. 2012). (Gebremedhin 2015) recognized that, Rift Valley is a place where modern irrigation in Ethiopia starts especially in the Awash River Basin at which adoption of pump-irrigation commences.

Similar reports such as Awulachew et al. (2007) defined that irrigated agriculture was began out in Ethiopia with inside the upper Awash Valley with the goal of producing commercial plants as sugarcane, cotton and horticultural crops on a large-scale basis, defined in an amazing emergence of irrigation improvement and established order of agro industrial centers. This turned into because of taking an advantage of the development of Koka dam aimed as a reservoir irrigation water supply, flood manage and hydropower generation.

2.1. Concepts of Deficit Irrigation

Currently and extra with inside the future, irrigated agriculture will be afflicted by irrigation water shortage, specifically with inside the areas with excessive evaporative demand, low and abnormal rainfall, and repeated drought period(Brouwer et al. 1989). Increasing demand and competition for irrigation water need leads to changes in irrigation management to improve crop water use and saving the scarce available water for agriculture. Deficit irrigation (DI) is now widely considered as one of the water-saving options (Pereira et al. 2002). It is critical for reducing irrigation water use and increasing water production in a variety of field crops (Fereres and Soriano 2007). The goal of DI 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). DI is an optimization method in which irrigation is applied during drought-sensitive growth stages of the crop (Geerts and Raes 2009).

DI is one of the promising irrigation strategies to maintain acceptable crop yield in the situation of water shortage and efficient tools to optimize water use efficiency Demelash (2013) and Tejero et al. (2011) defined as DI in many crops has frequently proved to be an efficient tool to optimize water-use efficiency. It aims at stabilizing yields and at attaining maximum crop water productivity rather than maximum yields (Geerts and Raes 2009). In deficit irrigation plants are exposed to certain levels of water stress during specific growth stages or throughout the whole growing season, without a significant reduction in yields (Kirda 2002).

According to Kirda (2002), Deficit irrigation practices differ from traditional water supplying practices. Prior to implementing the DI program, it is necessary to know the crop yield response to water deficit, either during the particular growth stages or throughout the whole season (Kirda et al. 1999). The crop yield reduction may be insignificant compared with the benefit gained through the diverted saved water to irrigate additional cropland (Kirda 2002; Patel and Rajput 2013). Deficit irrigation strategies, when used correctly, can result in significant savings in irrigation water allocation (Kirda 2002). The water saved by deficit irrigation of one piece of land might be used to irrigate additional cropland (Bekele and Tilahun 2007; English 1990; Kirda 2002).

a) Essential of deficit irrigation for crop production

The response of crops to water deficit depends on the extent and rate of water loss and its timing and duration (Tura and Tolossa 2020). Many investigations have been conducted to gain experience in the irrigation of crops to maximize performance, profitability, and efficiency. Yet, investigations in water-saving irrigation still are continued. Full irrigation is used by farmers in non-limited or even water-limited areas. In this method, crops receive full evapotranspiration requirements to outcome the maximum yield. Currently, full irrigation is considered an extra use of water that can be reduced with minor or no effect on profitable yield (Kang and Zhang 2004). However, the degree of irrigation decrease is crop-dependent, and most irrigation reductions are accompanied by no or minor yield loss, which increases water productivity (Ahmadi et al. 2010).

Several studies have been conducted on the effects of deficit irrigation on crop in different agro-climatic conditions such as (Bekele and Tilahun 2007; Biswas et al. 2017; El-Sherif and Ali 2015; Tezera Bizuneh 2019).

According to Tezera Bizuneh (2019), the effects of soil moisture stress on onion crop production in the central rift valley of Ethiopia, the result of the study directed that different soil moisture stress levels influenced the growth and the yield of the onion crop. The best marketable bulb yield was recorded at 100% ETc but it was statistically similar with 75% ETc, the lowest marketable yield was obtained under 40% ETc. The studies of Leskovar et al. (2010) showed that DI at 50% ETc decreased most growth components and reduce marketable onion yield by 27% and 19% in both the cropping seasons, while DI at 75% ETc reduce yield by 8% and 13% by saving 25% irrigation water in both growing seasons compared with a 100% ETc irrigation application. Generally, they conclude that onion yield can be affected by the amount of irrigation water application.

According to (Meskelu et al. 2017), the application of 85% and 70% of ETc DI strategies didn't show a significant wheat yield decline (.Deficit irrigation consists of finding the optimum balance between water use and crop yield. Under deficit irrigation, crop producers allow the crop to experience some water stress, but the water saved should allow an increase in the irrigable land, or it could be put to more productive use. DI is comparatively inexpensive to stabilize crop yield with limited water (Heng et al. 2009). ICARDA has proven that a 50% discount in irrigation water implemented reduced yields with the aid of using 10 to 15%, and general farm productiveness extended by 38% whilst the water saved turned into used on the extra land (Pereira et al. 2002). Narayanan and Seid (2015) reported as the highest grain yield of 8.4 tons per ha was obtained from conventional furrow irrigation at 100 percent of crop water application and had no significant difference with 85 percent of crop water application. This indicates that 15 percent saved water can be used to irrigate extra crop lands which will be enhancing the crop yield.

2.2. Concept of water productivity

Eshete et al. (2020) reported as the efficient use of Sub-Saharan Africa's water resources would substantially increase the production of food and export of highvalue crops. The main challenge of irrigated agriculture is how to improve water productivity and crop production from limited water supply (Igbadun et al. 2012). For the sustainability of irrigated agriculture, water productivity is used to identify the management strategies by which the yield per unit of water can be maximized (Mubarak and Hamdan 2018). Water productivity is the ratio of the net benefits from the crop, and forestry agricultural system to the amount of water used (Molden et al. 2010). Water productivity may be defined in terms of physical or economical productivity. Physical water productivity is defined as the ratio of yield of the crop to the amount of water used or applied. Crop water productivity means raising crop yields per unit of water consumed or applied (Kijne et al. 2003a). Increasing crop water productivity is an important pathway for poverty reduction and is appropriate in the area where water is scarce and computation for water is high (Geerts and Raes 2009). In the past, crop irrigation requirements did not consider the limitations of the available water supplies. Improving water productiveness is at once wanted in water-scarce areas. To minimize input cost and environmental damage, farmers will likely produce crops with less irrigation water in the future (Aguilar et al. 2007). With this in mind, crop water productivity (CWP) is a key term in the evaluation of DI strategies. Water productivity with dimensions of $kg/_{m}{}^{3}$ is defined as the ratio of the mass of marketable yield (Ya) to the volume of water consumed by the crop (ETa) or CWP is defined as the physical or economic output per unit of water application (Fereres and Soriano 2007; Kijne et al. 2003b; Molden et al. 2007). This can also determine as:

$$CWP = \frac{Ya}{ETa} \quad \text{……………………………………………………………… (1)}$$

Where, CWP is crop water productivity (kg/m^3), Ya is a marketable crop yield (kg/ha) and ETa is the volume of water consumed by the crop throughout the growing period of the crop (m^3/ha).

In situations of water constraint, deficit irrigation (DI), and water application systems in furrow irrigation are important concerns for increasing water productivity (Narayanan and Seid 2015).

a) Essential of deficit irrigation on water productivity

Deficit irrigation and application system in furrow irrigation are important concerns to improve water productivity in areas of water scarcity(Narayanan and Seid 2015). The application of deficit irrigation as much as

30% of crop evapotranspiration can save a significant amount of irrigation water without considerable yield reduction (Gebremariam et al. 2018). For a moist weather in which the soil is dominated with the aid of using clay and water is a liming factor, the alternate furrow irrigation approach with the suitable irrigation interval is taken into reflection as a suitable irrigation technique (Eba 2018). In areas where water resources are restrictive it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land. The saved water may be used for further purposes or to irrigate extra units of irrigable land. It is usually assumed that increasing agricultural water productivity is the most effective way to mitigate water shortage, and environmental problems in arid, and semi-arid areas. In dry areas, water is the most limiting resource for improving agricultural production. Maximization of yield per unit of water (WP), and not yield per unit of land (land productivity), is, therefore, a better strategy for dry farming systems (English 1990). So, the enhancement of WP in irrigated agriculture is very important.

The adoption of DI implies appropriate knowledge of crop ET, crop responses to water deficits including the identification of critical crop growth periods, and the economic impacts of yield reduction strategies. Zhang and Oweis (1999) stated that when strategies for deficit irrigation are derived from multi-factorial field trials, the optimal irrigation schedules are often based on the concept of water productivity (WP) or, as frequently named, water use efficiency (WUE). WP is a term used in the crop production system to describe the relationship between the amounts of water utilized in crop production, represented as crop production per unit volume of water.

Yihun (2015) reported as the rapid increase in population necessitates adequate management of Ethiopia's land and water resources. Increasing agricultural WP permitting families to generate better income, growing their resilience as well as changing their livelihoods stands out as the most pressing agenda now and for the approaching many years in Ethiopia (Mengistie and Kidane 2016). Hence, enhancing agricultural water control is essential and might be of social, cultural, and economic significance to the beneficiaries (Molden et al. 2010).

According to (Bekele 2017),Implementation of AFI saved 45 % of the water to be applied for additional irrigate land as compared to conventional furrow irrigation, Furthermore, application of 75 % ETc level saves 25 % of water without a significant effect on fruit yield of tomato.(Admasu et al. 2019) documented that in areas where water scarcity is high, 35 to 75% ETc application appears to be promising to depend on the availability of water resources with negligible trade-off in grain yield and water use efficiency.

According to (Meskelu et al. 2017), the decline of water from 100 to 30% ETc led to the raising of WP by 72%. DI has been widely investigated as a valuable and sustainable production strategy in dry regions (Pereira et al. 2002). DI is successful in enhancing water productivity for many crops without generating substantial yield decreases, according to different research findings. In agriculture, one is interested to produce more with less water because water is a limiting factor in many parts of the world. In this case, WP can be used in the evaluation of DI Water Resource Scarcity.

In northern Ethiopia, in which water is limiting rather than labor, each furrow-scientific scheduling can be an option (Mintesinot et al. 2004). Better crop water use efficiency and irrigation water use efficiency were obtained in the AFI while the applied water in AFI was reduced by 50% of the CFI. Therefore, it can be concluded that increased water saving and associated water productivity can be achieved without significant reduction of yield in AFI with 100% ETc of irrigation level and this saved water should be of significant value in everywhere to irrigate additional land it considered by (Mebrahtu et al. 2018) as a suitable method. The adoption of DI strategies where a 50% reduction of ETc restored is applied for the whole growing season or part of it could be suggested in processing tomato, to save water improving its use efficiency, minimizing fruit losses and maintaining high fruit quality levels(Patanè et al. 2011).

3. Challenges and Opportunities of adapting deficit irrigation in Ethiopia

3.1. Challenges

In Ethiopia adoption of deficit irrigation is affected by different factors. These challenges are the knowledge gap about DI; DI can only be effective if actions are taken to avoid salinization. By using DI strategies, over-irrigation rarely occurs. Therefore, the leaching of salts from the root area is inferior beneath DI than in full irrigation (Hsiao et al. 2007). This is typically located in arid and semi-arid regions wherein water is scarce coupled with warm temperatures (Fereres and Soriano 2007), which may affect the sustainability of irrigation projects.

According to Zwart and Bastiaanssen (2004), the major challenges that affect the use of DI could be summarized as, technical constraints, lack of knowledge under better and diversified irrigation agronomic practices, inadequate baseline data and information about the development of water resources, inadequate enjoy in design, construction and management of fineness irrigation projects, poor performance of existing irrigation schemes, lack of community involvement during planning, construction and use of irrigation development, and lack of capital for irrigation infrastructure development are some of them to mention.

3.2. Opportunities

The main advantage of deficit irrigation is the improvement of WP and increases in the overall yield of all crops due to expanding the irrigated area, irrigating by the saved water. It can also create reduced humid conditions around the crop in comparison with full irrigation, reducing the effect of fungal diseases. Although DI results in some yield reductions per hectare, the quality of the product is likely to be equal or even higher than under full irrigation in addition to this lowering irrigation water depth over the crop cycle will also decline agrochemical and nutrient losses through leaching from the root zone, reduce the fertilizer needs of the crop, and improves groundwater quality(Kirda et al. 2005; Moser et al. 2006). Moreover, in Ethiopian standard deficit irrigation is required to control water logging and minimize the total labor costs through growing season.

4. Conclusion

Deficit irrigation techniques have confirmed the option of attaining optimum yields by allowing a certain level of yield loss for each hectare however, advanced returns gained from irrigating extra land by the saved water. Since there is a reasonable increase in the price of agricultural production, great attention is required to increase water productivity (WP). By following the rising of water shortage and mounting competition for water, there will be more extensive adoption of DI, particularly in arid and semi-arid regions. Whereas there are huge prospects to adopt DI, it has been passed through (struggling with) many problems for instance information gaps, practical difficulties, improper water management approaches, and additional hazard of soil salinity. This revision could contribute to the advancement of improving the water productivity of crops under high water competition by providing yield consequence, overall yield increase by cultivating extra land using the saved water, increment of water productivity, and water saved documentation due to DI application. As a conclusion, in areas where water sufficiency and soil moisture is the restricting issue for crop production besides adequate arable land is available, the utility of DI is essential.

5. References

Admasu, R., A. W. Michael & T. Hordofa, 2019. Effect of moisture stress on maize (Zea Mays L.) yield and water productivity. Int J Environ Sci Nat Res 16(4):555945.

Aguilar, M., F. B. Muñoz & M. Espinosa, 2007. Agronomic response of maize to limited levels of water under furrow irrigation in southern Spain. Spanish Journal of Agricultural Research(4):587-592.

Ahmadi, S. H., M. N. Andersen, F. Plauborg, R. T. Poulsen, C. R. Jensen, A. R. Sepaskhah & S. Hansen, 2010. Effects of irrigation strategies and soils on field grown potatoes: Yield and water productivity. Agricultural Water Management 97(11):1923-1930.

Akele, Z., 2019a. Evaluation of alternate, fixed and conventional furrow irrigation systems with different water application level on onion yield in Dubti. Afar, Ethiopia.

Akele, Z., 2019b. Evaluation of Alternate, Fixed and Conventional Furrow Irrigation Systems with Different Water Application Level on Onion Yield in Dubti, Afar, Ethiopia. Evaluation 9(5).

Awulachew, S. B., T. Erkossa & R. E. Namara, 2010. Irrigation potential in Ethiopia. Constraints and Opportunities for Enhancing the System; International Water Management Institute: Addis Ababa, Ethiopia.

Awulachew, S. B., D. Merrey, A. Kamara, B. Van Koppen, F. Penning de Vries & E. Boelee, 2005. Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia, vol 98. IWMI.

Awulachew, S. B., A. D. Yilma, M. Loulseged, W. Loiskandl, M. Ayana & T. Alamirew, 2007. Water resources and irrigation development in Ethiopia, vol 123. Iwmi.

Ayele, G. K., 2011. The impact of selected small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana Basin of Ethiopia. Cornell University Ithaca.

Bacha, D., R. Namara, A. Bogale & A. Tesfaye, 2011. Impact of small-scale irrigation on household poverty: empirical evidence from the Ambo district in Ethiopia. Irrigation and Drainage 60(1):1-10.

Bank, W., 2014. World development report 2015: Mind, society, and behavior. The World Bank.

Bekele, S., 2017. Response of Tomato to Deficit Irrigation at Ambo, Ethiopia. Journal of Natural Sciences Research 7(23).

Bekele, S. & K. Tilahun, 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agricultural water management 89(1-2):148-152.

Bekele, Y., N. Tadesse & B. Konka, 2012. Preliminary study on the impact of water quality and irrigation practices on soil salinity and crop production, Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia. Momona Ethiopian Journal of Science 4(1):29-46.

Belay, M. & W. Bewket, 2013. Traditional irrigation and water management practices in highland Ethiopia: Case study in Dangila woreda. Irrigation and Drainage 62(4):435-448.

Biswas, S., D. Roy, K. Sarkar, A. Milla, K. Murad & M. Anower, 2017. Effects of Deficit Irrigation and Mulching on Seed Yield and Water Use of Onion (Allium cepa L.). International Journal of Plant & Soil

Science:1-10.

Brouwer, C., K. Prins & M. Heibloem, 1989. Irrigation water management: irrigation scheduling, Training manual No. 4. Natural Resources Management and Environment Dept, Food and Agriculture Organization (FAO) of the United Nations.

Demelash, N., 2013. Deficit irrigation scheduling for potato production in North Gondar, Ethiopia. African J Agric Res 8(11):1144-1154.

Eba, A. T., 2018. The impact of alternate furrow irrigation on water productivity and yield of potato at small scale irrigation, Ejere District, West Shoa, Ethiopia. Journal of Plant Sciences and Agricultural Research 2(2):16.

Eck, H., A. Mathers & J. Musick, 1987. Plant water stress at various growth stages and growth and yield of soybeans. Field Crops Research 17(1):1-16.

El-Sherif, A. M. & M. M. Ali, 2015. Effect of deficit irrigation and soybean/maize intercropping on yield and water use efficiency. Int J Curr Microbiol App Sci 4(12):777-794.

English, M., 1990. Deficit irrigation. I: Analytical framework. Journal of irrigation and drainage engineering 116(3):399-412.

Erkossa, T., S. B. Awulachew & D. Aster, 2011. Soil fertility effect on water productivity of maize in the upper Blue Nile basin, Ethiopia. Agricultural Sciences 2(03):238.

Eshete, D. G., B. G. Sinshaw & K. G. Legese, 2020. Critical review on improving irrigation water use efficiency: Advances, challenges, and opportunities in the Ethiopia context. Water-Energy Nexus 3:143-154.

Fereres, E. & M. A. Soriano, 2007. Deficit irrigation for reducing agricultural water use. Journal of experimental botany 58(2):147-159.

Garbero, A. & T. Songsermsawas, 2018. Impact of modern irrigation on household production and welfare outcomes: Evidence from the Participatory Small-Scale Irrigation Development Programme (PASIDP) project in Ethiopia. IFAD Research Series(31):1-47.

Gebremariam, H. L., K. Welde & K. D. Kahsay, 2018. Optimizing yield and water use efficiency of furrow-irrigated potato under different depth of irrigation water levels. Sustainable Water Resources Management 4(4):1043-1049.

Gebremedhin, G. H., 2015. Irrigation in Ethiopia, a review. Journal of Environment and Earth Science 5(15):141-147.

Geerts, S. & D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural water management 96(9):1275-1284.

Hagos, F., G. Makombe, R. E. Namara & S. B. Awulachew, 2009. Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation, vol 128. IWMI.

Haile, G. G. & A. K. Kasa, 2015. Irrigation in Ethiopia: A review. Academia journal of agricultural research 3(10):264-269.

Heng, L. K., T. Hsiao, S. Evett, T. Howell & P. Steduto, 2009. Validating the FAO AquaCrop model for irrigated and water deficient field maize. Agronomy journal 101(3):488-498.

Hordofa, T., Achievement and prospect of irrigation research for Central Rift Valley of Ethiopia. In: Achievements and Priorities in Irrigation Water Management Research in Ethiopia with Particular Reference to Amhara Region Amhara Region Agricultural Research Institute,, Bahir Dar (Ethiopia), 5-7 Dec 2005, 2006. Amhara Region Agricultural Research Institute, Bahir Dar (Ethiopia).

Hsiao, T. C., P. Steduto & E. Fereres, 2007. A systematic and quantitative approach to improve water use efficiency in agriculture. Irrigation science 25(3):209-231.

Igbadun, H. E., A. Ramalan & E. Oiganji, 2012. Effects of regulated deficit irrigation and mulch on yield, water use and crop water productivity of onion in Samaru, Nigeria. Agricultural water management 109:162-169.

Kang, S. & J. Zhang, 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. Journal of experimental botany 55(407):2437-2446.

Kijne, J. W., R. Barker & D. Molden, 2003a. Improving water productivity in agriculture: editors' overview. Water productivity in agriculture: Limits and opportunities for improvement:xi-xix.

Kijne, J. W., R. Barker & D. J. Molden, 2003b. Water productivity in agriculture: limits and opportunities for improvement, vol 1. Cabi.

Kirda, C., 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Food and Agricultural Organization of the United Nations, Deficit Irrigation Practices, Water Reports 22(102).

Kirda, C., P. Moutonnet, C. Hera & D. Nielsen, 1999. Crop yield response to deficit irrigation: report of an FAO/IAEA co-ordinated research program by using nuclear techniques: executed by the Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, vol 84. Springer Science & Business Media.

Kirda, C., S. Topcu, H. Kaman, A. Ulger, A. Yazici, M. Çetin & M. R. Derici, 2005. Grain yield response and N-fertiliser recovery of maize under deficit irrigation. Field Crops Research 93(2-3):132-141.

Leskovar, D., S. Agehara, K. Yoo & N. Pascual-Seva, Deficit irrigation and plant density impact on growth, yield, quality and quercetin of short-day onion. In: XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on 936, 2010. p 219-226.

Makombe, G., D. Kelemework & D. Aredo, 2007. A comparative analysis of rainfed and irrigated agricultural production in Ethiopia. Irrigation and Drainage Systems 21(1):35-44.

Mebrahtu, Y., A. Woldemichael & S. Habtu, 2018. Response of onion (Allium cepa l.) to deficit irrigation under different furrow irrigation water management techniques in Raya Valley, Northern Ethiopia. African Journal of Plant Science 12(5):105-113.

Mehari, A., F. Van Steenbergen & B. Schultz, 2011. Modernization of spate irrigated agriculture: A new approach. Irrigation and drainage 60(2):163-173.

Mengistie, D. & D. Kidane, 2016. Assessment of the impact of small-scale irrigation on household livelihood improvement at Gubalafto District, North Wollo, Ethiopia. Agriculture 6(3):27.

Meskelu, E., A. Woldemichael & T. Hordofa, 2017. Effect of Moisture Stress on Yield and Water Use Efficiency of Irrigated Wheat (Triticum aestivum L.) at Melkassa, Ethiopia. Acad Res J Agri Sci Res 5(2):90-97.

Mintesinot, B., H. Verplancke, E. Van Ranst & H. Mitiku, 2004. Examining traditional irrigation methods, irrigation scheduling and alternate furrows irrigation on vertisols in northern Ethiopia. Agricultural Water Management 64(1):17-27.

Molden, D., T. Oweis, P. Steduto, P. Bindraban, M. A. Hanjra & J. Kijne, 2010. Improving agricultural water productivity: Between optimism and caution. Agricultural water management 97(4):528-535.

Molden, D., T. Y. Oweis, S. Pasquale, J. W. Kijne, M. A. Hanjra, P. S. Bindraban, B. A. Bouman, S. Cook, O. Erenstein & H. Farahani, 2007. Pathways for increasing agricultural water productivity.

Moser, S. B., B. Feil, S. Jampatong & P. Stamp, 2006. Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. Agricultural Water Management 81(1-2):41-58.

Mubarak, I. & A. Hamdan, 2018. Onion crop response to different irrigation and N-fertilizer levels in dry Mediterranean region. Advances in Horticultural Science 32(4):495-501.

Narayanan, K. & M. M. Seid, 2015. Effect of deficit irrigation on maize under conventional, fixed and alternate furrow irrigation systems at Melkassa, Ethiopia. International Journal of Engineering Research & Technology (IJERT).

Patanè, C., S. Tringali & O. Sortino, 2011. Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Scientia Horticulturae 129(4):590-596.

Patel, N. & T. Rajput, 2013. Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation. International Journal of Plant Production 7(3):417-436.

Pereira, L. S., T. Oweis & A. Zairi, 2002. Irrigation management under water scarcity. Agricultural water management 57(3):175-206.

Tejero, I. G., V. H. D. Zuazo, J. A. J. Bocanegra & J. L. M. Fernández, 2011. Improved water-use efficiency by deficit-irrigation programmes: Implications for saving water in citrus orchards. Scientia Horticulturae 128(3):274-282.

Tesfaw, M., 2018. Small scale irrigation development. Irrigation Drainage Syst Eng.

Tezera Bizuneh, K., 2019. Effect of soil moisture stress on onion (allium cepa l) production and water productivity at Melkassa in the central rift valley of Ethiopia. HAWASSA UNIVERSITY.

Tilahun, H., E. Teklu, M. Michael, H. Fitsum & S. B. Awulachew, 2011. Comparative performance of irrigated and rainfed agriculture in Ethiopia. World Applied Sciences Journal 14(2):235-244.

Topçu, S., C. Kirda, Y. Dasgan, H. Kaman, M. Çetin, A. Yazici & M. Bacon, 2007. Yield response and N-fertiliser recovery of tomato grown under deficit irrigation. European Journal of Agronomy 26(1):64-70.

Tura, L. E. & T. T. Tolossa, 2020. Systematic review: Effect of Irrigation Water Quality and Deficit Irrigation on Crop Yield and Water Use efficiency. Turkish Journal of Agriculture-Food Science and Technology 8(5):1201-1210.

Yihun, Y. M., 2015. Agricultural water productivity optimization for irrigated Teff (Eragrostic Tef) in water scarce semi-arid region of EthiopiaAgricultural water productivity optimization for irrigated Teff (Eragrostic Tef) in water scarce semi-arid region of Ethiopia. Wageningen University and Research.

Zhang, H. & T. Oweis, 1999. Water–yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agricultural Water Management 38(3):195-211.

Zwart, S. J. & W. G. Bastiaanssen, 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural water management 69(2):115-133.