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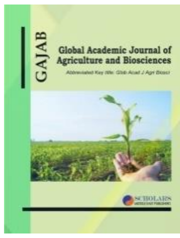

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Review Article

Improving Water Productivity in Irrigated Agriculture: A Review of Techniques and Water Conservation Methods in Ethiopia

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Abstract: Water is a scarce resource and the competition for it is increasing from time to time due to population growth and economic status change. The population growth leads to high expectations to produce more food from irrigated agriculture which could not be satisfied by rain-fed conditions. As irrigated agriculture is by far the largest water consumer in an inefficient way, improving water productivity has paramount importance both for the production of more food and for wise utilization of scarce water. Beyond these, studies suggest that improving water productivity in Ethiopia contributes to an increase in the irrigated area, reduced competition, and conflict between users, increased profitability due to reduced labor cost, water pumping and working time, and generally increased food production. Different water productivity improvement techniques and water conservation methods have been tested in different parts of the country. These include improving the performance of irrigation schemes, regulated deficit irrigation practice, partial root zone drying, application of irrigation on selected crop growth stages, supplementary irrigation, drip irrigation, surge and cutback irrigation, and water conservation methods like mulching and integrating irrigation with conservation agriculture. The level of water productivity improvement varies considerably for different methods, study areas, crop types, and seasons. Generally, more studies concentrated on deficit irrigation and irrigation application at different crop growth stages. Water conservation and integration of cultivation practices with efficient irrigation led to an improvement in water productivity. Despite few studies, scheme-level study results suggest that the level of deficit irrigation should be selected based on the available irrigation water and cultivable land area for maximizing the benefit of the scheme. According to the economic profitability, crop types and crop varieties also should be selected for production with site-specific conditions. Despite different types and levels of reduced irrigation leading to lower crop yield, the inclusion of the economic importance is essential as most crops showed higher water productivity at lower irrigation levels. On the other hand, studies on the integration of different water productivity enhancement techniques and crop planting patterns are minimal in the country, though current studies revealed better water productivity. Moreover, basin-level water productivity improvement studies could contribute to alleviating water competition and increasing irrigated areas. Therefore, studies on the optimization of these different methods could be done at the basin level for better water resource

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utilization. Government policies should also focus on water productivity improvement for the implementation of research findings.
Keywords: Irrigation, water conservation, water productivity, water productivity techniques.

1. INTRODUCTION

Water is a scarce resource used in different sectors like agriculture, domestic, industry, and the ecosystem. Water use has been growing globally at more than twice the rate of population increase in the last century, and an increasing number of regions are reaching the limit at which reliable water services can be delivered (FAO, 2016a). This leads to a water shortage which is one of the primary world issues, and according to climate change projections, it will be more critical in the future (Mancosu *et al*., 2015).

The demand for fresh water is on the increase, and irrigation consumes the bulk of the water extracted from various sources, hence the efficiency of its use is of outmost importance (Koech and Langat, 2018). Therefore, competition for water is increasing from time to time due to population growth and economic status change which leads to widely expect to produce more food from the agricultural sector (Scheierling *et al*., 2014). This could be achieved through development and expanding irrigated agriculture through efficiently utilizing the land and water resources to meet the rising food demand. On the other hand, agriculture is by far the largest water user worldwide, accounting for 70 percent of total freshwater withdrawals on average, and can reach as much as 95 percent in some developing countries (FAO, 2017). In addition to this, the availability of irrigation water is facing serious problems due to climate change as agriculture is highly sensitive to weather conditions (Jovanovic and Stikic, 2012).

Water is essential for agricultural production on which the food and nutritional security of present and future generations depend (FAO, 2016b). Due to the growing global population, 60 percent more food will be needed by 2050 to meet the food requirements. Despite the need for increasing food production through different techniques like irrigation, the amount of water withdrawn by agriculture can increase by only 10 percent (FAO, 2017). Therefore, for enhancing food production, much focus should be given to improving irrigation water productivity (Scheierling *et al*., 2014).

Due to high population growth, the need to produce more food through irrigation to add to the conventional rain-fed system in Ethiopia is increasing from time to time. The occurrence of drought and poor irrigation systems on the other hand leads to water scarcity for irrigation which is a burden on water resources (Tewabe and Dessie, 2020). The demand for fresh water is constantly increasing among all water users in small-scale irrigation schemes (Eshete *et al*., 2020). The occurrence and accessibility of water is also highly variable which varies from region to region and from season to season in the country (Kansal *et al*., 2014). Moreover, as agriculture is highly sensitive to climate change, the combination of high crop water productivity and improved crop yield is an important element of sustainable development in irrigated agriculture (Mekonnen and Sintayehu, 2020).

The average annual precipitation in the country is about 850mm which generates 123 BCM runoff despite the distribution being very uneven (Kansal *et al*., 2014). However, the dome-shaped topographic nature of the country favors the flow of rivers to neighboring countries. Moreover, groundwater potential varied from 2.6 to 13.5 BMC. But local experts advice that the potential could be much higher than this figure from the experience in different pioneering projects (Awulachew *et al*., 2010). Accordingly, the report of Kebede *et al*., (2020) indicated that the estimated amount of annual renewable groundwater resource is about 36 BMC. Water shortage is deeply rooted in the country mainly due to lack of water sector development, poor management, under-utilization of available water resources, and legal framework in the management and governance of water. The country has few reservoir storage facilities and water-saving practices are poor (Kansal *et al*., 2014).

In Ethiopia, small-scale irrigation is a key strategy to improve and sustain food production and economic growth (Amede *et al*., 2020; Assefa *et al*., 2021; Derib *et al*., 2011). In the past decade, small and large-scale irrigation schemes have expanded in Ethiopia to improve crop production and productivity (Zewdie *et al*., 2021). Besides the utilization of surface water, groundwater has also a potential for development, and farmers in different parts of the country are utilizing it by pumping from wells through motor pumps. However, irrigated agriculture consumes large amounts of water with inefficient management practices and it is a major concern in the country (Eshete *et al*., 2020).

Moreover, farmers have a tendency to over-irrigate due to the perception of 'high water high production' and poor extension regarding irrigated agriculture (Derib *et al*., 2011). The poor extension services on irrigation coupled with old-style agronomic practice leads to poor technical efficiency of farmers that practice irrigation in the country (Zewdie *et al*., 2021). Dried rivers, lakes, and depleted groundwater in different areas are the result of unbalance between the inflow and outflow of the hydrologic cycle due to such poor practice.

The expansion of irrigation areas with poor efficiency and limitations in water sources increases competition for water and it becomes a source of conflict between users in different parts of the country (Tesfaye *et al*., 2019). Unequitable distribution of irrigation water in schemes leads to application beyond the water holding capacity of the soil in the upper, middle, and near the canals aggravating irrigation water losses. This contributes to crop water scarcity and conflicts between users especially those far away and in lower parts of the schemes (Teshome *et al*., 2018).

Water scarcity become a common phenomenon in Ethiopia with drought frequency of at least once in three years despite the country owns large irrigation potential (Amede *et al*., 2020). Increasing the interest of water saving strategies aiming to produce more food per applied water is mainly due to increased pressure on fresh water, competition between different sectors, frequent droughts due to climate change, environmental issues, water pollution, and water pumping cost (Derib *et al.*, 2011; Jovanovic and Stikic, 2012; Mekonnen and Sintayehu, 2020). Despite farmers having been practicing irrigation for a longer time, still did not surpass subsistence farming due to different challenges including lower water productivity (Eshete *et al*., 2020). Poverty in the country remains a challenge and crop productivity remains very low (Zewdie *et al.*, 2021). Beyond field irrigation water management, water productivity enhancement in Ethiopia is challenged by factors like crop diseases, socio-economic factors, policy-related issues, and agricultural inputs (Eshete *et al*., 2020).

Moreover, water scarcity is one of the main constraints for the development of agriculture in moisture-stressed areas. Therefore, there is an urgent need for efficient utilization of water resources for irrigation using different water-saving techniques like as identifying and irrigating only the sensitive crop growth stage (Admasu *et al*., 2017). Several irrigation management strategies are currently practiced for the production of different crops. Among these deficit irrigation has been generally applied in areas with access to fresh water is difficult or expensive (Chand *et al*., 2021).

Different research reports in the country revealed that improving water productivity in irrigated agriculture could be achieved through different water conservation practices like conservation tillage and mulching (Assefa *et al*., 2021; Meskelu *et al*., 2018). Moreover, research reports on deficit irrigation practice on different crops in complete or certain levels of water stress during any of the growth stages or the whole growth stages lead to an improvement in water productivity and save irrigation water (Haileslassie *et al*., 2016; Hassen *et al*., 2019; Kassaye *et al*., 2020; Mekonnen and Sintayehu, 2020; Tewabe and Dessie, 2020; Yihun, 2015). Moreover, different efficient irrigation systems like drip irrigation and surge irrigation contribute to increasing water productivity (Assefa *et al*., 2021; Gudissa and Edossa, 2014; Kifle *et al*., 2017).

Improvement of water productivity under water scarce and conditions of high food demand is essential. Different research results worldwide showed that crop varieties responded differently to water productivity due to their water stress tolerance, variation in growing period, and yield variation. These could also vary due to differences in soil type and climate conditions. Moreover, different techniques and water conservation methods lead to the improvement of water productivity differently under specific conditions. Despite different review studies (Eshete *et al*., 2020) reporting on related issues, little information is available on water productivity enhancement techniques and water conservation methods proven in the country. Therefore, this review study was done based on the objective of summarizing research findings that lead to the enhancement of water productivity for the implementation of appropriate irrigation strategy in the country.

2. Irrigation Schemes Performance and Water Productivity

Irrigated agriculture is an important practice for improving the socio-economic status of the farming community. According to the study of Amede *et al*., (2020) in four regions (Tigray, SNNPs, Oromia, and Amhara) using a combination of participatory monitoring and evaluation tools (individual interviews, group discussion, key informants, review of relevant documents, and field observation), at least 50% of the farmers that practice irrigation improved their food security and income. The yield improvement especially in horticultural crops under irrigation increased by 35 to 200% as compared to rain-fed conditions, with much higher benefits obtained in potential areas with utilization of appropriate other input (Amede *et al*., 2020).

However, the performance of smallholder irrigation schemes is challenged by water insecurity and low water productivity in different parts of Ethiopia. According to the study by Haileslassie *et al*., (2016) in four regions in the country using household survey, field observation, canal water flow monitoring, and focus group discussion, the land and water productivity in smallholder irrigation schemes were found to be lower even to sub-Saharan Africa regional average except for vegetables.

In Ethiopia, irrigation is mainly implemented in small-scale irrigation schemes which are characterized by low water productivity despite water scarcity. The study of Derib *et al*., (2011) on a small-scale irrigation scheme in the highlands of the Blue Nile, Ethiopia revealed that 26% of the canal water was lost in the field canal while only 4.5 and 4.0% of water was lost in the main and secondary canals through canal seepage and evaporation, respectively. According to the study of Teshome *et al*., (2018) despite the poor performance of irrigation schemes, the conveyance efficiency of traditional surface irrigation canals of Wesha, Werka, and Wodesa schemes at Cheleleka watershed, Wondo Genet, Sidama Region is less than 50%.

However, despite the difference in water requirement, farmers apply almost equal amounts of water for different crops in irrigation schemes. For example, wheat and onion at the Guanta small-scale irrigation scheme received equal amounts of irrigation water. This leads to a water loss of 78% for teff due to flooding beyond its requirement (Derib *et al*., 2011). This contributes to crop water scarcity and conflicts between users especially those far away and in lower parts of the schemes (Teshome *et al*., 2018).

A wider land productivity range is also common in different irrigation schemes for example the Meki scheme was the highest land productivity both for onion and tomato with 14.55 and 10.29 t/ha, respectively (Haileslassie *et al*., 2016). Moreover, for cereals similar variation trend was reported. Maize and wheat land productivity range between 0.6 and 3.92 t/ha, and 0.6 and 1.56 t/ha which is below the sub-Saharan African regional average. These suggest the need to address yield-limiting factors in smallholder schemes in Ethiopia (Haileslassie *et al*., 2016).

Irrigation water productivity in different small holder farmers' schemes is lower especially for cereal crops despite high variation in schemes and reaches. Schemes with higher land productivity do not necessarily show higher water productivity. For example, the study of (Haileslassie *et al*., 2016) showed that modern schemes and head irrigators have higher land productivity but lower water productivity as compared with traditional irrigation and tail irrigators. That is mainly due to water shortage and practicing forced deficit irrigation and selection of low water requirement crops in traditional schemes and by tail irrigators.

Water productivity might vary within the same scheme due to variations in crop management and the amount of irrigation water application due to variations in the cost of water to bring to the field. For example, the study of Derib *et al*., (2011) at the Guanta small-scale irrigation scheme in the Blue Nile basin revealed that water productivity is higher for onion than for cereals in which the value ranged from 0.68 to 1.78 kg/m^3. However, different crops grown varied from 0.2 to 1.6 kg/m^3 and 0.82 kg/m^3 for the production of grass for livestock (Derib *et al*., 2011).

In small-scale irrigation systems, a significant volume of water is lost due to poor irrigation application which does not match with crop water requirement. However, the high pumping cost encourages water management through practicing deficit irrigation as pumping costs are high. This leads to saving water and improving water productivity even though yield reduction is common. Promoting sustainable and equitable water sharing in smallholder irrigation needs an integrated development intervention that includes optimal irrigation scheduling, canal maintenance, and different water-saving techniques to improve irrigation water productivity (Derib *et al*., 2011; Haileslassie *et al*., 2016).

3. Precision Irrigation Techniques

3.1. Deficit Irrigation

In Ethiopia, irrigation water productivity-improving techniques like proper scheduling and on-farm irrigation water management practices are poor. This is highly associated with crop management options as well as crop disease, socio-economic factors, institution, and policy-related issues, limitations in technical and human capacity, lack of agricultural input, and market for increasing the benefit from irrigated crops (Eshete *et al*., 2020). Optimization of cropping patterns and effective utilization of water are the management alternatives that improve water productivity and net benefit, especially during a shortage of water (Tewabe and Dessie, 2020). The development of optimum irrigation water management is important for water productivity and food security enhancement (Gebremariam *et al*., 2018). Moreover, water productivity could significantly vary over the years due to different agro-climatic variations and favorable environments for the specific crop (Yihun, 2015).

Different studies showed that dealing with regulated deficit irrigation practice leads to an improvement in water productivity especially when combined with identified non-sensitive growth stages of the crop (Yihun, 2015). Crops have different responses to deficit irrigation practices in different areas. For example, the study of Tewabe and Dessie (2020) showed that wheat, barley, and pepper were not attractive in the cropping patter system of the Koga irrigation scheme due to the low net benefit per amount of water used. Therefore, in such areas irrigators and irrigation managers should choose high-value crops and irrigation levels for selected crops that maximize net benefits and water productivity as well.

Different studies on deficit irrigation in the country revealed that it could be one of the great strategies for improving the water productivity of irrigated agriculture. For example, Gebremariam *et al*., (2018) conducted a field experiment on different levels of deficit irrigation to optimize yield and water productivity of furrow-irrigated potatoes in the Emba Alaje district, Northern Ethiopia. Their finding revealed that the application of 70% ET_C irrigation water level maximizes water productivity without significantly reducing the yield as compared with the maximum yield under optimum irrigation of affecting 100% ET_C. Maximum yield and water productivity of potatoes in the study area were associated with 100% ET_C (25.86 t/ha) and 55% ET_C (5.4 kg/m^3) irrigation levels. However, the application of a 70% ET_C irrigation level leads to a statistically similar yield (22.64 t/ha) with better water productivity (5.4 kg/m^3).

Table 1: Water productivity of different crop under optimum and deficit irrigation condition

Crop	Optimum irrigation condition		Deficit irrigation condition		Water saved (mm)	Location	Author
	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)			
Potato	25.86	4.3	22.64 (70% ET_C)	5.4	180	Emba Alaje	(Gebremariam *et al*., 2018)
Wheat	4.56	1.08	4.21 (70% ET_C)	1.38	118.8	Melkassa,	(Meskelu *et al*., 2017)
Teff	3.130	0.87	3.18 (75% ET_C)	1.08	86.0	Melkassa,	(Yihun, 2015)
Teff	0.859	0.31	0.653 (70% ET_C)	0.34	82.8	Dire Dawa	(Hilemicael and Alamirew, 2017)
Sesame	1.840	0.3358	1.785 (75% ET_C)	0.4281	131	Metema	(Mekonnen and Sintayehu, 2020)
Sesame	1.123	0.266*	Lower economic WP	-	-	Humera	(Tewelde, 2019)
			80% ET_C	Improved by 55%	Irrigated area increased by 27.4%	Koga	Tewabe and Dessie (2020)

Remark: * water productivity USD/m^3

This leads to reduce the irrigation amount from 604 to 423 mm which saves 181 mm of irrigation water that could be used to irrigate additional land in areas where the availability of irrigation water is a limiting factor. Their findings revealed that water productivity continuously improved as the irrigation level was reduced (Gebremariam *et al*., 2018).

Similarly, Meskelu *et al*., (2017) studied the effect of different levels of moisture stress on the yield and water productivity of wheat at Melkassa using field experimentation. Irrigation of 70% ET_C of the required irrigation depth leads to higher water productivity without significantly affecting grain yield. Their finding revealed that the reduction of irrigation water enhanced water productivity despite higher yield reduction as moisture stress further increased. However, under severe water stress conditions, wheat (Kekeba variety) could be irrigated with 40% ET_C with high water productivity of 1.70 kg/m^3 with a compromise of 30.7% yield reduction at Melkassa and similar agro ecology and on clay loam soil. Low water productivity in well-irrigated crops is majorly attributed to higher loss and higher water productivity in lower irrigated is mainly attributed to the efficient utilization of the available moisture (Meskelu *et al*., 2017).

A study conducted on teff under deficit irrigation practice at Dire Dawa, Eastern Ethiopia revealed that water productivity showed a decreasing trend both as the irrigation amount increase and decreased from 70% ET_C application (Hilemicael and Alamirew, 2017). Accordingly, they found that water productivity varies from 0.24 to 0.34 kg/m^3 for irrigation level that ranges from 50 to 125% ET_C. Similarly, Yihun (2015) also reported that under a 25% deficit, the yield of teff was 2.45 and 2.27 t/ha under 25 and 10 kg/ha seedling rates at Melkassa, respectively. This leads to higher water productivity of 1.16 and 1.08 kg/m^3 obtained at 25% of deficit irrigation for 25 and 10 kg/ha seeding rates, respectively. Similarly, a study conducted by Mekonnen and Sintayehu (2020) revealed that when deficit irrigation is applied in the whole growth stage, higher water productivity without significant yield reduction is associated with deficit irrigation of 25% for sesame at Metema North Wester Ethiopia.

Tewabe and Dessie (2020) studied water and land allocation for different crops using a linear programming (LP) model for defining cropping patterns and deficit irrigation levels at the Koga irrigation scheme, in Northern Ethiopia. Their findings revealed that the application of 20% deficit irrigation could lead to an increase of irrigated land area by 27.4%. This leads to an addition of 2,018 ha of irrigated land besides the current 7,361 ha with the same amount of available water. This could benefit the scheme with a net benefit of 284.7 million birr and water productivity of 5.3 birr/m^3 which leads to an improvement of 55% as compared with the existing irrigation practice (Tewabe and Dessie, 2020).

However, some studies results showed that some crops are sensitive and that deficit irrigation practice could lead to reduced water productivity as compared with optimum irrigation. For example, Tewelde, (2019) studied the effect of different deficit irrigation levels to evaluate the economic water productivity of sesame crops in the Humera area, Norther Ethiopia. Accordingly, the result revealed that economic water productivity was higher (0.266 USD/m^3) at full irrigation than at deficit irrigation levels, and as the deficit level increased to 70% ET_C water productivity reduced to 0.159 USD/m^3. Therefore, under such cases for a particular crop, the application of optimum irrigation is crucial as the crop is sensitive to moisture stress, high evaporative demand of the specific area or any other site, and crop-specific factors (Tewelde, 2019).

In areas where water is pumped to higher elevations from groundwater and valleys, the cost of pumping could substantially be reduced due to deficit irrigation beyond water productivity improvement. For example, the study of Derib *et al*., (2011) revealed that farmers upstream side of the gravity-fed scheme use motor pumps which include costs for fuel and technicians besides the cost of the pump to bring water to their fields. However, irrigation water is free for downstream farmers from the main canal, which resulted in higher irrigation water application than the upstream farmers despite a similar amount of water needed by the same plant (Derib *et al*., 2011).

3.2. Partial Root Zone Drying

Water scarcity is a major constraint for the production of food in arid and semi-arid areas which should be used efficiently. Water-saving techniques like alternate furrow and deficit irrigation have paramount importance in ensuring food security through irrigation practice under limited irrigation water available areas (Kassaye *et al*., 2020). This is especially important when the population increase is high and the availability of irrigation water is declining due to over-exploitation, climate change, and competition due to the establishment of irrigation schemes.

Alternate irrigation and deficit irrigation could reduce irrigation water due to evapotranspiration and deep percolation and have a great potential for improving water productivity and total production with the existing limited irrigation water. Therefore, an urgent shifting from the conventional irrigation technique to water-saving irrigation techniques is needed to improve water productivity and minimize the adverse effects of excess irrigation on the environment (Kassaye *et al*., 2020). Different research findings conducted in Ethiopia showed that the application of partial root-zone drying techniques, especially alternate furrow irrigation, could be used as a promising strategy for water productivity improvement.

Seid and Narayanan (2015) studied the effect of deficit irrigation levels with different irrigation water application techniques on the yield and water productivity of maize at Melkassa, East Shoa Zone, Ethiopia. Based on their finding, higher water productivity without significantly affecting the grain yield of maize was obtained at 70% ET_C under the alternate furrow irrigation technique. Despite the maximum grain yield (8.41 t/ha) observed in 100% ET_C under conventional furrow irrigation technique, it was the lowest (0.91 kg/m^3) in water use efficiency. On the other hand, application of 70% ET_C under alternate irrigation technique leads to the highest water productivity (2.06 kg/m^3) without significantly affecting the grain yield (6.66 t/ha) at Melkassa (Seid and Narayanan, 2015).

A field experiment conducted at Selekleka district, Norther Ethiopia also showed that alternate furrow irrigation with 100% ET_C leads to saving 50% of irrigation water used under a conventional system with a reduction of maize yield only by 8.31%. This leads to a water productivity of 1.89 kg/m^3 which is significantly higher than conventional furrow irrigation which scores water productivity of 0.99 kg/m^3. Beyond improving water productivity and saving water, working time and pumping fuel costs for irrigating a given land area were reduced significantly in alternate furrow irrigation applications (Gebreigziabher, 2020).

More improvement in water productivity is also possible through the combined effect of partial root-zone drying and the application of mulch to reduce evaporation. A field experimentation conducted by Meskelu *et al.*, (2018) revealed that despite higher yield associated with conventional furrow irrigation application technique through irrigating all furrows, both deficit strategies through application of alternate and fixed furrow irrigation methods improved water productivity than the conventional method.

Field experimentation conducted by Kassaye *et al.*, (2020) on the influence of alternate furrow irrigation methods with different irrigation levels on yield and water use efficiency of potatoes revealed that seasonal irrigation water saved due to 100% ET_C under alternate furrow irrigation technique (226 mm) as compared with the 100% ET_C under conventional furrow irrigation technique (442 mm). This report revealed that application of 100% ET_C under conventional furrow irrigation technique leads to the highest tuber yield (38.41 t/ha) with the lowest water productivity (8.73 kg/m^3). On the other hand, application of 100% ET_C under alternate furrow irrigation technique leads to statistically the same tuber yield (37.42 t/ha) as the optimum with better water productivity (16.58 kg/m^3).

Table 2: Water productivity improvement due to partial root-zone drying technique

Crop	**Optimum irrigation (CF 100% ET_C)**		**Partial root-zone drying technique**		**Water saved (%)**	**Location**	**Authors**
	Yield (t/ha)	**WP (kg/m^3)**	**Yield (t/ha)**	**WP (kg/m^3)**			
Maize	8.41	0.91	6.66 (AF 70% ET_C)	2.06	50	Melkassa	Seid and Narayanan (2015)
Maize	7.32	0.97	6.71 (AF 100% ET_C)	1.78	50	Selekleka	Gebreigziabher (2020)
Potato	38.41	8.73	37.42 (AF 100% ET_C)	16.58	49	Kulumsa	Kassaye *et al.*, (2020)
Onion	25.46	4.93	24.54 (AF 100% ET_C)	8.39	46.5	Dubti	Akele (2019)

Under limited irrigation water availability conditions, different studies revealed alternate furrows for the production of different crops and improved economic, environmental, and social performance of the irrigation schemes (Kassaye *et al.*, 2020). Despite improving water productivity, the application of a partial root zone drying technique might lead to yield reduction which might be unacceptable in areas where the availability of irrigation farm size is the major limiting factor than water resources. For example, the study of Meskelu *et al.*, (2018) on maize crop in Koka area, Central Rift Valley, revealed that yield was reduced from 6.29 to 4.20 t/ha when the irrigation technique changed from conventional furrow irrigation (irrigation of all furrow) to fixed furrow irrigation (continuously irrigating same furrow every irrigation event).

The finding of Akele (2019) also revealed that the application of irrigation water using alternate furrow irrigation with 100% ET_C leads to an improvement in water productivity without significantly reducing onion bulb yield at Dubti, Afar region, Ethiopia. Accordingly, maximum irrigation water productivity (8.39 kg/m^3) was recorded when 100% ET_C was applied using alternate furrow without significantly affecting the yield of onion (24.54 t/ha). On the other hand, the minimum water productivity (4.93 kg/m^3) and bulb yield of 25.46 t/ha were obtained under optimum irrigation under conventional furrow irrigation due to the application large amount of irrigation water. With the same amount of irrigation water, adapting alternate furrow irrigation with 100% ET_C could able to increase 0.868 ha net additional irrigable land per hectare because of the saved water (46.47%) from the conventional method at Dubti (Akele, 2019).

Moreover, the application of partial root-zone drying as a technique for water productivity improvement in irrigated farms is also economical as it reduces related costs of water and labor. According to the report of Kassaye *et al.*, (2020) the marginal rate of return of 74.7 was recorded when alternate furrow irrigation was applied with deficit irrigation at 75% ET_C level at Kulumsa, Ethiopia. This could enable farmers to save irrigation water, minimize conflict due to competition, and earn high returns due to the reduction of investment for labor to irrigate a given land. Moreover, this could be a good solution for improving total production in areas where water is a limiting factor than the available irrigable land especially when combined with plastic mulching to minimize evaporation (Meskelu *et al.*, 2018).

3.3. Irrigation at Different Crop Growth Stages

Under current and predicted climate conditions of drought and scarce water supply, the challenge for agricultural production is to increase water productivity and to sustain or even increase crop yield using different techniques (Jovanovic and Stikic, 2012). Among these techniques, irrigation of only the sensitive growth stage of crops is common as crop sensitivity varies from stage to stage. Therefore, the identification of crop sensitive growth stage that leads to higher water productivity without significantly affecting yield is vital. The saved irrigation water due to such practice could contribute to water productivity improvement especially when the yield penalty is minimal (Yihun, 2015).

In Ethiopia, different research findings revealed that the application of irrigation water during the non-sensitive growth stage of different crops leads to the implementation of water productivity. For example, depriving irrigation water at the initial and late season stages leads to improved water productivity without significantly affecting the yield of onion at Melkassa (Dirirsa *et al.*, 2021). Moreover, crop response to different levels of irrigation water management varies considerably, especially when different water productivity-improving techniques like deficit irrigation and irrigation at different levels are combined. For example, the study of Yihun (2015) revealed water productivity improved due to different deficit irrigation levels at different growth stages.

Gebreselassie *et al.*, (2015) studied deficit irrigation levels at different growth stages of maize (variety BH-140) on yield and water productivity at Arbaminch. According to their result, the highest yield (8.84 t/ha) was obtained when the deficit was imposed at mid and late stages with an application of only 50% ET_C. The yield obtained under this condition is statistically similar to optimum irrigation (7.21 t/ha) and the water productivity (1.77 kg/m^3) is higher than the optimum irrigation (1.01). Their result showed that the minimum yield (5.26 t/ha) was obtained when water deficit during the whole growing season except the initial stage. Moreover, the highest water productivity (2.11 kg/m^3) was obtained when all stages received only 25% ET_C except the initial stage, and the minimum (0.93 kg/m^3) was due to full irrigation except during the late season received 75% ET_C. Generally, a water deficit of 50% ET_C during the third and fourth growth stages had no significant effect on the grain yield of maize and it is worthwhile to save irrigation water during these growth stages. The study of Meskelu *et al.*, (2014) also revealed that moisture stress only during the initial stage (25 to 30) after germination and well-established, leads to equivalent grain yield and higher water productivity (1.25 kg/m^3) than the optimum irrigated one (0.99 kg/m^3) on maize. Moreover, the study revealed that combined moisture stress at the development and mid-season stages critically reduces both grain yield and water productivity (Meskelu *et al.*, 2014).

Despite the similarity in crop type, specific varieties might have different responses to moisture stress and water productivity levels. For example, the study of Admasu *et al.*, (2017) at Haru, western Ethiopia on maize (BH-660 hybrid variety) revealed that any moisture stress at any of the growth stages significantly affects grain yield. Accordingly, irrigating all stages led to the highest grain yield of 8.36 t/ha despite its water productivity being the lowest (0.50 kg/m^3) which was followed by irrigating all stages except the initial stage with a grain yield of 6.89 t/ha with statistically similar water productivity (0.57 kg/m^3). On the other hand, the highest (2.65 kg/m^3) water productivity was observed when irrigating only the initial stage which might be a result of the application of minimum irrigation water.

Bisa *et al.*, (2018) studied the effect of moisture stress at different growth stages of tomatoes in the Ada'a district, near Addis Ababa. Their finding revealed that irrigating only the first two stages (initial and development) gives higher water productivity (14.13 kg/m^3) without significantly reducing the yield (42.4 t/ha) for the growing period from January 23 to May 22. This contributes to saving more than 52% of irrigation water used for tomatoes in the area based on optimum irrigation. However, rainfall contributes 41 and 26% (103.2 and 60.7 mm) of the crop water requirement at mid and late stages. On the other hand, optimum irrigation of all growth stages leads to a maximum tomato yield of 46.9 t/ha with a minimum water productivity of 7.40 kg/m^3.

Under the specific conditions where rainfall during the mid and late seasons, the application of irrigation in these growth stages leads to lower irrigation water productivity. On the other hand, withholding water in one of the first two growth stages adversely affects tomato plant survival and total yield beyond reducing water productivity (Bisa *et al.*, 2018).

Hassen *et al.*, (2019) studied a field experimentation of moisture stress at different growth stages on yield and water productivity of wheat (Gambo variety) at Werer, Afar Region Ethiopia. Their finding revealed that moisture stress either at the initial or maturity stage provides statistically similar grain yield with irrigation of all stage which provide the maximum grain yield of 2.99 t/ha. However, this leads to lower water productivity (0.36 kg/m^3) as compared with the stressed once. On the other hand, irrigating at all stages except initial and maturity leads to a grain yield of 2.67 t/ha and water productivity of 0.62 kg/m^3. Moreover, irrigating all stages except the mid- stage leads to lower water productivity (0.33 kg/m^3) and grain yield of 1.94 t/ha. Maximum water productivity of 0.79 kg/m^3 was obtained when wheat was irrigated only at the initial stage despite the lowest grain yield (1.29 t/ha). For the production of wheat under water-scarce conditions, moisture stress during development and mid-season stages should be avoided to improve water productivity in semi-arid areas like Werer (Hassen *et al.*, 2019).

Dirirsa *et al.*, (2021) also studied the effect of moisture stress at different growths on yield and water productivity of onion at Melkassa. Accordingly, maximum yield (31.5 t/ha) was obtained at full irrigation in all stages whereas water stress during the initial and late season did not affect bulb yield which saved 29.3% of irrigation water with a 2.5% yield reduction. According to their report, higher water productivity (8.80 kg/m^3) was recorded when irrigation was applied only during the development and mid-season stages. Soil moisture stress imposed at combinations of development and bulb formation stages decreased yield highly which leads to a minimum water productivity (3.41 kg/m^3).

Table 3: Water productivity under full irrigation and stressing different growth stages

Crop	Optimum irrigation condition		Moisture stress at selected growth stage		Water saved (mm)	Location	Authors
	Yield (t/ha)	WP (kg/m^3)	Yield (t/ha)	WP (kg/m^3)			
Maize	7.21	1.01	8.84 (50% ET_C during M & L)	1.77	221	Arbaminch	Gebreselassie *et al.*, (2015)
Maize	9.25	0.99	10.5 (stress only at I)	1.25	94.6	Koka	Meskelu *et al.*, (2014)
Maize	8.36	0.50	6.89 (stress only at I)	0.57	-	Haru	Admasu *et al.*, (2017)
Tomato	46.9	7.40	42.4 (stress at M & L)*	14.13	52%	Ada'a	Bisa *et al.*, (2018)
Wheat	2.99	0.36	2.67 (stress at I & L)	0.62	-	Werer	Hassen *et al.*, (2019)
Onion	31.5	6.38	30.72(stress at I & L)	8.80	144.7	Melkassa	Dirirsa *et al.*, (2021)
Onion	46.7	7.7	13.1 (stress at L & 75% ET_C at IDM)	39.1	304.5	Ambo	Temesgen *et al.*, (2018)
Teff	3.21	0.99	2.94 (50% stress at L)	0.99	28	Melkassa	Yihun (2015)
Sesame	1.84	0.3358	1.766 (stress at I)	0.3582	52	Metema	Mekonnen and Sintayehu (2020)

Remark: * Rainfall contributes 41 and 26% (103.2 and 60.7 mm) of the crop water requirement at mid and late stages. I, D, M, and L: initial, development, mid-season and late stages.

Therefore, moisture stress at the mid-season stage especially combined with the development stage should be avoided for better yield and water productivity for onion (Dirirsa *et al.*, 2021).

Similarly, a field experiment conducted by Temesgen *et al.*, (2018) revealed that the highest total onion yield (46.7 t/ha) was associated with full irrigated treatment despite lower water productivity (7.7 kg/m^3). However, it was statistically similar with skipping either the initial or late stage, while irrigating the rest of the stages with 75% ET_C which led to a water productivity of 10.8 and 13.1 kg/m^3, respectively. Accordingly, the water productivity of onion varied from 7.7 kg/m^3 for control and 14.9 kg/m^3 for the 50% stressed and not irrigated during the maturity stage.

Yihun (2015) also conducted a field experiment to identify different deficit irrigation levels at different growth stages, and its impact on the water productivity of teff at Melkassa. The study revealed that application of optimum irrigation in all the growth stages (irrigation depth of 330.5 mm) under 25 kg/ha seeding rate leads to an average maximum grain yield of 3.21 t/ha with water productivity of 0.99 kg/m^3. On the other hand, statistically similar grain yield (2.94 t/ha) and water productivity (0.99 kg/m^3) were recorded under a maximum water deficit of 50% only during the late season stage (irrigation depth of 302.5 mm) which leads to saving irrigation water by 28 mm. Moreover, 50% of the water deficit during the initial leads to a similar yield with the optimum irrigation. Teff is very sensitive to water stress during the mid-season stage even for a mild deficit of 25% leads to a yield reduction of 1 t/ha. Moreover, a deficit level of more than 50% in any of the growth stages leads to a significant yield reduction of teff (Yihun, 2015).

Mekonnen and Sintayehu (2020) also conducted a field experiment study to identify sesame critical growth stages most vulnerable to soil moisture deficit and to evaluate the crop water productivity at Metema North Western Ethiopia. Their result revealed that deficit irrigation could be practiced for sesame both during different growth stages and whole growth stages with reduced irrigation. However, sever yield reduction is caused when moisture stress at the mid-season growth stage leads to a yield response factor of 1.9 which reflects the sensitivity of the crop to moisture stress at this stage (Mekonnen and Sintayehu, 2020).

On the other hand, the water productivity of sesame varied from 2.04 (deficit at the mid-season stage) to 0.377 kg/m^3 (deficit during the development stage) due to deficit irrigation at different growth stages. Therefore, inducing deficit irrigation for sesame during mid-season (flowering and capsule bearing stages) should be avoided as this is the sensitive stage to moisture stress, and yield reduction is amplified. However, the late season stage is tolerant and has limited impact on sesame yield and the application of deficit irrigation in this stage could contribute to water productivity improvement (Mekonnen and Sintayehu, 2020).

3.4. Supplementary Irrigation

Supplemental irrigation has been widely reported as one of the different strategies used for crop yield improvement in rain-fed agriculture in areas where moisture availability for the crop is a limiting factor (Oweis and Hachum, 2012). Though the effect varies from crop and soil type, the application of an additional amount of irrigation water to rain-fed crops during the moisture deficit due to lack of rainfall improves the yield of crops (Haghverdi *et al*., 2019). A field experiment in Nebraska, USA on maize under different irrigation levels combined with different nitrogen fertilizer rates showed a high variation of water productivity (from 0.90 to 2.81 kg/m^3) due to supplementary irrigation (Rudnick *et al*., 2016). Water is the most limiting factor for agricultural production in dryland areas crops require supplementing of adequate water for stabilizing yield and increase production in Ethiopia (Wale *et al*., 2019).

A field experiment conducted at Humera, norther Ethiopia on the effect of different supplementary irrigation levels and nitrogen fertilizer rates on the performance of sesame revealed that significantly higher grain yield (455 kg/ha) was associated with the application of six supplementary irrigation than the rain-fed and four supplementary irrigation. The study revealed that the application of supplementary irrigation could be an important climate change adaptation strategy despite full irrigation is not possible (Girma, 2019).

Similarly, Moges and Adugna (2020) conducted a field experiment on supplementary irrigation levels for chickpea (Hebru variety) production in Asosa district, western Ethiopia. According to their report, the highest grain yield (890 kg/ha) was observed when full supplementary irrigation was practiced. However, the maximum water productivity was observed when only two irrigation, one during the flowering and the other during the fruit setting stage provided. Under rain-fed conditions, the yield was only 430 kg/ha however when the application of two irrigation at the flowering and fruit setting stage the yield was increased to 655.42 kg/ha.

Wale *et al*., (2019) conducted a field experiment at Sekota district Wag-Himra zone in northern Ethiopia to determine the supplementary irrigation level and scheduling during the moisture stress period on yield and water productivity of sorghum (Miskre variety). Their result revealed that supplementary irrigation at different growth stages significantly improved sorghum yield and water productivity. Accordingly, supplementing full CROPWAT-generated irrigation depth both during the development and mid-season stage at eight days intervals leads to the second-highest yield (2.13 t/ha) and the highest water productivity (1.77 kg/m^3). The maximum grain yield (2.24 t/ha) was obtained when supplementary irrigation was applied starting from development to maturity. However, the water productivity was far beyond the former one scoring 0.86 kg/m^3. Moreover, under rain-fed conditions, sorghum yield was 1.40 t/ha with water productivity of 1.11 kg/m^3.

Similar research conducted at Kobo-Girana valley norther Ethiopia also revealed that the application of supplementary irrigation leads to a significant improvement in grain yield and water productivity of sorghum (Teshale variety) during two seasons. According to their report, the average maximum grain yield (3.03 t/ha) was recorded when full irrigation was applied from the development stage to maturity with an eight-day irrigation interval with water productivity of 0.48 kg/m^3. However, the minimum grain yield (1.88 t/ha) was obtained under rain-fed conditions with maximum water productivity (Wondatir and Getnet, 2021).

Mebrahtu and Tamiru (2018) also studied the effect of different supplementary irrigation levels on yield and water productivity of maize at Mehoni, Raya Valley northern Ethiopia, where crop failure due to the erratic nature of the rainfall is common. According to their result, the application of 100% ET_C supplementary irrigation in the study area led to the highest grain yield (5.94 t/ha) despite the maximum water productivity obtained under rain-fed conditions (3.07 kg/m^3). This leads to an improvement in grain yield by 23.2%. However, the application of 75% ET_C supplementary irrigation provided a statistically similar yield (5.75 t/ha) with higher water productivity (1.46 kg/m^3) than 100% ET_C supplementary irrigation which scored water productivity of 1.25 kg/m^3.

4. Innovative Irrigation Techniques and Water Conservation

4.1. Drip Irrigation

The capability of the drip system to deliver water uniformly for plants, reduce water application to open ground, and minimize water losses contributes to water productivity improvement as compared with conventional irrigation systems in smallholder farmer conditions in Ethiopia. Beyond improving water productivity, these could contribute to minimizing the overexploitation of water resources through wisely and efficiently utilizing the scarce resource (Assefa *et al.*, 2021).

Different studies in Ethiopia revealed that drip irrigation contributes to the improvement of water productivity under water-scarce conditions. Yimam *et al.*, (2020) studied the effect of tillage practice with drip irrigation on the water productivity of different crops at Robit and Dangishta, in the sub-humid Ethiopian Highlands. Accordingly, they found that the Kc value of crops was significantly reduced by 20% for onion, cabbage, and garlic under conservation agriculture. Moreover, pepper Kc was reduced by 10% during the whole growing season. This leads to a saving of irrigation water that ranges from 14 to 28% for different vegetables under conservation agriculture (CA) as compared with conventional tillage (CT).

Ambomsa *et al.*, (2020) also studied the effect of irrigation methods and soil moisture depletion levels on the yield and water productivity of onions at Melkassa. According to their findings, a maximum marketable onion bulb yield of 38.39 t/ha and water productivity of 13.05 kg/m3 were recorded when irrigation was applied after 80% of the management allowable depletion level using the drip irrigation method. On the other hand, the minimum marketable yield (31.6 t/ha) and water productivity (6.84 kg/m^3) were recorded when irrigation water was applied after 120% of the allowable depletion level using the furrow irrigation method (Ambomsa *et al.*, 2020). This encourages frequent irrigation with drip irrigation methods for onion at Melkassa.

According to the study of Muktar (2019) on drip irrigation and furrow irrigation methods, significantly higher onion marketable yield was obtained under the drip irrigation method (43.08 t/ha) than the furrow irrigation method (27.95 t/ha) at Melkassa. Application of 85% ET_C irrigation level using drip irrigation techniques for onion was statistically similar in marketable yield with higher water productivity (12.36 kg/m^3) than 100% ET_C (11.13 kg/m^3) and recommended for water-scarce conditions. Moreover, when combined with water conservation methods like conservation agriculture improvement of water productivity will be higher as it enhances soil fertility and moisture content like organic matter, total nitrogen, and water holding capacity of the soil (Yimam *et al.*, 2020).

4.2. Surge and Cutback Irrigation

Surface irrigation has low-performance efficiencies due to unavoidable irrigation water loss through excessive runoff and deep percolation (Beshaw, 2011). This should be minimized with different irrigation water application techniques like surge and cutback irrigation. Surge irrigation water application methods are a practice that leads to improved water productivity of irrigated agriculture in furrow irrigation by creating a series of 'on' and 'off' cycles which leads to fast advance (Borhade, 2018).

Different research findings worldwide revealed that surge and cutback irrigation systems contribute to the improvement of water productivity. For example, the study of (Wood *et al.*, 2017) showed that surge irrigation reduced the amount of water applied per irrigation event and total water applied in the season by 22 and 24% and increased irrigation water use efficiency by 29% as compared with the conventional continuous flow irrigation method. Studies conducted in Ethiopia revealed that surge irrigation could lead to an improvement in water productivity. Application of irrigation water using surge irrigation improves water use efficiency than continuous irrigation for the production of onion at Mekelle, Northern Ethiopia (Kifle *et al.*, 2008).

According to the study of Gudissa and Edossa (2014) based on an objective to evaluate surge, cutback, and conventional flow furrow irrigation systems in Gambela Western Ethiopia, the surge flow furrow irrigation technique was found to be effective in terms of agronomic performance of pepper production and its water productivity. Based on their result, surge flow furrow irrigation leads to an advance time ratio that ranges from 0.57 to 0.70. This leads to an improvement in application, storage efficiency, and uniformity of water distribution than cutback and conventional furrow irrigation methods. Minimum deep percolation (14.3%) and tail-water (20.5%) losses were also associated with the surge flow furrow irrigation technique.

Similarly, in terms of the agronomic performance of pepper, surge flow furrow irrigation performs more than both cutback and conventional furrow irrigation methods. The minimum yield (6.45 t/ha) and irrigation water productivity (1.13 kg/m^3) were associated with conventional furrow irrigation technique and the maximum yield (9.37 t/ha) and irrigation water productivity (1.65 kg/m^3) were associated with surge flow furrow irrigation with ½ cycle ration. Surge and cutback flow furrow irrigation systems could be used as promising technologies for pepper production in Gambela areas with minimal water use to improve the hydraulic performance of furrow irrigation and water productivity than the continuous flow system (Gudissa and Edossa, 2014).

Similar field experimentation was conducted by Beshaw (2011) to evaluate flow characteristics and technical efficiency of alternate and conventional furrow irrigation under surge flow for onion production in Humbo district, Wolaita zone, Ethiopia. Their result revealed that the advance rate of the waterfront was significantly improved. This contributes to better application efficiency, storage efficiency, distribution uniformity, and reduced tail water and deep percolation under surge irrigation with two cycles than the conventional irrigation system. The water productivity was higher (8.03 kg/m^3) when alternate furrow irrigation was applied under a surge irrigation system whereas, the least (4.06 kg/m^3) was observed under a conventional (every furrow) irrigation system (Beshaw, 2011).

The study of Kifle *et al*., (2008) also revealed that application efficiency, distribution uniformity, storage efficiency, and yield of onion were improved. This contributes to the improvement of water productivity in which the maximum water productivity (2.27 kg/m^3) was observed when surge furrow irrigation was applied with 1/3rd cycle ration with 1 lit/sec discharge and the lowest (1.68 kg/m^3) was obtained when conventional irrigation used. Surge irrigation is a promising irrigation practice for the production of onion in Norther Ethiopia to save water, reduce the irrigation period, and increase crop yield (Kifle *et al*., 2008).

Kifle *et al*., (2017) studied to evaluate the effect of surge flow and alternate furrow irrigation on irrigation performance indicators, water use efficiency, and crop yield in semi-arid areas in northern Ethiopia. Based on the field experiment result, the irrigation system does not affect the yield of onions despite flow methods affecting irrigation water productivity and other irrigation performance indicators like application efficiency, distribution uniformity, deep percolation, and tailwater runoff losses. Higher water use efficiency of 1.96–2.55 kg/m^3 resulted due to surge flow and alternate irrigation compared with conventional and continuous methods of 1.36–1.65 kg/m^3 (Kifle *et al*., 2017).

4.3. Water Conservation Methods

For water productivity improvement, soil management is equally important to save water used for irrigation and improve soil fertility, which could be used for irrigating additional farmland in case of water-limiting conditions (Assefa *et al*., 2021). Different studies in Ethiopia revealed that soil management practices and water conservation measures like conservation agriculture and mulch application for irrigated farms enhance water productivity. Moreover, integrating different water-saving and soil management conditions could improve water and crop productivity, and benefits from irrigated farms (Assefa *et al*., 2021).

Yimam *et al*., (2020) studied the effect of tillage practice with drip irrigation on the water productivity of different crops at Robit and Dangishta, in the sub-humid Ethiopian Highlands. Accordingly, they found that the Kc value of crops was significantly reduced by 20% for onion, cabbage, and garlic under conservation agriculture. This leads to a saving of irrigation water that ranges from 14 to 28% for different vegetables under conservation agriculture (CA) as compared with conventional tillage (CT). Moreover, conservation agriculture improves different soil productivity parameters like moisture content, organic matter, total nitrogen, and water-holding capacity of the soil (Yimam *et al.*, 2020).

Similarly, Assefa *et al*., (2021) studied the effect of an integrated approach of soil management using conservation agriculture, solar pumps, and drip irrigation using field experimentation for different crops in different parts of the norther and north-western parts of the country to evaluate water productivity and crop yield. According to their finding compared to farmers' practices, drip irrigation, and conservation agriculture lead to better water productivity of garlic, cabbage, and potato. The improvement in water productivity of garlic, cabbage, and potato was 256, 43, and 53% as compared with conventional tillage and irrigation practices at the Alefa and Affesa areas of northern Ethiopia.

Moreover, utilization of water resources through solar pumps contributes to water productivity through significant water-saving benefits. According to the study by Assefa *et al.*, (2021), the combined use of solar pumps with conservation agriculture and drip irrigation leads to an improvement in water productivity compared with traditional irrigation by 38 and 33% for potatoes and onions, respectively. Therefore, solar-powered drip irrigation systems under conservation agriculture farming systems could benefit farmers by improving the productivity of crops and efficiently utilizing limited resources. This could contribute to the improvement of smallholder farmers' livelihood in the country and the expansion of small-scale irrigation (Assefa *et al*., 2021). On the other hand, conservation agriculture (CA) has an advantage in improving water productivity through water saving and crop yield improvement both under drip and overhead irrigation (Assefa *et al*., 2021).

Water-saving methods like the application of mulch in irrigated farms could substantially reduce the evaporation of moisture from the soil. The study by Meskelu *et al*., (2018) revealed that irrigation water conservation measures through mulching in furrow irrigation leads to an improvement in water productivity and yield of maize under deficit irrigation practice in the Koka area, Ethiopia. The application of mulch in irrigation could improve water productivity mainly through water conservation by minimizing evaporation and enhancing transpiration with the available limited irrigation water amount applied to the soil. The interaction effect was significant and plastic mulch when combined with alternate and fixed furrow leads to improved water productivity. In this study maximum water productivity for maize was 2.06 kg/m^3 when the land was mulched with black plastic and only half of the furrows were irrigated with an alternate furrow irrigation technique (Meskelu *et al*., 2018). Under different irrigation water application levels, lower water productivity is associated either with higher irrigation application or lower yield. Accordingly, Meskelu *et al*., (2018) reported that lower water productivity (1.05 kg/m^3) of maize crop was observed when irrigating all furrows in a conventional system. Moreover, the yield of maize was changed from 4.67 t/ha under no mulching condition to 5.46 t/ha when plastic mulching was applied under different furrow irrigation techniques.

5. CONCLUSION

Improving water productivity in irrigated agriculture could contribute to saving large amounts of water as it is the major water consumer. In Ethiopia improving water productivity contributes to increasing the irrigated area, reduced competition and conflict between users, and increased profitability due to reduced labor cost, water pumping, and working time. Major water productivity improvement techniques include improving the performance of irrigation schemes, regulated deficit irrigation practice, partial root zone drying, application of irrigation on selected crop growth stages, supplementary irrigation, drip irrigation, and surge and cutback irrigation. Water conservation methods like mulching and integrating irrigation with conservation agriculture are also verified as a strategy for improving water productivity in the country. The Integration of efficient irrigation methods like drip irrigation with conservation agriculture, deficit irrigation with mulching, and deficit irrigation with surge flow application further showed an improvement in water productivity in different parts of the country. Studies on scheme-level optimization on the level of deficit irrigation for different crops revealed that increasing water productivity and irrigated areas with the saved could be an option for maximizing the net benefit of the scheme under limited water conditions. Different water productivity-improving techniques lead to a reduction in labor working time and costs associated with pumping. However, these should be researched and quantitative information should be delivered to the farming community to increase the implementation of water productivity improvement techniques. This could be taken as an intervention mechanism as the economic return from low pumping and labor costs attracts farmers to practice water productivity improvement techniques. Moreover, large-scale studies in a basin or sub-basin level could contribute to improving water productivity at the basin level than plot-level studies. Therefore, studies on the optimization of these different methods could be done at the basin level for better water resource utilization. Beyond field irrigation water management, proper soil fertility and crop disease management, agricultural inputs, socio-economic factors, marketing conditions, and policy-related issues could contribute to the improvement of water productivity. Therefore, the government's commitment through appropriate policy implementation is essential for irrigation water productivity improvement.

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